JOSEP LLORCA BOFÍ

THE GENERATIVE, ANALYTIC AND INSTRUCTIONAL CAPACITIES OF SOUND IN ARCHITECTURE

Fundamentals,
tools and evaluation
of a design methodology

DOCTORAL DISSERTATION 2018

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Architectural Representation Department
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To my parents

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We regret for having to write about sound.

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01. ***2018*** **Llorca, Josep**, Ernesto Redondo, Jesús Alba, and Héctor Mendoza, 'Generation of Architectural Designs Using Soundscapes: First Findings', in *DAGA 2018 München* (München: DEGA, 2018), pp. 1046–48

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03. ***2018*** **Llorca, Josep**, 'Virtual Reality for Urban Sound Design: A Tool for Architects and Urban Planners', in *Artificial Intelligence - Emerging Trends and Applications*, ed. by Dr. Marco Antonio Aceves-Fernandez (Intech Open, 2018)

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06. ***2018*** Campanyà, Carles, David Fonseca, Núria Martí, Enric Peña, Alvaro Ferrer, and **Josep Llorca**, 'Identification of Significant Variables for the Parameterization of Structures Learning in Architecture Students', in *WorldCIST'18 2018: Trends and Advances in Information Systems and Technologies* (Springer, Cham, 2018), pp. 298–306

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13. ***2013*** **Llorca, Josep**, 'La Complejidad Común: De La Composición Arquitectónica y Musical', *Palimpsesto*, 2013, 12–13

14. ***2010*** **Llorca, Josep**, and Doménec Llorca, 'La Tourette y Metastaseis : De Cómo Ordena El Material Un Arquitecto y Un Músico.', *Circuito de Arquitectura*, 1 (2010), 5–16

Introducción

Introduction

...es preciso tener talento y afición al estudio; puesto que ni el talento sin el estudio, ni el estudio sin el talento, pueden formar un buen arquitecto: Debe pues, éste estudiar Gramática; tener aptitudes para el Dibujo; conocer la Geometría; no estar ayuno de Óptica; ser instruido en Aritmética y versado en Historia; haber oído con aprovechamiento a los Filósofos; tener conocimientos de Música; no ignorar la Medicina; unir los conocimientos de la Jurisprudencia a los de la Astrología y movimientos de los astros.

Vitruvio (80 a.C. -15 a.C.), *Los diez libros de la arquitectura*, Libro primero, Capítulo I

Como arte cósmico, la tectónica [la arquitectura] constituye una tríada con la música y la danza, poque, cada uno en su campo, no son artes imitiativos. Pero las tres, con sus propias y diferentes herramientas de representación, proceden de un modo similar cuando conciben cósmicamente su tarea específica: como dar al material su expresión ideal.

Gottfried Semper (1803-1879), *El estilo. Los elementos básicos de la arquitectura.*

En cuestión de segundos, un paisaje sonoro revela mucha más información desde muchos puntos de vista, desde los datos cuantificables a la inspiración cultural. la captación visual encuadra implícitamente una perspectiva forntal limitada de un contexto espacial, mientas que los paisajes sonoros ensanchan este alcance a un total de 360 grados, envolviéndonos totalmente. Y mientras una imagen vale más que 1,000 palabras, un paisaje sonoro vale más que 1,000 imágenes.

Bernie Krause (1938-), *The voice of the natural world.* TEDGlobal junio 2013

...it is necessary to have talent and a fondness for study; since neither talent without study, nor study without talent, can form a good architect: he must therefore study Grammar; he must have aptitudes for Drawing; he must know Geometry; he must not be out of Optics; he must be instructed in Arithmetic and versed in History; he must have heard the Philosophers well; he must have knowledge of Music; he must not ignore Medicine; he must unite the knowledge of Jurisprudence with that of Astrology and the movement of the stars.

Vitruvius (80 a.C. -15 a.C.), *The ten books of architecture*,
First book, Chapter I

As cosmic art, tectonics [architecture] forms a triad with music and dance, since, like them, it is not an imitative art; moreover, all three have the same cosmic concept of their mission and similar idealistic form of expression, although each one acts differently.

Gottfried Semper (1803-1879), *The style. The basic elements of architecture.*

In a matter of seconds, a soundscape reveals much more information from many perspectives, from quantifiable data to cultural inspiration. Visual capture implicitly frames a limited frontal perspective of a given spatial context, while soundscapes widen that scope to a full 360 degrees, completely enveloping us. And while a picture may be worth 1,000 words, a soundscape is worth 1,000 pictures.

Bernie Krause (1938-), *The voice of the natural world.*
TEDGlobal June 2013

En estas tres citas está condensada la triple voluntad de esta tesis doctoral: mostrar la capacidad generativa -Semper-, analítica -Krause- y pedagógica -Vitruvio- del sonido en la arquitectura. La disciplinas del espacio y la del sonido forman dos dominios a los que resulta atrevido comparar, pues es obvio que son de naturaleza distinta. La música ocurre en el tiempo, mientras que la arquitectura en el espacio. No obstante, desde los primeros tratados tanto de arquitectura como de música, se pueden leer repetidas llamadas a la comparación, al complemento y a la influencia de ambas disciplinas, cuanto menos a la constatación de ciertos órdenes comunes entre ambos dominios. En esta tesis doctoral no ponemos en cuestión todo este corpus teórico que ha venido enriqueciendo la relación entre ambas disciplinas. Lo recibimos y nos unimos a esa corriente de conocimiento. En lo que sí que reparamos, en cambio, es en la pregunta casi impertinente que surge seguidamente: ¿puede el sonido ayudar al arquitecto en sus tareas diarias? Y, por tanto, ¿cuáles son las constribuciones del sonido para el arquitecto?

El contenido de cada capítulo posee una caracterización propia y los temas tratados gozan de cierta autonomía. No obstante, los nueve capítulos se dividen en tres secciones de tres capítulos cada una. La primera sección trata de explicar las capacidades proyectuales o generativas del sonido para el arquitecto. La segunda sección trata de explicar las capacidades analíticas del sonido para el arquitecto. Finalmente, la tercera sección trata de explicar las capacidades pedagógicas del sonido para el arquitecto. Transversalmente, estas tres secciones son abordadas desde tres premisas: los fundamentos teóricos, las herramientas, y la evaluación. Esta interacción de tres partes con las tres premisas da lugar a los nueve capítulos de la tesis. No es de extrañar, entonces, que los diferentes capítulos se puedan leer como estudios con cierta independencia entre sí, aunque enmarcados en en la pregunta fundamental que hemos formulado anteriormente.

In these three quotations the threefold aim of this doctoral thesis is condensed: to show the generative -Semper-, analytical -Krause- and pedagogical -Vitruvio- capacity of sound in architecture. The disciplines of space and sound form two domains to which it is daring to compare, since it is obvious that they differ in nature. Music happens in time, while architecture happens in space. However, from the first treatises on both architecture and music, repeated calls for comparison, complementarity and influence of both disciplines can be read, at least to the observation of certain common orders between the two domains. In this doctoral thesis we do not question this whole theoretical corpus that has been enriching the relationship between both disciplines. We receive it and join that stream of knowledge. What we do notice, however, is the almost impertinent question that follows: can sound help the architect in his daily tasks? And, therefore, what are the contributions of sound to the architect? The content of each chapter has its own characterisation and the subjects covered enjoy a certain degree of autonomy. However, the nine chapters are divided into three sections of three chapters each. The first section tries to explain the project or generative capacities of sound for the architect. The second section one presents the analytical capabilities of sound for the architect. Finally, the third section explains the pedagogical abilities of sound for the architect. Transversally, these three sections are approached from three premises: theoretical foundations, tools, and evaluation. This interaction of three parts with the three premises gives rise to the nine chapters of the thesis. It is not surprising, then, that the different chapters can be read as separate studies with a certain independence from each other, although they are framed in the fundamental question that we have previously asked.

	FUNDAMENTOS	**HERRAMIENTAS**	**EVALUACIÓN**	
PROYECTO	**Capítulo 1** Fundamentos del proyecto *Aspectos sistemáticos de la creación arquitectónica y musical*	**Capítulo 2** Herramientas de proyecto *Realidad virtaul para el diseño del sonido urbano: una herramienta para arquitectos y urbanistas*	**Capítulo 3** Evaluación del proyecto *Elpaisaje sonoro para el diseño arquitectónico: Soundscape for architectural design: un estudio quasi-experimental*	**PROYECTO**
ANALISIS	**Capítulo 4** Fundamentos del análisis *El plano y la partitura: el dibujo analítico de los elementos de la arquitectura y la música*	**Capítulo 5** Herramientas del análisis *Los paisajes sonoros de Ciutat Vella, Barcelona: La relación entre la configuración del espacio público y la música callejera*	**Capítulo 6** Evaluación del análisis *Una pequeña revisión de los métodos de evaluación de la acústica subjectiva-objectiva*	**ANALISIS**
PEDAGOGÍA	**Capítulo 7** Fundamentos de pedgagogía *El luthier de la ciudad*	**Capítulo 8** Herramientas para la pedagogía *El estudio del patrimonio acústico urbano como herramienta*	**Capítulo 9** Evaluación de la pedagogía *Enseñar acústica con el diseño*	**PEDAGOGÍA**

FUNDAMENTOS **HERRAMIENTAS** **EVALUACIÓN**

	FUNDAMENTALS	TOOLS	EVALUATION	
GENERATION	**Chapter 1** Fundamentals on generation *Systematic aspects on architectural and musical composition*	**Chapter 2** Tools for generation *Virtual reality for urban sound design: a tool for architects and urban planners*	**Chapter 3** Evaluation of generation *Soundscape for architectural design: a quasi-experimental study*	GENERATION
ANALYSIS	**Chapter 4** Fundamentals on analysis *The plan and the score: the analytic drawing on the elements of architecture and music*	**Chapter 5** Tools for analysis *Urban Soundscapes in Ciutat Vella, Barcelona: The Relationship between the Configuration of Public Space and Street Music.*	**Chapter 6** Evaluation of analysis *A short review on evaluation methods of subjective-objective acoustics*	ANALYSIS
INSTRUCTION	**Chapter 7** Fundamentals on instruction *The urban luthier*	**Chapter 8** Tools for instruction *The study of the acoustic urban heritage as a tool*	**Chapter 9** Evaluation of instruction *Teaching room acoustics by design*	INSTRUCTION

FUNDAMENTALS TOOLS EVALUATION

El primero de los capítulos abre el curso sentando los fundamentos teóricos de la creación arquitectónica y musical. Este capítulo muestra, de la mano de dos autores del siglo XX -el arquitecto Dom Hans van der Laan y el compositor Olivier Messiaen- que la creación en ambas disciplinas es de naturaleza sistemática. Este postulado se opone a la noción de arbitrariedad en la creación arquitectónica y musical, y defiende la necesidad en ambas disciplinas de disponer de un sistema para enfrentarse a la creación. El segundo capítulo sigue ahondando en la capacidad proyectual que el sonido ofrece a la arquitectura. Aquí se presentan algunas herramientas que ayudan al estudiante de arquitectura para diseñar espacios arquitectónicos acústicamente controlados. Para ello, se introduce el concepto de 'objeto sonoro' acuñado por Pierre Schaeffer, que permite distinguir entre la fuente sonora -emisión primera del sonido en un espacio arquitectónico- y el objeto sonoro -la percepción sonora desde el receptor de la fuente sonora modificada por su interacción con el espacio arquitectónico-. Esta distinción pone fin a la concepción sintética y hermética del fenómeno acústico y abre una nueva comprensión de los diferentes actores que forman la escena acústica: la fuente sonora (que se convertirá en la señal anecoica) y el objeto sonoro (que contendrá la modificación realizada por la arquitectura sobre esa señal anecoica). Esta separación de los actores es la que permite ofrecer herramientas potentes de realidad virtual y auralización que pueden ayudar al arquitecto a crear los espacios de acuerdo a los requerimientos sonoros. El tercer capítulo es el útlimo que aborda la capacidad proyectual del sonido, y lo hace evaluando esta capacidad. Se centra en el concepto de paisaje sonoro, como registro auditivo de una realidad construida. Presenta un primer experimento docente donde un paisaje sonoro que describe un escenario arquitectónico es el motor y generador del diseño arquitectónico de dicho espacio. El resultado del experimento muestra la multiplicidad de diseños que un mismo paisaje sonoro puede suscitar y evalúa la efectividad, eficiencia y eficacia de este proceso. Con este tercer capítulo se cierra la sección sobre la capacidad generativa del sonido para la arquitectura habiendo explorado tanto sus fundamentos teóricos, algunas de sus herramientas para el diseño arquitectónico desde el sonido y la evaluación de una experiencia docente.

The first chapter opens the dissertation by laying the theoretical foundations of architectural and musical creation. This chapter shows, by the hand of two 20th century authors - the architect Dom Hans van der Laan and the composer Olivier Messiaen - that creation in both disciplines holds a systematic nature. This postulate opposes the notion of arbitrariness in architectural and musical creation, and defends the need in both disciplines to have a system for dealing with creation. The second chapter continues to delve into the design capacity that sound offers architecture. Here there are some tools that help the student of architecture to design acoustically controlled architectural spaces. To this end, the concept of 'sound object' coined by Pierre Schaeffer is introduced. It makes possible to distinguish between the sound source - the first emission of sound in an architectural space - and the sound object - the perception of sound from the receiver of the sound source modified by its interaction with the architectural space. This distinction puts an end to the synthetic and hermetic conception of the acoustic phenomenon and opens up a new understanding of the different actors that comprise the acoustic scene: the sound source (which will become the anechoic signal) and the sound object (which will contain the modification made by the architecture on this anechoic signal). The separation of the actors offers powerful virtual reality and auralization tools that can help the architect to create the spaces according to the sound requirements. The third chapter is the last one that deals with the design capacity of sound, and does so by evaluating this capacity. It focuses on the concept of soundscape as an auditory record of a constructed reality. It presents a first educational experiment where a sound landscape describing an architectural setting is the engine and generator of the architectural design of the space. The result of the experiment shows the multiplicity of designs that the same soundscape can arouse and evaluates the effectiveness, efficiency and efficacy of this process. This third chapter closes the section on the generative capacity of sound for architecture having explored both its theoretical foundations, some of its tools for architectural design from sound and the evaluation of a teaching experience.

El cuarto capítulo abre la sección dedicada a la capacidad analítica de la música para la arquitectura. Este capítulo, en concreto, expone los fundamentos teóricos de esta capacidad analítica. Buscamos los sistemas analíticos de representación de la forma tanto en arquitectura como en música que, empezando por las características básicas de sus elementos, puedan concluir en una notación simbólica y una herramienta de análisis de la obra. Estos sistemas son el plano y la partitura, que plasman en el papel tanto la forma y el estilo de la arquitectura y la música. El quinto capítulo muestra algunas herramientas de análisis acústico de la arquitectura. En particular, se aborda el análisis acústico de espacios exteriores y su relación con la configuración urbana de estos espacios. El capítulo pretende mostrar que el análisis acústico ayuda a entender el movimiento y flujo de las personas en situaciones de música callejera. Esta herramienta de análisis arquitectónico y urbano muestra una de las capas de la ciudad y la arquitectura intangible: sus valores sonoros. Con este análisis se desvelan potencialidades y oportunidades que toda ciudad y arquitectura tienen. El capítulo sexto cierra la segunda sección con una revisión de los métodos de evaluación de los parámetros subjetivos y objectivos de la acústica arquitectónica. Se sacan a la luz los procedimientos de valoración de la acústica más recientes y contrastados.

La última de las tres secciones se abre en el séptimo capítulo con la presentación de los fundamentos de la capacidad pedagógica de la música para el arquitecto. Esta lección presenta al estudiante de arquitectura la creciente separación entre la música y la arquitectura que se ha venido acentuando hasta nuestros días. Explicar esta separación en la primera de las lecciones sobre pedagogía, define en qué lugar histórico nos encontramos para ser conscientes de nuestra posición actual y entender el curso del presente. La octava lección contiene alguna de las herramientas pedagógicas que el sonido ofrece a la arquitectura. En particular, se presenta el estudio del patrimonio acústico como herramienta pedagógica. De nuevo, la realidad virtual ofrece al estudiante de arquitectura una plataforma para el aprendizaje de la acústica. Por último, el capítulo nueve evalúa la capacidad pedagógica del sonido para los arquitectos. Un último experimento docente, donde los alumnos son instruidos mediante métodos de "aprendizaje activo", muestra que en la enseñanza del sonido para los arquitectos debe priorizar el "aprender escuchando" que no un "aprendizaje pasivo".

The fourth chapter opens the section dedicated to the analytical capacity of music for architecture. This chapter, in particular, sets out the theoretical foundations of this analytical capacity. We look for analytical systems of representation of form in both architecture and music that, starting with the basic characteristics of their elements, conclude in a symbolic notation and an analysis tool of the work. These systems are the plan and the score, which capture on paper both the form and the style of the architecture and the music. The fifth chapter shows some tools for acoustic analysis of architecture. In particular, it deals with the acoustic analysis of outdoor spaces and their relationship with the urban configuration of these spaces. The lesson aims to show that acoustic analysis helps to understand the movement and flow of people in street music situations. This architectural and urban analysis tool shows one of the layers of the city and its intangible architecture: its sound values. This analysis reveals the potential and opportunities that every city and architecture has. The sixth chapter closes the second section with a review of the methods for evaluating the subjective and objective parameters of architectural acoustics. The most recent and proven acoustic assessment procedures are brought to light.

The last of the three sections opens in the seventh chapter with a presentation of the foundations of the pedagogical capacity of music for the architect. This lesson introduces the student of architecture to the growing separation between music and architecture that has been accentuated to this day. Explaining this separation in the first of the pedagogy chapters defines where we are in history to be aware of our current position and understand the course of the present. The eighth lesson contains some of the pedagogical tools that sound offers architecture. In particular, the study of acoustic heritage as an educational tool is presented. Again, virtual reality offers the student of architecture a platform for learning acoustics. Finally, chapter nine assesses the pedagogical capacity of sound for architects. A final teaching experiment, where students are instructed using *active learning* methods, shows that when teaching sound to architects, *learning by listening* should be a priority rather than *passive learning.*

A cada capítulo lo acompaña un pequeño subcapítulo que muestra ejemplos prácticos o teóricos de lo que se ha hablado en el capítulo. Estos subcapítulos están escritos sobre páginas grises. Se deben leer como ampliación y ejemplificación del contenido al que acompañan.

Este trabajo presenta una aproximación particular a la relación sonido-arquitectura centrada en las tres grandes etapas del proceso arquitectónico (generación, análisis y eduación). Cabe destacar que no pretendemos agotar la rica relación entre ambas disciplinas, pues sería iluso intentar sintetizar el encuentro entre dos colosos de la creación en unas pocas palabras. Más bien pretendemos iluminar algunos puntos de encuentro específios en los cuales la arquitectura puede beneficiarse del conocimiento y manejo de las características propias del sonido. Es por tanto, una pequeña aportación sobre cuestiones particulares que abe las puertas a nuevos desenlaces.

En esta tesis, en suma, se asiste al desarrollo poliédrico que la realidad arquitectónica despliega al entrar en contacto con el sonido. Desde el análisis acústico, hasta las reflexiones compositivas, pasando por herramientas de enseñanza, el hecho de acercar ambas disciplinas hace aflorar un conjunto de consideraciones muy dispares entre sí pero con un hilo conductor claro: el sonido puede ayudar al arquitecto en sus tareas cotidianas.

Nota: a lo largo de esta tesis doctoral encontrará material sonoro al cual puede acceder usando un lector de códigos QR. Recomendamos descargarse la siguiente aplicación disponible para Android, iPhone y Windows desde *Play Store* o *App Store*:

QR Code Reader

Each chapter is accompanied by a brief subchapter showing practical or theoretical examples of what has been discussed throughout the chapter. These subchapters are written on grey coloured pages, which facilitates their visual recognition. They should be read as an extension and example of the content they accompany.

This work presents a particular approach to the relationship between sound and architecture, focusing on the three main stages of the architectural process (generation, analysis and education). It should be noted that we do not intend to exhaust the rich relationship between the two disciplines, since it would be deluded to attempt to synthesize the encounter between two giants of creation in a few words. Rather, we aim to illuminate some specific meeting points where architecture can benefit from the knowledge and handling of sound characteristics. It is therefore a small contribution on particular issues that opens the door to future outcomes.

To sum up, in this thesis, we see the polyhedral development that architectural reality unfolds when it joins sound. From acoustic analysis, to compositional reflections, to teaching tools, the fact of presenting the two disciplines together brings to light a set of considerations that are different from each other but with a clear guiding thread: sound can help the architect in his daily tasks.

Note: throughout this doctoral thesis, you will find sound material to which you can access by using a QR code reader. We recommend downloading the following app available for Android, iPhone and Windows from *Play Store* or *App Store:*

QR Code Reader

Objetivos

Aims

Esta tesis doctoral propone un método de diseño arquitectónico basado en el sonido. El método será útil para la arquitectura si consigue dar respuesta a necesidades proyectuales, analíticas y pedagógicas en la arquitectura. Éste se define mediante la explicación de sus fundamentos teóricos, desde la enumeración de herramientas para hacerlo factible, y desde la evaluación del mismo. A continuación se presentan los objetivos detallados. Se pueden dividir en tres grupos:

Objetivos respecto a la capacidad generativa del sonido. Estos objectivos se abordan en los capítulos 1, 2 y 3, respectivamente:

1. Mostrar los fundamentos teóricos de la capacidad generativa del método.

2. Enumerar herramientas para la capacidad generativa del método.

3. Realizar una evaluación de la capacidad generativa del método.

Objetivos respecto a la capacidad analítica del sonido Estos objetivos se abordan en los capítulos 4, 5 y 6, respectivamente:

4. Mostrar los fundamentos teóricos de la capacidad analítica del método.

5. Enumerar herramientas instrumentales para la capacidad analítica del método.

6. Realizar una evaluación de la capacidad analítica del método.

Objetivos respecto a la capacidad docente del método. Estos objetivos se abordan en los capítulos 7, 8 y 9, respectivamente.

7. Mostrar los fundamentos teóricos de la capacidad pedagógica del método.

8. Enumerar herramientas instrumentales para la capacidad pedagógica del método.

9. Realizar una evaluación de la capacidad pedagógica del método.

This doctoral thesis presents a method of architectural design based on the sound. The method will be useful for architecture if it is able to respond to project, analytical and pedagogical needs in architecture. This is defined by explaining its theoretical foundations, from the enumeration of tools to make it feasible, and from the evaluation of it. The detailed aims are presented below. They can be divided into three groups:

Aims regarding the generative capacity of the sound. These objectives are addressed in Chapters 1, 2 and 3, respectively:

1. *To show the theoretical foundations of the generative capacity of the method.*

2. *To list tools for the generative capacity of the method.*

3. *To carry out an evaluation of the generative capacity of the method*

Aims regarding the analytical capacity of sound. These objectives are addressed in Chapters 4, 5 and 6, respectively:

4. *To show the theoretical foundations of the analytical capacity of the method.*

5. *To list instrumental tools for the analytical capacity of the method.*

6. *To conduct an assessment of the analytical capacity of the method.*

Aims regarding the instructive capacity of the method. These objectives are addressed in Chapters 7, 8 and 9 respectively.

7. *To show the theoretical foundations of the pedagogical capacity of the method.*

8. *To list instrumental tools for the pedagogical capacity of the method.*

9. *To carry out an evaluation of the pedagogical capacity of the method.*

Chapter 1

Fundamentals on generation

Systematic aspects on
architectural and musical
composition

Chapter 1

Fundamentals on generation

Systematic aspects on
architectural and musical
composition

The present chapter is derived from the work entitled *Aspectos sistemáticos de la composición arquitectónica y musical: Van der Laan y Messiaen*. This work was presented by the author as Master Thesis in Barcelona School of Architecture on July, 2016. Furthermore, this chapter includes the article *Van der Laan and Messiaen's creative from a system* presented by Juan José Madrigal and the author in *ACE* journal.

Fig. 1. Opposite page. Window of the façade of the house Amatller de Puig i Cadafalch in Barcelona. 1898-1900. The spatial composition of the whole shows the perfect coexistence between ornamental freedom and the submission to both visual and structural orders.

1.1. Introduction: freedom from order

The multiplicity of manifestations of human creativity does not cease to surprise us day after day, year after year, century after century... However, all these manifestations are the fruit of the same consciousness, that of the human being. He creates from an inheritance and from his imagination to enlarge unlimitedly that which we call culture. So we ask ourselves: is it not perhaps that human creation makes systematic use of elements and relationships to produce the whole display of works that surround him? Do we not call this set of elements and hyper-productive relationships as a *system*? Hence, the fascination for the variety produced from an elemental core. Hence the amazement at the heterogeneity of results from the same human thought. Despite the unbridled production of works, the artistic disciplines will never be exhausted. The old architects who squeezed the possibilities of yesterday's architecture to pave the way for the new architects of space will die. Future composers will be born and will experience new ways of making the music of tomorrow, replacing the old poets of sound. But art will not expire with the passage of time. Because the elements on which they are based and the relationships between the elements they use, truly constitute a system from which infinite variations can be made.

From the outset, it should be noted that this work is the very opposite of any attempt to satisfy value judgements of the works studied. If the works can more or less please the reader, it is not the purpose of this doctoral thesis to defend or justify that subjective taste. Rather, the aim is to show by means of analytical judgements that the process of composing the works is systematic and not arbitrary in nature, and that this process offers results that are different from one another but that refer to the core of the control of the system.

For this reason, two concrete examples are used in this chapter, taken from disciplines of different nature whose final perception is apparently opposite to each other. If, on the one hand, the Abbey of St. Bendictusberg by the architect Dom Hans van der Laan has an ascetic character, on the other, the eighth movement of the Turangalîla Symphony by the composer Olivier Messiaen is overflowing with his exuberant productivity. However, both examples use some elements and rules as a basis for the production or creation of concrete works: Van der Laan from his reflection on the *plastic number*, on the distances of contemplation of architecture, and Messiaen from the development of the *modes of limited transposition* as a systematic basis for the creation of his works. Both show the lack of arbitrariness in the generation process that is typical of architecture and music.

The chapter focuses on the specific character of each artistic discipline - architecture and music - with the awareness that it is precisely the autonomy and the particular way of behaving independently what allows us to meditate on their reciprocal relations. It is a matter of comparing these disciplines taking into account that, although music has a very formalised symbolic notation and that it does not happen to the same degree with architecture, both use certain elements and rules as a basis for the production or creation of specific works. Moreover, the number - the measure - is present in them, as it has a constituent, 'ontogenetic' role in both of them.

Fig. 2. Opposite page. Threshold to the *Patio de los Leones* in the *Alhambra in Granada*. The exuberance of the whole is at the service of creating a place in the dark before going out into the sunshine of the courtyard. The position of the small columns and the multiplication of the shadows in the nooks and crannies of the plasterwork are subjected to the same intention: to adapt the light to the eye of the visitor.

The journey begins, then, by introducing the cultural panorama that is justified by arbitrariness, in order to detect the possible weaknesses of this approach. In contrast to this, an analytical view of reality is based on the primacy of form, that is, by focusing on the system of relations that constitute things and not on things themselves. In order to do this, it will be necessary to understand the composition from that point onwards as handling and control over the form, momentarily stripping the work of the other characters, such as the value of the limits, their colours, textures, dynamics or timbres. Once this frame of reference has been drawn in the first section, we arrive at the fork where our two authors and their respective disciplines divide the discourse. The detailed study of the two project systems occupies the second part of the chapter, in which they are applied in the aforementioned works. Once the stripping of the work is finished, it is shown that the other characters (limits, colours, textures...) reinforce the order established by the form and that there is no arbitrariness in the decisions of the final result, but the use of freedom, and the possibility of choice between different options.

The unbridled force of the artist's imagination comes to the surface with impetus every time he sets out to throw a stroke, to model a piece of clay or to place his fingers on the piano. Anyone who has devoted himself, however little it may be, to creating something new with his hands has experienced the thrust of the indomitable spirit which, with spontaneous outbursts, leads him to make bold and often capricious project decisions.

But in the same way, he has also seen with the passing of time that perhaps his work no longer has the strength it had at that moment. And, perhaps, not even that courageous decision can now contain the grimace of its own creator.

Time has passed, fashions have changed. Also tastes, as creator and observer. And the work remains there, the fruit of that moment of productive euphoria. But only from that moment. What a pity! This work was not the result of a project process; it was only the result of a moment. And the time, which took that moment, was taken with it to the work. And what could have been a logical construction solidly built, remained as a couple of arbitrary decisions, which at the time they where valuable for the creator. Perhaps invaluable, and unjustifiable. But now they're buried next to the great, brilliant ideas of fashion: old-fashioned.

On the other hand, there were others who decided not to found their works on such quicksand and on the basis of much exercise managed not to be enslaved by the overwhelming impulse of the moment. These men were very astute, as they discovered ways to justify their project decisions by creating relationships between the parts and the whole and, moreover, by taking up the tradition they had received. In short, they built logical systems that sustained and continue to sustain the works of their hands.

This radical decision did not suppress in them the unbridled force of imagination. Rather, it recognized this force and gave it its rightful place in the creative process: to continually offer the creative consciousness new combinations of that system which, thanks to its axiomatic nature, produces infinite results.

Fig. 3. Opposite page. Façade of the cloister of the Monastery of Pedralbes, Barcelona. The economy of the rhythms set between arches and the sobriety in the ornamentation are a clear commitment to objectivity in the project decisions.

History testifies that the latter are the true geniuses: those who manage to lock their work to an undeformable network of relationships. Those who do not expect the immediate reward of their work, but trust in the timelessness of the system. Those who do not try to imprint their unique stamp on the work, but offer the legacy of the discipline a way to make it reflect on the discipline itself. And thanks to them, the coffers of the disciplines are filled with incalculable treasures, with invaluable relationships.

He who opens these treasures and understands the ins and outs of these systems understands the course of history. For this reason, this doctoral thesis also has a didactic vocation, since it aims to make the works studied better understood by deepening their systems and by trying to comprehend that understanding and working on the basis of an orderly system is a guarantee of universality and fruitfulness. So much so, that we dare to proclaim *freedom from order*.

1.2. Against arbitrariness

From order I will extract creative power and power of self-criticism to give form to this unusual one.

That's where Beauty will be born.

Louis Kahn. *Form and Design*

And Beauty will set us free.

Dostoevsky. *The Karamazov brothers*

It seems that for the last few decades, a growing praise for arbitrariness in the world of creation has been evident. Rafael Moneo, in his public reception speech at the *Real Academia de Bellas Artes de San Fernando*, has already pointed out the arbitrariness of architecture as a characteristic of our time. He supports his argument with a reading of the past that pivots between the forces of arbitrariness and *formativity*. Other authors who have noticed the same phenomenon cited in this speech are Luis Rojo de Castro, Rem Koolhaas and Franco Purini. Moneo's words leave no doubt about the growing presence of this phenomenon:

> It is interesting, however, to note that in the last quarter of the 20th century, the architects who used the concept of arbitrariness to base their work were numerous, although they have always avoided openly confessing that this was the case. [1]

1 Rafael Moneo, *Sobre el concepto de arbitrariedad en arquitectura* (Madrid: Real Academia de Bellas artes de San Fernando, 2005).

Another discipline of art, music, also became aware of this situation in the mid-twentieth century and was highlighted by the composer Igor Stravinsky:

> The individual whim and intellectual anarchy that tend to dominate the world in which we live isolate the artist from his peers and condemn him to appear in the eyes of the public as a monster: a monster of originality, inventor of his language, of his vocabulary and of the rigging of his art. The use of materials already experienced and of the established forms is commonly forbidden. He ends up speaking a language that has no relation to the world that listens to him.[1]

But it seems that it is not only a phenomenon of artistic creation, but also, and above all, of contemporary man, from which creative arbitrariness inevitably follows. As a sign of critical thinking in the face of praise for arbitrariness, the words of the philosopher Romano Guardini (1885-1968) -a very influential figure in the architect Mies van der Rohe- should be highlighted, stressing the lack of order in the society of his time, which has been growing up to the present day:

> We have completely lost the sensitivity to know when it is time for everything. Everyone reads any book at any time. Everybody sings any song at any time. We believe that we can have any conversation at any time, write any letter now as well as later: how uprooted we have become, how homeless our words are, how misplaced our deeds are! [2]

There are three aspects to be considered in this situation. First of all, instruments and means have gained prominence with respect to ends and purposes. The technological revolution of the last decades has put the accent on an unbridled race of competition that offers the artist an infinite number

1 Igor Stravinsky, *Poetics of music in the form of six lessons* (Cambridge: Harvard University Press, 1970)

2 Romano Guardini, *Cartas para la formación de sí mismo* (Madrid: Palabra, 2009).

of techniques. These, used as instruments, can greatly enhance creation, but when turned into ends in themselves they enslave the creator, and the resulting work will be an experiment predestined to remain on the market for as long as the technology that has engendered it. In other words, it's at the mercy of fashion and the passage of time. On the other hand, the true aims and purposes of artistic disciplines do not change over time. Today, any creative act is justified on the grounds that it is an experiment, that it is going nowhere and that it is not accountable to anyone.

Secondly, there is a desire to avoid the normative. We are aware that today's world is more complex than the previous one, and this pleases today's man to the point where he praises this complexity and condemns everything that might disturb it: order. In fact, order terrifies the contemporary artist because order is associated with what has been reduced. But order must be related to complexity, because order allows us to placate the complication and show it as something accessible, with the apparent elementary clarity. And the element is not a reduction or schematization but a condensation of reality. If complexity is born of deploying the elemental, and the element is born of condensing complexity, the elemental is both the starting point and the goal. That is why it is clear that if complexity does not manifest itself as elemental, it is unsupportable. There are diseases such as Parkinson's or aphasia in which people who suffer from them lose the basic sense of the act of walking or talking to the point that it becomes so complicated that it is no longer a reflection. For them, the apparent unity of things allowed them to act in an automatic and practical way, a skill they have lost over time. So, in reality,

Fig. 4. On Via San Giovanni, which leads to San Gimignano, Italy, the complexity of the alignments of the houses is appeased by the uniformity of materials and colours, thus forming an orderly whole.

the order is not simple, it is complex. Moreover, order is what allows complexity to be inhabited.

Finally, freedom today is defined as falling outside the very character of discipline. Many of the latest artistic trends confuse the norm with dogma and believe that innovation means betraying the ethos of things, their own character. Artistic creation has become expressive debauchery instead of taking root in a true original freedom. If original freedom is based, above all, on the awareness of the specific character of the discipline in question (architecture, poetry or music), expressive licentiousness proclaims that one can only be truly original if one escapes from the origin, which is still a contradiction.

For all the above reasons, we want to show that freedom is not at odds with order. On the contrary, freedom needs order. Just as there is no shadow without light, no opacity without transparency, no sound without silence, no treble without bass. This paradox is, as we see, necessary. And so it is that, in the end, it is not a contradiction.

With the intention of showing this hypothesis is of great importance, both for the elementary understanding of architecture and its compositional base, we resorted to the testing of the same hypothesis in another discipline of composition: music. In this way, it can be demonstrated that both of them have their place in the establishment of their own systems. Each of the disciplines is personified by a renowned author. Dom Hans van der Laan (1904-1991), on the one hand, bases his architecture on the system of measurements of the *plastic number*, which he himself developed. Olivier Messiaen (1908-1992), on the other hand, composed his extensive musical work based harmonically and melodically on the *modes of limited transposition*, a discovery which deepens into the laws of harmony. Both impose a system on which they create their own individuality as creators and both rely on the system to bring their work to fulfillment.

For both, the creation of the system prevents them from the whims of their own will. These systems, being rooted in tradition, know how to look to the past and not build a self-referential world where the worst slavery is the self.

Fig. 5. Detail of the *Creation*. Michelangelo Buonarroti. 1511.

Fig. 6. Ceiling of the *Nordic Pavilion in Venice*. Sverre Fehn. 1958-1962

Fig. 7. The first two pages of *Symphony No. 2, Resurrection*. Gustav Mahler. 1888-1894.

Fig. 8. Frame from the film *Modern Times*. Charles Chaplin. 1936.

1.3. The primacy of form

The cultural objects that, unlike the natural ones, are the product of man, speak to us of many aspects: of the historical moment in which they were built, of the material from which they are made, of the light that bathes them, of the symbolic references to which they refer, and, ultimately, of the internal logical structure that sustains them: of the form. And we say ultimately because this is the last aspect of which one is aware, but at the same time, the most profound, since, according to the *Real Academia Española de la Lengua*, form is "the active principle that determines matter so that it can be something specific". Therefore, form has primacy over matter in constituting the specific. [1]

In this subseection we will try to observe and analyze reality from this aspect, from the form. And for this it will be necessary to make a stripping of the other aspects in order to keep only this one. But then one could object that form is not the only aspect of reality and that, in fact, when we live, the world comes to us in its totality, everything is experienced, it is a synthesis and the elements that make it up are not loose, but rather united in a whole. True, but if we wish to offer an analytical vision of this reality - or what is the same, the basis of possible analytical judgments - we must first separate the elements in order to understand them in their individuality and then understand the relations between them in

1 The distinction between *form*, *figure* and *image* must be made clear. The *form* asks to be described. If you look at it only, it is shown synthetically as a *figure*. The analysis of the *figure* allows, it is a door, to enter into the *form*. Just as the *figure* immediately manifests what it is *image* of, so too is every *form* an *image* of things, but between the *form* and that of which it is *image* there is no figurative similarity. In other words, there is a structural similarity between *form* and that of which it is an *image*.

order to reach totality. In this regard, we must recall Condillac's words on the analysis:

> To analyze, then, is nothing more than to observe in a successive order the qualities of an object, in order to give them in the soul the simultaneous order in which they exist. [2]

But the reader can insist: what are the benefits of this effort to dispossess the work? What need do we have to do this if the work is already understood? Why this effort to stand alone in front of the form and dispense with everything else? Because form is the only way to connect what man does - cultural objects - with what is given - natural objects.

Specifically speaking of architecture, the order given to the architect comes in terms of use, site and technique. And these are the three conditioning factors from which the architectural work is born. [3] As Professor Antonio Armesto says:

> the three ingredients refer to nature in an obvious way: the use is identified with life; the context as a scene on earth and under the sky, as geography or topography; the technique because it takes its materials from nature even though it skillfully transforms them to make their origin unrecognizable. Nevertheless, artistic events, when they really become such, escape this natural determination and become specific and autonomous, that is to say, they obey the general laws that govern nature but also, and this is essential, they have their own laws. Uses, contexts and techniques are articulated and composed, formalized, over time in cultural objects. These, therefore, are a human form of nature.
>
> So art is, then, an artificial creation that possesses a formal substance. The world of the formal is the world of operations with things, of the relative positions between them, of their relations, therefore, is abstract with respect to nature, as are architecture, mathematics or music. The history of art itself

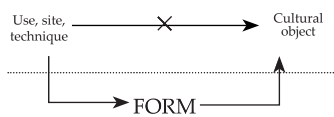


Fig. 9. Attic vessels to preserve ointment. 4th century A.D.

Fig. 10. Ornaments, utensils and Bootchmanian weapons.

2 Condillac, *La lógica o los primeros elementos del arte de pensar* (Barcelona: Imprenta de Gorchs, 1827), p. 27.

3 Antonio Armesto, 'Arquitectura y naturaleza: tres sospechas sobre el próximo milenio', *DPA: Documents de Projectes D'arquitectura*, 2000.

allows us to understand that cultural objects should not be confused with use, context or material technique. All you have to do is to establish some correspondence or relationships with them. And it does this through the construction of limits: spatial limits, temporal limits. Therefore, with the notion of limit, a world is inaugurated that runs parallel to the uses, contexts and techniques and lends them their form. For this reason, there is no cause-and-effect relationship between them and the artistic form, since the form is not derived from the use, context or technique, but rather between them and what we call a formal analogy is established. [1]

A formal analogy, according to the Greeks, was an equality of reasons: A/B = C/D. In this way, analogies can be drawn between different universes: the relationship between the warp and the weft in a fabric is the same as that between the axis of rhythm and the axis of musical harmony and that between the *decumanus* and the *cardus* of cities. While the first elements - warp, rhythm and *decumanus* - are the main elements in the establishment of such systems, the second elements - weft, harmony and *cardus* - are the consequence of and depend on the former.

Let's take some examples from the field of architecture again: is there life in the carved stones of *El Escorial*? Does the Wright's *Fallingwater House* resemble the natural context that surrounds it? Is

1 Íbid.

Fig. 11. South view of the Monastery of *San Lorenzo del Escorial* with the town behind it. The constant visual rhythm of the windows of this façade is an explicit sign of composition by means of a purely formal procedure: repetition.

nature alive in the pillar of Mies van der Rohe? Our thesis defenses the opposite. Neither the granite blocks of *El Escorial* contain a wisp of life even though it serves life, nor do the forms of nature that surround the *Fallingwater House* resemble the house itself, except that there is a naturalistic imitation in the stratification of the surrounding rocks, nor is there a blind or mechanical prolongation of the laws of nature in the pillar of Mies van der Rohe. What there is in all cases is a relationship between these three conditioning factors - the use, the context and the technique - and the final work through form. The stones of *El Escorial*, properly placed, serve an architectural program. The forms of the *Fallingwater House*, properly placed, are adjusted to the context. And Mies van der Rohe's abutment, which assembles metal profiles in a suitable manner, offers the structural inertia required by industrial technology.

It is therefore appropriate that from now on we do the exercise of stripping the work. We are aware that it requires effort, and that in today's society it is even more complicated because you have to go through all the layers to get to the foundation that is at the bottom. But all the other strata rest on those foundations that have been removed.

Warning to the reader

Since the subject in the chapter is going to be studied in two different disciplines, but with points of contact between them, from this point onwards the even numbered pages will take the voice of architecture and the odd numbered pages will take the voice of music. This way the reader interested only in architecture can read the left chapter and the reader interested in music can read the right chapter. However, for a correct understanding of the thesis defended, it is advisable to read the different chapters together. In the last section of the chapter, we will reconnect the two disciplines in conclusion.

Architecture

Music

The exercise of stripping of the architectural work referred to above begins by recognizing it as such in all its complexity. Looking at it directly, without expecting anything in return, is the first step.

However, in order to acquire a knowledge of the architectural work, it is not enough to see it all at once, it is necessary to see one part and then another and, instead of embracing everything in one glance, to stop successively the sight of one object in another.[1] That's when we realize that the architectural work has parts included in a whole. One only needs to realize this to distinguish hierarchies of spaces that include other smaller spaces or successions of spaces that lead to a culminating point. All these procedures make the existence of environments possible. These environments are separated from each other by thresholds that may be more or less transitive.

If we continue analyzing these environments, we realize that they are formed by delimited spaces, by architectural units with their own character that we call architectural elements or that have an elemental character. And these can be of three types: covered and closed; uncovered and closed; and covered and open, that is: classrooms, enclosures and porches, following the conceptualization used by Antonio Armesto in his doctoral thesis.

Finally, we can see that these spatial units are made up of limits which, each of which is responsible for constraining the direction of the space, can be distinguished between the wall as the horizontal limit, the ceiling as the vertical limit and the floor as the limit given a priori.

1 Condillac, p. 22.

The exercise of stripping the musical work referred to above begins by recognizing it as such in all its complexity. Looking at it directly, without expecting anything in return, is the first step.

But to acquire a knowledge of the musical work, it is not enough to see it all at once, it is necessary to see one part and then another, and instead of embracing everything in one glance, to stop successively the sight of one object in another.[1] That's when we realize that the musical work has parts included in a whole. One only needs to realize this to distinguish hierarchies of musical fragments that include other musical fragments or successions of fragments that lead to a culminating point. All these procedures make the existence of formal functions possible. These formal functions are separated from each other by cadences that act as a threshold, characterizing the passage as closed or open.

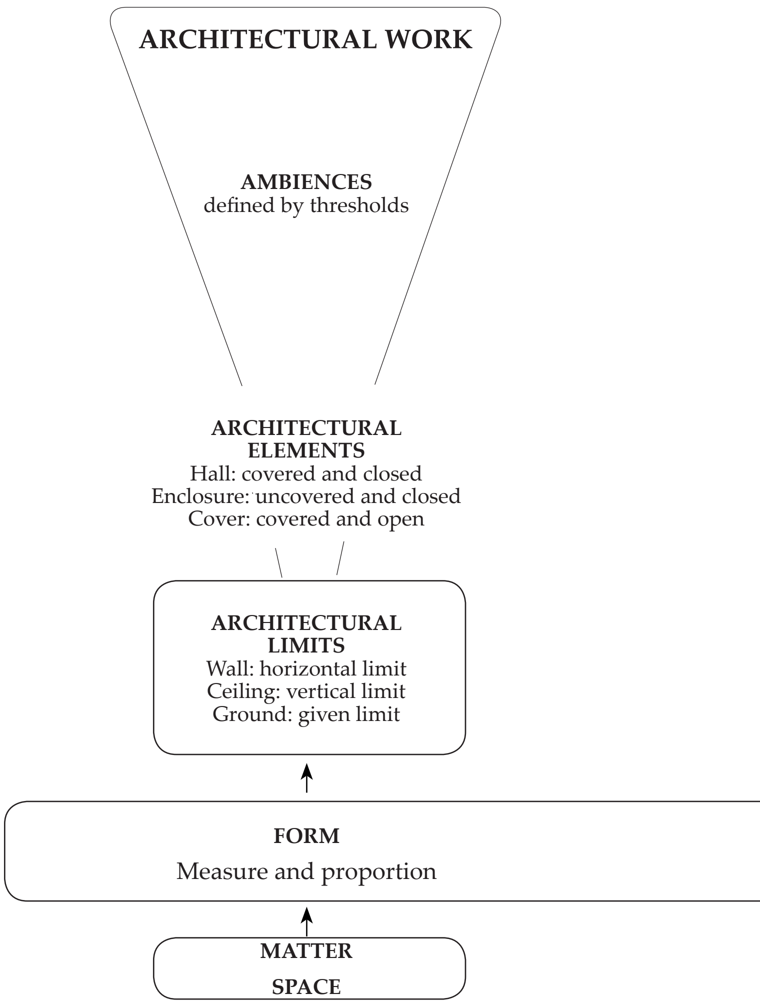
If we continue analyzing these functions, we realize that they are formed by fragments, by musical units with their own character. These are, in a hierarchical order: periods, phrases, motifs and cells. We can see that these units are composed of notes or musical elements which, in charge of clearly defining what will be played, synchronize the two other musical elements: rhythm and harmony.

These musical elements have at their root the notion of limit: limit to amorphous sound and limit to homogeneous time given by nature.

Well, it is precisely at this point that it is the form in charge of giving a piece of nature the capacity to act as a limit, giving it measure and proportion to crea-

1 Condillac, p. 22.

Well, it is precisely at this point that the form is responsible for giving a piece of nature the capacity to act as a limit, giving it measure and proportion to create the wall, the ceiling and the floor. And it is right here that the system has the role of deciding what measure and what proportion is to be given to that amorphous nature to define the limit. It is, therefore, here that a system of proportions and measures such as Van der Laan's has its justification. And it is from this point of view that we are going to analyse.



te rhythm, harmony and, ultimately, note. And it is right here where order has the role of deciding what measure and what proportion is to be given to that amorphous nature to define the note. It is, therefore, here that a system of proportions and measures such as Messiaen's has its justification. And it is from this point of view that we are going to analyse.

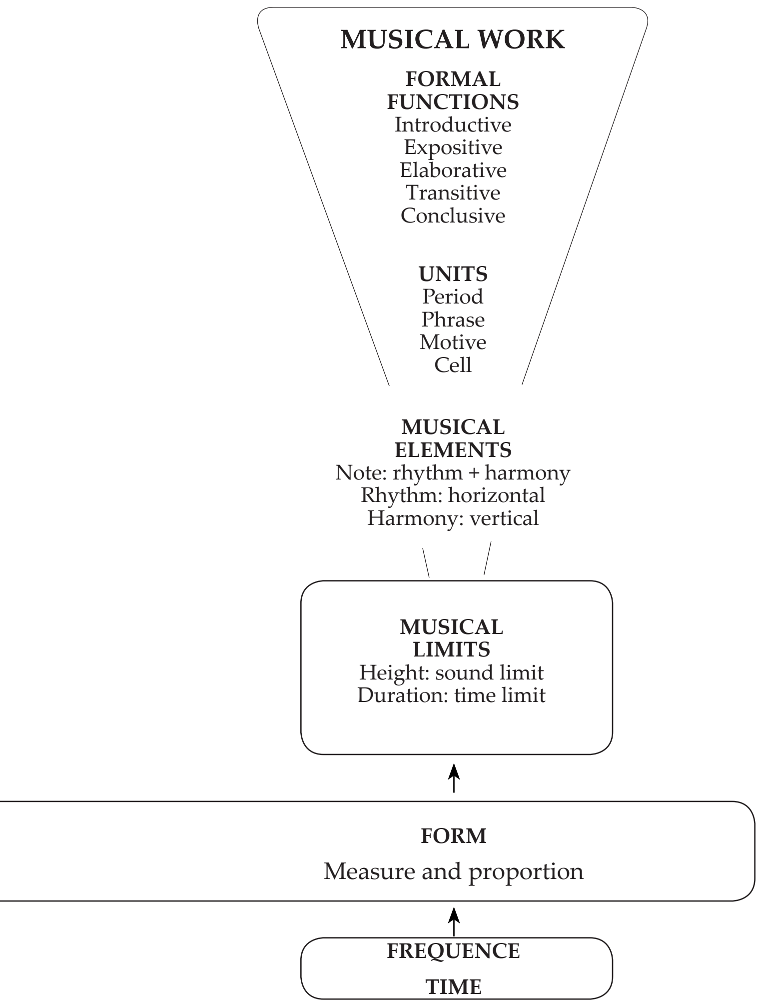


Fig. 12. Village near Taohua Niger. This village near Taouhua Niger, a clear example of topological space, is made up of only the same barns arranged on an infinite plane, where what counts are the relative positions.

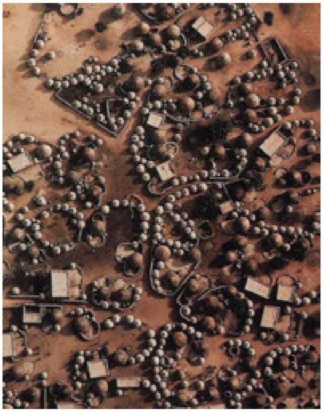
Fig. 13. In the next African village, on the other hand, there is already a will to create roads and enclosures with walls and accumulations of huts.

1.4. The systematic in architecture

The conceptions of systems in architecture have varied throughout history depending, among many physical and social factors [1] , so an exhaustive list of them would be impossible to cover in this work. In addition, different conceptions of order coexist in the same period, which are not contradictory but complementary. For this reason, a possible point of view is offered here for analyzing order in architecture.

1.4.1. Between topological space and metric space

The consciousness of the inside and the outside in a space seems to precede the consciousness of the measure of that space. Hence, we can distinguish between a topological space and a metric space of architectural reality. If on the one hand the topological space does not know about measurements but about relative positions -inside, outside, superimposed, adjacent, etc-; the metric space, on the other hand, knows about distances and pays less attention to the positions of objects.



What we usually call Neolithic[2] space, and which we can characterize as the space of the vessels and containers, follows a topological order, since it pla-

1 In this respect, some work has been carried out which shows that not only have there been many conceptions of order in architecture, but that, in the 20th century, the proliferation of the avant-garde has motivated the creation of new orders which are justified by certain principles. See Monataner, Josep Maria. *Sistemas arquitectónicos contemporáneos*, (GG: 2008)

2 The word "Neolithic" means "of the modern stone", being synonymous, in prehistoric language, of "polished stone", because it constitutes one of its most characteristic features; others also call it "of the domestic animals", because it is the time when man definitely domesticated the dog, the horse, the ox, the pig, etc. J. Vilanova i Piera. In Martínez, Francesc A. and Laguna, Antonio (2007). "From nomads to citizens." *La gran historia de la Comunidad Valenciana*. Valencia: Editorial Prensa Valenciana.

1.5. The systematic in music

From the moment a man hit an object to produce rhythms, from the moment he blew through a hole to make sounds, from the moment he rubbed two materials together to get some vibrations into the air, he always had the need to decide how often he hit to get rhythms or how long the tube he was blowing through was to get an accurate height. The need to impose limits on the infinite possibilities offered by the natural world has always been present.

1.5.1. Musical systems in history

There is a historical parallel between European music and successive attempts to explain the world by reason. Already the antiquity, with Pythagoras, Plato and others, tried to introduce universal laws in the musical discourse attracting to the field of the abstraction, that is to say, of the formalization or systematization, the immediate data of the sonorous perception and of the musical construction.[1]

The system, as a structural necessity that governs the relations between sound events, is born in the beginning, it is connatural to the birth of music itself. The establishment of laws or rules governing the choice of certain frequencies and their combinations was the result of efforts to justify the perception of tunes and dissonances and the construction of the musical instruments themselves. As early as the 6th century, Pythagoras had demonstrated the numerical foundation of music. It was, above all, about the intervallic proportions. According to

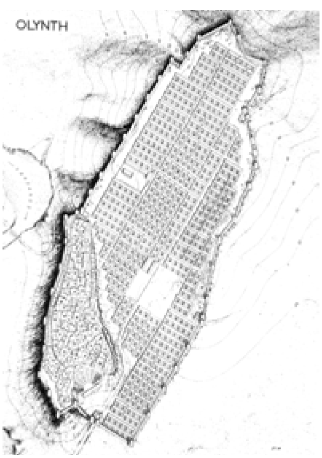
1 Iannis Xenakis, *Música i arquitectura* (Barcelona: Antoni Bosch editor, 1982).

Fig. 14. The map of the planned city of Hat-hetep Senusret shows a direct correlation between the house and the street

Fig. 15. As in the planning of the city of Olinto, the different blocks that make up the street are directly related to the houses they contain.

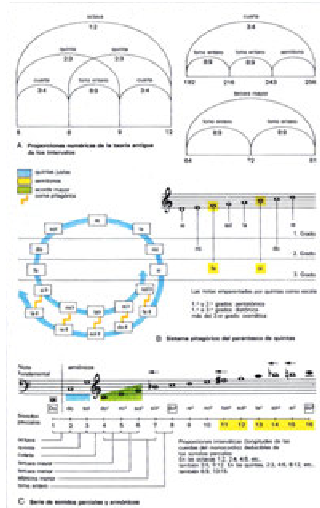
ces the accent on placing containers -which offer interior space- and leaving the interstices between them like the rest -which will be treated as exterior space-. This phenomenon can be seen in some African villages, where the different dependencies are upside-down vessels placed side by side and generating a complex space around them: a void that floods everything and runs through it. There's only interior space here if we get into the object. In contrast, the space of the Greek city, that of the polis, which is built with premeditated planning, follows a metric order. This is the case of cities like Olinto or Memphis. There is a kind of correlation between the house and the street. Whereas in the African village there was only space when there was a concave object in which to put and store things, now the object has become space and its limits have the will to form both the house and the street.

This shift from topological to metric order in architecture is a fact that has been taking place at various times in history and in different parts of the world: the birth of the Greek polis, the rise of monasteries in the Middle Ages, or the transition from the countryside to the cities in the era of industrialization are examples of this phenomenon. In all of them, the operation of moving from the barn to the house, from the object to the space, from the interstitial topological order between objects of the village to the systematic order of the city is carried out.



In the systematic city, the metric order is imposed. Olinto had a need to grow up and didn't grow up the old-fashioned way.

However, it is not always possible to distinguish precisely whether the order of a city is topological or metric. Moreover, to classify architecture in boxes the latter, from the octave, which is deduced from sounding a string and comparing it with the frequency produced by another string with the same tension and half the length of the first string (1:2) the fifth (2:3) and fourth (3:4) are originated by harmonic division; from the fifth the major (4:5) and minor (5:6) thirds are originated by harmonic division and from the major third a small whole tone (7:8) and a large whole tone (8:9) are originated. But this demonstrates the difficulty of this Pythagorean system in demonstrating that it does not close, since the sum of 6 whole tones does not result in an octave. The difference between the large and the small whole tone is 81:80, or 21.5 cents, or one fifth of a semitone. In the tuning system called tempering, this comma has been removed and all the intervals enlarged proportionally to close the circle.[1]



But behind this system of intervallic proportions «was hidden the belief that the movement of the cosmos and the human soul are founded on the same harmonic numerical proportions. Music is therefore, by virtue of its numerical principle, the transcript of the universal order, but it also influences the mood and character of men; it becomes a moral and social factor to be taken into account in education and public life. Music becomes a danger when it breaks the framework of old and severe orders, expanding into new orgiastic forms and uncontrollable subjectivism».[2]

Fig. 16. Ordenations and relationships between sounds. In A, you can see the proportions between the sounds derived from Pythagoras' studies. In B, the circle of fifths with its corresponding Pythagorean coma. And in C, the series of partial sounds and harmonics.

Aristogens of Tarentus (354-300), an Aristotelian disciple, who, in contrast to the Pythagoreans, does not refer to the number, but to the auditory expe-

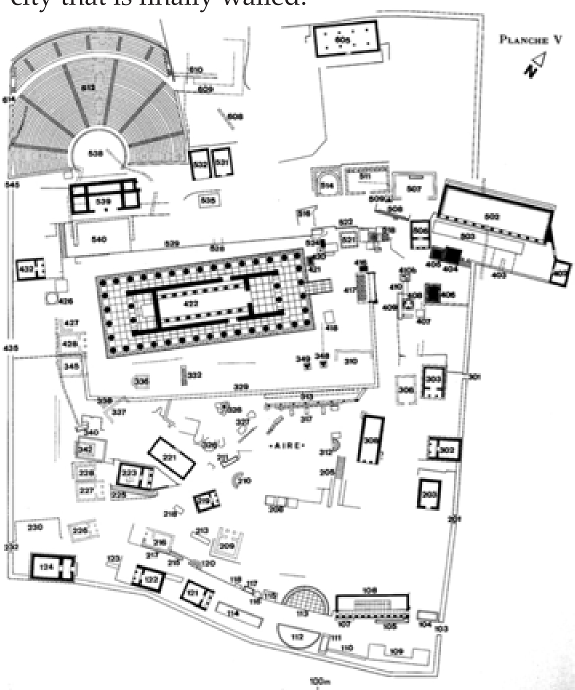
1 Michels Ulrich, *Atlas de Música, I* (Madrid: Alianza Editorial, 1982). Pg. 89, 175

2 Ulrich. Pg. 175

Fig. 17. On this map of the Delphi sanctuary we can see the buildings drawn. Although the paths are not sketched, thanks to the metric condition of the space, they can be seen.

of this type would derive into reducing it and not to value its richness. It is precisely here that most architecture is to be found, in the wise combination of systems that are governed by measurement and systems that focus their attention on the object and its relationship with others.

Take, for example, the case of the sanctuary of Delphi. Due to its steep, growing slope towards the northwest, the landscape was colonised by a path that zigzagged up from the lowest part to the position of the theatre. As you climb up the slope the procession finds on the right and left esplanades, tholos, megarones and temples that colonize the land. Each one has a different orientation, does not follow a regular metric order, and also, the empty space between the pieces forms angles, fragments and interstices that close visuals, open views or allow the presence of esplanades. However, there is a desire to build a street with the same limits as the buildings and this gives it the character of a small city that is finally walled.



rience, is considered to be the initiator of musical theory. This was followed by Euclid of Alexandria (about 300 B.C.) and numerous theorists, who dealt with the problems of harmony, intervallic proportions, rhythm, music notation, etc. This gave rise to Greek musical notation (from the 6th century B.C.), which played an important role in theory and teaching. The Greek tonal system is the foundation of the modern system. After the pentatonic period of the primitive period, heptatonism prevailed from the 8th century onwards. Shortly afterwards, we were in the presence of the teleion diatonic system. In the late classical and Hellenic periods, chromaticism and harmony arose, and at the same time the description, transmission and modification of this teleion system began.[1]

In the Roman Imperial period, the tradition and improvement of music theory was of particular significance. This is Greek ideological heritage, which he compiled in part from a consciously historical perspective.[2] Byzantine ecclesiastical music dates back to the traditions of Greek, Syrian and synagogue singing. It makes use of the modal system of diatonic melodies already used by the Greeks.[3]

At the end of the 6th century, Pope Gregory I carried out a reform of the Roman liturgy that gave the melodies a flatter and easier to grasp shape, as far as possible. The liturgical, homophone and Latin chant of the Catholic Church, which is still practiced today, was called by the Pope as "Gregorian chant". In the Middle Ages, this singing was noticeable by means of pneumatics. Its modal system is known as

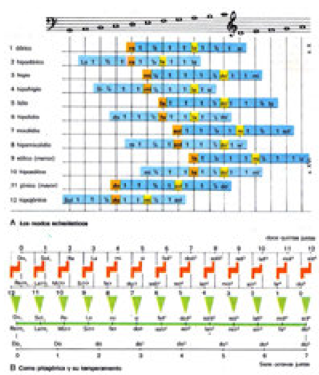


Fig. 18. Note in A that the ecclesiastical modes arise from correlatively ordering the natural scale of seven sounds except the one that could be mounted on the B note, resulting in six authentic modes and their plagal or complementary. In B the temperament of the Pythagorean coma is observed throughout the circle of fifths.

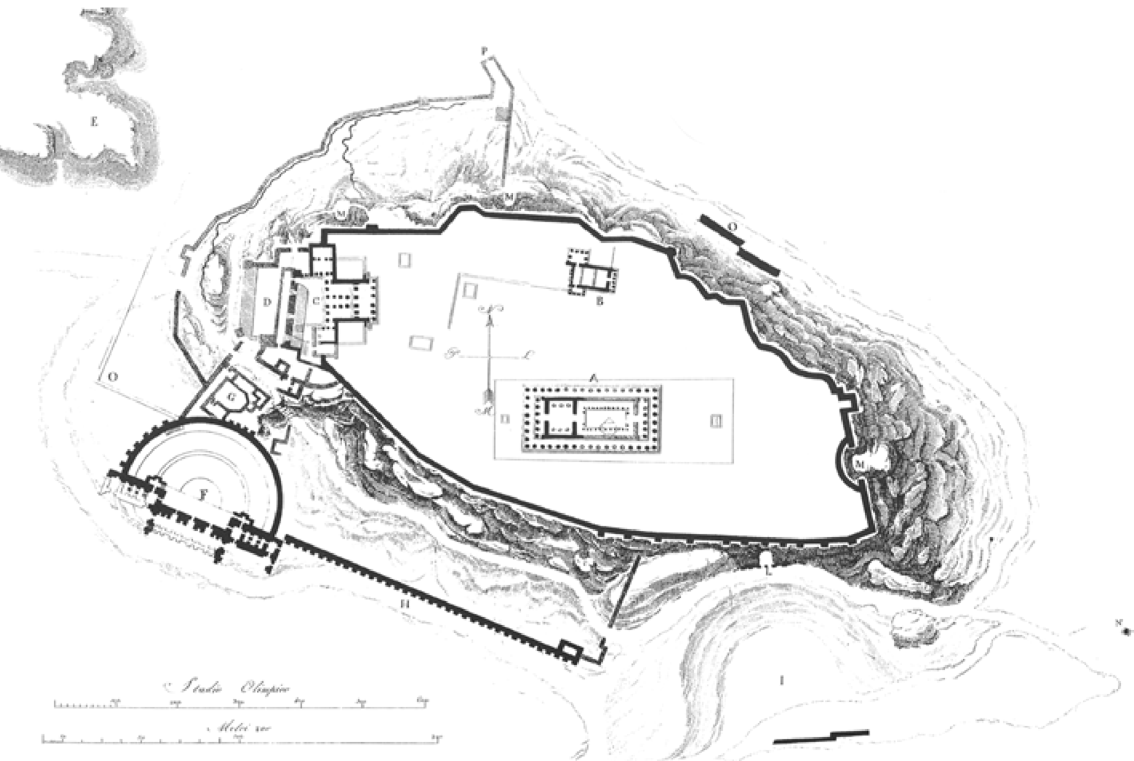
1 Ulrich. Pg. 178

2 Ulrich. Pg. 180

3 Ulrich. Pg. 183

Fig. 19. The Acropolis of Athens.

The Acropolis of Athens itself contains elements that are conceived from a purely metric order and which, at the same time, are inserted into a large esplanade where the resulting space follows a topological order. The Parthenon follows a rigorous metric order where the measurements between the columns in the two directions of the plane form a grid from which the position of the cell emerges. And at the same time it establishes relations with the other pieces of the ensemble that do not speak of a systematic order like that of Olinto. There is no will to create a metric order that serves to grow indefinitely. Rather, it seems as if the angles that crea-



"ecclesiastical modes" based on the fourth or four-chord interval, with a total of 8 modes.[1]

In the 17th century, the major and minor modes gradually displaced the ecclesiastical modes. The modern major-minor tonal system, however, could only be fully developed with the tempered tuning throughout the 17th-19th centuries, eliminating the differences (commas) of the previous systems by mathematically dividing the octave into 12 exactly equal parts. This tonal system survives to the present day.

The 20th century entered with force, displaying the diversity of avant-garde movements that predicted the elimination of all fundamental systems. However, some of the greatest exponents of these avant-garde movements continued to recognize that the step that had to be taken in music at that time was not one of arbitrariness, but of remaining faithful to a system. Igor Stravinsky, in 1940, when addressing the academy, placed order and discipline as supreme values instead of taste and meaning:

> During the extension of my course and at all times I will continually call upon your taste and sense for order and discipline. These - nourished, shaped, and sustained by positive notions - form the basis of what is called dogma.[2]
>
> […]
>
> Because it is not art that falls from the sky in the song of a bird, and art is, instead, without a doubt, the simplest modulation conducted correctly. Art, in its exact meaning, is a way of making works according to certain methods obtained, either by learning or by invention. And the methods are strict and determined ways that ensure the correctness of our operation.[3]

1 Ulrich. Pg. 189

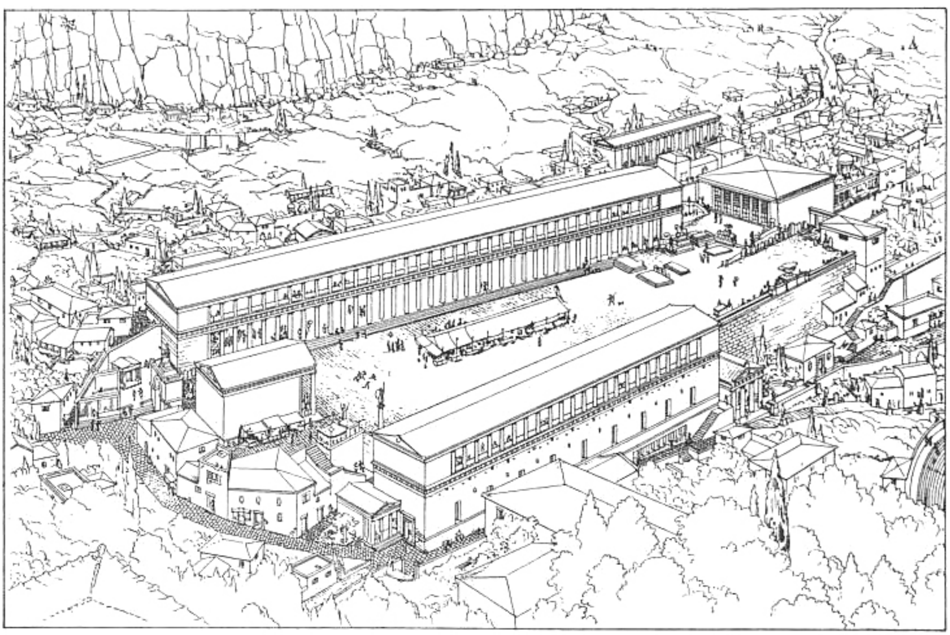
2 Stravinsky. Pg. 12

3 Stravinsky. Pg. 28

Fig. 20. Assos agora in a hypothetic reconstruction. A big void formed by the agora compared to the rest of the city and natural environment.

te the pieces together have the will to show from the entrance of the propileos that rhythm of the columns in foreshortening with all their power.

Cities like Ispahan, where the grouping of houses leaves interstices in the streets that are the result of the need for minimal passage, do not cease to have an echo in the African village. There, the mosques, houses of worship and temples are joined together, leaving only the space between them that is indispensable for the connection that leads to a large rectangular square, like an enclosure, and which reminds us of the Greek Agora, the place of public relations between people.

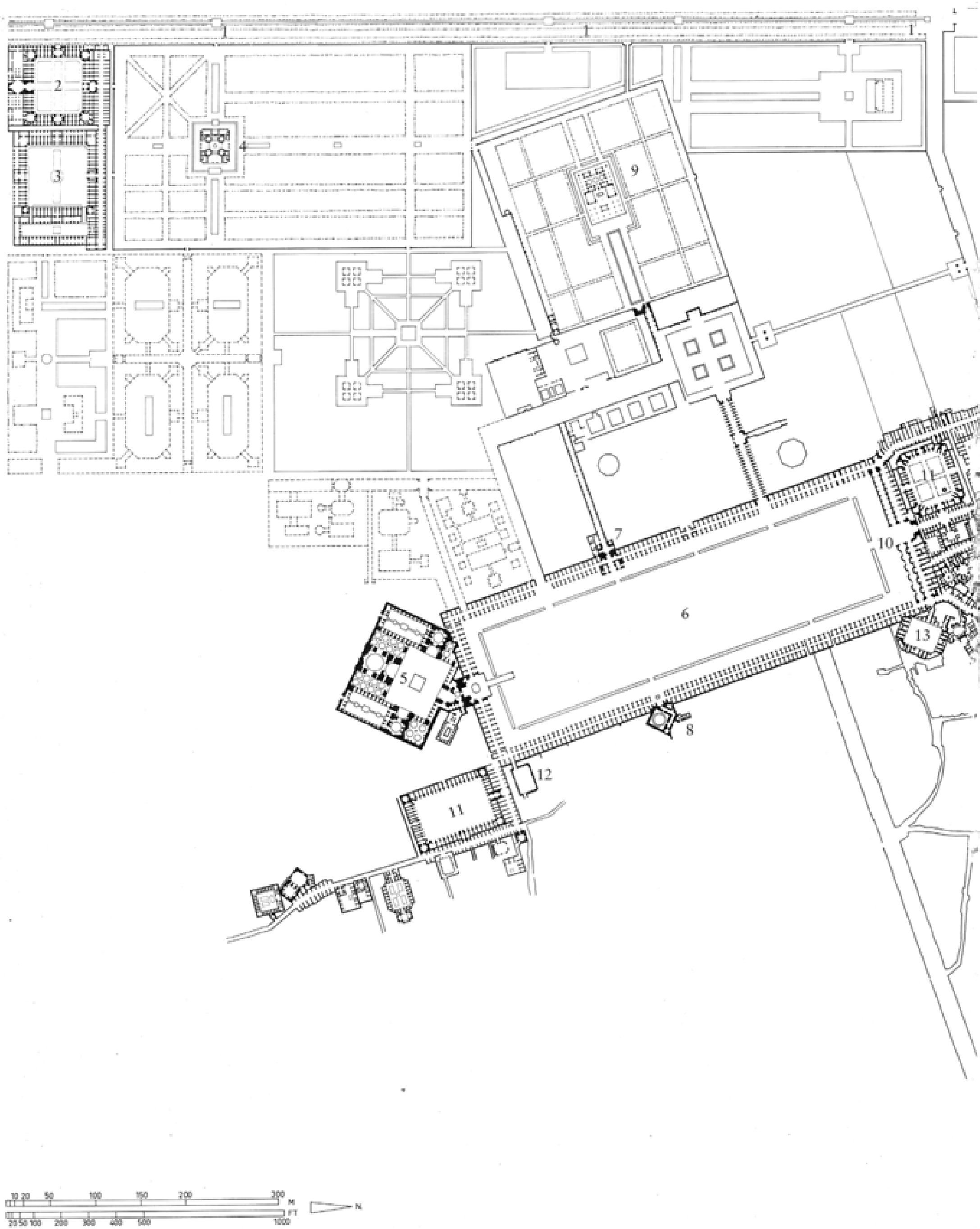


Stravinsky's words are blunt and they hit the nail on the head of the musical creation. For him, creative freedom is necessarily linked to the limit imposed on human activity. Without limits there is no freedom, indeed, from the limit one achieves true freedom:

> The old original sin was essentially a sin of knowledge; the new original sin, if I can express myself in this way, is, of course and above all, a sin of ignorance: ignorance of the truth and of the laws to which it gives rise, laws that we have called fundamental.
>
> […]
>
> The function of the creator is to sift through the elements he receives, because it is necessary for human activity to impose its limits on itself. The more art is watched, the more limited and worked on, the freer it is.
>
> […]
>
> Am I, therefore, obliged to lose myself in this abyss of freedom? What can I hold onto to escape the vertigo that attracts me to the virtuality of this infinite? But I must not perish. I will overcome my terror and become firm in the idea that I have seven notes of the range and their chromatic intervals, that the strong time and the weak time are at my disposal and that I thus have solid and concrete elements that offer me a field of experimentation as vast as the discomfort and the vertigo of the vertigo that frightened me before. From this field I will extract my roots, completely convinced that the combinations that have twelve sounds in each octave and all the varieties of rhythm promise me riches that all the activity of the human genius will never exhaust.[1]

Stravinsky was not the only one who thought in this way that it may seem only proper to the musical currents that have their sources of inspiration in the classical masters. The initiator of so-called dodecaphonic music, Arnold Schönberg, who in his mature work erased the classical relationships be-

1 Stravinsky. Pg. 51, 66-67



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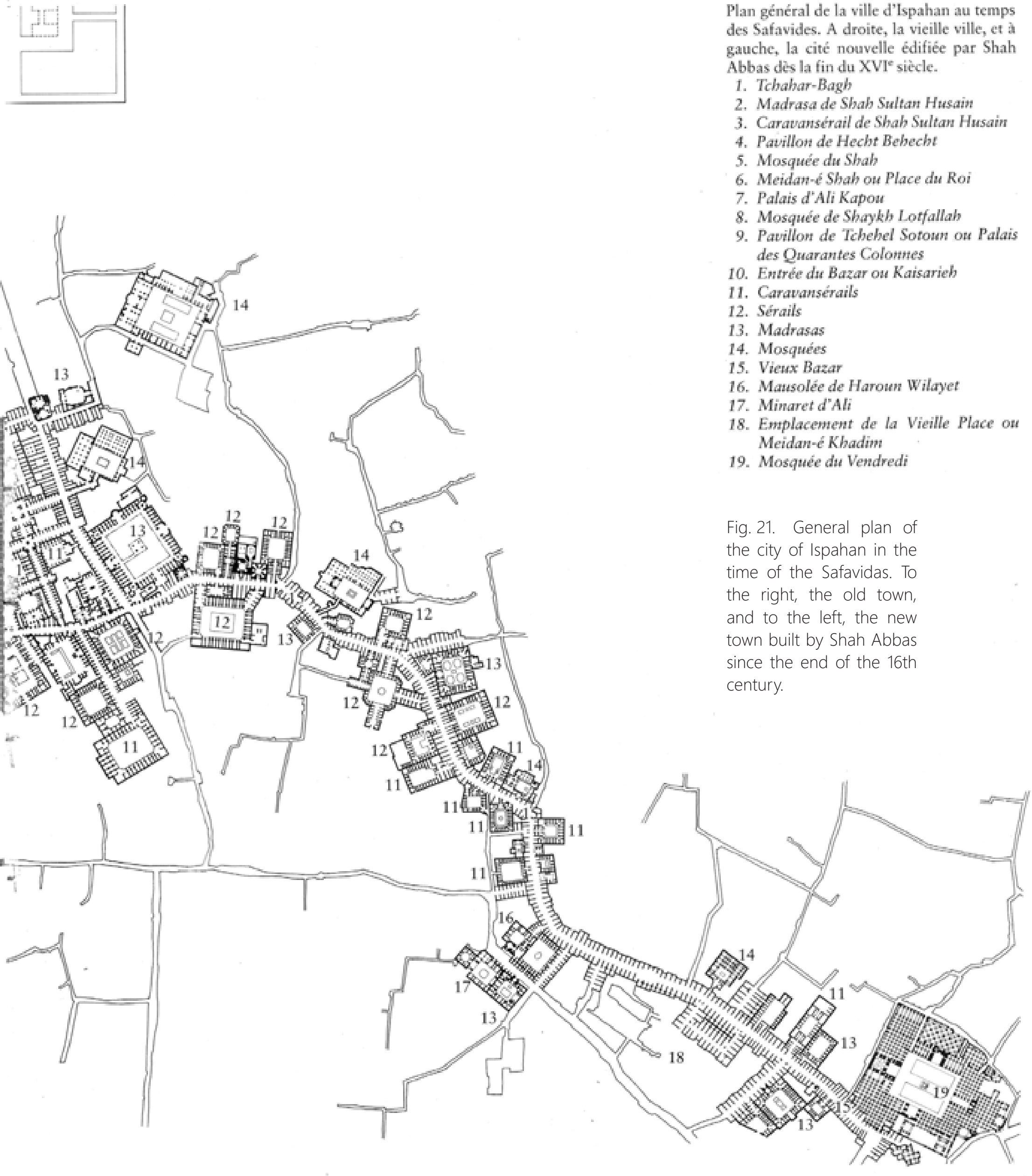


Plan général de la ville d'Ispahan au temps des Safavides. A droite, la vieille ville, et à gauche, la cité nouvelle édifiée par Shah Abbas dès la fin du XVI[e] siècle.

1. *Tchahar-Bagh*
2. *Madrasa de Shah Sultan Husain*
3. *Caravansérail de Shah Sultan Husain*
4. *Pavillon de Hecht Behecht*
5. *Mosquée du Shah*
6. *Meidan-é Shah ou Place du Roi*
7. *Palais d'Ali Kapou*
8. *Mosquée de Shaykh Lotfallah*
9. *Pavillon de Tchehel Sotoun ou Palais des Quarantes Colonnes*
10. *Entrée du Bazar ou Kaisarieh*
11. *Caravansérails*
12. *Sérails*
13. *Madrasas*
14. *Mosquées*
15. *Vieux Bazar*
16. *Mausolée de Haroun Wilayet*
17. *Minaret d'Ali*
18. *Emplacement de la Vieille Place ou Meidan-é Khadim*
19. *Mosquée du Vendredi*

Fig. 21. General plan of the city of Ispahan in the time of the Safavidas. To the right, the old town, and to the left, the new town built by Shah Abbas since the end of the 16th century.

tween the heights of sounds to build a new musical language, kept alive, in 1975, the awareness that the work needs an intelligible discourse based on the relationships between its parts:

Fig. 22. Opposite page: aerial view of the city of Isfahan.

> Used in an aesthetic sense, the word form means that a piece is "organized", that is, it consists of elements that function like those of a living "organism".
>
> Without organization, music would be an amorphous mass, as unintelligible as an essay without punctuation marks, or as unconnected as a conversation that jumps from one subject to another without purpose.
>
> The fundamental requirements for the creation of an intelligible form are "logic" and "coherence". The presentation, development and interconnection of ideas must be based on a "kinship" or relationship. Ideas should be differentiated according to their importance and function.
>
> […]
>
> Freedom works best when it's under control.[1]

But even those tendencies that have put chance as the basis of musical composition and that have John Cage as their main precursor, look for a system or method to produce their works:

> In writing these sounds [produced electronically], as well as writing for percussion instruments alone, the composer is dealing with materials that do not fit into orthodox scales and harmonies. It is therefore necessary to find some other way of organizing than this one used for symphonic instruments. [...] A method analogous to the twelve-note system may be useful, but, [...] because of the nature of the materials involved, and because their characteristics of duration can be easily controlled and related, the means are more than likely to be rhythmic.[2]

The system of cards that include indetermination or new notations are the "methods" Cage was looking

1 Schönberg, *Fundamentos de composición*

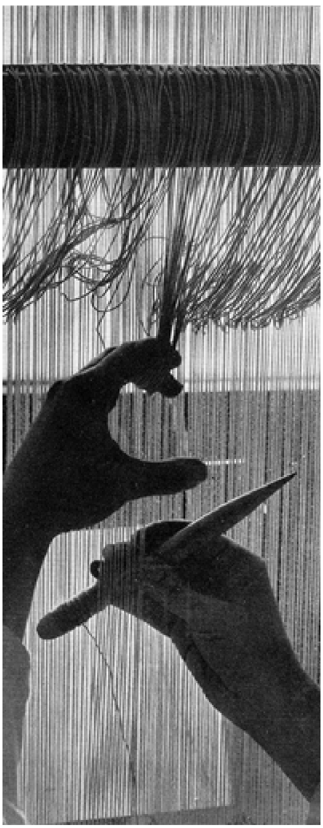
2 Cage, John, 1942

Fig. 23. The act of weaving requires some systematic movements so that the weft passes between the warp which are the base and indispensable condition to produce the desired fabric.

1.4.2. The systematic in architecture

The map of the city of Ispahan that we have just seen is very revealing to speak of the systematic in architecture. Let us take it as an example of the following statements that serve to explain the systematic aspect of architecture, that is, that which allows us to see it as a system of relations.

We have already made a distinction between natural objects and cultural objects that helps us to understand the distinction between natural and artificial languages. While we inherit natural languages, we build artifitial ones. Natural languages are what we speak every day,



> these complex instruments of communication that only generative grammars today seem capable of describing in a relatively appropriate way, these languages which, rudimentary in nature, are made up of a lexicon - an end - and a set of rules that allow the elements of this lexicon to be combined to the infinite.
>
> […]
>
> What we are laxly calling "artificial languages" are generally precision languages, artificial means of expression constructed by scientists in order to formulate more accurately the relationships between the objects studied by their respective sciences. [1]

The pure structure, that is to say, the systems of relations are what logicians, like Alfredo Deaño, call "logical calculation", which are composed of the following:

1 Alfredo Deaño, *Introducción a La Lógica Formal* (Madrid: Alianza Editorial, S.A., 1999).

for. They later derived into "serial music", which, by assimilating series of sounds to series of times, dynamics and timbres, turns the work into a systematized product. This method came to an end just under a decade after its invention.

1.5.2. The systematic in music

The history of music shows, then, that there is no music without prior awareness and application of certain laws to the shapeless sound obtained from nature. These laws may change or be perfected over time. The systems adapt to the discoveries of the time and the consciousness with them. But the systematic nature of music, as a human creation, remains.

Let's take Bach's fugue as an example of the following statements that serve to explain the systematic side of music, that is, the one that allows us to see it as a system of relationships. To do so, we will follow the same process that is being carried out in this same document with the architecture. It is therefore recommended to read both parts in parallel.

We recall once again the distinction between natural and cultural objects that we have made in the past[1] and that serves to distinguish between natural and artificial languages. Well, artificial languages are those that are scientifically constructed to formulate more accurately the relationships between the objects studied. Logics call relationship systems "logical calculation", which are pure structure and are made up of the following (see definitions on the opposite page):

1 See Alfredo Deaño's definition of natural and artificial languages in supra. Page 36.

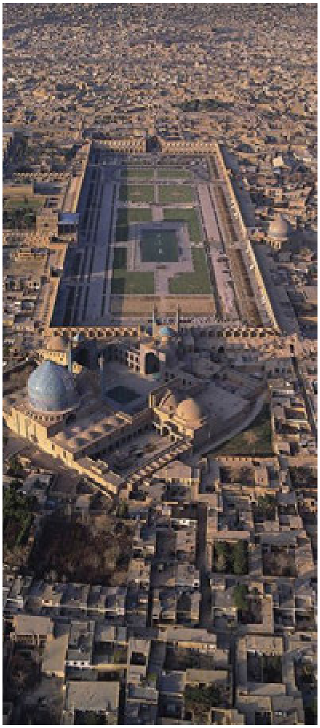


Fig. 24. Aerial view of the city of Ispahan.

1. A set of primitive elements. They are the parts to be handled within the system. It is absolutely essential to point out that this set of primitive elements must be defined in an effective way, that is, that we can discern it from any object from the set in question. For example, the set of squares in the city of Isfahan is not an effectively defined set: there are many cases that would raise serious doubts, such as those that mix with the interior space of mosques. For this purpose we can: a) list them exhaustively (the King's Square, the courtyard of the Friday Mosque, etc.); or b) define the complex by means of a sufficiently precise property to allow a decision in the sense indicated: "The set of enclosed spaces in their horizontal dimension and open in their vertical dimension", that is to say the set of enclosures.

2. A set of rules - "rules of formation" or "rules of construction" - that establish what are the possible correct combinations of these elementary symbols. The set of training rules must provide an effective definition of the notion of well-formed expression in the calculation, so that it is possible, in the face of any combination of symbols, to say whether or not it is a well-constructed formula. It is a perfect occurrence in spoken language to understand that the phrase "so welcome, but singularly metempsychic bureaucrats" is poorly constructed. Similarly, the "enclosure" element is constructed only by placing vertical boundaries on a given horizontal plane and not by placing vertical boundary sheets hanging from a balloon.

3. A set of "transformation rules". By applying

1. A set of primitive elements. For example, the set of sound events or notes that are defined by having a specific height and duration.

2. A set of rules - “rules of formation” or “rules of construction” - that establish what are the possible correct combinations of these elementary symbols. The laws of harmony govern the harmony and dissonance between combinations of notes, the laws of rhythm govern the times between notes, etc.

3. A set of “transformation rules”. By applying them, we can transform a well-constructed combination of elements into another combination that will be equally well-constructed. Direct, inverse or retrograde imitation, by augmentation, by diminution, canonical imitation, invertible counterpoint, stretto or episode are all counterpoint procedures that transform well-constructed note combinations into other well-constructed note combinations.

If we transform this logical calculation into a language by interpreting its symbols, we turn it not into a natural language, but into an artificial one. In the case of Bach’s escape, we could say that those elements that we have called notes, which are abstract and opaque elements, can be given meaning, that is to say that the notes designate a sound with a certain timbre and intensity. [1] This is where they come in, from the powerful sound of the pipe organ to the delicacy of a harpsichord. An artificial language with a logical calculation structure is what we call a formalized language.

But we have done the opposite of what we usually do. If the first entry to music can be by extension

1 See and listen in the following page an example of Bach’s fuge.

> them, we can transform a well-constructed combination of elements into another combination that will be equally well-constructed. If you reverse the order of the enclosure that surrounds the porch in the Roman Forum you obtain a Hypetro Peripterous Temple, where the porch surrounds the enclosure, as Professor Antonio Armesto explains.

Deaño goes on to explain that a calculation is not, therefore, a language, insofar as it is not a means of communication, but a pure syntactic framework. Its elements are meaningless. They are not signs, but opaque entities that we manipulate according to a series of rules. We can, however, transform a calculation into a language by interpreting its symbols, giving its symbols a meaning. In the case of the city of Ispahan, we could say that those elements that we have called enclosures, which are abstract and opaque elements, can be given meaning, that is, that the enclosures will designate enclosed spaces in their horizontal dimension and open in their vertical dimension. This is where the courtyards of the mosques and madrasas enter the courtyards of the houses themselves.

Now we're not running a pure calculus anymore. By interpreting its symbols, we have turned calculus into a language. However, it is not a language like Spanish, Batu or Servo-Croatian. It is not a natural language, but a formalized language, a language with a calculation structure, as Deaño shows us.

But we have done the opposite of what we usually do. If the first entry into architecture can be by extension - which consists of collecting the wonders of architecture -, the second entry can be by condensation - which consists of seeing what those won-

- which is to collect the wonders of music - the second entry can be by condensation - which is to see what those wonders have in common. Both entries are complementary. We are interested in this last entry, however, because the first one is very busy as there may be as many jobs as there are individuals that take millions of years to collect the immense variety. On the other hand, delving into the fundamentals that all music shares brings us a little closer to the way of being of the discipline, to the system that sustains it. In this way, the systematic is not only proposed as an instrument for the analysis of existing music, but also becomes, and here lies the interest, a method of musical creation that supports individual creation.

Fig. 25. In Fugue XIV of Johann Sebastian Bach's Well-Tempered Clavier we explicitly see the three components of logical calculation. In red and green we see the apparitions of the primitive elements - the subject and the counter-subject -. The training rules allow the subject and counter-subject to be combined simultaneously. Finally, the rules of transformation modify the relative position of the subject and counter-subject, generating new positions of these by cutting them out, lengthening them, or moving them to the point where a fragment of the subject, in blue, becomes a new motif of connection.

#. *Fugue XIV.* J. S. Bach. Minute 00´50´´

ders have in common. Both entries are complementary. However, we are interested in this last entry, because the first one is very busy, as there may be as many jobs as there are individuals who take millions of years to collect the immense variety. On the other hand, delving into the foundations that all architecture shares brings us a little closer to the way of being of the discipline, to the system that sustains it. In this way, the systematic is not only proposed as an instrument of analysis of the constructed reality, but it becomes, and here lies the interest, in a method of architectural creation.

1.4.3. The logical elements of architecture

Professor Dr. Antonio Armesto presented one of the chapters of his doctoral thesis: *El aula sincrónica. Un ensayo sobre el análisis en arquitectura* [1], the possibility of drawing up a Logical Table from the elements of Architecture, defined in his thesis (Hall/Enclosure/Porch). This table - already initiated by him - would show architecture in history as a syntactic game, an *ars combinatoria*, in a more analytical way than that provided by the typological procedure, providing very useful support for the work of the Project and a greater knowledge of the ethos of architecture.

To refer to the elements of Architecture, we will quote a fragment of its definition in this thesis:

> The enclosure is defined as an architectural arrangement that constrains or limits the dimensions x-y and leaves the z dimension free.
>
> The portico, complementary to the enclosure, limits the size z, and leaves the dimensions x-y free, not determined.

1 Antonio Armesto, *EL AULA SINCRÓNICA. Un ensayo sobre el análisis en arquitectura.* (Barcelona. ETSAB: Tesis doctoral, 1993).

1.5.3. The logical elements of music

The definition of the logical elements of music changes between different authors. Rhythm, time, melody, harmony, timbre, sound, dynamics or form are some of the terms used to define the elements.

One of the authors who best defines these elements is Aaron Copland in his book Cómo escuchar la música, in which he argues that:

> Music has four essential elements: rhythm, melody, harmony and timbre. These four ingredients constitute the composer's materials. He works with them in the same way as any other artisan works with his own. From the lay listener's point of view, they have only a limited value, since that listener rarely realizes any one of them separately. In their combined effect - the seemingly inextricable sound network they form - what matters most to listeners.[1]

But if we want to be rigorous we cannot put all these terms on the same plane; we discover that there is a prevalence among them. Pierre Schaeffer, in his Tradition of Musical Objects, explains that when an instrument is played primitively,

> (...), prior to any codification of the rhythmic or melodic structures, we see four games appear: two of them are relatively explicit, the one of the rhythms and the one of the heights; the other two, the one of the timbres and the one of the intensities, are implicit. Finally, we can classify these four levels of intervention as dominant.[2]

Despite this disparity of opinions, most authors seem to agree that music is composed of a horizontal axis, which is time, and a vertical axis, which is sound. Within the dimension of time we can include different facets that qualify it, such as rhythm,

Fig. 26. Opposite page. Enclosure: Amphitheatre of Pompeii.

Fig. 27. Opposite page. Porch: Hippodrome of La Zarzuela. Eduardo Torroja.

Fig. 28. Opposite page. Hall: lobby of the National Bank of Denmark. Jakobsen.

1 Aaron Copland, *Cómo escuchar la música* (United Estates of America: McGraw-Hill Book Company, 1994).

2 Pierre Schaeffer, *Tratado de Los Objetos Musicales* (Madrid: Alianza Música, 1988). Pg. 35

The hall would result from the sum of the topological constraints or boundaries of its components, determining the space in x, y, z.

It could also be characterized as part of a more complex whole that would be the classroom, thus expressing a commutative property, a reversibility. The complexity of the elements referred to above is due precisely to this condition of a structured whole, of a system, which they form together.

[…]

The enclosure consists, then, of that arrangement that determines a soil region but leaves the vertical dimension undefined. According to this, any procedure that would define a soil region would create an enclosure, not being necessary, for the moment, to erect or elevate anything. What is important is the idea of soil limitation and the way in which it is carried out.

It is thought possible to build enclosures within other enclosures in an indefinite number.

The porch is a ceiling above the floor and determines what the enclosure left undefined. The essence of the porch, at this level of the definition, is the existence of the roof and it does not matter, for now, how it is sustained.

Porches can be stacked on top of each other indefinitely so that the floor of one becomes the ceiling of the other.

The hall performs the total constriction, defining a region within the general space, a capable vessel containing a portion of atmosphere, soil and sky, a volume. The hall, defined as a radical, three-dimensional limit, is not a denial of space but the creation of a true universe, a kind of sensitive homotecia of the Universe or a part of it that somehow contains it.

A hall may contain others in indefinite number and in different dispositions. [1]

If we look for examples of the enclosure we find from the minimum expression of the carpet, the marks of the football field on the ground, the fence

1 Armesto, *EL AULA SINCRÓNICA. Un ensayo sobre el análisis en arquitectura.*

meter, tempo, agogy, etc. Likewise, within the dimension of sound, we can include melody, harmony, dynamics, timbre, etc. For this purpose, Igor Stravinsky, in his Poetics of Music, states that:

> The musical phenomenon is nothing but a phenomenon of speculation. This expression should not frighten you in the least. It simply presupposes, at the basis of the musical creation, a previous search, a will that is placed beforehand in an abstract plane, in order to give form to a concrete matter. The elements that necessarily concern this speculation are the elements of sound and time. The music is unimaginable, detached from them.[1]

The musical note seems to be the one that gathers these two elements: in it a precise portion of height is condensed with a concrete portion of time. For Schaeffer, it is the parallel to the phoneme:

> Its relevant features will be the height and duration that play a functional role in musical structures.[2]

The musical note is a fragment of a melody. At the same time, it contains various harmonies linked to it, has a specific duration, is played by a particular timbre and provides it with a specific dynamic. It therefore contains all possible elements combined and condensed. Taking as an example a parallelism with chemistry we could say that

> Chemistry calls water H2O. But that H2O appears in a continuous chain of situations, each of which represents a link between links. The cloud, the raindrop, the drizzle, the rain and the downpour; the snowy field and the simple snow crystal, the sleet, the hail and the ice; the fog and the dew; the spring, the stream, the stream, the ocean; the steam and the mist: which is the real H2O of them all? It is liquid, solid and gaseous; it is colorless, greenish and dark blue. Even the rainbow is H2O under certain conditions. Let us put the note

Fig. 29. Opposite page. Enclosure: Neuendorf house. John Pawson.

Fig. 30. Opposite page. Porch: Nordic pavilion at the Venice Biennale. Sverre Fehn.

Fig. 31. Opposite page. Hall: philharmonic of Berlin. Hans Scharoun.

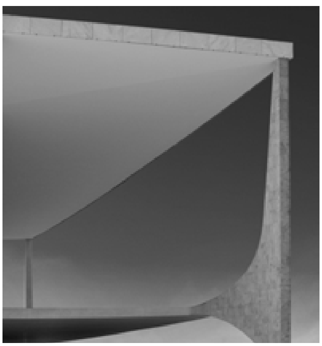
1 Stravinsky. Pg. 31-32

2 Stravinsky. Pg. 174

of the property, the bathtub, the empty swimming pool, the hedge fence, the patio of the house, the square, the hortus conclusus, the circle around the fire, the clearing of the forest, etc.

Examples of porches include the hat, umbrella, canopy, pergola, shade, treetop, vine arbour, covered terrace, loggia, gallery, well, etc.

Finally, the minimum expression of the classroom is the coffin or the funerary glass, and in larger scales we find it in the room, the complete house, the theatre hall, the sports hall, the church, the cell of the Greek temple, the English hall or the French salle, the guard house, the igloo, the hut, etc.



The enclosure is characterised by the fact that it restricts the horizontal dimension and leaves the view of the whole sky free. In a way, the more you restrict horizontal vision, the less eye contact you have with your neighbor, but in return you offer me the entire infinite sky cut out by the edge of the enclosure.

The porch is characterised by the fact that it constrains the vertical dimension and leaves the horizontal view free. The porch takes over the infinity of the horizon and puts it in the visual field of the inhabitant.

The hall is characterised by the fact that it constrains the two dimensions of space. Having no visual contact with either the horizon or the sky creates a new horizon and sky that define this microcosm of the interior of the classroom. There, a new world is emerging to be discovered. It follows that the more space is restricted, the more it is given the character of a new world, the more that new domesticated atmosphere appears, which is architecture.

> in the place of the molecule and we will find ourselves before the multiplicity of its manifestations.[1]

We could say that the musical note is the minimum expression of complete music. However, there are other structures that combine these two basic elements and form a unit with meaning, and from smaller to larger scale are the cell, the motif, the phrase, the period, the section, the movement, or the entire work. It is therefore necessary to find a term that designates all these units as complete, that is, the musical unit in which their sound and time are perfectly defined. For the moment, we give the note that status. However, we are looking for terms that have these characteristics and that also encompass several scales at the same time, that do not have the specificity of a specific size, but that, unlike the note, are capable of retaining the concept of a specific idea without having to resort to a specific size.

For this purpose, we have used the German term leitmotiv. According to White, the reason is "the smallest structural unit with a thematic identity". It is true that the word leitmotiv has operatic connotations linked to Wagner, but we want to adhere to Adorno's observation of the false use of the word, since the motif cannot be simultaneously the bearer of the expression and the musical "gesture" because this reduces the emotional content to the mechanical process. He notes that even in Wagner's day the public made a crude relationship between the leitmotivs and the people he characterized because people's innate mental processes did not necessarily correspond to Wagner's subtle intentions or opti-

Fig. 32. Opposite page. Enclosure: Attic Beistegui, Paris. Le Corbusier.

Fig. 33. Opposite page. Porch: Federal Supreme Court, Brasília. Oscar Niemeyer

Fig. 34. Opposite page. Hall: Bagsvaerd Church, Copenhagen. Jörn Utzon

1 Ernst Toch, *Elementos Constitutivos de La Música* (Barcelona: Idea Books, 2001).

mistic expectations. That's it, go on:

> The degeneration of the leitmotif is implicit in this.... It comes directly from film music, where the only function of the leitmotif is to announce heroes or situations to allow the audience to find their way more easily.[1]

The leitmotif should not, therefore, be associated with the presentation of a character in an opera. The leitmotif is somewhat more generic. In German, the leit- prefix means "thread". Leitmotiv embodies the idea of a driving motif, a motif, a theme or a theme around which the musical work unfolds. A leitmotif can be an interval, a chord, a timbre, a rhythm, a musical phrase or a short melody. Here is the key to giving it the privileged position we are looking for: an element that, admitting several scales of size at the same time, is capable of containing sound and time perfectly defined.

Thus, the basic elements of music are summarized as follows:

The rhythm. It delineates the horizontal dimension of music, time, and constrains it.

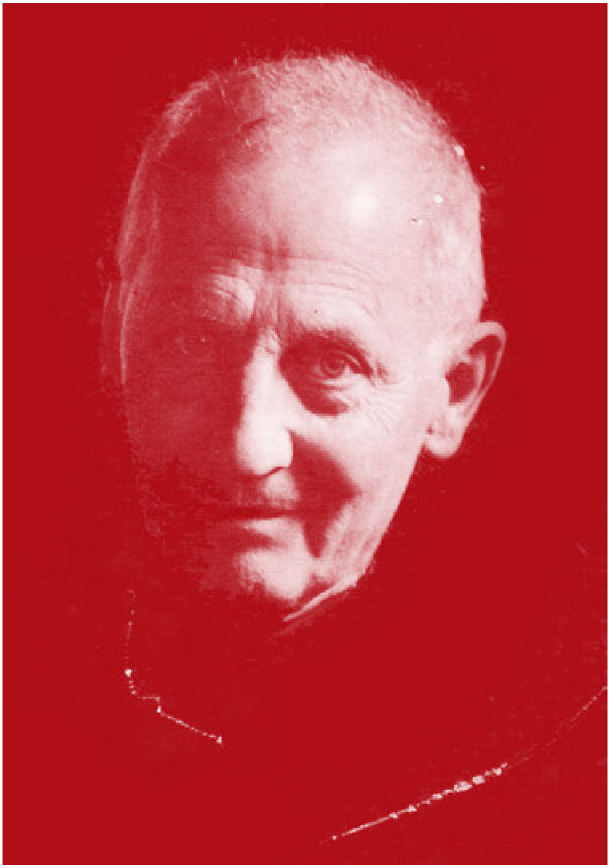
The harmony. It delineates the vertical dimension of music, sound, and constrains it.

The note or leitmotif. It limits both time and sound. It is the cell, the motif, the phrase, the period, the section or the whole work. It is, by antonomasia, the first element, containing all other elements.

Fig. 35. Opposite page. A clean and lightful hall: Church in Aachen by Rudolf Scwarz.

1 Theodor Adorno, *In Search of Wagner* (London, 2005).

1.6. Case study: DOM HANS VAN DER LAAN



1.7. Case study: OLIVIER MESSIAEN

Fig. 36. Van der Laan in his own work exposition in 1982.

About this Benedictine monk, Richard Padovan explains that "he dedicated himself to the search for the primitive origins of architecture: to that fundamental link between the technical art of building and our need to define and arrange the space around us, without which he himself believed that neither education nor practice was possible".[1] Born in 1904, his generation ran after the leaders of the modern movement, many of whom were born in the 1980s. He began his studies of architecture in 1923, after having studied one year of mathematics.

Many stories of modern architecture begin around 1750, with the beginning of the industrial revolution, the beginnings of romanticism, and the emergence of radical theorists and designers such as Lodoli, Laugier, Piranesi, Boullée, Ledoux, etc. But the fact is that the modern movement only emerged a century and a half later, around 1920. During the second half of the 20th century, theorists and historians such as Kaufmann, Pevsner and Giedion coined the term modern architecture as a search for unity and objectivity. However, since everything built in a given period of time is an unavoidable fact in the history of architecture, modern architecture is inevitably multiple and discontinuous, and cannot be fully identified with the modern movement. However, the decision to take 1750 as the beginning of the modern era is not entirely arbitrary; at that time there were recurrent trends. Among these themes, perhaps the most important is the search for an authentic root, a primitive origin from which everything new would emerge.[2]

1 Richard Padovan, *Dom Hans van Der Laan: Modern Primitive* (Amsterdam: Architecture & Natura Press, 1994).

2 Padovan. Pg. 16

Olivier Messiaen was born on December 10, 1908 in Avignon. His mother was the poet Cecile Sauvage. His father was an English teacher, renowned for his translations of Shakespeare's complete works, and from him he acquired a love of the English author's works, which he vigorously declaimed, while from his mother a love of poetry and fantastic stories.

His taste for music was awakened a little later by the scores of Faust Damnation by Bruckner and Mozart's Don Giovanni, which he received as a gift on Christmas 1916. Two years later, the Messaiens moved to Nantes and there young Olivier attended harmony classes with Jehan de Gibon. What Messiaen most appreciated about him was that at the age of ten he gave him the birth of Debussy's Pelléas et Mélisande; in Messiaen's own words he was "a real bomb... probably the most decisive influence of my life". In 1919 his father moved to Grenoble, taking the family to the mountains, which were his main source of inspiration. In the same year, Messiaen entered the Paris Conservatory. Since then, his musical education followed the normal paths, although always with points in the path that made him stand out over a traditional education. Between 1926 and 1929, he won 5 awards and still had time to devote himself to the study of Hindu rhythms, Greek modes, and Gregorian chant.

Finally, or perhaps in the first place, through these influences and activities, Messiaen maintained one of his threads without breaking it throughout his life. "I am fortunate," he said, "to be a Catholic; I was born a believer... a great number of my works are dedicated to shedding light on the theological truths of the Catholic faith. This is the most

Fig. 37. Olivier Messiaen in 1930.

Fig. 38. Van der Laan in frnt of the staircase of the first cloister of the church of Vaals.

Van der Laan was completely detached from the notion of historical progress on which the modern movement was based. In this sense, Van der Laan was more than modern, he was primitive. While the primitive perspective diverges from a point of origin, the modernist one converges towards unity. For this reason, "the primitivist vision not only embraces diversity, but explains it".[1] This is not a question of primitivism': a superficial imitation of archaic tribal models. The primitive here implies "archetypal" rather than "archaic":

> ...to descend to the fundamentals of architecture - to follow the functional condition to which the house first responds.[2]

There is no doubt, then, that we are dealing with a unique character. Freely removed from public life, subject of his own free will to the Benedictine rule, he traversed the fundamentals of architecture, responding from his point of view to the claim what Laugier himself had made years earlier:

> We have too many treatises on architecture, in which the measurements and proportions are developed with enough accuracy, the different orders treated in detail, and the models provided for all kinds of construction techniques. But we do not yet have a single work that firmly establishes the principles of architecture, that manifests its true spirit, or that provides rules capable of directing talent and establishing taste. It seems to me that in arts that are not purely mechanical, it is not enough to know how to work; it is above all important to learn how to think.[3]

1 Padovan. Pg. 18

2 Van der Laan, letter to Richard Padovan (August 6, 1938). In Padovan. Pg. 17

3 Laugier, *Essai Sur l'Architecture*. Pg. xxxiii

important aspect of my music.... perhaps the only one I will not be ashamed of for the rest of my life."[1]

To understand the way Messiaen developed as a composer, it is necessary to bear in mind that his roots lie in Debussy's anti-symphonic vision rather than in the 19th century symphonic tradition. At the Paris Conservatory he was trained in traditional musical forms, including fugue and sonata, but the approach to these forms seems to reside more in their section structure than in their organic content:

> In 1942, Messiaen published his theoretical treatise Technique de mon langage musical in which he exposes the main characters of his early musical language. His sectional, rather than organic, conception of traditional forms, especially the sonata form, is revealed in his discussion of his own procedures derived from these traditional forms. The situation could hardly be otherwise, since a traditional symphonic process grew from a harmonic practice that depended on the progressions and on the tensions and relaxations created by the principle of dissonance and resolution. For Messiaen, on the other hand, harmony is more decorative than functional, and tonality is absorbed by a broader conception of modality. This fact endows his music with a quality more static than dynamic, his harmony exists in a state of neither tension nor relaxation - the atmosphere of movement is captured and transfigured in an absence of time that is implicit in the music itself. The result is a harmony in which writing does not really have a function, a harmony that is totally vertical rather than horizontal.[2]

Fig. 39. Messiaen immersed in a "natural" dictation of the singing of birds.

1 Roger Nichols, *MESSIAEN* (London: Oxford University Press, 1975).

2 Musical forms are models abstracted from works of art. They try to capture structural and architectural relationships under multiple aspects. Fugue and sonata are considered one of the most important musical forms in the history of music. The fugue, (from the lat., fugue -of some voices over others-) was initially a mere denomination of the canonical style of writing, where the different voices appear consecutively carrying the theme of the work, or subject. For a compact explanation of the main musical forms and genres see: Ulrich.: Michels Ulrich, *Atlas de Música, I* (Madrid: Alianza Editorial, 1982). p. 109.

1900

Nace en __ 1904

1929 MIES VAN DER ROHE *Pabellón Barcelona*

Capilla de Saint Salvator en Baarle-Nassau 1929
1930

1937 ALVAR AALTO. *Villa Mairea*

Ala de invitados del noviciado benedictino en Oosterhout 1938

1946 LE CORBUSIER. *La Tourette*

Capilla de Saint Joseph en Helmond 1948

1953 LE CORBUSIER. *Ronchamp*

Abadía de San Benedictusberg en Mamelis, Vaals 1956
1957
1958
1959

1960 ARNE JACOBSEN. *Hotel SAS*

1960
1961
1962
1963
1964
1965
1966

Het plastisch getal 1967 Iglesia de la abadía de San Benedictusberg en Mamelis, Vaals 1967
1968

Casa Jos Naalden en Best 1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982

Abadía de Rossenberg en Waasmunster, Bélgica 1972
1973
1974

De architectonische ruimte 1977 Iglesia de Bethlem en Breda 1977
1978
1979

Het vormenspel der liturgie 1985

Monasterio Benedictino en Tomelilla, Suiza 1986
1987
1988
1989
1990

Muere en Vaals 1991

2000

1900

1908 Nace en Aviñón

ÍGOR STRAVINSKY *La consagración de la Primavera* 1913

1928 *Le banquet celeste*
1929 *Huit préludes*
1930 *Trois mélodies, La Mort du nombre, Diptyque, Les Offrandes oubilées*
1931 *Le Tombeau resplendissant*
1932 *Hymne, Thème et variations, Fantaisie burlesque, Apparition de l'Église éternelle*
1933 *L'Ascension (orchestre)*
1934 *L'Ascensión (orgue)*
1935 *Pièce pour le tombeau de Paul Dukas, Vocalise, La Nativité du Seigneur*
1936 *Poèmes pour Mi*
1937 *Poèmes pour Mi,* ***O Sacrum Convivium****, Fêtes des belles eaux*
DMITRI SHOSTAKOVICH. *Sinfonía nº 3* 1953
1938 *Chants de terre et de ciel*
1939 *Les Corps glorieux*

1941 *Quartor pour la fin du Temps*
1942 *Technique de mon langage musical*
1943 *Rondeau, Visions de l'Amen*
1944 *Trois petites liturgies de la Présence divine, Vingt regards sur l'Enfant Jésus*
1945 *Harawi*
1946 *Chant des déportés,* **Turangalîla-Symphonie** *(hasta 1948)*
IANNIS XENKAIS. *Metastaseis* 1946

1948 *Cinq rechants*
1949 *Cantéyodjaya*
1950 *Quatre études de rythme, Messe de la Pentecôte*
1951 *Livre d'orgue, Le Merle noir*
1952 *Timbres-durées*
1953 *Réveil ds oiseaux*
DMITRI SHOSTAKOVICH, *Sinfonía nº 10* 1953

1955 *Oiseaux exotiques*
1956 *Catalogue d'oiseaux* (hasta 1958)

1959 *Chronochromie* (hasta 1960)
1960 *Verset pour la fête de la Dédicace*
1961 *Sept haikaï*

1963 *Coleurs de la Cité céleste*
1964 *Et expecto resurrectionem mortuorum*
1965 *La Transfiguration de Notre-Seigneur Jésu-Christ* (hasta 1969)
WITOLD LUTOSLAWSKI, *Sinfonía nº 2* 1967

1969 *Neuf méditations sur le Mystère de la Sainte Trinité*
1970 *La Fauvette des jardins*
1971 *Des canyons aux étoiles...*
1972
1973
1974
1975 *Saint Françoise d'Assise* (hasta 1983)

1984 *Livre du Saint Sacrement*
1985 *Petites esquisses d'oiseaux*
1986 *Un vitrail et des oiseaux*
1987 *La Ville d'en haut*
1988 *Un sourire*

1991 *Pièce pour piano et quartuor à cordes, Concert à quatre, Éclairs sur l'Au-delà*
1992 Muere en París, Francia

2000

1.8. The Plastic Number

1.8.1. The mid-point

Van der Laan left his architectural studies at the end of his third year in Delft, and the following year, in 1927, he entered the Benedictine Abbey of St. Paul in Oosterhout, five kilometres north-east of Breda, as a novice. It was a sister house of the abbey of Solesmes in France, founded in 1833 by the monastic and liturgical reformer Dom Prosper Gueranger.

What Van der Laan left as a legacy to the Benedictines, and what he learned from them, was not a severe asceticism but the principle of order and measure, the middle way. In fact, in a letter about the church of the Abbey of Vaals, Van der Laan specifically related its design to the principle of moderation of St. Benedict:

> It was natural for us, with this first great building, to limit ourselves to the first and most obvious aspects of the theory and, therefore, to place the emphasis on Vitrubio's "modicum", which so closely corresponds to the vision of St. Benedict, who wanted everything to be done "in moderation". When I was asked to say something about my work in the filling of the building, I put the emphasis on this point on everyone: "Not too small, not too big; not too long, not too wide; not too thin, not too thick; not too open, not too closed; not too dark, not too bright." [1]

This could be said as a summary of Van der Laan's entire theory of architecture: space has to be moderated by mass, solid by vacuum, large by small. His system of proportions - the plastic number, which he discovered while still a novice

1 Letter from Van der Laan to Richard Padovan (12 December 1984). In Padovan. Pg. 83

1.9. Limited Transposition Modes

1.9.1 The charm of impossibilities

Messiaen finished his musical studies at the Paris Conservatory in 1930. And the following year, at the age of 22, he was placed as official organist of the Sainte Trinité in Paris.

His continuous search for the unspeakable and the inexplicable in his music encouraged all his musical research. His is a language of fantasies and sound wonders that moves between two great limits: the expression of the earthly pleasurable -which is embodied in human desires for the sensitive-, and the expression of the infinite -which has its ultimate end in human desire for the divine-. This middle ground is what he himself called the "charm of impossibilities":

> On one point we must first look at: the charm of impossibilities. What we are looking for is a music of sparkle and clarity that gives the ear voluptuously refined pleasures. At the same time this music must be able to express noble feelings (and especially the noblest of all: the religious feelings that exalt the theology and the truths of our Catholic faith). This spell, both voluptuous and contemplative, lies above all in certain mathematical impossibilities of a modal and rhythmic nature. The modes, which can only be transported a certain number of times, because they always end up on the same notes; the rhythms, which cannot be retrograded because they then return to the same order of values: here are the two relevant impossibilities. [...] The analogy between these two impossibilities and how they are completed is immediately apparent, since the rhythms perform in the horizontal sense (retrogradation) what the modes perform in the vertical sense (transposition).[1]

1 Olivier Messiaen, *Technique de Mon Langage Musical* (Paris: Alfonse Leduc, 1944). Pg. 8.

in Oosterhout - is determined by, and contained between, two limits: a lower limit below which the difference between two measurements is too small between them to be discernible to the eye, and an upper limit above which the difference between two measurements is so great that they can no longer be compared. And between these two boundaries, Van der Laan preferred the middle way. For the floor plan of his church he chose the middle point between the square and the longest rectangle generated by the system: "We saw it as the proportion that resides between the square room and a long gallery." [1]

Against the orderly background of monastic life, the still unresolved problem continued: the search for the fundamental principles of architectural form. After his entry into the monastery he largely lost contact with his friends in Delft, with the exception of "Prof" (Granpré Molière), his younger brother Nico, and his fellow student S. J. van Embden.

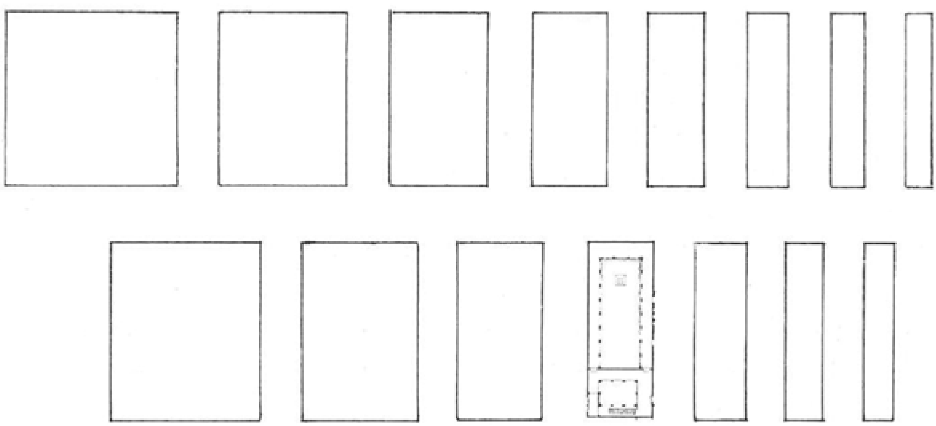


Fig. 40. Plan of the abbey church, Vaals, related to the 8 authentic figures and the 7 derivatives generated by the plastic number; the plan occupies the central derived figure.

1 Padovan. Pg. 81-83

This charm for the impossible and the unattainable is omnipresent in his musical work and it is what produces in the listener a certain sense of recession of the musical advance for the sake of a continuous state of contemplation. Both the modes of limited transposition and the non-retrogradable rhythms are the technical means that Messiaen consciously puts in the spectator's ears to fall unconsciously into the charm of impossibilities. Therefore, this is a case in which perception is intimately connected with the formal ins and outs that sustain the composition.

> Let us now think of the listener of this modal and rhythmic music: in the concert he will not have time to check the "no transportation" and "no retrogradations", and then he will no longer be interested in them: his only desire will be to let himself be captivated. And this is precisely what will happen: even without wanting to, he will experience the strange charm of impossibilities: a certain effect of tonal ubiquity in non-transposition, and a certain unity of movement (in which principle and end, because they are identical, are confused) in non-retrogradation. All this will progressively lead him to that kind of "theological rainbow" that pretends to become the musical language whose edification and theory we are searching for. [1]

While it is true that many elements of his musical research are involved in this "charm of impossibilities", his musical career could be said to have been, in his own words at the Kyoto conference, a search for "complex sounds that are at the same time complex colours".[2]

Out of the ordinary, Messiaen directly associated the height relationships between sounds with colors. This synaesthetic[3] quality allowed him to

1 Messiaen, *Technique de Mon Langage Musical*. Pg. 18.

2 Olivier Messiaen, 'Conferencia de Kyoto', *MINERVA*, 19.I (2012), 49–53.

3 Synaesthesia is the disease that associates colors with sounds.

1.8.2. The plastic number [1]

The first element of the theory that crystallized was the plastic number and is what we will deal with in this work.[2] He had been fascinated by the problem of proportion since childhood. In a letter he tells how, seeing his father and older brother working in his architectural office, he wondered where the measurements he saw transcribed from the sketches to the working drawings came from, and from the working drawings to the building itself:

> Above all, I was looking for the origin of these measures, but they vanished into the vagueness of the design sketches, which at the time were mostly made by my older brother.... Delft's course had not taught him fixed rules for design, just as I would find myself. At BSK we try to discover them for ourselves, and the story I tell below belongs to that period.
>
> On Sundays my father smoked cigars.... On the inside of the cigar box cover there was a view of the Domtoren [bell tower] in Utrecht... During my adolescence this image served as a model for my games with building blocks. I have never been to Utrecht, but when I heard that my family's uncle had moved there, I immediately asked if I could go and spend some time there. I wanted to know how the tower was composed, to use it as a starting point for my own designs. For two days I sat from morning to afternoon in a corner of the cloister, and finally hit the simple and regular outline... The next day I entered the work offices of the choir restoration being carried out, and was able to examine the drawings of the tower, complete with measurements that corresponded beautifully to the outline I had drawn... in which all the measurements were multiple of others. I spoke of this seve-

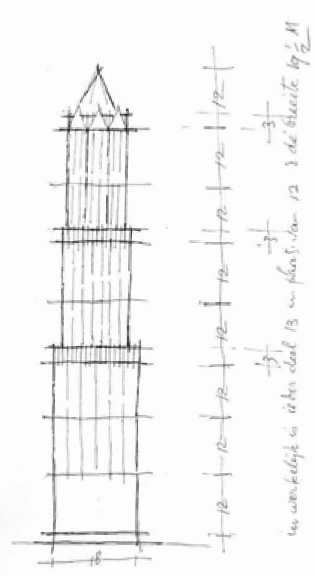


Fig. 41. Van der Laan's drawign on Domtoren proportions.

1 For a full description of the process of discovery and explanation of the Plastic Number see chapter five in Padovan.: Richard Padovan, *Dom Hans van Der Laan: Modern Primitive* (Amsterdam: Architecture & Natura Press, 1994). Here is a translated, summarized and commented version of this chapter by the author.

2 Without disregarding the other concepts of Van der Laan's architectural theory - the relationship between nature and architecture, society, the solid and the void, inside and out - we focus our attention on the concept of plastic number as it is the root of his measurement system. The development of his entire theory would be the subject of a larger project.

grant to the relations of height between sounds, that is, to harmony, a pre-eminence in his works. Its harmony is unmistakable, but at the same time as it has Messiaen's personal mark, it is characterized by being the result of reflecting on the characters of music, on its intrinsic laws. For this reason, his discovery, rather than invention, of the modes of limited transposition in 1927 is of such importance that it accompanied his entire musical production.[1]

On the other hand, we must make it clear that talking about Messiaen also means talking about rhythm, that is, the time relationships between sounds. He himself defined himself as a Rhythmist.[2] According to Messiaen, true rhythm is just the opposite of what an ordinary music lover understands by the word rhythm. In the first volume of his treatise, Messiaen writes that rhythm contains periodicity, "but true periodicity, that of the waves of the sea, which is the very opposite of pure and simple repetition. Each wave is different from the one that precedes it and the one that follows it because of its volume, its height, its duration, its slowness, the brevity of its formation, the power of its climax, the prolongation of its fall, its movement, its fall..."[3]

1 Olivier Messiaen, *Traité de Rythme, de Couleur, et D'ornithologie* (1949-1992) En Sept Tomes (Paris: Alphonse Leduc, 2002). Tome VII. Pg. 126.

2 Claude Samuel, *Permanences d'Olivier Messiaen (Dialogues et Commentaires)* (Paris: Actes Sud, 1999). Pg. 102.

3 Messiaen, *Traité de Rythme, de Couleur, et D'ornithologie (1949-1992) En Sept Tomes*. Tome I. Pg. 42.

ral times to the BSK group, but I always ended up in conflict with the Prof, who interpreted the balustrades as intermediate elements that united the larger parts, while I saw them as reflections on the parts of the composition of the whole: one eighth of each subdivision, just as the area of the terrace was one eighth of the entire tower.[1]

The phrases "all the measures were multiple of the others" and "reflections on the parts of the composition of the whole" contain the essence of what later became the plastic number, and in addition to Van der Laan's whole theory of design.

The second stage in the process of discovery began with his encounter with the golden section, through the Benedictine architect Dom Paul Bellot de Solesmes (1876-1944), designer of the abbey in Oosterhout (1907-12). However, when Van der Laan tried to convince himself of the supreme value of this section, he found that everything that had to do with architecture seemed to be

...just another arbitrary mathematical formula. Above all, as soon as I saw that when a line is bisected in this proportion, and the long part is bisected again, a measurement is produced identically to the original smaller part, I was no longer interested from an architectural point of view. Instead of a resemblance between parts, the successive bisections turned out to be a kind of equality. What I needed the ratio to overcome this, I didn't see yet.[2]

The meaning of this comment needs to be explained. When an AB line is divided by C in golden ratio and the largest part BC subdivided in D in the same ratio, CD is equal to AC. Subsequent divisions lead to more duplication of efforts. Thus it can be argued that the golden section directly fixes only three

Fig. 42. Drawing by Van der Laan for the votive chapel in Baarle-Nassau, where we see the project process for the proportions of the tower.

1 Letter from Van der Laan to Richard Padovan (December 12, 1984), pp. 1-2. In Padovan.: Pg. 84.

2 Letter from Van der Laan to Richard Padovan (29 May 1984). In Padovan.: Pg. 85

1.9.2. Limited transposition modes[1]

The first work in which Messiaen systematically explored these ideas was the organ cycle La Nativité du Seigneur (1935), in which the small program that was distributed to listeners on the day of its premiere in the church of the Sainte Trinité in Paris could be read:

> Emotion, sincerity and musical work: to be at the service of the dogmas of Catholic theology.
>
> To be expressed by melodic and harmonic means: the progressive growth of intervals, the chord on the dominant one, the pedal notes, the embellishments and the extended appoggiatura.
>
> And even more rhythmic means: rhythms immediately preceded or followed by their increases and sometimes increased by a note of short value (medium added value).
>
> And above all because of my limited transposition modes: the chromatic modes, used harmonically, the strange colour of which derives from the limited number of possible transpositions (2, 3, 4 and 6 according to each mode).
>
> Does the theological motive matter? The one that more, because it contains all the motives. And this abundance of technical means allows the heart to flow freely.[2]

Did these comments not indicate a certain control of the systematic aspects of the creative imagination? Wasn't he looking for a final perceptual effect through tools derived from his own discipline? In fact, Messiaen's entire effort to produce the effect of ubiquity in the listener goes through the systematization of this exuberant imagination, imposing an order on it, adhering to well-defined

1 For a full description and example of the modes of limited transposition see chapter XVI in Messiaen, *Technique de Mon Langage Musical.*

2 Peter Hill and Nigel Simeone, *Messiaen* (Yale University Press, 2005). Pg. 59.

consecutive measures: the whole and its two parts. But among the parts of the design Van der Laan was looking for a reflection, not a repetition: a proportion that would allow the six segments produced by the two subdivisions - AB, AD, BC, AC, CD and BD - in a continuous ratio, forming an additive geometric progression. The six consecutive measures would then be brought together in one unit.

It was during the design of the tower of the votive chapel of Baarle-Nassau helping the Dom Bellot project that he finally faced the problem:

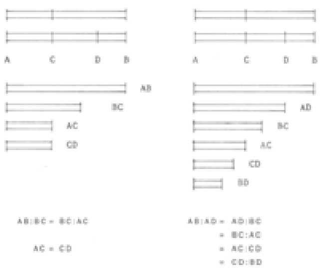


Fig. 43. Comparison of the proportional systems of the golden section (left) and the plastic number (right).

> But the golden section of Dom Bellot had the great disadvantage that a second division in this proportion produced a measure identical to the smallest part resulting from the first, and therefore did not provide sufficient basis for a series of proportional relationships. So I looked for a ratio between the parts such that when the larger parts are divided, the ratio of the larger parts is equal to that between the original parts....
>
> ...and so I arrived at the first division entirely at a ratio of about 3:4... The further development from this ratio to completing the system of measu-rements was not difficult... I came up with the idea as the spatial equivalent of the abstract number, so I later came to call it the plastic number.[1]

This last statement must be explained by the fact that the plastic number can measure the continuous space while the abstract one measures in a discreet way. When we count things, we treat each thing as a finite entity - an indi-visible unit - corresponding to an integer. For example, we can count exactly the number of "individuals" in a room: "individuals" literally means "indivisible". But if we want to measure the heights of these same people, there is no such intrinsic unity; space (like time) is an

1 Letter from Van der Laan to Richard Padovan (24 August 1984). In Padovan.: Pg. 87

rules. It is this order that gives him the freedom not to fall out of the discipline and to achieve the task he had set himself: to pass through the "charm of impossibilities".

Having already spoken about them in La Nativité du Seigneur, in his Technique de mon langage musical he gives a detailed explanation of the mechanism of the modes of limited transposition among other concepts of his musical theory.[1]

These modes, based on the current chromatic system - a tempered system of twelve sounds, which is called the material scale - take certain notes exclusively from this system. The notes that compose them form several symmetrical groups, in which the last note of each group is always "common" with the first of the next group. After a certain number of transpositions, i.e. upward or downward movements of the unit, which vary according to the mode, they can no longer be transported. The 4th transposition gives exactly the same notes as the 1st, for example, or the 5th the same notes as the 2nd, etc.[2]

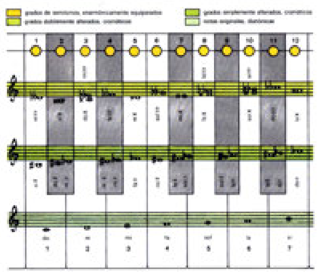


Fig. 44. The tempered system projected on a keyboard. You can see in the lower staff the diatonic scale of C major, in the middle staff the chromatic scale of twelve tones and in the upper staff the double enharmonies, which in our case are less interesting.

Put another way: from the material scale, sounds are chosen and brought together in a reference system around a central or fundamental sound, which is called tonality. If you sort the notes of the reference system, you will get what is called a scale of use. The scale of use is always within

1 Without neglecting the other concepts of Messiaen's music theory - Hindu rhythms, added value and non-retrogradable rhythms, polyrhythm, rhythmic pedals, added notes, clusters of chords, polymodality - we focus our attention on the modes of limited transposition because they are the root of his system of relations between the heights of notes. The development of his entire theory would be the subject of a larger project.

2 We must bear in mind that when we speak of the same notes, we speak inharmonically, and always within our tempered system, in which the C sharp is equivalent to the D flat.

infinitely divisible continuum. If time and space were not continuous, all growth, all movement and all change would be impossible, and the world would be absolutely static. Consequently we can measure lengths, such as the heights of a number of people, only by imposing something artificial, a strange unit such as the millimeter. Then we approximate each height by counting those units, ignoring the rest.

But this way of measuring is not useful for the creative act of design, which does not measure in the normal sense - from something that is already known - but gives a measure to that which is immeasurable. Just as music and dance measure time, architecture - or perhaps the plastic number embodied in architecture - measures space. The object of the plastic number is to fill the gap between the intellect and the unseen continuity of the natural quantity.

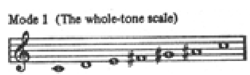
The plastic number comprises a series of relationships between the small prime numbers (1,2,3 and 7 and their multiple numbers) that make it similar to the first family of proportional scales in the history of mathematics: the one that belongs to the commensurable[1] scale used by Alberti and Palladio and derived from the Pythagorean and Platonic division of the eighth. Such proportions are essentially arithmetical, intellectual and static.

1 The distinction between commensurate and immeasurable proportion systems corresponds in some ways to Hambidge's distinction between static and dynamic symmetry in Jay Hambidge, *The Elements of Dynamic Symmetry* (Mineola: Dover Publications, 1967). Pages xiii and xv. For an explanation of proportion systems in architecture see P. H. Scholfield, *Teoría de La Proporción En Arquitectura* (Barcelona: Biblioteca universitaria labor, 1971).

the one-octave range. The way of subdividing the octave and the distances between the sounds of the scale of use determine the genre, which can be pentatonic, by whole tones, diatonic or chromatic. Well, Messiaen's modes are a genre derived from the whole-tone scale because they have the same limited transposition characteristics. In fact, the whole-tone (or hexatonic) scale is the first of the limited transposition modes.[1]

These modes are three, plus four others that are six times transportable and of less interest, precisely because of their large number of possible transpositions. All "limited transposition modes" can be used melodically (i.e. to produce single voice lines) and, above all, harmonically (i.e. to produce simultaneous voices), with the melody and harmonies never using notes other than those of the mode.

We spoke earlier of the spell of impossibilities, for it is this impossibility of transposition that gives rise to the strange charm of these modes. They are in a multi-tonal atmosphere without resorting to polytonality and the composer is free to let one of these tonalities predominate or leave a fluctuating tonal impression.



The first mode divides the twelve-tone material scale into six symmetrical groups of 2 notes each. Due to the presence of six identical groups it can have as reference points six different shades. It is transportable twice. Each symmetrical group is at a distance of two tones from the next. It is the scale for "tones". Calude Debussy and Paul Dukas, as well as other authors, used it admirably. So

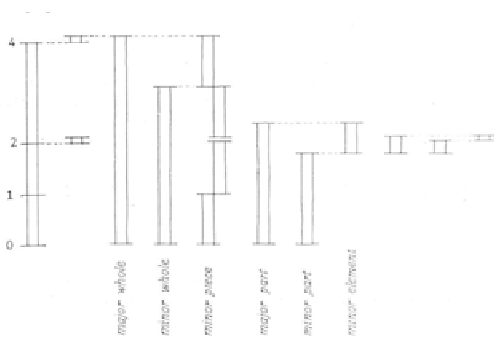
Fig. 45. To the left of the Van der Laan diagram a representation of the progression based on the double arithmetic (such as the series of octaves) has been added for comparison. Van der Laan's diagram shows the presence of the "little quanta".

Fig. 46. Comparative table between the relations derived from the plastic number and the Pythagorean relations.

But at the same time, the plastic number is not simply measurable and arithmetical. Its measurements are transformed, by the addition of a "small quanta", into an additive series that tends towards geometric progressions, the second of the two families with an immeasurable limit, which corresponds to all systems - such as Le Corbusier's modulor - founded on the immeasurable proportions generated by geometric constructions, such as the golden section. This type of proportions is rooted in the phenomenon of continuity and growth: in the measure of a natural space by geometry. The plastic number, however, differs from the golden section in that it is neither derived from a geometric construction nor can be discovered in natural forms. And, unlike the modulator, it is neither based on a relationship nor on a fixed dimension, derived from the human body.

Thus we see that the plastic number throws a bridge, where there are, between two exclusive types of quantity, the how many ["hoeveelheid" literally means "how many"] and the how much ["hoegrootheid" literally means "how much"]. Sorting based on this number can be defined as an arithmetic order that pays attention to certain tolerances.[1]

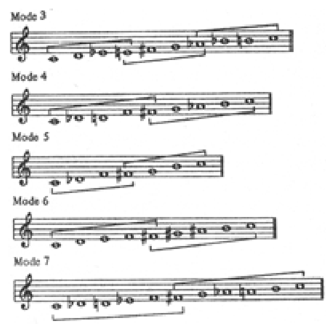
Plastic Number relations		**Pitagorean relations**		
1:1		1:1		unison
7:8	(56:64)	7:8	(56:63)	tone
3:4		3:4		quart
2:3		2:3		quint
4:7	(36:63)	4:7	(36:64)	two quarts
1:2		1:2		octave
3:7	(12:28)	4:9	(12:27)	two quints
3:8		3		octave + quart
1:3		1:4		octave + quint
2:7	(8:28)	2:7	(8:28)	three quints
1:4		1:4		two octaves
3:14	(6:28)	3:14	(6:28)	two octaves + a tone
3:16		3:16		two octaves + quart
1:6		1:6		three octaves
1:7	(4:28)	1:7	(4:28)	three octaves + tone



Messiaen carefully avoids making use of it unless he hides in some overlapping way that makes it unrecognizable.

The second mode divides the twelve-tone material scale into four symmetrical groups of 3 notes each. Due to the presence of four identical groups it can have as a reference point four different shades. It is transportable three times. Each symmetrical group is at a tritone distance from the next, which gives it the structure of what is known as a diminished 7th chord.

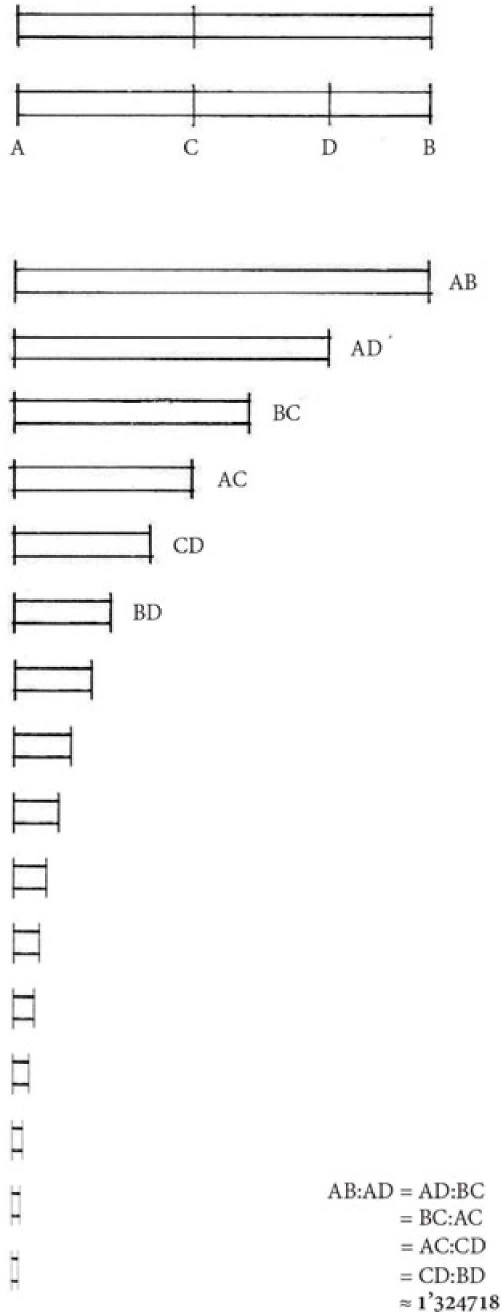
The third mode divides the twelve-tone material scale into three groups of 4 notes each. Due to the presence of three identical groups it can have as a reference point three different shades. It is transportable four times. Each group is at a greater third distance from the next, which gives it the structure of what is known as an augmented fifth chord.



The fourth, fifth, sixth, and seventh modes divide the twelve-tone material scale into two symmetrical groups. There are four of them, bringing the total number of transports to seven. Due to the presence of two identical groups, two different shades of colour can be used as a reference point. Each group is at an increased fourth distance.

With the discovery of "limited transposition modes", Messiaen launches a bridge, where it exists, between two types of ordering the heights of sounds: the homogeneous order of the Schönberg dodecaphonic series, and the polarization of the traditional tonal system. We can define sorting based on these modes as a homogeneous order that pays attention to certain tonal poles.

Fig. 47. Graphic table showing which of the notes of the twelve-tone material scale are chosen to form the "limited transposition modes" with their possible transpositions.



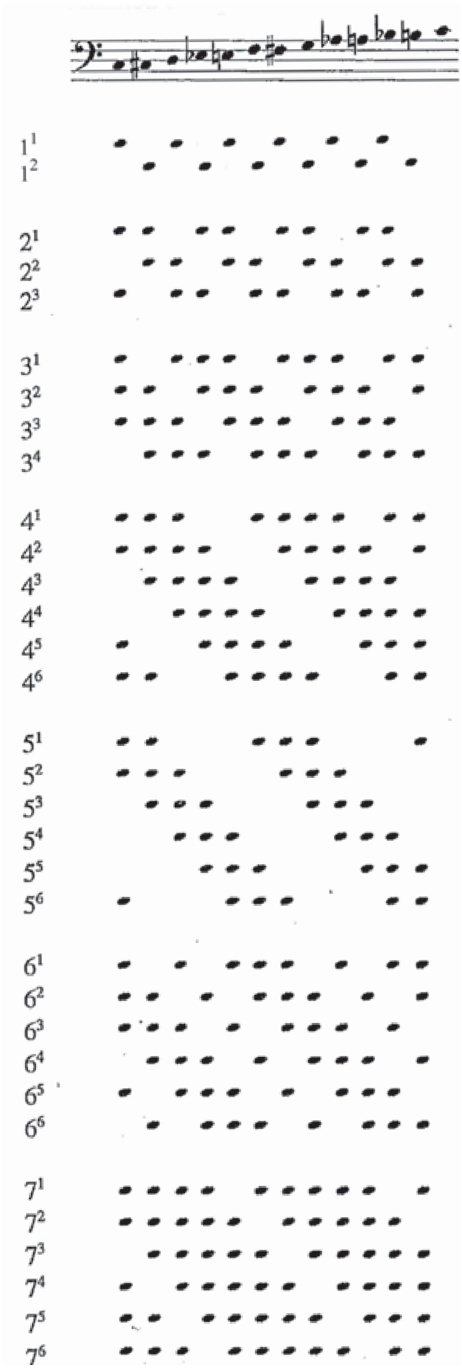


Fig. 48. Graphic table showing which of the notes of the twelve-tone material scale are chosen to form the “limited transposition modes” with their possible transpositions.

1.10. The Abbey of St. Benedictusberg in Vaals

1.10.1. The project in its history[1]

Fig. 49. Interior of the chuch in Saint Benedictusberg Abbey.

Fig. 50. 1970. Aerial view of the abbey, with the church on left hand side.

Vaals is located in Limburg, in the southern part of the Netherlands, which has suffered from Belgian, Dutch and German influences at various stages of its history. The abbey is located a short distance from the German border on a hill. The construction work began in 1922; the monastery is destined for the Merkelbeek hospice and monasticism, the first Benedictine institution on Dutch territory after the reform.

Abbot Dom Romuald Wolters entrusts the project to Dominikus Böhm, an architect who is already renowned for his many religious buildings in Germany, and to Martin Weber. The project takes on a traditional Benedictine monastery layout and is characterised by two cylindrical towers with conical roofs attached to the south, while the Romanesque church is to be built to the north.

But already the year after the arrival of the monks and having begun the construction work, these are interrupted due to lack of funds. It was resumed in 1927 thanks to the passage of the monastery from the congregation of Subiaco to that of Beuron, undergoing a new arrest with the outbreak of the Second World War, leaving the church unfinished, in particular. During the war period, an internal crisis caused by tragic political events led the community to abandon the building and, at the end of the conflict, the abbey was adapted as a barracks

1 Translated and completed by the author, from the text devoted to Saint Benedictusberg Abbey in the book *Dom Hans van der Laan* by Alberto Ferlenga and Paola Verde.

1.11. Turangalîla Symphony

1.11.1. The work in its context

Messiaen was involved composing the Symphony Turangalîla for two years, from mid 1946 to the end of 1948. It was commissioned by Serge Koussevitzky for the Boston Symphony Orchestra, which premiered under the direction of Leonard Bernstein on December 2, 1949. It consists of ten extensive movements that, taken together, last an hour and a quarter. Throughout the work, several cyclic themes are used in combination with others that are specific to each movement. There are also traces of traditional symphonic forms, such as the Scherzo (fourth and fifth movement), the variations (ninth movement), and the sonata form (last movement). According to Messiaen's own description, the eighth movement forms the "section" of development of the symphony as a whole. This movement will illustrate our work.

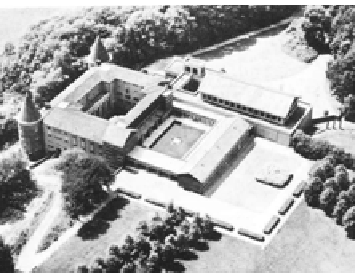
The word Turangalîla is a combination of two Sanskrit words. Lîla literally means "game", "sport" or "entertainment"; it is "game" in the sense of divine action in the cosmos; that is, the act of creation, destruction, reconstruction and the game of life and death. It can also mean "love". Turanga means "time", the time that runs like the horse's galloping, or the time it spends like the sand on a clock, as well as movement and rhythm. [1]

Fig. 51. Messiaen and Bernstein, during a rehearsal of *Turangalîla Symphony* on 1949 with Boston Sinfony Orchestra.

1 Robert Sherlaw Johnson, *Messiaen*, J. M. Dent & (London, 1989). Pages 82-83

for the American army and a hospice for families repatriated from Indonesia; only thanks to the vigilance of a Dutch monk was part of the library and the sacred objects preserved.

In 1947, the complex was linked to the abbey of Oosterhout, from which thirteen monks came who, on 15 November 1951, under the direction of Dom Vincent Truyen, began the rebirth of Vaals. In 1956, Hans van der Laan was entrusted with the task of completing the construction of the church: it was finally a matter of giving body to the church and completing the conventual part with the construction of the library, the sacristy and an open gallery around a new cloister.



At the arrival of Van der Laan, the abbey is made up of an enclosed building, with a historicist air and brick in view. Inside, around the central courtyard are the abbot's quarters, the cloister and the refectory and the latticework distributed on three levels. Van der Laan's restoration and adaptation operation interprets the existing building by inserting behind the original space. Van der Laan's restoration and adaptation operation interprets the existing building by inserting original spaces that emerge from his theories. The intervention foresees, among others, the elimination of the cylindrical stair tower of romantic taste and the opening of the south side, corresponding to the refectory. But it was not really until 1956 that Van der Laan expressed himself fully. The construction lasted for a period of thirty years at the same time as his training as a man, monk and architect, offering the opportunity to apply and verify his theory day after day and in all stages of his development.

Fig. 52. The roof of the church rises over the whole construction.

Fig. 53. 1985. Last stage of the building, with the second cloister already finished.

The word as a whole, then, means “a song of love”, “a hymn to joy”, time, movement, rhythm, life and death. When Messiaen speaks of joy in connection with Turangalîla, he describes it as a superhuman, overflowing, brilliant and excessive joy; and love, meant by lily, is presented under the same aspect: fatal, irresistible, transcending love, suppressing everything outside of it, a love that is symbolized by the elixir of Tristan und Isolde.

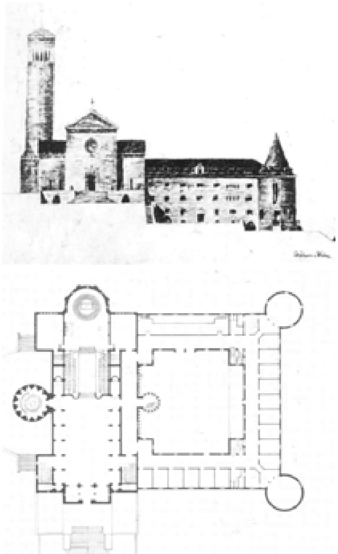
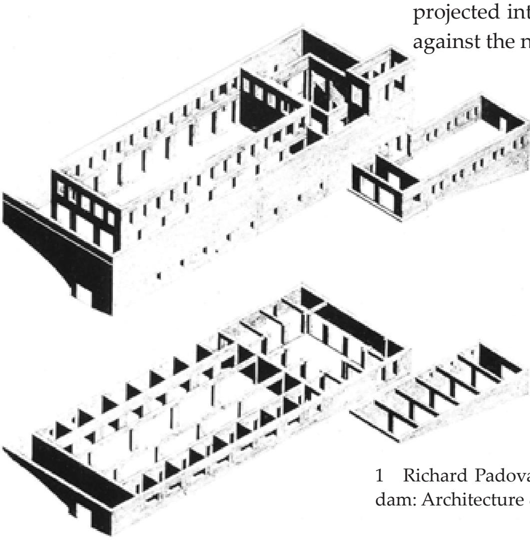


Fig. 54. Original project by Böhm and Weber, with the never built church.

Fig. 55. Axonometric drawing of the structural walls of the new church by Van der Laan.



1.10.2. Van der Laan's design

As one can imagine, the expressionism of Böhm and Weber's building was far from Van der Laan's "intellectual" and austere language. From his alterations and additions to the abbey between 1960 and 1986 he placed himself in an effort to purify the German architects' design of many of its most romantic and picturesque features.

The first step, and the most radical of all, was to abandon the original floor plan of the church without building it and place it at a right angle to the existing building. A 90-degree turn from the original project proposal clearly solved the problem of a potential collision between the "sensuality" of German architects and their own "intellectual" architecture. It also offered the new church the dramatic, temple-like relationship on a hill.

As one approaches the monastery from the west, the view is now dominated by the low long wall of the church, with a small building in the foreground and next to the Böhm and Weber building behind it. To the north, before the new Van der Laan Cloister was completed in the 1980s, the church was projected into the open landscape as a free, erected volume against the neutral background of Böhm's incomplete wall. [1]

1 Richard Padovan, *Dom Hans van der Laan: Modern Primitive* (Amsterdam: Architecture & Natura Press, 1994). Pages 171-172.

1.11.2. The symphony's thematic material

As mentioned, Messiaen cites four main cyclical themes in Turangalîla. In addition to these, there are others that are related to a greater or lesser extent to cyclical themes [1] ; these play a subordinate role in the work. Three of the four main cyclical themes have symbolic meaning and are named to identify them and relate them to their symbolism. The first is the thème-statue, or "statue-theme", which appears strongly in trombones and tuba near the beginning of the first movement, and near the beginning of the eighth movement, as well. For Messiaen, this theme recalls the heaviness, the terrible brutality of ancient Mexican monuments: "I have always been reminded of a terrible and fatal statue" [2] . This theme is associated with the masculine character of love:

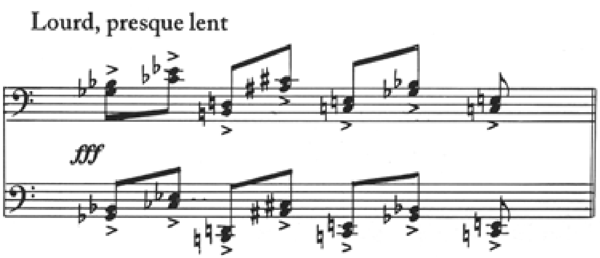


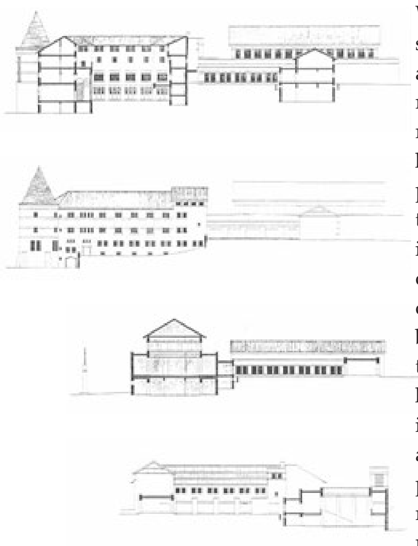
Fig. 56. Statue-theme

1 A musical theme is a rhythmic, melodic or harmonic material which is a root for a developement of a musical discourse. Normally, the theme is buit from motives: little rhythmical or melodica ideas enough defined to preserve their own identity when elaborated or transformed and combined with other musical materials. See Josep Antoni Martinez i Lerma, *Anàlisi I. Apunts de Classe*. (Conservatori Professional de Música d'Oliva).

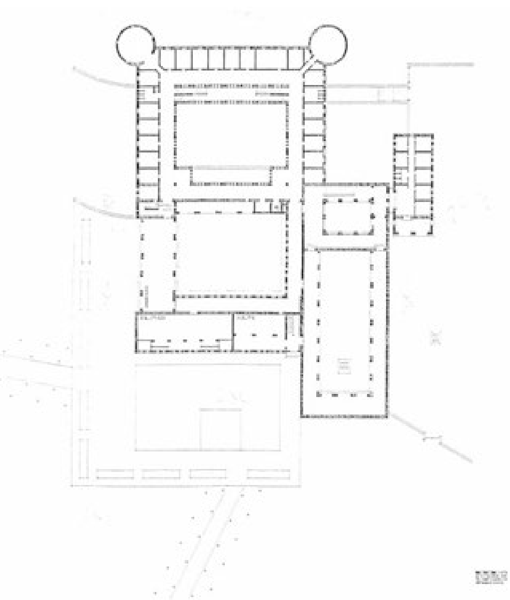
2 Messiaen. Page 159.

Fig. 57. Plan and sections for the new church by Van der Laan.

Van der Laan himself gives a description of the building that clarifies the intentions of the new architecture.



We have recognized that the separation of an architectural space from the natural space requires three elements: a wall, an inside and an outside... Here the church has been placed relatively independent of the main building, and located directly in the natural landscape. An "outside", consisting of a half-enclosed preliminary courtyard, is defined by the open porch of the goalpost construction that is at right angles to the long side wall of the church... However, to manifest the inside-outside relationship to the church space, a portion of delimited space[the atrium or courtyard] is conceived and designed as an outside. The ascent of the stairs, necessary because the church rests on a higher level, gave us a pretext to achieve this end, but re-entering an exterior space after having already passed through the interior space of the goal is a strong architectural effect quite intentional. The need for a roofed upper gallery is likewise exploited to articulate two parts of this small artificial outside: an open central space, related to the galleries, which are one after the other directly related by large ones to the interior of the church.[1]



1 Padovan. Page 172.

The second cyclic theme is called the thème-fleur or "theme-flower" because it is tender, a flexible curve, "like the tender orchid, the ornamental centre or the gladiolus red" [1] . This theme is associated with the feminine character of love.

Fig. 58. Thème fleur

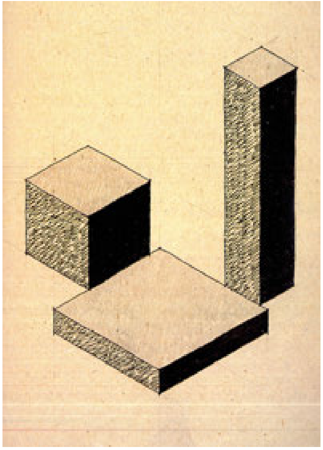
The third cyclical theme is the thème d'amour or "love-theme". Both male and female characteristics of the first two cyclical themes intervene in the "love-theme", one transforming the other, to produce a new theme of different character from the two and symbolizing the union of Tristan und Isolde:

Fig. 59. Thème d'amour

The fourth cyclical theme is the "chord theme" or thème d'accords, which has no symbolic meaning. It is associated with other motifs, ending in a fragmented and often widespread way.

Fig. 60. Thème d'accords

1 Messiaen. Page 159.



1.10.3. From the system to the work

The design of the entire new building was carried out simultaneously from the outside in and from the inside out, and was governed in both cases by the plastic number. Contrary to the apparent innocence of such an intention, Van der Laan developed the Bank of Forms method to control all the measurements of the new building. The logic behind this method of classifying forms can be found in the fourth lesson of Van der Laan Architectonic Space's book. Starting with the natural prototypical form, the sphere, Van der Laan describes the stages in which it develops, extending one dimension towards the cylinder or two towards the disc:

> Since this lengthening of the dimensions leads to the shape progressively away from the primary shape, the cylinder, which is lengthened in only one direction, must be considered as closer to the primary shape than the disc, which has been lengthened in two... In architecture these shapes are square, as the clay ball is given the rectangular shape of the brick. Then we no longer speak of sphere, cylinder and disc, but of disc, block and plate. [1]

As the cylinder is an intermediary between the sphere and the disc, so is the bar between the block and the blade. The Shapes Bank comprises the entire range of three-dimensional shapes generated by the plastic number - thirty-six in total. Every solid or spatial element in the church of Vaals can be assigned to one of these thirty-six forms. In the Bank of Forms, these three elementary forms form a large triangle, with the smallest one, the cube, in the corner. The successive elongations of this cube produce the bar-shape, occupying the right angle of

Fig. 61. The three olements which constitute the banc of forms: the block, the sheet and the bar.

1 Hans van der Laan, *Architectonic Space* (Leiden: E.J. Brill, 1983). Pages 34-35.

1.11.3. From the system to the work

Messiaen knew full well that each mode had its own character. Moreover, he himself saw in each mode a range of associated colors and understood music as correspondences between colors [1] . Therefore, all the orchestration, the disposition of the voices, the dynamics, etc. were always supporting that search: the correspondence between the searched perception of the work and its compositional mechanism.

In the case of the VIII movement of the Turangalîla Symphony we detect the use of three of its modes: the 2nd, 3rd and 4th. In order to understand the correspondence between the final result of the work and its compositional procedure, we will observe each of these moments.

At the end of the [14] the whole orchestra accompanies the piano with scales formed by the 2nd mode in the 2nd transposition. This mode, in Messiaen's own words, is displayed as "spirals of gold and silver, on a background of vertical brown and ruby red bands" [2] . This pictorial fragment produces an effect of decentralization or destonalization that reinforces the tonal insecurity just before the first explosion of the "love-theme". The fragments [26] and [41] are transpositions of a higher hue and augmented fourth each and thus vary the chromatic spectra and accentuate decentralization.

In [15], the appearance of the "love-theme" in C major is accompanied by the 2nd mode in its 3rd

1 Messiaen. Tome VII. Page 97.

2 Messiaen. Tome VII. Page 118

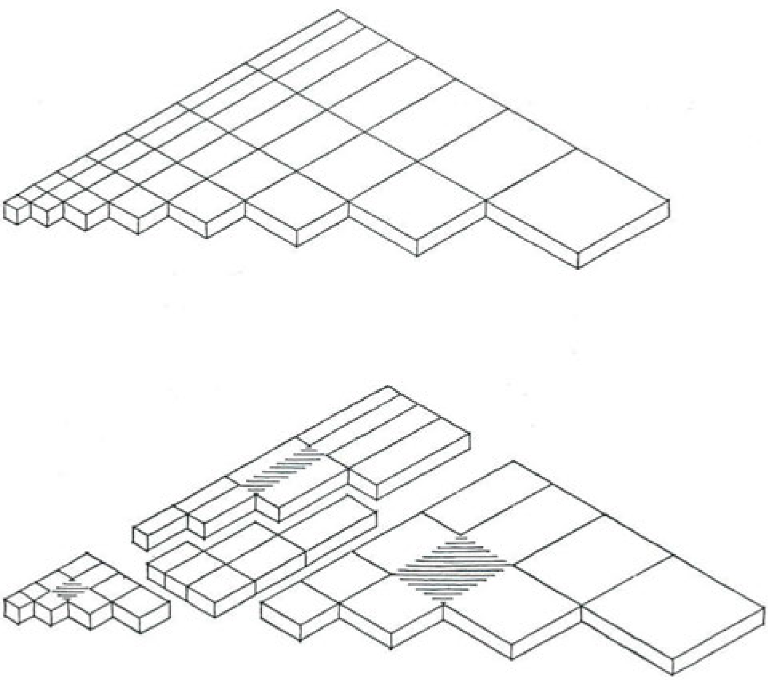
Fig. 62. The Bank of Forms in its compact and triangular definition. In the bottom part the three families of forms can be distinguished: blocks in the left vertex, plates in the ritght vertex and bars in the upper vertex. In the center the white forms can be seen. With a diagonal lined filling the mean pieces can be found.

the triangle; it widens, producing the widest sheet-shape, occupying the third angle.

Four types of shapes can be distinguished in the total range of thirty-six: ten blocks, ten bars, ten plates and finally six white "shapes", which, according to Van der Laan, share certain properties of the other three without being confused with them.

The block has three equal or significantly equal dimensions; the bar has a significantly longer dimension than the others; and the sheet has a significantly shorter dimension than the others. The white "forms" have something in common with each of the other types:

> The three categories, block, bar and plate are found together in an ideal form that does not exist as such but is presented as a block in one form, bar in another and plate in the third. [1]



1 Van der Laan. Page 122.

transposition on the 4th degree, i.e. Fa M. This mode is displayed as "light green and grassy green foliage, with blue, silver and reddish orange spots" [1] . Then the 1st degree, Do M, is accompanied by the 2nd mode in its 1st transposition, which is displayed as "blue purple rocks, dotted with small grey, cobalt blue, dark Prussian blue cubes, with some purple, gold, ruby red, and purple, black and white reflections" [2] . The fragments [27] and [42] are, again, transpositions of a higher hue and increased fourth each and thus vary the chromatic spectra and accentuate the brightness.

Finally, the passage[16-17], which closes the first section, is again constructed from an ascending scale of four-sound chords in the 4th mode in the 4th transposition in wood, "a bit like petunia flowers: violet shade, violet white and purple violet", and of an ascending scale of three-sound chords in the 3rd mode in the 1st transposition, "orange tablecloth with gold and milky white patterns, and some ash-gray spots (these dots are dotted with purple or red or green)", while cello and double basses play a scale by tones, or what is the same, the 1st mode in the 2nd transposition, of which Messiaen gives no pictorial description.

In short, Messiaen builds a particularly luminous work where each passage shines in sparkles of varied colors. An experience that he himself compares to that of the stained glass window of the Apocalypse of the Cathedral of Bourges:

> This group of stained glass windows shines in the sun like gems that throw their lights at night. They are a set of sa-

Fig. 63. Stained glass wihdow of the Apocalypse of the Catheral of Bourges.

1 Messiaen. Tome VII. Page 119.

2 Messiaen. Tome VII. Page 118.

Van der Laan compared the Bank of Forms to the colour spectrum. Block, bar and plate corresponded to the three primary colors and the other forms to the different shades of color. “In the painter’s palette, however, white is prominent. It’s as if without this piece of light the colours were missing the key”.

By analogy, the white forms - and in particular the central piece - play a key role in architecture.

pphires, rubies and amethyst. This window is a diamond, and like many others, it projects multicolored rainbows. [1]

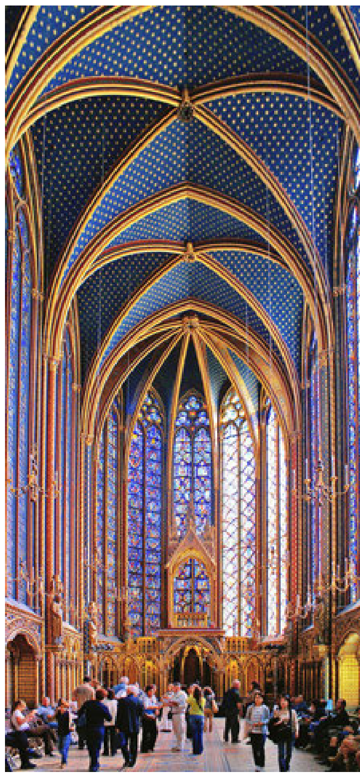
Fig. 64. Sainte Chapelle, Paris.

And in another passage he describes his experience:

Around the age of 10, I first saw the windows of the Sainte Chapelle in Paris, and these windows marked me for life. I also love the stained glass windows in Bourges Cathedral, the red and blue ones are extraordinary, but nothing can replace the Sainte Chapelle, which is all glass.

(...)

And I realized that I too tied colors to sounds, but intellectually, not through the eyes. In fact, since always, when I listen to or read music (internally in the ear), I see colour complexes in the head that work and move with sounds that are also complex.



1 Messiaen. Tome VII. Page 129.

1.10.4. The revised version of the Vaals church

For this reason, Van der Laan selected this prismatic form - which his determining rectangles have the reasons 4:7, 3:7 and 1:4 - for the outward form of his ideal revision of the church's design. This ideal version was the result of studies carried out when the current church was already built and could be seen in a model in 1981. In spite of the differences, in the built church the dimensions are based on the prism closest to this hypothetical and, therefore, these differences are not very notable, although in the purest sense they do not embody the ideal to perfection.

Fig. 65. Outside view of the volumes of the entrance pavilion, the bell tower and the church in the rear position.

1.11.4. Eight movement: Development of Love

Fig. 66. A motif.

The eighth movement of the Turangalîla Symphony, the Development of Love, is both a musical and symbolic development of the whole work. Here, all cyclical themes are used, but the "theme-love" is the main one to be developed. The main body of the movement is interrupted three times by ever-longer and more ecstatic portions of the "love-theme". These "theme-love" explosions, as Messiaen himself calls them, "symbolize Tristan and Iseult transcended by Tristan-Isolda, and the climax of the whole symphony".

He begins this movement with an introduction, where the repetition of a capicúa rhythm introduces a piano solo leading to the thème-statue, the trombones, amputated on its first and last note, which gives it an even more terrible character.

After the introduction, the great development takes place. It begins with an A motif in F# major, the last three chords of which will serve, repeated several times, as a link between the three different sections of the development itself:

In the first section, the motif A sounds in its simplified form accompanied by the piano by the "chord theme", the last three chords being repeated in the orchestra and the solo piano,

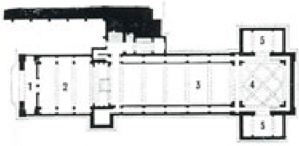


Fig. 67. Plan of the church of the Abbey of Quarr, designed by Dom Bellot. The elongated and tripartite layout can be seen in its parts: 1. porch, 2. conregation, 3. monks' choir, 4. sanctuary, 5 chapel.

Fig. 68. Stairs leading up to the church floor in the entrance cloister.

The following description is based on this ideal version of the church, in which, as in the built one, the figure of the floor plan established a series of proportions that linked all its dimensions. However, these dimensions were determined not only by the external form of the church, but also by its internal liturgical use. The starting point was the reaction that Van der Laan had already mentioned against the long and tripartite arrangements of Dom Bellot's churches in Oosterhout and Quarr.

> When I entered the monastery I quickly opposed this arrangement, which turned the liturgy into a spectacle rather than a collective action. So I decided that the altar should be placed between the monks' choir, between the seats of the choir. From the moment I was sacristan I dreamed of this disposi-

giving way to the first appearance of a fragment of the "theme-love" in Eb major. Emergence of the "flower-theme" with an effect of estrangement and remoteness. Again, motif A accompanied by the "chord theme" with its repetition of the last three chords, giving way to the second appearance of

Fig. 69. First aparition of love-theme.

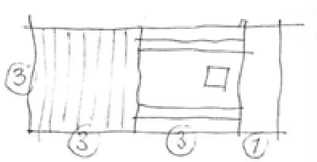


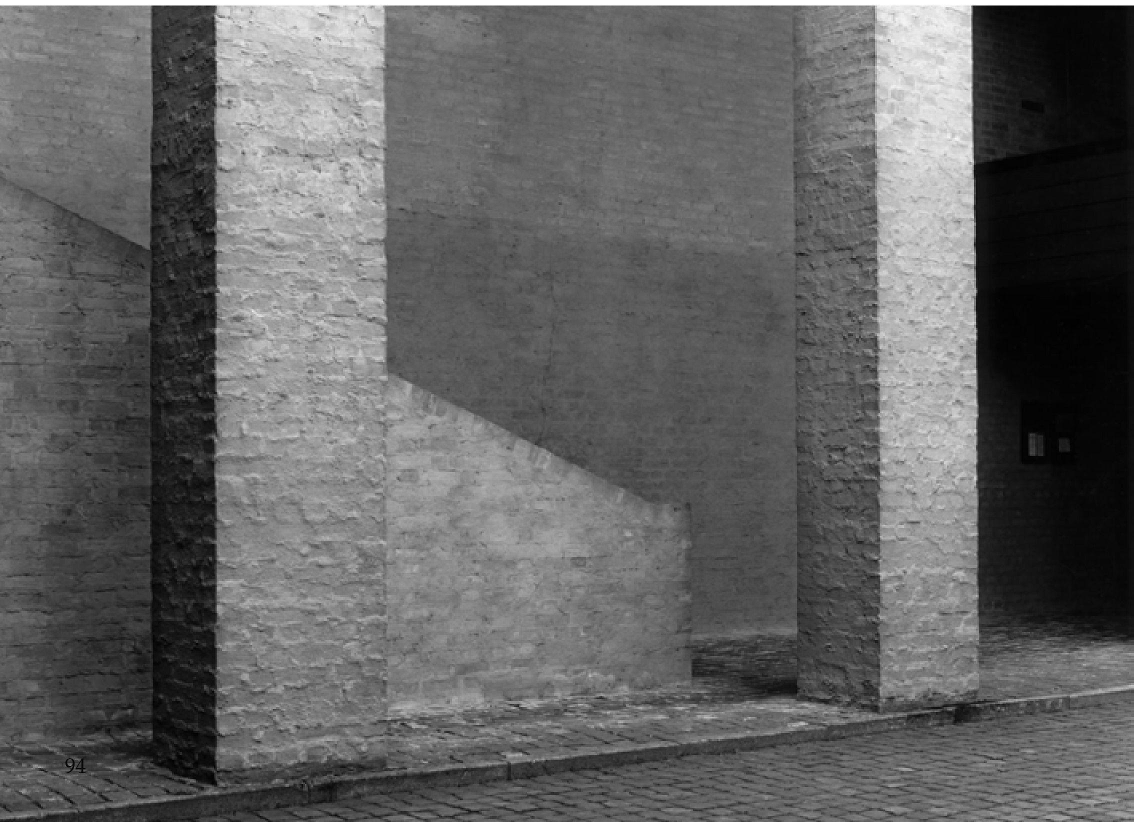
Fig. 70. Diagram of the proportions of the church of the abbey of Vaals by Van der Laan.

Fig. 71. Stairs leading up to the church floor in the entrance cloister.

tion, which has been confirmed by Vatican II. It was mainly for this reason that the two designs I made for the church in Oosterhout after the war were set aside.... The church that was consecrated there in 1956 still follows Dom Bellot's formula.

For me, the space of the choir and the altar should be approximately one square, with a narrow elongation behind to allow the ceremonies to be performed in front of the congregation. The space in front of it for the congregation should be as wide as it is long, because a longer space would prevent the faithful from participating fully in the liturgy. Then I should have reached the total space with a ratio of 3:7, but as I have already described, at the time I had only the ratio derived from it, 3:8.[1]

1 Van der Laan, unpublished letter from Van der Laan to Richard Padovan (24 January 1985). Pg. 12-14. In Padovan.



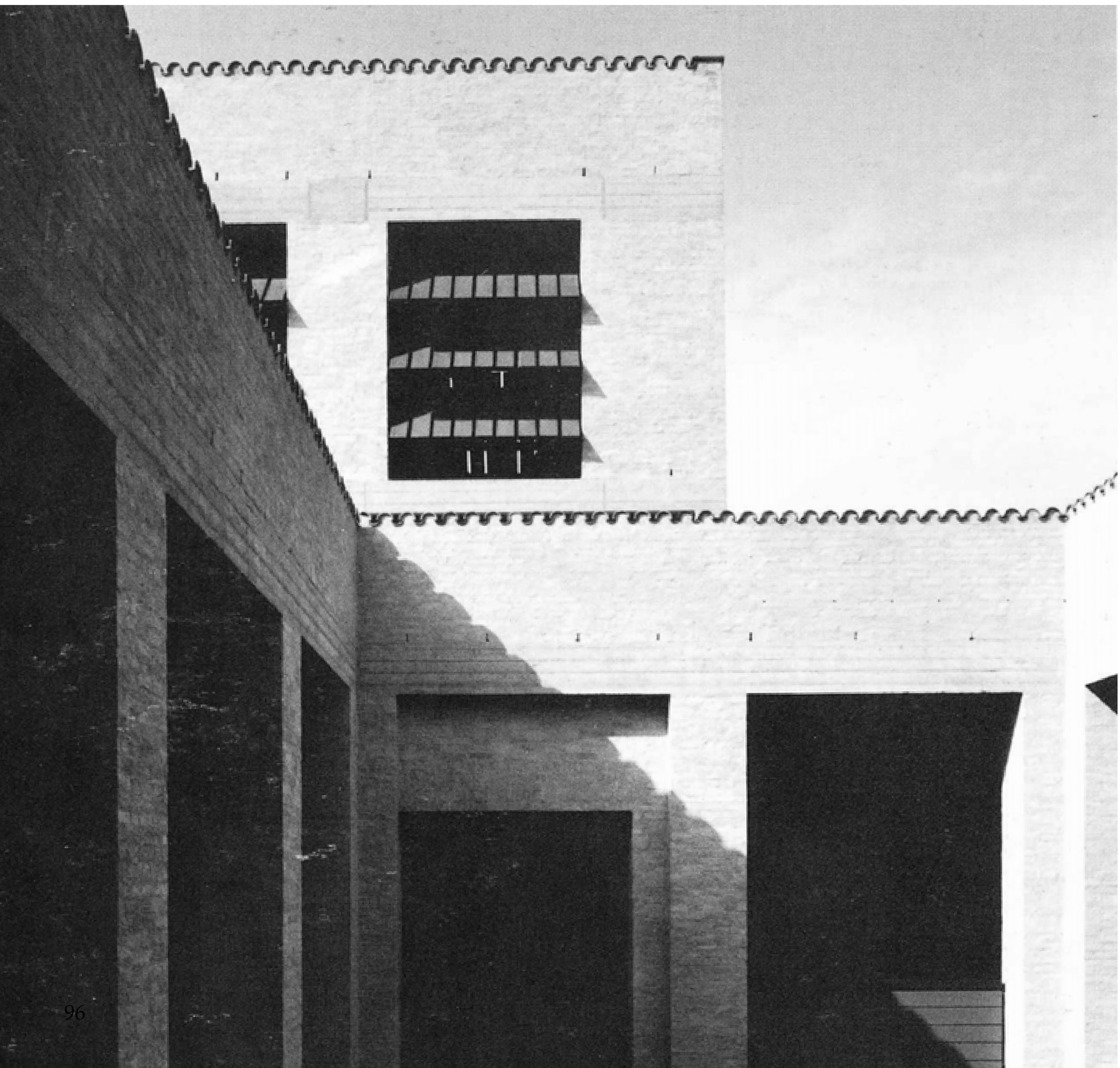
the fragment of the "love-theme", this time in E major for the tutti. Note that the appearances of the "theme-love" are made half tone higher and higher, a mechanism that underscores the brilliance effect of the theme. The "flower theme" appears again. And then the last three chords of Motive A are repeated continuously. While the piano threshes the last repetitions in different registers, the string quartet moves towards the treble, the double basses together with the wind towards the bass, slowing down the tempo more and more, reaching the "slow", very strong, of the following section, by a double ascending-descending conduction, in two contrary movements of 3-sound chords and in the second transposition mode of mode 2. Note that this is the first appearance of the limited transposition modes in the whole movement, here producing a decentralization or destonalization effect that reinforces the tonal insecurity just before the first explosion of the "love-theme".

Very strong and clearly with a C major tonal centre, this first explosion of the "theme-love" is built on a succession of IV-I degrees on the C major scale. But as if this were not enough, the 4th degree C major is overlaid with notes that complete the 2nd mode in 3rd transposition and the 1st degree C major is overlaid with notes that complete the 2nd mode in 1st transposition. The two appearances of the limited transposition modes that have taken place so far confirm the versatility of Messiaen's system for dialogue with both tonal center and non-tonal systems. When the explosion is over, a motif B (fig.) appears.

Fig. 72. B motif.

Fig. 73. Upper gallery of the cloister at the entrance to the church.

All the dimensions of the Vaals church are the ultimate result of two premises - one functional and determined from the inside out, the other proportional and determined from the outside in. The first was based on the position of the altar, with its surrounding ceremonial space, between the two levels of the choir stalls, and on the requirement that the total space be somewhat longer than a double square. The second was the 3:7 decision for the entire plan.



"The chords played by the English horns, the melodies of the violas, the ascending glycans in harmonic sounds of the violins whistling like the wind of tempest, the descending glycans of the Onde Martenot with loose elements, and above all the two clashes of the second minor of the trumpets and trombones, all concur to draw this terrifying passage."[1] Next, a retrograde rhythmic canon between wood and trombones. This passage that closes the first section is again constructed from an ascending scale of four-sound chords in the 4th transposition mode in the wood, and an ascending scale of three-sound chords in the 3rd mode in the 1st transposition, while cello and double basses play a scale by tones, or what is the same, the 1st mode in the 2nd transposition.

The second section of the great development makes sound again what he has already said in the first section, reworking the ending. Thus, it begins with the motif A in the mainsail, a third minor sharper than the first appearance in the first section. This mechanism leads, once again, to polishing the apparitions of the motif. The last three chords of motif A are repeated again, giving way to the appearance of the fragmented "theme-love". The "flower theme" appears again. Again, motif A accompanied by the "chord theme" with its repetition of the last three chords, giving way to the second appearance of the fragment of the "love-theme", this time in Eb major for the tutti. The "flower theme" appears again. Next, the repetitions of the last three chords of motif A are more numerous than in the first section and it will then be necessary for the second

1 Messiaen, *Traité de Rythme, de Couleur, et D'ornithologie (1949-1992) En Sept Tomes*. Tome VII. Pg. 319.

Fig. 74. View towards the back of the church.

None of these three internal dimensions of the central space or “hall” can be reached directly. The starting point is the white shape containing the entire volume of the upper church, including the sloping roof: the height of the roof, the widths of the two side galleries and the depth of the atrium and final gallery. The “room” space derives its shape not from the galleries, nor from the space between the pillars, but from the outer walls. This is why, in the two designs of the church, the original and the revised, neither the width nor the height of the central space, but the total width between the outer walls, is an exact measure of the plastic number.

explosion of the'theme-love' to be longer and more important than in the first section.

The third and final section of the great development takes up again from the beginning the motif A in F# major. The "chord theme" appears again in exactly the same tempo as in the first section. There is an interpolation of motif B within the appearances of motif A, since motive B constantly interrupts motive A, with a pressing insistence. In [31] a retrograde rhythmic canon between strings and trombones appears again, the same as in [17]. In [32] a repetition of [29-31] is done, only motif A is in G major. The interpolation of motif B continues. We still find the retrograde rhythmic canon between strings and trombones, carried one tone higher. In [35] the repetitions of the last three chords of motif A are in B major, D major, and F # major - they further prepare the last explosion at the figure [42], where the third explosion of the "love-theme" will take place.

> As all three chords end in the 7th dominant (+6 chord or sensitive sixth chord) of F# major, and the explosion of [42] is made on the 4th major F# degree, everything here is tonaly preparing this explosion. But this one will be much more intense, and much longer than the two previous ones, it will be the top piece and undoubtedly the summit of the whole symphony. It is necessary, therefore, to prepare it at length, and that we see it as worthy of coming. Moreover, the latter will be noble and luminous, and must be painful, gasping, feverish and acidic. By contrast, the lightning of light colors and slower durations will be more violent.[1]

Motif B, which constantly interrupts motif A, is becoming more and more important. In [37], the final development of motif B begins. But the three chords of motif A are still there. In [39], finally, A

Fig. 75. Third and last appearance of the theme-love in the VIII movement, in the number [42].

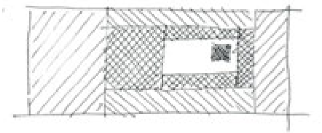


Fig. 76. Diagram of Van der Laan's proportions for the church of Vaals. The faithful, the monks and the final ambulatory surround the altar like a circle around the central event: the Eucharist.

Fig. 77. Frontal view of the church.

A final description of the church by Van der Laan himself suggests that the composition was conceived as an overlap of concentric volumes, beginning (or ending) with the altar. The altar, as the "key piece of the whole composition", can almost be considered as a surplus volume of the superimposed space around it; it stands clearly as a block-core, superimposed on the plinth. By analogy, the plinth is in turn superimposed over the ceremonial area, and this area over the central space of the room. Finally, the central space of the hall is not, in this way, a surplus of subtracting the atrium and the galleries, but a positive volume superimposed on the whole space of the church.

disappears completely and the development of B is in its splendor.

> B gets increasingly excited, in a long uphill march of three attempts at completion. At each of the three attempts, the chords of the higher voices are raised by half a pitch, while the fifths of the basses are raised by one pitch. The result is that each attempt has different chords. On the other hand, the two second-highest clashes of trumpets and trombones never change. The whole passage is an army of furious waves hurling themselves at the assault of a fortress. In the lead, the leaders who fight against a summit of anguish and who beat relentlessly against an invisible glass that cannot be broken. The last attempt at completion, the stacking of strings still exceeds the previous effort and goes in the reverse direction of a piano descent. When the crossing is in full swing, the three chords of A reappear and their even more numerous repetitions (7 in C in the first, 9 in D in the second, and 11 in F# in F# in the celle-ci) will bring about the third and final explosion of the "love-theme" which will be - (and by far!) - the most terrible of all.
>
> Number [42]. This is the summit of the entire Turangalila Symphony. The climax of material intensity of the orchestration, the climax of spiritual intensity of the feeling of love. Blinding light, very strong in metals, long-lasting. and the fourth degree of the major tone, as in the Transfiguration for love at the end of the "Death of Iseult", as in the Redemption for love at the end of the "Death of Brunhild", in Richard Wagner, as in all the lyrical effusions that end a work of some importance. [...] The previous passionate growth has exceeded its purpose: it is no longer a man and a woman, it is Tristan-Isolda with the suppression of the syllable and, it is love magnified to the mythical state, a reflection of Eternal Love. [...] Tristan and Iseult are transcended by Tristan-Isolda, in a superior love, archetype of all loves.[1]

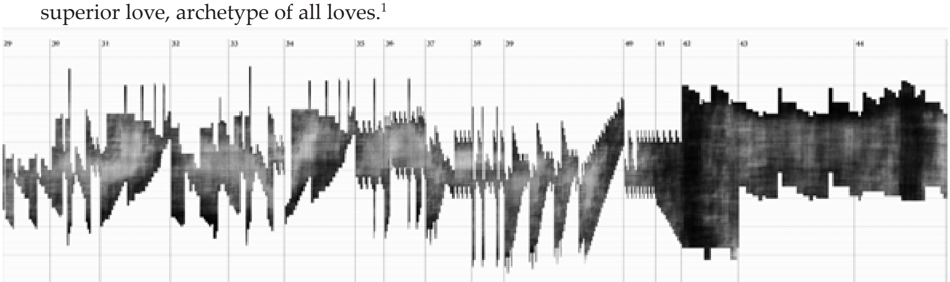


Fig. 78. Third and last section of the VIII movement, comprising the numbers [29]-[44].

#. *Turangalîla Symphony. 8th movement.* Olivier Messiaen.

1 Messiaen, *Traité de Rythme, de Couleur, et D'ornithologie (1949-1992) En Sept Tomes.*

1.12. Conclusion

In the introduction of the chapter we asked ourselves about the phenomenon of the hyper-production of a few elements towards the multiplicity of the real world, we called it a system. After having investigated the nature of this from two different disciplines, and having verified its versatility in two works of opposite appearance, it seems that we are in a position to reaffirm ourselves in those intuitions that incited our investigation.

Indeed, two considerations have been made explicit here. The first emphasizes the general concrete nature of the systematic nature of human production. Both the history of our culture and the concrete examples of both authors, Van der Laan and Messiaen, show that man cannot prepare to create without establishing a playing field and laws, that is, a system. This fact, which we had already intuited in the beginning, has not only been explained by history in the sections entitled "Between the topological and the metric space" and "The musical systems in history", but also has its support from the formal logic, as Alfredo Deaño has taught us in the section entitled "The systematic in architecture" and "The systematic in music".

The second consideration has to do with the specific nature of the works. While creative freedom is initially constrained by submission to the laws of the system, once it is known and mastered, freedom resurfaces strengthened and capable of absorbing the so-called exceptions to the system: those moments when it seems that the system lacks what the creator has to offer. It is the same system that accepts exceptions. Moreover, the exceptions arise from the reflection of the system itself, since when the system exposes its playing field it makes explicit what is outside and within its boundaries. In this way, the exceptions we find in the works legitimise, to a certain extent, the presence of the system. One can only look at the decision to turn the floor plan of the Vaals church 90 degrees, because although Van der Laan legitimizes it as a separation from the previous construction, through this movement he inaugurates the entire repertoire of new measures for the new church that will allow it to fit everything together through the *plastic number*. We can also look at the *Development of love* and see that the work is divided into three great attempts to culminate the theme-love, each in a different and ever sharper tone (C, D and F#), which although Messiaen explains that each attempt is going to be more and more terrible, this apparently capricious decision does not fail to be framed within a general scale plan where the first two sections (C and D) are the preparation for the explosion of light of the third (F#), the mother tone of the entire symphony.

Van der Laan and Messiaen's creative freedom from a system

The remarkable variety of artistic manifestations all around the world and in all times generates considerable interest in studying the nature of the creative process. The fact that this huge amount of work is conceived by the human brain suggests the possibility of a systematic nature of human creativity.[1] A system is a basic structure composed of some elements and the relations among them.[2] However, it is commonly believed that following a system's rules leads to a lack of creative freedom.

This phenomenon affects all artistic production: from the most intangible of the arts (music) to the most material of them (architecture). An analysis on all artistic disciplines would be a titanic task and that is one of the reasons for choosing architecture and music as study cases. Furthermore, the significant amount of literature defending their interrelation attracts widespread interest in the comparison of both disciplines.[3] But the real reason for putting together architecture and music is the fact that neither need to reproduce the real world, in the same way as literature, theatre or painting. They possess a non-linguistic scaffolding within a coherent system. In other words, architecture and music do not use linguistic signs but rather composed designs where the interrelations constitute ordered systems.

In the recent years, it has been generally accepted that the artist can do whatever they want in order to achieve their desires and this leads to arbitrariness.

1 Stravinsky.

2 Schönberg. *Fundamentos de la Composición.*

3 Wittkower; Moreno Soriano; Xenakis, *Música I Arquitectura.*

For example, Rafael Moneo showed that there is an increasing number of architects that found their project decisions to be arbitrary[4] and, previously Igor Stravinsky illustrated that today's artist is somebody who speaks their own language and nobody understands them . More work is needed to explain that artistic disciplines have a systematic nature and to defend that its knowledge brings a major control of the discipline itself.

This part of the chapter analyses two artistic creators that used a coherent system in their work: the composer Olivier Messiaen and the architect Dom Hans van der Laan. By analysing their work, we can illustrate the systematic nature of the disciplines that provides the tools for the freedom achieved in their creations. Our research reveals through particular examples from both authors that those systems helped them to reach their creative purpose.

4 Pierre Schaeffer, *Tratado de Los Objetos Musicales* (Madrid: Alianza Música, 1988).

Between pure mathematics and aesthetics

There seem to be three possible approaches to the relation between art and mathematics. The first one can be named as Pure Mathematics, in which mathematics solves problems that are unlinked to the artistic interests and mathematics covers the entire question. The second one can be named as Universal Necessity, in which the problems of art have an explanation in mathematics and the mathematical solution is artistically interesting. The third one considers the problems of art as a question of pure taste and there is no place for the mathematical or logical reasoning, known as Aesthetics.

Nevertheless, we announce that our paper is not going to base its investigation in the first approach neither the third one. It is the second one, the conjunction of an artistic necessity and a mathematical way of resolution of this necessity, what we find necessary to explain.

Pure Mathematics

Mathematics are intended to describe many of the properties and processes in the world; its language, however, must be precise to the extent of appealing to the human reasoning rather than to sensible experiences. In its more rigorous and toughest expression, modern mathematics rely on the Axiomaic System of Zermelo-Fraenkel (with Choice) which is stated in first-order logic language.

In this setting mathematics only cares about “what is true”, without ever considering “why” or “for what purpose". The following example will clarify this perspective.

Suppose we are given the following mathematical issue: "Find the ratio of a rectangle that may be decomposed into a square and smaller rectangle with the same (reversed) ratio."

Fig. 79. Both grey rectangles are proportional.

Even when this issue is not stated in terms of this rigorous language, it may be translated into such terms, and the answer would be: "There exists exactly one (bigger than one) real number

$$x=(1+\sqrt{5})/2$$

for the ratio of such rectangle" which is the fundamental golden number ϕ."

Now suppose we are given another slightly different mathematical issue: "find the ratio of a rectangle that may be decomposed into two squares and smaller rectangle with the same (reversed) ratio."

Fig. 80. Both grey rectangles are proportional.

And again, there is a precise answer: "there exists exactly one (bigger than one) real number

$$x=1+\sqrt{2}$$

for the ratio of such rectangle."

Both numeric solutions above studied solve the pure mathematical statements that were asked.

They are the unique solutions to their problems. Moreover, these numbers hold natural and artistic significations, and they are included in the family of metallic means, as is widely explained in Spinadel . For that reason, we can clearly see that in this point there is already a necessity that is covered by these numbers. Hence, they do not serve only to the "pure mathematics", but they cover a necessity, that we name as "universal necessity".

Universal Necessity

If the first approach to the relation between art and mathematics is pure mathematics, as we have just seen previously, the second step links art and mathematics by a necessity that nature needs to solve. Therefore, this second approach deals with a natural necessitiy that only has one possible answer. When a natural necessity falls into a unique solution we can treat it as an objective necessity, because the result follows the only possible way. Some literature has been written in this field and every author uses a different term to describe this reality. Doyal and Gough prefer the terms "objective" and "universal" to describe human necessities: "objective" because its theoretic and empiric specificity is independent to the individual preferences and "universal" because its concept is the same for all cases . Kant also speaks about an "objective necessity" as the necessity that remains along the time . In the case of art and mathematics, we cannot consider artistic necessities as natural necessities, because art is artificial, and this term can lead to confusion. But once the necessities of art are treated by a universal approach, we can call these necessities as "universal necessities".

There are lots of examples where we can find a "universal necessity" translated into a mathematical property. However, not every mathematical property (discussed in 2.1) may come from a "universal necessity".

Despite the fact that we are going to centre our attention into the relation between art and mathematics, we find it interesting to show an example where nature and mathematics link into such a "universal necessity". After this example we will explain the "universal necessity" in art and mathematics.

The golden number $\phi=(1+\sqrt{5})/2\approx 1.618$

has many demonstrations in nature: flower petals, seed heads, shells... Plants usually pack their leaves or seeds in arrangements involving the golden ration. This is studied in phyllotaxis and is a most known effect, whose reasoning includes both an evolutionary advantage and mathematical property. Let's discuss this phenomenon further.

Plants can grow new cells in spirals; the spiral happens naturally because each new cell is formed and put after a turn. But the angle of the turn made before putting a new cell is crucial.

Suppose a plant puts a new cell with an angle equal to 2/5 a complete turn, that is, (2/5) x360º = 144º,

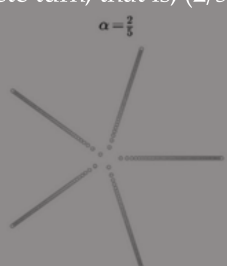


Fig. 81. Spatial distribution for α=2/5.

This is rather a bad distribution for the seeds to be equally spaced and profiting the sunlight. If we take α to be the ratio of a complete turn to be made, then α should not be a rational number, otherwise inconvenient branch patterns will arise.

We need some irrational number, what about $\alpha=\pi$?

Fig. 82. Spatial distribution for α=π.

That is not good either. One may notice the formation of seven curved branches. Why? Well, we must remember that π is really close to 22/7

π=3.1415…

22/7 = 3.1428...

so similar behavior is to be expected! π is not equal to 22/7, so the branches are not straight, but curved.

How can we realize that a number is close to very simple ratios? Mathematics has a concise language to this issue: continued fractions:

$$\pi = 3 + \cfrac{1}{7 + \cfrac{1}{15 + \cfrac{1}{1 + \cfrac{1}{243 + \cfrac{1}{1 + \cdots}}}}}$$

The process is quite simple: we subtract the whole part, and the decimal part (less than 1) is then equal to 1/b, for some real number b greater than one, and so on. Large numbers imply a nice approximation by truncating the continued fraction:

$$\pi = 3 + \cfrac{1}{7 + \cfrac{1}{\mathbf{15} + \cfrac{1}{1 + \cfrac{1}{243 + \cfrac{1}{1 + \cdots}}}}} \approx 3 + \frac{1}{7} = \frac{22}{7}$$

Then there should be small numbers appearing in the continued fraction of α! And the best candidate for such a job is the golden number

$$\phi = 1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cdots}}}}}}} \approx 1.618$$

or its inverse

$$\phi^{-1} = \phi - 1 = 0 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cdots}}}}}}} \approx 0.618$$

and it works!

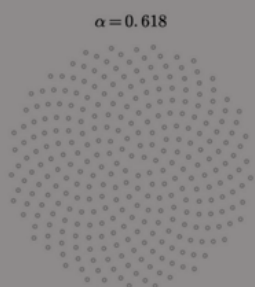


Fig. 83. Spatial distribution for $\alpha=\phi$, the golden number.

Here the universal necessity was the best distribution for the seeds to be equally spaced and profiting the sunlight.

Aesthetics

Finally, the third approach to the relation between art and mathematics is "aesthetics". A lot of work in the field of aesthetics of mathematical forms has been written.[1] We are not going to focus in this insight here. Nevertheless, our aim in this article is to highlight the procedures in which art and

1 Padovan.

mathematics help each other solving “universal necessities”. As we have announced before, it is the second approach that we are interested in.

Background

As the two study cases belong to different disciplines: architecture and music, we must do a concise framework on the relation of them. A big amount of work about the relation between architecture and music has been written since the treatises to the modern architects and composers, passing through philosophers and art historians.[1] Some of the writings argue how difficult the reconciliation of both disciplines is,[2] whereas others show the similarities as the basis for a unified insight.[3]

Much work hast been done in the field of recognition of the treatises[4] and in the regarding of modern artists.[5] In particular, there are many investigations around the figure of Van der Laan and his proportional system. Similarly, a big amount of investigations about the figure of Messiaen and his combinational system of notes have been arisen since its invention.[6] Nevertheless, the information regarding these two authors under the same consideration -the mathematical view- is inexistent and this paper aims to cover this hole and use this argument to defend that creative freedom can be reached from a systematic approach.

1 Laugier, Essai Sur l’Architecture.

2 Roger Nichols, *MESSIAEN* (London: Oxford University Press, 1975).

3 Ulrich.

4 Padovan.

5 Padovan.

6 Padovan.

Methodology

The methodology used in this section of the chapter consists of describing the systems used by Van der Laan and Messiaen, and the verification of their creative freedom in decision making. For this purpose, we show the characteristics of both systems in order to be aware of the application in their works. Subsequently, we analyze their application to personal works: Saint Benedictusberg Abbey new church and 8th movement of Turangalîla Symphony. Finally, we show those points where the system has helped them or not to the creative freedom.

On one hand, Van der Laan used his Plastic Number system in the construction of Saint Benedictusberg Abbey new church. Firstly, an enumeration of the strengths and weaknesses of this system is showed in the first part of the article. Secondly, a detection of the points where the system guided him to build the church is shown. Finally, we indicate those points where the system specially helped him to reach the creative freedom.

On the other hand, Messiaen uses his Limited-transpositional Modes system in the conception of the 8th movement of Turangalîla Symphony. Again, an enumeration of the strengths and weaknesses of this system is showed in the first part of the article. Secondly a detection of the points where the system guided him to conceive the movement is outlined. Finally, we indicate those points where the system specially helped him to reach the creative freedom.

The comparison between the two systems in this article allows us to explain that the two disciplines (music and architecture) share a systematic nature.

Moreover, with this method, it is easy to sum up that two different disciplines possess different systematic roots and, at the same time, this systematic root can be seen as the link between them. Not only differ one from the other but also can be compared through this systematic view.

The systems of Van der Laan and Messiaen

The universal necessity of Van der Laan

Dom Hans Van der Laan dropped out his architecture degree in 1926, when he was in the third year in Delft. He decided to consecrate his life to God as a Benedictine monk and, at the same time, aimed to search the "primitive origins of architecture: to that fundamental link between the technical building art and our need of order and definition in the space around us".[1] His discovery of the Plastic Number must be related to his fascination with measurements and proportions since he was at his father's architecture workshop.[2] The major problem he looked for was the possible division of a segment AB by C and the subsequent division of BC by D in which AB, AD, BC, AC, CD and BD were in a continuous proportion. Furthermore, the Plastic Number is determined by, and contained within, two limits: an inferior limit in which the difference between two measurements cannot be distinguished by human eye, and a superior limit in which two measurements are so different that they cannot be compared.

1 Padovan.

2 Padovan.

The Plastic Number system is flexible enough because it defines a scale of measures from a given measure but does not allow to establish a fixed grid.[3] In this aspect, Van der Laan's system is similar to Le Corbusier's. But, unlike Le Corbusier's Modulor system, Plastic Number system consists of a proportion and not a fixed scale.[4] For this reason, the Plastic Number must be used carefully because of its most characteristic aspect: the ability for measuring continuous world into a discontinuous system. This fact can, hence, fall into total permission of measuring and into total restriction of measuring.

We have already mentioned that Van der Laan was searching for the possible division of a segment AB by C and the subsequent division of BC by D in which AB, AD, BC, AC, CD and BD were in a continuous proportion. We all know that this statement belongs to the pure mathematics field. But we can also know that this statement is the formalization of a real problem that Van der Laan expressed in one of his letters.[5] Speaking to architect Richard Padovan about how was he searching for this proportion when he was young. He had been fascinated by problem of proportion since childhood. He wondered where the measures of the buildings came from:

> Above all, I sought the origin of these measures, but they vanished into the vagueness of the design sketches, which by that time were mostly done by my elder brother… The course at Delf had taught him no fixed norms for design, just

3 Jay Hambidge, *The Elements of Dynamic Symmetry* (Mineola: Dover Publications, 1967).

4 P. H. Scholfield, *Teoría de La Proporción En Arquitectura* (Barcelona: Biblioteca universitaria labor, 1971).

5 Messiaen, *Technique de Mon Langage Musical.*

> as I would find myself. In the BSK we tried to discover them for ourselves, and the following story belongs to that period.
>
> On Sundays my father smoked better cigars than during the week… Inside the lid of the cigar-box was a view of the Domtoren (cathedral tower) of Utrecht… For much of my boyhood this image served as a model for my play with building-blocks. I had never been to Utrecht, but when I heard that my uncle's family had moved there, I immediately asked if I could come and stay. I wanted to know how the tower was composed, so as to use it as point of departure for my own designs. For two days I sat from morning to evening in a corner of the cloister, and I finally hit on the very regular and simple scheme… next day I got into the works office for the restoration of the choir which was then under way, and was able to examine the drawings of the tower, complete with measurements which corresponded wonderfully with the scheme I had mapped out… in with all measures were multiples of each other. I several times spoke about this to the BSK group, but always came in conflict with the Prof, who interpreted the balustrades as intermediate elements uniting the larger parts, whereas I saw them as reflections in the parts of the composition of the whole: and eighth part of each subdivision, just as the roof zone was an eighth part of the whole tower.
>
> (…) And I recognized in each of the three parts its own crowning in the form of the balustrades. This last was something that had fascinated me ever since my childhood: to find in the subdivision of a thing the aspect of the whole.

Padovan notes that the phrases "all measures were multiples of each other" and "reflections in the parts of the composition of the whole" contain the essence of what later became the plastic number, and indeed of Van der Laan's whole theory of design. In fact, this phenomenon should have a formalization in mathematics, Van der Laan thought. This "universal necessity" should have a mathematical expression. Finally, this expression is Plastic Number.

In a lecture, Van der Laan concludes that the plastic number is contained between a geometric and arithmetic conception of quantity:

> So we see that the plastic number throws a bridge, as it were, between the two mutually exclusive kinds of quantity, the how-many and the how-much. We can define the ordinance based on this number as an arithmetical order in which attention is paid to certain tolerances.

Translating the how-many by arithmetic conceptions and the how-much by geometric conception.

Van der Laan and the Plastic Number

Van der Laan's universal necessity may be translated into mathematical terms as follows:

to divide a segment in several pieces, so that the lengths of the resulting pieces (or the union of adjacent ones) fit neatly into a (decreasing) geometric progression.

For this requirement to be studied we will focus first on the simplest examples.

One cut and two pieces

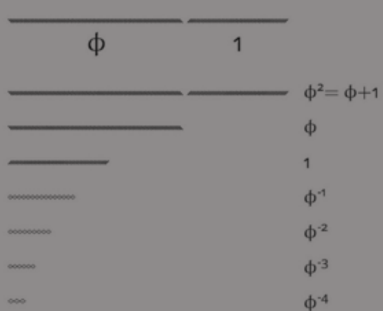


Fig. 84. Golden number

Fig. 85. Plastic number.

Taking as unity measure the length of the shorter piece and ϕ the length of the bigger, our defining equation becomes

$$\phi^2=\phi+1$$

whose positive solution is the ubiquitous golden number.

$$\phi=(1+\sqrt{5})/2\approx 1.618$$

When the geometric progression is continued, the new lengths may be arithmetically obtained from larger ones. This is because our defining equation may be multiplied or divided by a power of ϕ

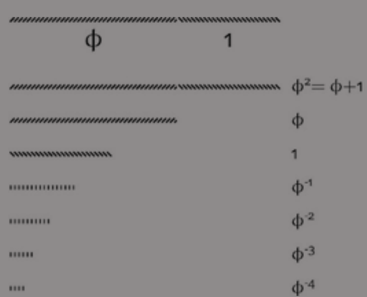
$$\phi^2=\phi+1) \Longrightarrow \phi^{k+2}=\phi^{k+1}+\phi k \ , \quad k\in Z$$

and thus each new length is the difference of the two previous ones. One may notice that this number satisfies the pair of equations

$$\phi+1=\phi^2$$

$$\phi-1=\phi^{-1}$$

Two cuts and three pieces



Proceeding as before, our defining equation becomes

$$\psi^3=\psi+1$$

The function f(x)=x3-x-1 has only one real root

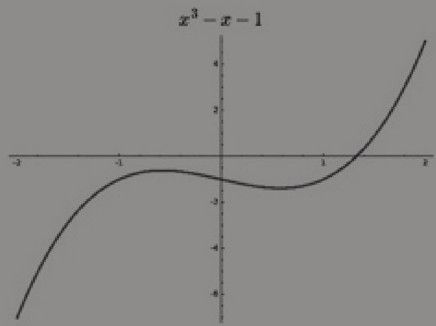


Fig. 86. Root of the function.

whose value is the plastic number

$$\psi = \frac{\sqrt[3]{12(9+\sqrt{69})} + \sqrt[3]{12(9+\sqrt{69})}}{6} \approx 1.325$$

As above, when the geometric progression is continued, the new lengths may be arithmetically obtained from larger ones.

$$\psi^3=\psi+1 \Longrightarrow \phi^{(k+3)}=\phi^{(k+1)}+\phi^k \ , \qquad k\in Z$$

And thus each new length is the difference between the third before and the first before. But surprisingly enough, it is also the difference between the fifth before and the fourth before, thus enriching the systems of measure.

Due to these considerations, the following pair of equations is satisfied:

$$\psi+1=\psi^3$$

$$\psi-1=\psi^{(-4)}$$

For a division of the initial segment into pieces satisfying our requirement, we first need a ratio $\eta>1$ such that

$$\eta+1=\eta^m$$

$$\eta-1=\eta^{-n}$$

for some integer numbers *m* and *n*, because we want that for each pair of consecutive lengths their sum and difference belongs again to our geometric progression. This system, though, has been already studied, and their solutions called morphic numbers. And as matter of fact, it has been proven that there are no morphic numbers greater than 1 other than the golden number and the plastic number.[1] This being so, we may assert that the golden and plastic systems of measures are the only ones that both combine geometric and arithmetic relations in the way described above.

The universal necessity of Messiaen

Olivier Messiaen finished his music studies in 1930 at Paris Conservatory and he decided to devote his life to musical composition, musical teaching at Paris Conservatory, and musical interpretation as an organist in Sainte Trinité church in Paris. His discovery of Limited-transpositional Modes must be related to his fascination with the "charm of impossibilities" since he searched continuously for music with plenty of light and color.[2] The major

1 Messiaen, *Technique de Mon Langage Musical*.

2 Olivier Messiaen, 'Conferencia de Kyoto', *MINERVA*, 19.I (2012), 49–53.

problem he looked for was the possible arrangement of notes –or what is the same, a scale which is able to possess not just one center of attraction but more than one. This search lead him to those scales containing symmetric patterns of notes. In addition, the last note of each pattern is the first of the next pattern. For this reason, transpositions of the scales (or modes, in Messiaen's terminology) are limited and, consequently, it encourages the apparition of several centers of attraction inside the mode.[3] In words of Messiaen :

> One point will attract our attention at the outset: the charm of impossibilities. It is a glistening music we seek, giving to the aural sense voluptuously refined pleasures. At the same time, this music should be able to express some noble sentiments (and specially the most noble of all, the religious sentiments exalted by the theology and the truths of our Catholic faith). This charm, at once voluptuous and contemplative, resides particularly in certain mathematical impossibilities of the modal and rhythmic domains. Modes which cannot be transposed beyond a certain number of transpositions, because one always falls again into the same notes; rhythms which cannot be used in retrograde, because in such a case one finds the same order of values again –these are two striking impossibilities [universal necessity].[4]

Messiaen recalls the same necessity some pages below :

> Let us think now of the hearer of our modal and rhythmic music; he will not have time at the concert to inspect the nontranspositions and the nonretrogradations, and, at that moment, these questions will not interest him further; to be charmed will be his only desire [universal necessity]. And that is precisely what will happen; in spite of himself he will submit to the strange charm of impossibilities: a certain effect of tonal ubiquity in the nontransposition, a certain unity of movement (where beginning and end are confused

3 Messiaen, *Traité de Rythme, de Couleur, et D'ornithologie (1949-1992) En Sept Tomes.*

4 Claude Samuel, *Permanences d'Olivier Messiaen (Dialogues et Commentaires)* (Paris: Actes Sud, 1999).

> because identical) in the nonretrogradation, all things which will lead him progressively to that sort of theological rainbow which the musical language, of which we seek edification and theory attempts to be.[1]

To sum up, we can recall that the universal necessity of Messiaen consists of some "modes which cannot be transposed beyond a certain number of transpositions" and "rhythms which cannot be used in retrograde". Finally, Messiaen's "universal necessity" considers that the desire of the hearer is just "to be charmed". This universal necessity should have a mathematical expression. And in the case of the modes, which is what we are going to focus on, Messiaen's Limited-transpositional Modes is the solution.

Messiaen and the Limited-transpositional Modes

Messiaen's universal necessity may be translated into mathematical terms as follows:

> to find all the possible bullet-cross patterns in a row of 12 elements, up to cyclical reordering, that fit into the repetition of a pattern in a subset of 1, 2, 3, 4 or 6 elements

Here you have an example of such a pattern:

Fig. 87. Example of the pattern

Let's start by direct inspection in subsets of size 1, 2, 3 or 4. As stated we consider cyclical reordering as repetition to get the number of genuine patterns.

1 Messiaen, *Traité de Rythme, de Couleur, et D'ornithologie (1949-1992) En Sept Tomes.*

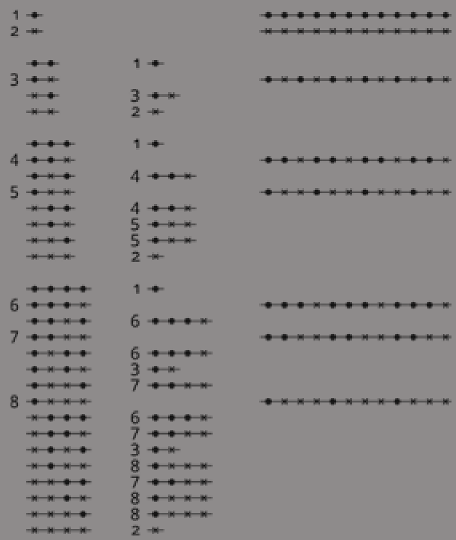
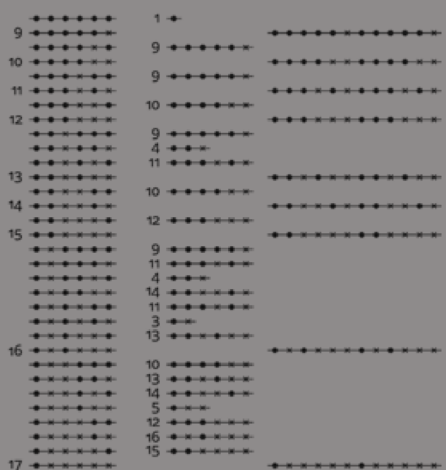


Fig. 88. Permutations for 1, 2, 3 and 4 subsets

Fig. 89. Permutations for the 6 subset

For a subset of order 6, we may suppose that our pattern starts with a bullet, since cyclical reordering may place a bullet in the first position (if there are no bullets at all, this is the empty pattern already considered).



Now we note that there are less Messiaen's limited-transpositional modes than possible permutations on the mathematical reasoning. In particular, there

Fig. 90. Opposite page: each part of the church (right) corresponds to a form in the Morphotek (left).

Fig. 91. Bottom: the section along the path beginning from the entrance and finishing into the church, through the crypt and the courtyard. On the top of the section we can see every measure corresponding to the Plastic Number series (on the left)

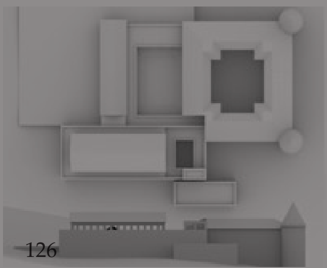
are 17 possible permutations whereas there are only 7 Messian's limited-transpositional modes. How can it be possible? This is a perfect example of combination of mathematics and art, in which neither pure mathematics nor pure aesthetics form the law, but a balance between reason and emotion.

In fact, only the permutations 3, 4, 6, 10, 12, 11 and 9 correspond to Messiaen's limited-transpositional modes 1, 2, 3, 4, 5, 6 and 7. The rest is considered just as the dodecaphonic scale (1), the null scale (2), the seventh diminished chord (5 and 13) and scales without the necessary number of notes capable of a continuity (7, with too big intervals; 8, with only three notes; 14, 15, 16 and 17, with too few notes)

How did Van der Laan and Messiaen use their systems

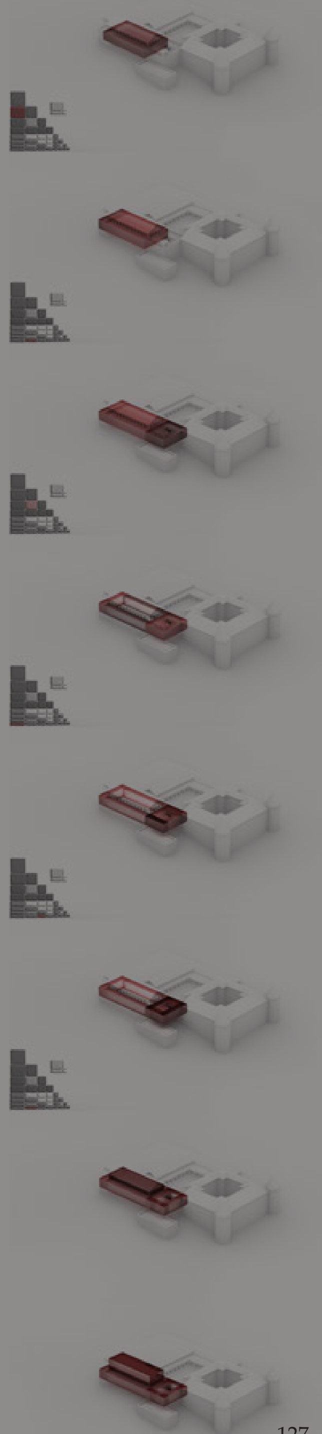
Van der Laan's new church for Saint Benedctusberg Abbey

Van der Laan used the plastic number system of proportions firstly in Saint Benedictusberg Abbey new church, near the village of Vaals, Limburg (Netherlands). Having been commissioned in 1956, the building was not finished until thirty years after this date. This fact allows van der Laan the chance for the application and verification of this theory day after day and in every stage of the building development . Hence, the entire design of the



building is governed by plastic number and the methodology he used when applying the system of proportions can be found in the fourth lesson of van der Laan's *Architectonic Space* book :

> Every form is determined by three dimensions, measured perpendicularly to each other; the smallest of the three early servers as a yardstick. For the sphere all three dimensions are equal; for the cylinder one dimension is enlarged and the other two have the size of the yardstick; for the disc two dimensions are enlarged and only one corresponds to the yardstick. (…) In architecture these forms are squared, just as the ball of clay is given the rectangular form of the brick. We then speak no longer of sphere, cylinder and disk, but of block, bar and slab .
>
> Block, bar and slab are the three extremes of a number of forms that Van der Laan arranges in his Morphotek, which is used rigorously in the conception of every space in the church: the central hall, the galleries around it, the courtyard in front of it, the galleries of the courtyard and, finally, the entire building, as we can see in figure.



Van der Laan not only considers his system as useful for the big scale of his building, but also he also uses it in the measures of the walls, columns and lintels, as we can see in figure 6. Every single part of the building is formed under the proportions derived from the Plastic Number system:

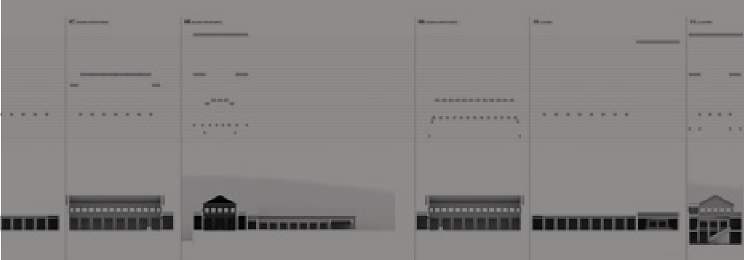
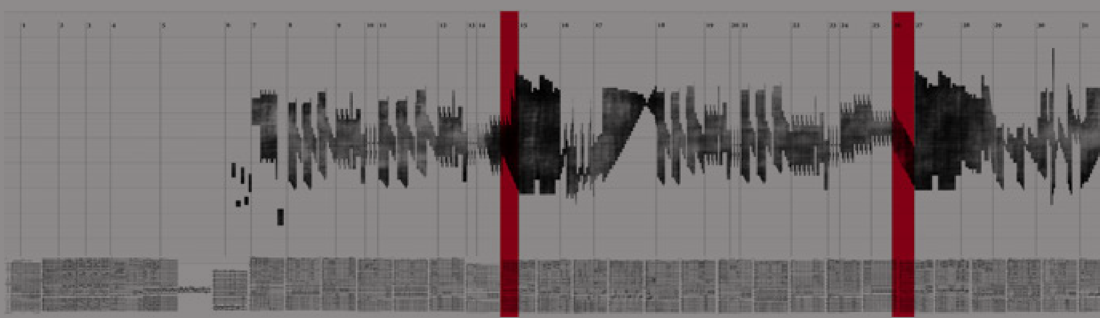


Fig. 92. Bottom: The whole third movement of Turangalîla Symphony with the studied sections marked.

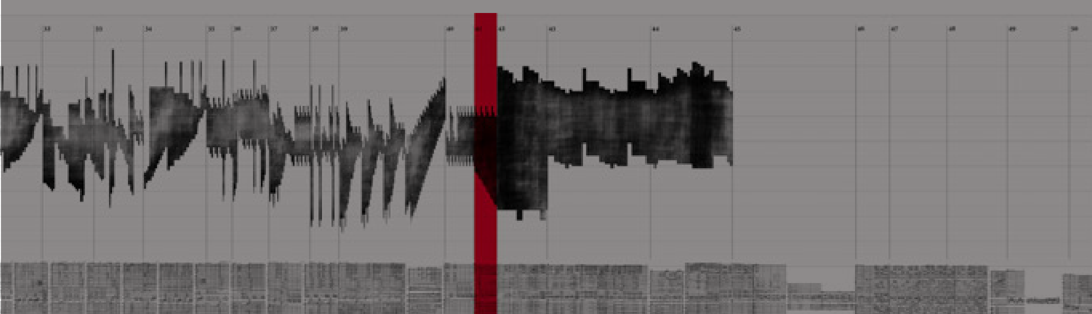
Messiaen's 8th movement from Turangalîla Symphony

Olivier Messiaen, on the other hand, used his Modes of Limited Transposition in some works before the Turangalîla Symphony. This fact allowed him to have plenty control of the system in this work. Being commissioned by serge Koussevitzky for the Boston Symphonic Orchestra, it was premiered in 1949 under Leonard Bernstein's conduction. Messiaen uses his Modes of Limited Transposition in the whole symphony. For our study, the 8th movement is going to be useful on account of the clarity of its use in the work.

As said before, these modes, which are based on the twelve tone chromatic system, take certain notes



from it. These notes form some symmetric patterns in which the last note of each pattern is always the first of the next pattern. This fact leads into the limitation of the number of the mode transpositions and the sense of ubiquity searched by Messiaen in his "charm of impossibilities". There are only seven Modes of Limited Transposition that fulfill these conditions and Messiaen uses them in all his work. In the 8th movement of the symphony, Messiaen uses the 2nd, 3rd and 4th modes in combination of some moments of tonal harmony centered in C, D and F sharp. We can easily hear the presence of the 2nd mode preceding the three entrances of the main theme of the movement . This presence is highlighted by the scales played by the lowest and highest parts of the entire orchestra: the double basses and the flutes, as we can see in the following figures:



As we said before, the common belief is that following a system decreases creativity. But in the case of Van der Laan and Messiaen we can disagree this statement.

Van der Laan uses his plastic number in order to build a bridge between two exclusive kinds of quantity, "the how-many and the how-much" attending to the universal necessity of discrete measurements of a continuous reality, that is the discrete human measurements into the continuous nature. This necessity, mathematically speaking is translated into a proportion able to combine geometric and arithmetic relations in the way described above. This connection between the continuous world of natural objects to the discontinuous fact of mathematical measurements demands the viewer's attention and is fulfilled by the architectonic building . In other words: his system tends to search a marriage between nature and human being in a way that can include all kind of spatial possibilities, that is, the definition of architecture. This achievement may be seen as a product of the systematic use of the architectonic discipline rather than arbitrary use of some architectonic elements.

Messiaen, on the other hand, uses the system of limited-transpositional modes in order to achieve a bigger range of musical possibilities in his work. The three extracts showed before are followed by three consecutive explosions of tonal harmony centered in C, D and F sharp. This connection between his modal system to the tonal system demands the listeners' attention and fulfills the "charm of impossibilities" created by the system itself . The fact that this system is able to connect with other musical systems brings him more freedom in creative decision making. In other words, his music tends to cover a wide variety of music harmonies that goes from the serialism to the tonal harmony and the modal scales, all by means of coherence and proficiency. This achievement may be seen as a product of the systematic use of the musical discipline rather than an arbitrary use of some musical elements.

Chapter 2

Tools for generation

Virtual reality for
urban sound design:
a tool for architects
and urban planners

Chapter 2

Tools for generation

Virtual reality for urban sound design: a tool for architects and urban planners

The present chapter is derived from the work entitled *Virtual reality for urban sound design: a tool for architects and urban planners*. This work was presented by the author as a chapter of the book *Artificial Intelligence,* IntechOpen 2018.

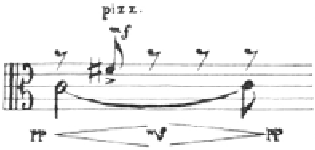
2.1. Introduction

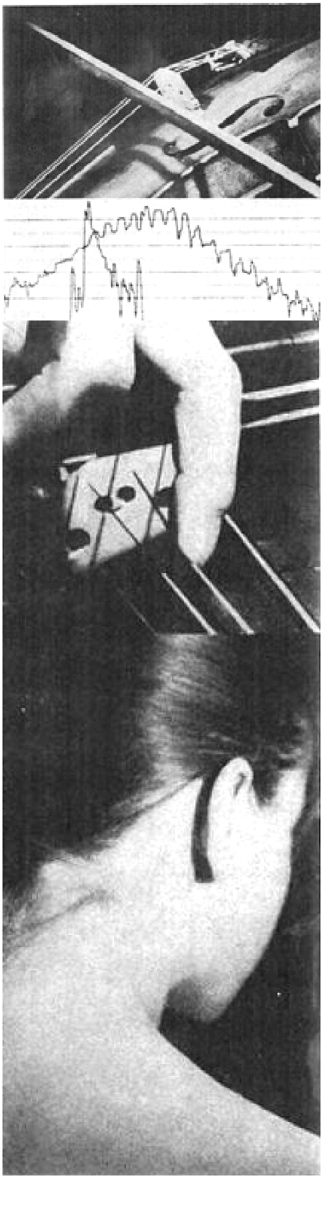
Sound continuously surrounds and envelops us, whether we are indoors or out, at work or play, in cities or the country. We hear birds, voices, machines, wind, water, thunder, whispers, steps, calls, whimpers, doors, windows, floors, chairs, etc. Some of these sounds are heard clearly, others overlap. Sometimes they come together in a yell, at other times they succeed one another. Then, you can hear noises, sounds, music, background, rhythms, accelerando, harmonies, dissonances, cacophonies, echoes, vibratos, repetition, melodies, etc. At times sounds remain masked by distance; at other times, some frequencies are highlighted. They are modified by echo, reverberation, coupling, absorption, brightness or localization. They have the capacity to make us rejoice, to sadden, pacify, sweeten, amaze, frighten, annoy, alert, stress, upset, attack or madden. At the same time, they can make you dance, swing, feel dizzy, sing, whistle, imitate, keep quiet, laugh or cry. When you try to emulate them, you can beat, rub, blow, strum, nip, strike, haul, move or pat something. Some sounds can be anticipated, others come as a surprise. Sometimes, you know how they are going to sound, but you do not know when. At other times you know when you will hear them, but not how they are going to sound. In some cases, the sound has been heard, but you do not know where it has come from. At certain times, it is known that a sound is going to happen, but you do not know why. Thus, anticipation, prevision, effect, surprise, timbre or production techniques contribute to hearing a sound as a source of pleasure, such as when it turns into music.

This chapter describes some attributes of sound object design in architecture and urbanism, and explains a useful tool for designing and experiencing a sound object. The first part of the chapter defines the sound object in the built environment through some considerations of its temporal composition, and the treatment of the city as a sonic instrument. The second part of the chapter translates these concepts into a powerful representation tool – virtual reality – as a useful instrument for architects and urbanists of today, and then reviews the software that meets these needs and describes some case studies. Finally, the last part of the chapter provides an overview of how acoustic virtual reality can take advantage of some current developments in artificial intelligence.

Fig. 1. The explosion of the *mascletà*, Valencia, Spain. An extremely noisy urban situation in which sound involves the whole urban space. Such soundscape is accuratedly designed by the *piroctènic*, the technitian who manages time, space, frequency, loudness, timbre, colour and smell. Everything is melt as a powder symphony, which can only be enjoyed by the live expectator.

#. *Mascletà* 18th March, 2017. Falles València.





2.2 Sound objects

2.2.1. Some features of the architectural and urban sound object

To define what an architectural and urban sound object is, we must refer to the creator of the term "sound object". In 1966, in his famous *Traité des objets musicaux*, Pierre Schaeffer broke with the academic classifications of noise, sound and music, and created a new musicology. His work presented a phenomenology of the audible. The key concept was not defined as a musical object, but as a sound object that could represent any environmental sound. The notion is quite complex and its richness cannot be demonstrated in a few words.[1] Nevertheless, Pierre Schaeffer himself defined what a sound object is, pointing out that:

> It is obvious that in saying "that's a violin" or "that's a creaking door" we are alluding to the sound produced by the violin or the creak of the door. But the distinction that we want to establish between the instrument and the sound object is even more radical: when we are presented with a magnetic strip in which an unknown sound is recorded, what are we listening to? It is precisely what we call a sound object, regardless of every causal reference designated by the terms sound body, sound source or instrument.[2]

In this way, the term "sound object" is grounded in our subjectivity, despite the fact that it is not modified by individual variations in hearing, or continuous variations in our attention and sensitivity. Far from a subjective issue – in the individualist, incommunicable and practically

1 Jean François Augoyard and Henri Torgue, *Sonic Experience : A Guide to Everyday Sounds* (McGill-Queen's University Press, 2010).

2 Pierre Schaeffer, *Treatise on Musical Objects : An Essay across Disciplines*, 1966th edn (Oakland: Univertisy of California Press, 2017)

elusive sense – sound objects can be well described and analysed.[3] In other words, the sound object is the sound that reaches the listener's ear and is analysed just before entering it. The sound object is never well revealed, as in the effect and content of blind hearing.

Pierre Schaeffer defines sound objects by comparing illuminating and sonic phenomena. This comparison is reproduced here, as it provides a clear explanation:

> Two big differences separate the experience of illuminating and sonic phenomena. The first consists of the fact that most visual objects are not sources of light, but simply objects, in the usual sense of the word, with light shining on them. Physicists are therefore quite accustomed to distinguishing light from the objects that reflect it. If the object itself gives out light, then we say it is a light "source".
>
> With sound there is nothing like this. In the overwhelming majority of sonic phenomena, sound as originating from "sources" is emphasized. However, the classic distinction in optics between sources and objects has not been imposed in acoustics. Attention has been given to the sound (as we say the light) considered as an emanation from a source, its paths and deformations, without the appreciation of the shapes and contours of this sound apart from the reference to its source.[4]

It can be easily assumed that the distinction between sound source and deformations of the sound source can refer to a probable distinction between sound source and modifications to the sound added by the architecture. In other words, we can refer to the distinction between music and architecture in the process of hearing. However, before a conclusion is drawn, another quote by Schaeffer could provide clarification:

Fig. 2. Opposite page: five different ways of representation of the same "sound object": sustained note followed by a pizzicato.

3 Schaeffer.

4 Schaeffer.

> This attitude has been reinforced by the fact that sound (prior to the discovery of recording) has always been linked in time with the energy phenomenon that was its origin, to the extent that it has been practically confused with it. However, a fleeting sound is only accessible to one sense and remains under single control: the sense of hearing. In contrast, a visual object has something stable, and this is the second of the aforementioned differences. It is not confused with the light that illuminates it, it appears with permanent contours under different lights, and it is accessible to other senses: it can be felt, weighed and smelled; there is a form that our hands feel, a surface that touch explores, a weight and an odour.
>
> It is understood that the notion of object barely had the strength to impose itself on the physicist's attention. As the natural tendency of physics is to lead facts to their causes, great satisfaction is found in the energetic evidence of the sound source. There is no reason why the ear, at the end of the propagation of the mechanical relations in an elastic medium (the air), should perceive anything other than the sound source itself.
>
> In fact, there is nothing false in the reasoning. Let us just say that, while it is valid for a physicist or an electroacoustic device builder, it is not, however, suitable for a musician or even for an acoustic ear [or an architect]. In fact, the latter do not concern themselves with the way a sound is born and propagated, but only with the way it is heard. Now, what the ear hears is neither the source nor the "sound", but the true sound objects in the same way that the eye does not see directly the source, or even its "light", but the luminous objects.

What Schaeffer wants us to realize is that what the ear hears is not the source, the "sound", or even the pure music, but the real sound objects, which are the-music-with-the-architecture, in the same way that the eye does not see the source directly, or even its "light", but the illuminated architecture. What the ear hears is, in fact, musicalized architecture.

Notably, when virtual reality tries to represent the sound world of an environment, it always does so for a subjective position of the listener, with an individual and unique point of view. The listener as a receiver perceives the effects and the sound content there, and interactively in virtual reality the sound is heard once it has been mixed with the architecture. Therefore, the listening point of the listener includes not only the sound source, but also the modifications caused by the place in which the sound moves, that is, the sound object. In this context, the notion of sound object provides an appropriate theoretical framework for this type of representation, since the sound object is revealed in the blind listening of the effects and the sound content, as explained previously.[1]

2.2.2. The city as a sound instrument and the architect as a luthier of the city

Another issue in considerations of the sound object is the notion of identification of the sound source. While it is true that a sound sounds different in each architectural or urban space, we can also say that we continue to recognize the original sound and distinguish it from other sounds, despite the effects with which the architectural space modifies the sound source. To understand this issue, it can be explained as follows.

We can say that an acoustic musical instrument has three elements, of which the first two are essential. These are: the vibrator that starts to vibrate, and the exciter that causes the initial vibration or prolongs it in the case of maintained sounds. The third element, which is accessory, but always present, is the resonator, that is, a device designed to add its own effects to those of the body in vibration in

1 Schaeffer.

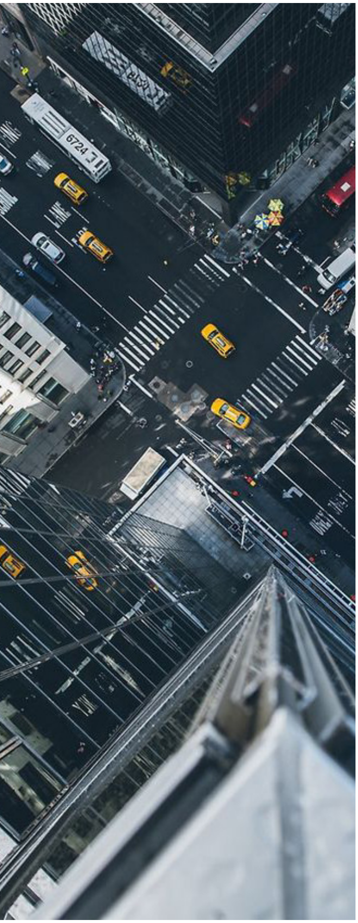


Fig. 3. The three elements of the city as a sound instrument: the cars as exciters, the pavement as a vibrator and the architecture as a resonator.

order to amplify them, prolong them or modify them in some way.[1]

If we transfer this concept to the city, we can also distinguish three elements: the vibrator or the elements of the construction: stony floors, street furniture, walls, etc.; the exciter or the man with his footsteps, movements and actions, the wind, the water; and the resonator or architecture. From this point of view, we consider architecture as a large-scale instrument. This classification into three elements presents the city as a great sound instrument and the architect as a manufacturer of musical instruments without knowing it.

Thus, we can easily compare a church, a street and a square. All of them have elements of vibration: the stone walls of the church, the asphalt of the street, and the sheet of water on the fountain of the square. The exciter for the church are the people who pray, while in the street it is the friction of the car wheels, and in the square the jet of water that falls from the top of the fountain. Finally, the first two spaces have an open-air resonator, while the church is a closed space of resonance.

This classification introduces great clarity in the approach, so that we can move on to another more difficult classification: that of the sound objects themselves, obtained from sources or sound bodies. The murmur of the people praying in the church is infinitely closer to the sound of the fountain in the square than to the shrill sound of a shout in the church, which in turn can approach the braking of a car on the street.

1 Schaeffer.

Once a sound source has been discovered, two possibilities are offered to the instrument manufacturer: repeat the same source and multiply it in different measures, or keep the same source and try to vary it. Schaeffer argues that the second procedure is not the simplest, because it inextricably links the three elements: vibrator, exciter and resonator. It is likely that contingencies force the instrumentalist not to use these variations in mutual independence, but to associate them immediately with the level of aesthetics of the object.[2]

However, if we refer to multiple instruments composed of a collection of vibrating bodies, like the city, we see at once that each of them repeats the triple combination of the elements. Architecture proposes a change in the collection of vibrators (each piece of architecture has different construction elements), a change in the collection of exciters (people change), and a change in the resonator (although the architecture does not move, there are as many pieces of architecture as places; due to the movement of the spectator, the architectural scene changes). Therefore, it is an instrument that varies greatly.

If we listen carefully to the same sound – an oboe – from different points of the same architecture, there is hardly anything in common between the various results produced by the same reproduction-resonance device. But this does not prevent the musician from speaking about the "timbre" of the oboe as an identity. Certainly, the oboe's timbre is recognizable, and the most disfigured of the halls allows the oboe to be identified by an uneducated listener. So, we can state a priori that, although

2 Schaeffer.

the entire room has a timbre, each of its spatial positions also has its own timbre: the same word with two different meanings. Therefore, we define architecture as an acoustic instrument:

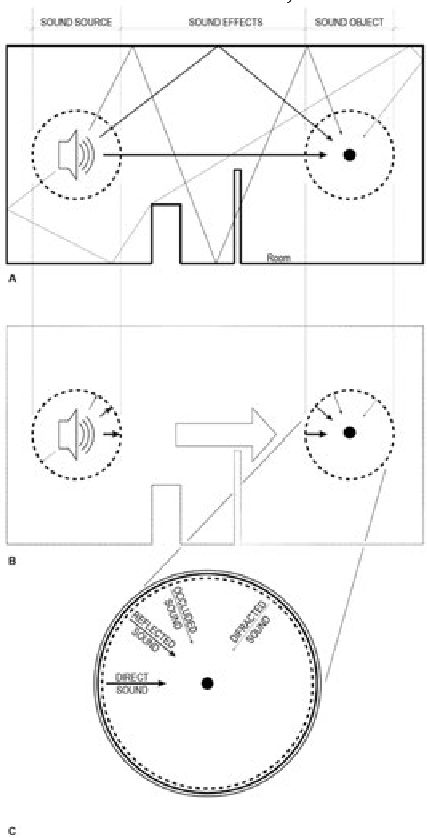
> Any device that allows us to obtain a varied collection of sound objects or varied sound objects, maintaining in spirit the presence of a cause, is an instrument of music in the traditional sense of experience common to all civilizations.[1]

1 Schaeffer.

2.3. Virtual reality as a tool for acoustic design

Fig. 4. Representation of the operation of acoustic virtual reality applied to a closed architectural environment. A: real environment. B: virtual environment. C: zoom into the sound object.

Virtual reality is the simultaneous representation and perception of reality and its physical attributes in an interactive computer-generated environment.[2] One of these physical attributes is sound. The following diagram shows the operation of acoustic virtual reality applied to a closed architectural environment. Three elements can be distinguished that act in the process: the emission of a sound source, the addition of sound effects, and the perception of the final sound object.



2 Michael Vorländer and others, 'Virtual Reality for Architectural Acoustics', *Journal of Building Performance Simulation*, 8.1 (2014), 15–25

The process described above is based on auralization. Following the concepts of simulation in acoustics and vibrations, Michael Vorländer[1], describes auralization as (a) the separation of the process of sound generation, propagation and reproduction into three separate blocks, and (b) the representation of these blocks with systems theory tools:

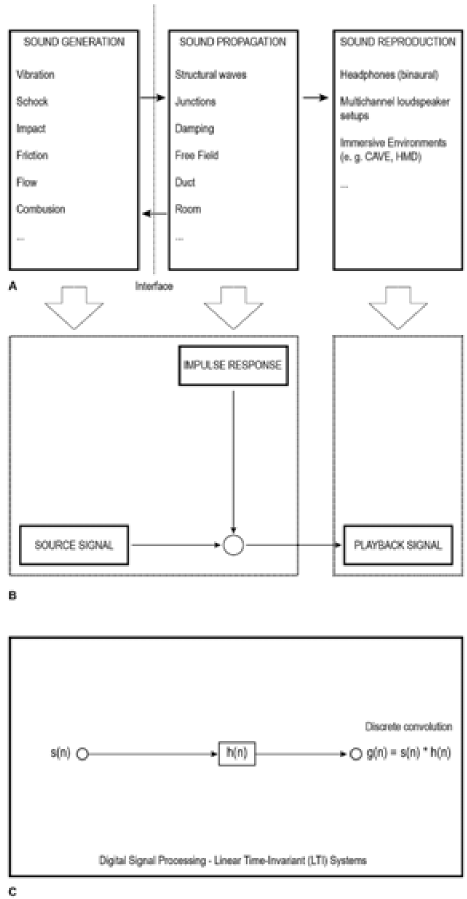


Fig. 5. Representation of the operation of auralization. Redrawn from Vorländer et al. (2014). Generation and propagation of sound and its representation in the physical domain (A and B), and in the domain of acoustic signal processing (C). In the physical domain, sound source characterization and wave propagation can be either modelled or measured. The components will be combined in a synthesis of source signals and impulse responses.

1 Vorländer and others.

The primitive signal, s(n), is called “dry recording”. It contains the mono sound signal without any reverberation. Normally it is a sound source recorded at a distance and in a specific direction in an anechoic chamber. The resulting sound signal after the sound propagation in (or between) rooms, g(n), contains characteristics of both the sound source and the transmission system. Here, the propagation of sound in a room usually adds the phenomenon of reverberation to the source signal, while a sound event transmitted through the walls is characterized by a lower sound pressure and a dark sound (with the characteristics of a low pass). The operation of a sound transmission system in physics is represented by the impulse response of the system, h(n). The sound signal at the position of the receiver is achieved by convolution operation of the original “dry recording” with the impulse response (usually represented by a digital filter).[2] This method can be easily understood as an acoustic filter that contains the impulse response as a function of the position in the hall.[3]

In the framework of a tool for the architect and urban planner, we need to summarize which requirements the acoustic virtual reality must meet to satisfy the design needs of architects and urban planners:

1. The tool must be able to correctly represent the location of the sound sources.

2. It must allow the attenuation of sound with distance.

2 Vorländer and others.

3 Josep Llorca and others, ‘Acoustic Filter’, in *Learning and Collaboration Technologies. Novel Learning Ecosystems* (Springer, Cham, 2017), pp. 22–33

3. It must be able to include the effects added to the source by the geometry of the built environment. To do this, you must calculate the bounces with the adjacent geometry.

4. It must change the resulting sound depending on the materials of the building elements.

5. It must be interactive, that is, allow movement through the environment, and even modification and testing in real time of the elements in the scenario.

2.3.1. Virtual acoustics software: a quick review

The market offers a series of virtual reality tools that address virtual acoustics. These can be divided into two types: auralization engines for computer games, and acoustic simulation programs.

Regarding the first type, the sound of a computer game is the result of work done by the sound designer. A sound designer usually creates audio content (sound effects and music) and then creates sound events to launch the audio content. Sound events are normally monitored using tools such as Wwise or FMOD and are launched by them in the game.

Audiokinetic Wwise[1] is a solution for sound design in computer games that consists of a powerful application to create audio and animation structures; define the propagation; control the sound, music and integration of movement; profile the reproduction; and create banks of sounds. In addition, Wwise is a sophisticated audio engine that

1 https://www.audiokinetic.com/

handles audio processing, animation and a series of functions optimized for each platform. The program interprets LUA scripts and reproduces exactly how the sounds and the animation behave in the game, allowing the validation of specific behaviours and outlining the Wwise acuity in each platform before the integration of sound into the game. It also contains a series of plug-ins that are divided into those that serve to generate audio and movement, such as the tone generator, and those that create audio effects, such as reverberation. Finally, it is an interface between Wwise and the visualization programs of the three-dimensional world.

FMOD Studio[2], like Wwise, this is an application dedicated to sound in video games. This software, developed by Fireflight Technologies in 2002, is one of the industry's standards and has been the basis of award-winning projects. FMOD Studio is a flexible and intuitive solution for audio in video games. It allows sound in the game to be designed using a DAW interface without knowledge of the required programming. FMOD can be incorporated into almost all platforms. In addition, the program allows real-time mixes and balances. This aspect allows you to make changes and listen to them without having to re-record the scene. FMOD consists of several separate tools in different programs such as "FMOD Designer" that correspond to the main window of the program, where the main work of creating the events and the parameters to be called by the video games is done.[3]

2 https://www.fmod.com/

3 Christian Rehren and Jorge Cárdenas, 'Motores de Audio Para Video Juegos', *Síntesis Tecnológica*, 4 (2011), 81–99

Pure Data[1] is a visual open source environment that works from any personal computer to smartphones and iOS. It is one of the major branches of the family of programming languages known as Max, originally developed by Miller Puckette at IRCAM. Pure Data allows musicians, visual artists, researchers and developers to create programs graphically without writing a line of code. It can be used to process and generate sound, video, 2D/3D graphics, interface and MIDI sensors.

Propagate[2] is a system for Unity that allows you to incorporate immersive audio that propagates realistically through the geometry of the scene quickly and efficiently. It is a simple interface that allows you to propagate the audio in real time, even when the sound sources move. The program is based on three principles of sound reception: the occlusion system simulates the transmission of sound waves by paraments and geometries, taking into account their materials and thus modifying the volume and frequency distribution. The diffraction system simulates the passage of sound waves through holes and corners between geometries. The perception system simulates how the perception of sound changes with the position in geometry.

Acoustic simulation programs, the second group of virtual reality programs with acoustics treatment, are programs that rely on and are completely dedicated to the faithful reproduction of sound in a space. Usually, they do not pay attention to the visual aspect of space, so their three-dimensional representations are not realistic, but rather

1 https://puredata.info/

2 https://www.assetstore.unity3d.com/en/#!/content/40200

schematic. Here we collect three powerful samples: RAVEN, EVERTims and CATT-Walker.

RAVEN. Developed at ITA in RWTH Aachen university, it is based on knowledge about today's acoustic simulation techniques and allows fairly faithful physical auralization of the propagation of sound in complex environments, including important effects such as sound diffusion, room isolation and sound diffraction. Instead of this rendered realistic sound field, the sound sources are distributed and move freely, and the receivers listen to them in real time. In addition, manipulations and modifications of the environment itself are supported. The acoustic simulation of RAVEN combines the method of deterministic image sources (IS)[3] with a stochastic ray-tracing algorithm.[4] This framework allows physical computations of high-quality impulse responses in real time, where, apart from the components of the reflected specular sound field, the phenomenon of sound diffusion, sound transmission, and diffraction are taken into account. The environment is completely written in C ++, supports the operating systems of Windows, Linux and Mac OX X, and allows parallel computing in machines where memory is shared, in machines with memory distributed over the network, or in a combination of both.[5]

3 Dirk Schröder and Tobias Lentz, 'Real-Time Processing of Image Sources Using Binary Space Partitioning', *Journal of the Audio Engineering Society*, 54.7/8 (2006)

4 D. Schröder, P. Dross and M. Vorländer, 'A Fast Reverberation Estimator for Virtual Environments - RWTH AACHEN UNIVERSITY Institute of Technical Acoustics - English', in *Proceedings of the 30th AES International Conference*, 2007

5 Dirk Schröder and Michael Vorländer, 'RAVEN: A Real-Time Framework for the Auralization of Interactive Virtual Environments', in Forum Acusticum (Aalborg - Denmark, 2011)

EVERTims[1] is an open source framework for the auralization of 3D models, which offers real-time feedback on how the acoustics sound in any given room during its creation. The framework is based on three components: a Blender plug-in, a C ++ Ray plotter, and a JUCE auralization motor. While a 3D model in Blender is devised, the plug-in continuously increases the geometry and the details of the materials to the ray tracing. On the basis of this information, the client simulates how the waves propagate there. The result of this simulation is then released to the auralization engine that reconstructs the Ambisonics sound field in any position for binaural listening. The environment takes advantage of the Blender Render Engine to support the auralization of the game for interactive exploration of the designed model.[2]

Finally, with the **CATT-Walker module[3],** CATT-Acoustic software has a powerful tool for real-time auralization in a microcomputer. CATT-Walker manages this dynamic audible restitution by continuously interpolating the impulse responses previously calculated in B format (surround coding). Hearing is performed in binaural mode from appropriate ambisonic decoding. To maintain a sufficiently low latency, CATT uses Lake Technology's split FIR convolutional filtration technique. To reproduce the simulated acoustic environment as closely as possible, the modelled space must be sampled more or less densely by

1 http://evertims.github.io/

2 David Poirier-Quinot, Markus Noisternig and Brian F G Katz, 'EVERTims: Open Source Framework for Real-Time Auralization in VR', in *12th International Audio Mostly Conference*, 2017.

3 https://www.catt.se/walker.htm

distributing the reception points around the source and in the evolution zone.

2.3.2. Five virtual acoustics applications for architects and urban planners

After the description of the properties of Virtual Acoustics and the software on offer that can support virtual acoustic simulation tools, we propose five applications of virtual acoustics in the process of design and architectural and urban analysis.

2.3.2.1. Invisible sound objects

The first case is for the phenomenon of sound objects that are heard, but you cannot see them (incongruence), the visible objects that you see, but cannot hear (incongruence), or the sound objects that you see in a different place to which they are heard (delocalization). Do such phenomena generate any design problems?

In contrast to the experimental conditions, the listener immersed in a real environment relies on all the senses to structure a representation of the environment.[4] A sensory modality could also pay attention to a different modality, and even influence the same perception more strongly. This raises questions about whether the resources of attention are controlled by a supramodal system or by various modalities of attention systems. In conditions of focused attention, it is difficult to judge each signal (sound and vision) separately when incongruent signals occur in the same

4 Jon Driver and Charles Spence, 'Attention and the Crossmodal Construction of Space', *Trends in Cognitive Sciences*, 2.7 (1998), 254–62.

place, at least much more difficult than when the incongruent signals come from different points and attention is divided.[1] The most feasible model for today's knowledge consists of a multilevel attention mechanism with a multimodal component above the sensory component. In the context of perception of the sound environment, this could be interpreted as a stronger emphasis on visible sources, but at the same time, a lower probability of identification of the deviant sounds if these sounds come from the same place as the visual stimulus.

The mechanisms of multisensory attention also have a very strong temporal component. The sound stimuli presented in temporal congruence with the appearance of the visual objective make the visual objective stand out in the scene.[2] Based on this knowledge of multisensory perception, one can solve a nineteenth-century concern of sound landscape designers, at least partially: is it good to hide the sources of unwanted sounds from view? From the perspective of attention, we can conclude that when the sound is not very prominent and therefore does not attract much attention, we can avoid noticing the sound by eliminating congruent visual stimuli. Similarly, a desired sound should be accompanied by a visual stimulus to ensure that it receives sufficient attention. In contrast, we must emphasize that in the case of very prominent sounds that will attract attention, the absence of a

Fig. 6. Acoustic screens by Enric Miralles over Ronda de Dalt, Barcelona. The panels try to reduce the direct sound from the down street to the dwellings nearby.

1 Valerio Santangelo, Sabrina Fagioli and Emiliano Macaluso, 'The Costs of Monitoring Simultaneously Two Sensory Modalities Decrease When Dividing Attention in Space', *Neuroimage*, 49.3 (2010), 2717–27.

2 Durk Talsma and others, 'The Multifaceted Interplay between Attention and Multisensory Integration.', *Trends in Cognitive Sciences*, 14.9 (2010), 400–410.

visual stimulus could appear as a surprise, which would influence the perception.[3]

In this context, the virtual reality tool offers a scenario to test the congruence between the sounds that are seen and heard. For this, the possible options to be evaluated must be simulated:

- A not very prominent and seen sound source: there is weak incongruence.
- A not very prominent and not seen sound source: there is weak congruence.
- A very prominent and not seen sound source: there is strong incongruence.
- A very prominent and seen sound source: there is strong congruence, and control of the situation.
- A desired sound source and view: there is strong congruence, and control of the situation.
- A desired and unseen sound source: there is strong inconsistency, discomfort and lack of control of the situation.
- An unwanted and seen sound source: there is strong congruence, annoyance and control of the situation.
- An unwanted and unseen sound source: there is strong inconsistency, discomfort and lack of control of the situation.

3 Jian Kang and Brigitte Schulte-Fortkamp, *Soundscape and the Built Environment* (Boca Raton: CRC Press. Taylor & Francis Group, 2016).

2.3.2.2. The influence of materials

Architects and urban planners are constantly concerned about the visual impact that the finishing will have on the built work. Although the visual impact affects the perception of space[1] and can affect the mood of the users[2], the sound impact has a no less important effect on the perception of space[3] and the users' mood[4].

We also know that visual perception in virtual reality environments is related to the geometric representation of the space, and to the material representation of this geometry. If we focus on the representation of the materials, their treatment and properties are paramount. Therefore, base colour, glossiness, roughness, normal or bump and displacement are some of the techniques that virtual reality software has developed to simulate the materials of the represented reality.

Even though this fine detailing could also seem to be necessary for acoustic virtual reality representations, there is a big difference between acoustic and visual materials. Small details in visual perception are negligible in acoustic perception. For this reason, a plane wall behaves acoustically similarly to a

1 Lieve Filbrich and others, 'Shaping Visual Space Perception through Bodily Sensations: Testing the Impact of Nociceptive Stimuli on Visual Perception in Peripersonal Space with Temporal Order Judgments', ed. by Suliann Ben Hamed, *PLOS ONE*, 12.8 (2017).

2 Filbrich and others; O. Vartanian and others, 'Impact of Contour on Aesthetic Judgments and Approach-Avoidance Decisions in Architecture', *Proceedings of the National Academy of Sciences*, 110.Supplement_2 (2013), 10446–53.

3 Christopher J. Plack, *The Sense of Hearing*, 2nd edn (London: Taylor & Francis Group, 2014)

4 Yuan Zhang, Jian Kang and Joe Kang, 'Effects of Soundscape on the Environmental Restoration in Urban Natural Environments.', *Noise & Health*, 19.87 (2017), 65–72.

rough wall at low frequencies[5]. However, some phenomena linked to materiality, such as acoustic porosity and absorption, are linked to visual glossiness and roughness and, therefore, could have a big influence both visually and acoustically. In this context, the fine representation of both visual and acoustical properties of materials in virtual reality would turn this tool into a convincing way of representing the environments designed by architects and urban planners.

2.3.3. Concavity and convexity in architectural forms

There has always been a debate among architects about the suitability of curved shapes versus straight forms, and vice-versa. At both extremes, these tendencies can be classified as the purest rationalism, that of rectangular forms, straight lines, repeated and constant rhythms[6]; and the organicism that its formal referents have in nature.[7] Experimentally, curvilinear, sinuous, parabolic or circular shapes have been shown to affect neural activity more strongly than rectangular or quadrangular ones.[8] The visual influence of this type of geometry both in architectural interiors and in urban exteriors is also very important in the

5 Heinrich Kuttruff, *Acoustics* (New York: Talyor & Francis, 2004).

6 Kenneth. Frampton, *Modern Architecture : A Critical History* (1980 Thames & Hudson, 2007).

7 Mark Mumford, 'Form Follows Nature: The Origins of American Organic Architecture', *Journal of Architectural Education*, 42.3 (1989), 26–37; Linda R. Krause, 'Frank Lloyd Wright: Organic Architecture for the 21st Century', *Journal of Architectural Education*, 65.1 (2011), 82–84; James M. Dennis and Lu B. Wenneker, 'Ornamentation and the Organic Architecture of Frank Lloyd Wright', *Art Journal*, 25.1 (1965), 2–14.

8 Maryam Banaei and others, 'Walking through Architectural Spaces: The Impact of Interior Forms on Human Brain Dynamics.', Frontiers in Human Neuroscience, 11 (2017), 477.

acoustics of these spaces. The graphical acoustics of ray tracing[1] shows us how concave shapes reinforce sound at a point or in a concentrated area, while convex shapes scatter sound in multiple directions.

This affects the way sound is perceived in interiors and can produce undesired effects in these places. One clear example of this phenomena can be tested when seated at specific points in Coderch's new building for the *School of Architecture of Barcelona*. The curved walls concentrate student's whispers in some areas that reinforce the noise perception at these points. The same effect can happen when, in an urban environment, a curved design of walls concentrates the sound rays in one area.

Acoustic virtual reality should consider this effect as a product of design. For this purpose, therefore, a rough approximation of the architectural geometry is not enough. More detail in the representation of these nuances would lead to a more realistic and credible representation of reality with this tool.

2.3.4. The sound object as a reason for the architectural project

This case study deals with the sound object not as a pretext for comfort in architecture, through congruence with visual, acoustic comfort or a sound impact. The sound object is now a topic of design. The design of the sound object must meet all the requirements that the solution to a specific problem requires, as in any architectural design process. Architectural design is a creative process,

Fig. 7. Barcelona School of Architecture by Coderch. The curved walls form concave and convex areas.

1 Charles B. Officer, *Introduction to the Theory of Sound Transmission : With Application to the Ocean / C.B. Officer. - Version Details - Trove* (New York: McGraw-Hill, 1958); Lawrence E. Kinsler, F*undamentals of Acoustics* (Hoboken: Wiley, 2000).

but its additional emphasis on the definition phase of the problem[2] places it in a special category. When the term "creative" is used in its most general sense, to describe a process in which an agent (a personal product and in the environment) interacts with the material to form a new synthesis of essential novelty, it embraces the entire design process, but is too general to be particularly useful. However, when used in a more specific sense, relating pure arts and sciences, it usually allows for more self-original and self-motivated input, deriving from sensitive perception in art, and critical observation in science of the selected phenomenon. It is, then, a creative process of synthesis, preceded by analysis and followed by validation, especially in science, which ends up consisting of a piece of art or a hypothesis or validated theory.[3] This process of synthesis-analysis-synthesis, which summarizes all attitudes of observation of reality, [29] is the same as occurs in the process of auralization: synthesis of the sound emitted by the sound source, whose sound waves come from a single point; analysis or separation by parts of the different types of waves that bounce, pass or diffract in the elements of the built environment; and synthesis that is collected in a single point and that we have qualified as the "sound object". Below, we present a series of examples of acoustic targets, extracted from *Soundscape and the Built Environment*[4]:

- Moving water or sounds of nature should be the dominant sound heard.

2 George Frederick. Kneller, *The Art and Science of Creativity* (Holt, Rinehart and Winston, 1965).

3 Gilbert Herbert, 'The Architectural Design Process', *The British Journal of Aesthetics*, 6.2 (1966), 152 <https://doi.org/10.1093/bjaesthetics/6.2.152>.

4 Kang and Schulte-Fortkamp.

- Only the sound of nature should be heard.
- A specific sound should be clearly audible in some areas.
- Mostly (nonmechanical, nonamplified) sounds made by people should be heard.
- The sounds of people cannot be heard.
- Suitable for hearing unamplified/amplified speech (or music).
- Acoustic sculpture/installation sounds should be clearly audible.
- Sounds conveying a city's vitality should be the dominant sounds heard.
- Sounds that convey the identity of a place should be the dominant sounds heard.

However, the process of designing the sound object, like any architectural design process, requires that the solution to the problem addressed by the sound object is not just the solution that meets the functional requirements. In addition to fulfilling the requirements satisfactorily, it offers the user an integrated solution with the pre-existing environment and has its own entity as a newly created element. Here are some possible guidelines for achieving such goals:

- A solution integrated with the pre-existing environment: it may contain vernacular sounds of the area or neighbouring territory, replicating or imitating them. It can present contrasting sounds, highlighting those of the pre-existing environment. It can modulate pre-existing sounds, reinforcing some frequencies or switching off others.

- A solution that has its own entity as a newly created element: it can present a characteristic rhythm, whether regular or irregular. It can present a characteristic tonic, either monophonic or polyphonic. It can present characteristic timbres or textures that are produced by concrete materials.

2.3.2.5. Artificial intelligence and acoustic virtual reality

Even though the framework depicted here seems easy to implement, the reality is rather different. In 2003, Kang et al. highlighted the introduction of new EU noise policies[1] and noted that noise-mapping software/techniques are being widely used in European cities[2]. Nevertheless, they stated that these techniques provide an overall picture for macro-scale urban areas. The micro-scale, for example an urban street or a square, could be more effectively studied using detailed acoustic simulation techniques. In addition, applications that predict and measure micro-scale environments, such as auralization techniques for indoor spaces[3], are still not sufficiently user-friendly, and the computation time is rather long. Kang et al. presented two computer models based on the

1 'EUR-Lex - 32002L0049 - GA - EUR-Lex' <http://eur-lex.europa.eu/legal-content/GA/TXT/?qid=1399875039336&uri=CELEX%3A32002L0049> [accessed 9 November 2017].

2 'Welcome to Schal' <http://www.tpsconsult.co.uk/schal.aspx> [accessed 9 November 2017].

3 Yun Jing and Ning Xiang, 'A Modified Diffusion Equation for Room-Acoustic Predication', *The Journal of the Acoustical Society of America*, 121.6 (2007), 3284–87.

radiosity and image source methods in an attempt to present to urban designers an interface that could be useful in the design stage, using simple formulae that can estimate sound propagation in micro-scale urban areas. However, the answer still has not been found.

Artificial intelligence can be applied to virtual reality in many ways. In the user interface, we need systems that behave rationally, e.g. reflect user mo vements as accurately as possible. Content production needs tools for optimizing the layout of virtual worlds, and virtual world simulation needs methods for approximating the behaviour of the environment.[1] This last challenge relates strongly acoustic virtual reality and artificial intelligence and might be the key factor in progress in the simulation of both closed spaces and open environments. Some studies have already included artificial intelligence in the field of acoustics. In particular, new methods identify room acoustic properties based on evolutionary algorithms (EA)[2]. Focused on the problem of learning from real acoustics, Kendrick et al.[3]developed a new method employing machine learning techniques and a modified low frequency envelop spectrum estimator, to estimate important room acoustic parameters including Reverberation Time (RT) and Early Decay Time (EDT) from received music signals. What is known

1 Seppo Laukkanen and others, 'Adding Intelligence to Virtual Reality', in *ECAI 2004 : Proceedings of the 16th European Conference on Artificial Intelligence* (IOS Press, 2004), p. 1136.

2 A. Poteralski and others, 'Hybrid Artificial Immune System in Identification of Room Acoustic Properties', *Inverse Problems in Science and Engineering*, 21.6 (2013), 957–67...

3 P. Kendrick and others, 'Room Acoustic Parameter Extraction from Music Signals', in *2006 IEEE International Conference on Acoustics Speed and Signal Processing Proceedings (IEEE)*, V, V-801-V-804.

as the machine audition field[4] therefore presents a promising method that can establish and enhance classical methods of acoustics. More specifically, architects and urban planners always need comprehensive visualizations of the reality that they are designing. Approximation of the behaviour of the environment on which they are working is therefore a major concern in their representations. For this reason, artificial intelligence could be a good way to solve some problems that still remain today. These questions draw possible future paths for investigation that we can sum up in the two following points:

- The wide variety of case studies that an architect deals with in everyday practice require an easy method for acoustic representation. Otherwise, decisions are taken by approximation only, or the effort of representation is too great for one studio. For this reason, a database of urban spaces with their defined acoustic features would be useful. The acoustic features could be used as the hidden layer in a neural network framework for rapid prediction of the behaviour of the environment in future modifications.

- Measurements of acoustic properties of an architectural space need highly specialized equipment and special conditions. Not every architectural studio has the opportunity or means for making such measurements. Investigations to extract acoustic information from everyday recordings could help not only to analyse the current environment, but also to predict new architectural designs.

4 Wenwu Wang, *Machine Audition : Principles, Algorithms, and Systems* (Information Science Reference, 2011).

2.4. Conclusions

Acoustic architectural and urban design is an area that still needs to be addressed. Despite the fact that a considerable amount of research has been done on architectural acoustics, urban soundscape, and noise treatment, few real applications of these theories can be found in built projects. This chapter links Schaeffer's theory on sound objects to acoustic virtual reality, to describe a potential way of understanding the role of acoustic virtual reality in the field of architecture and urbanism. The main tools that could help practitioners have been presented here. Moreover, five specific applications have been proposed. However, much more work is needed to apply the theory to daily practice, and all efforts at bringing scientific research into everyday activity are welcome. The direction of artificial intelligence seems plausible in the future. Sound design is an old concern, and still remains as elusive and unpredictable today as it can be when it turns into music.

Case study

#. Soundscape track listened by the students in this experiment.

Soundscape as a tool for generation architectural designs

An architectural design experiment was done in Facutlty of Architecture at RWTH Aachen University. The details of the experiment setup are explained as a pilot study in the example section of chapter 6. In this section we show the graphic results of this experiment. Firstly, some screens from the experiment setup and, then, the results of the designs done by the students.

Fig. 8. Empty semi-anechoic chamber at ITA RWTH Aachen University

Fig. 9. Experiment setup at the semi-anechoic chamber.

Fig. 10. Next page: Experiment setup at the semi-anechoic chamber.

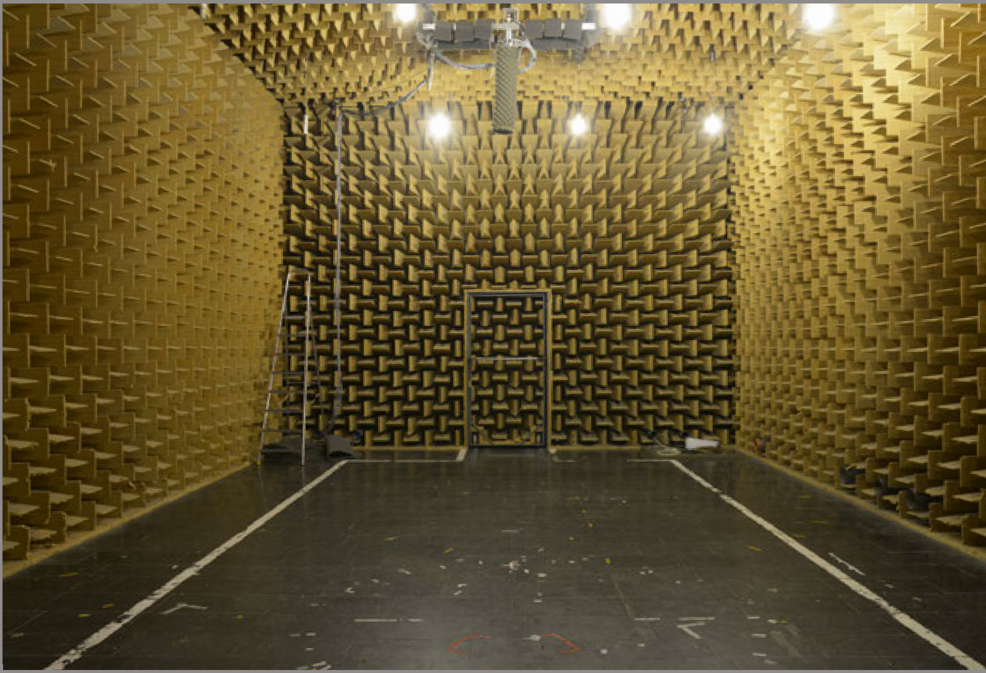



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Fig. 11. Superposition of all plans and sections drawn in the experiments by architecture students.

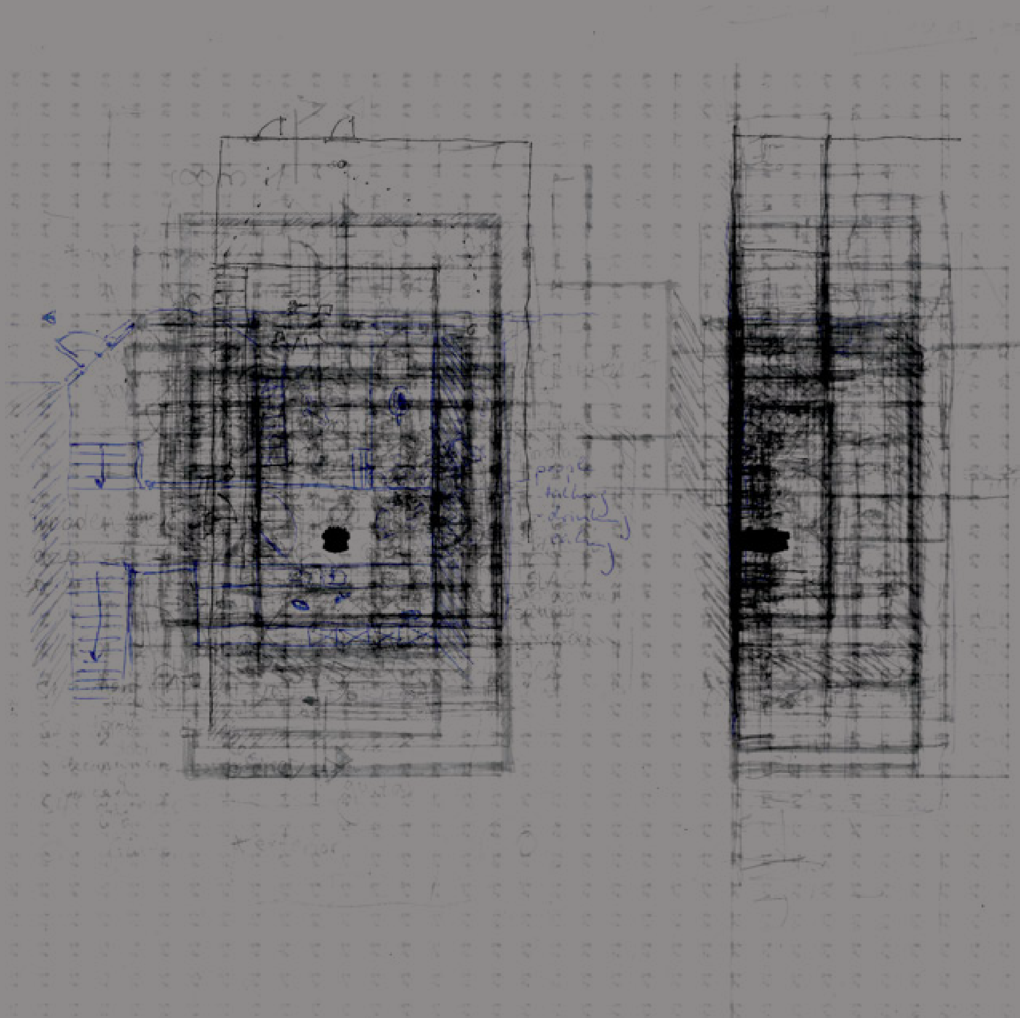
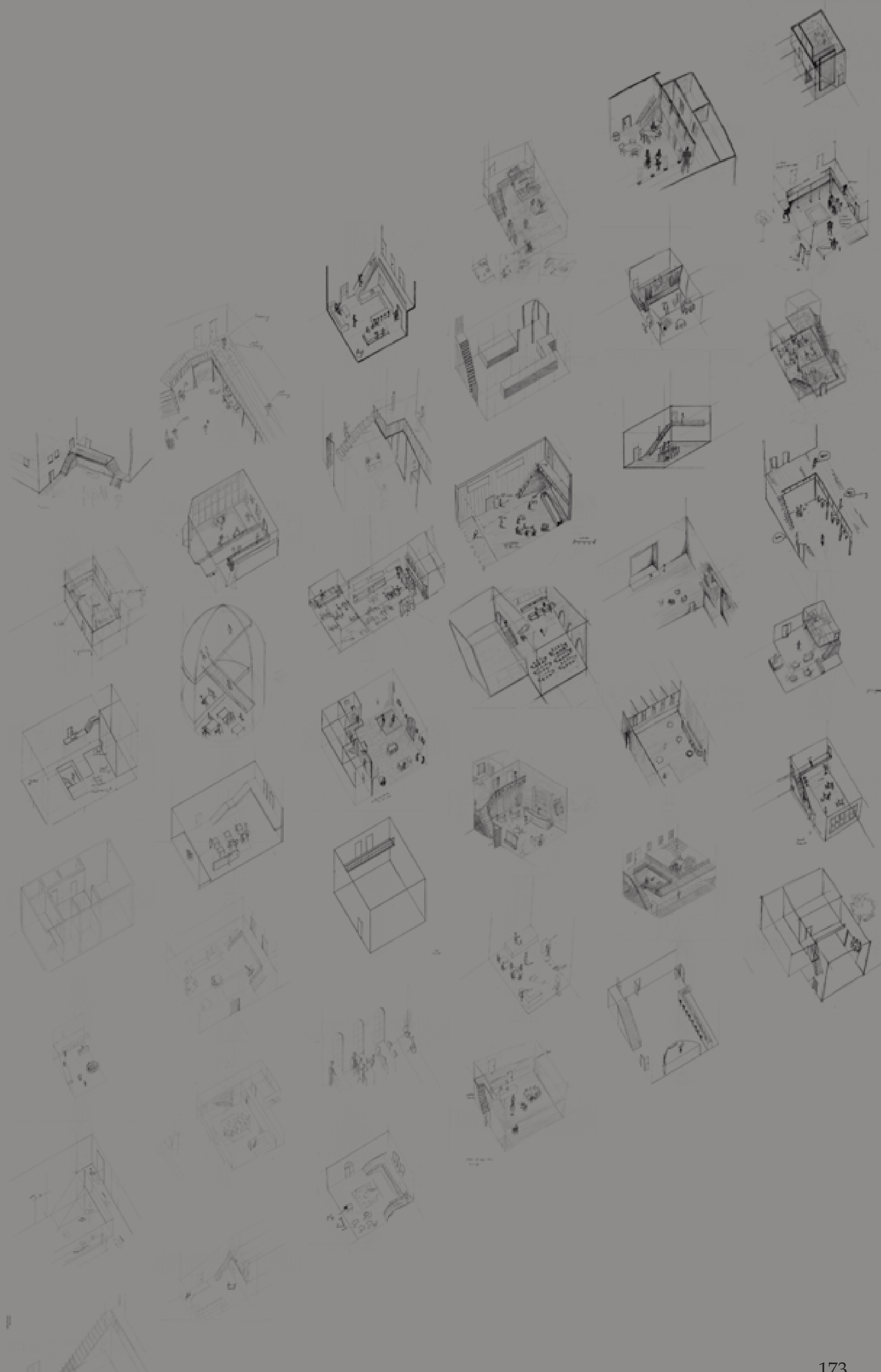
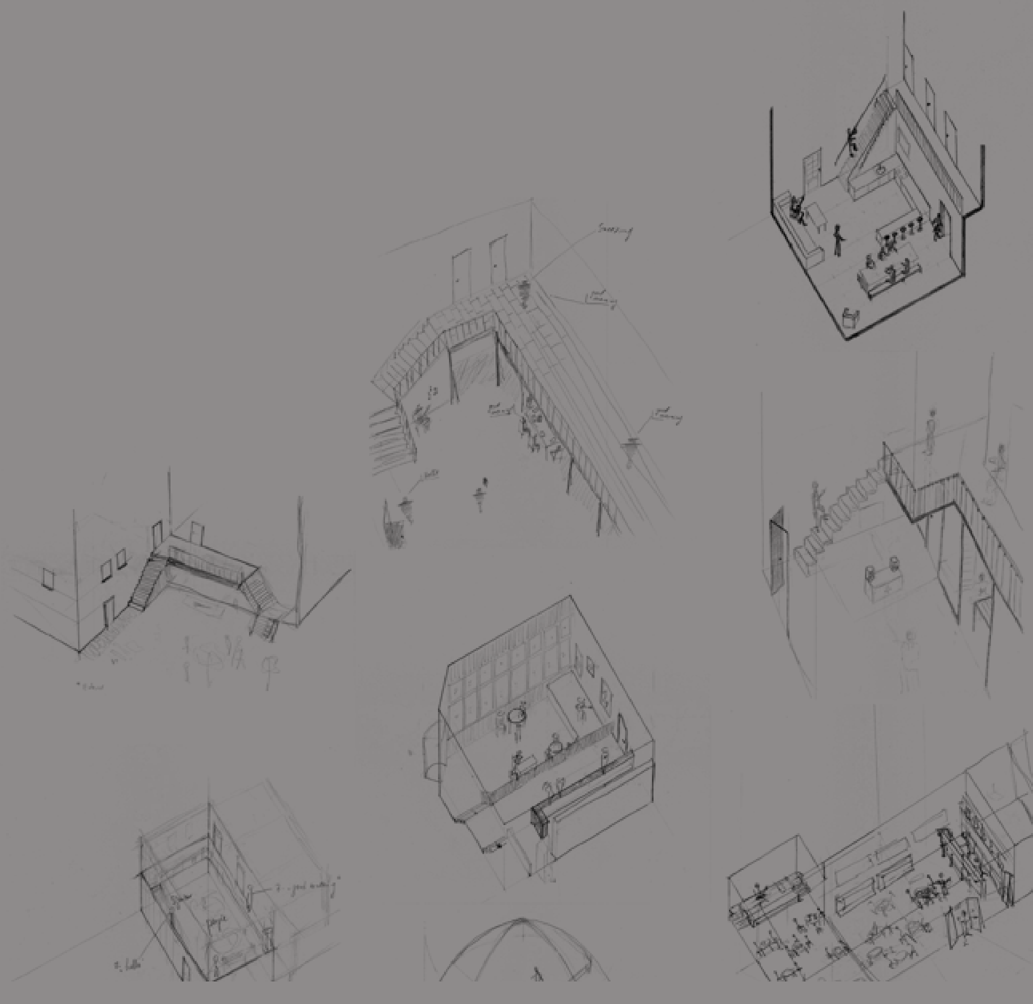
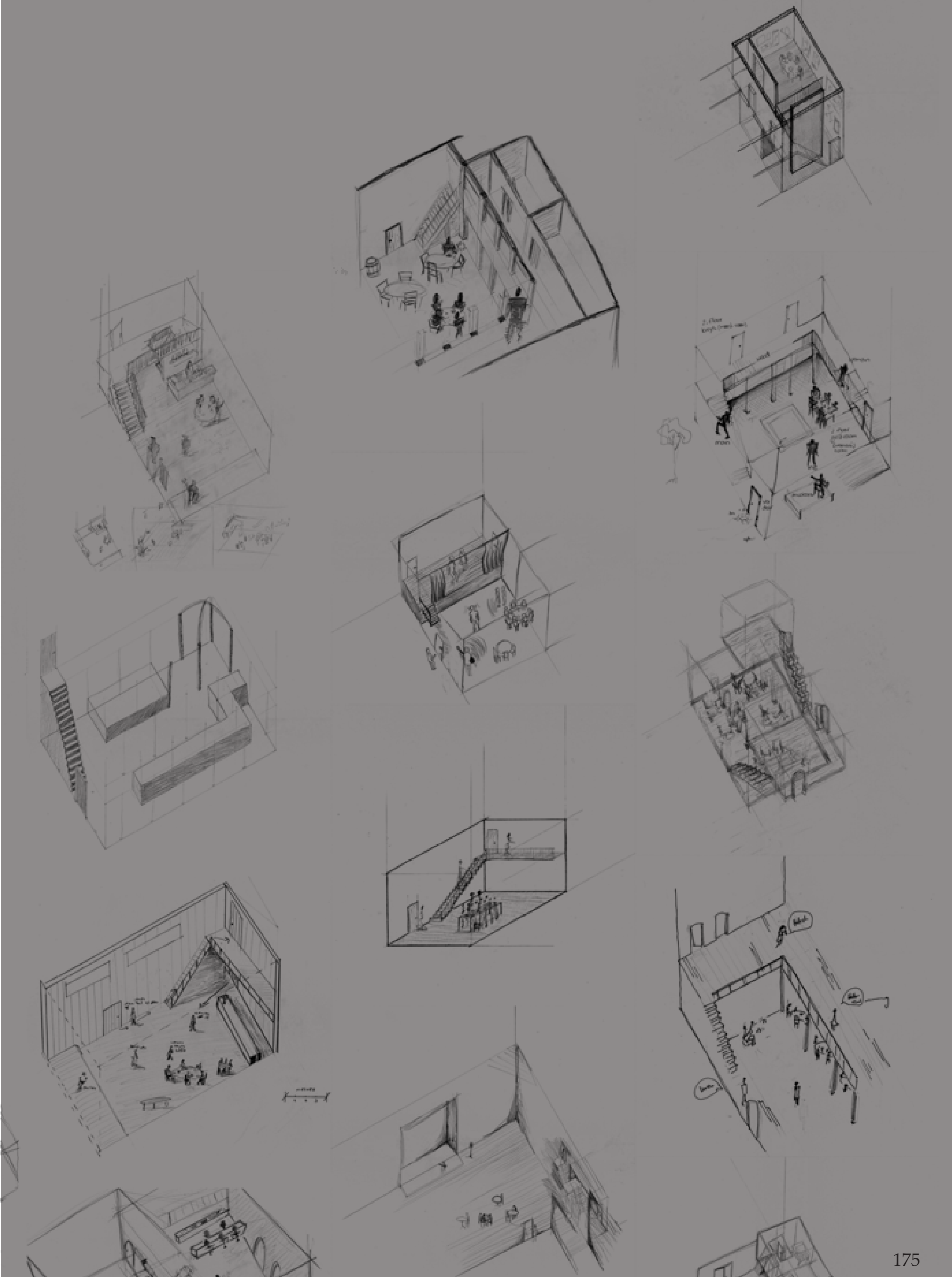


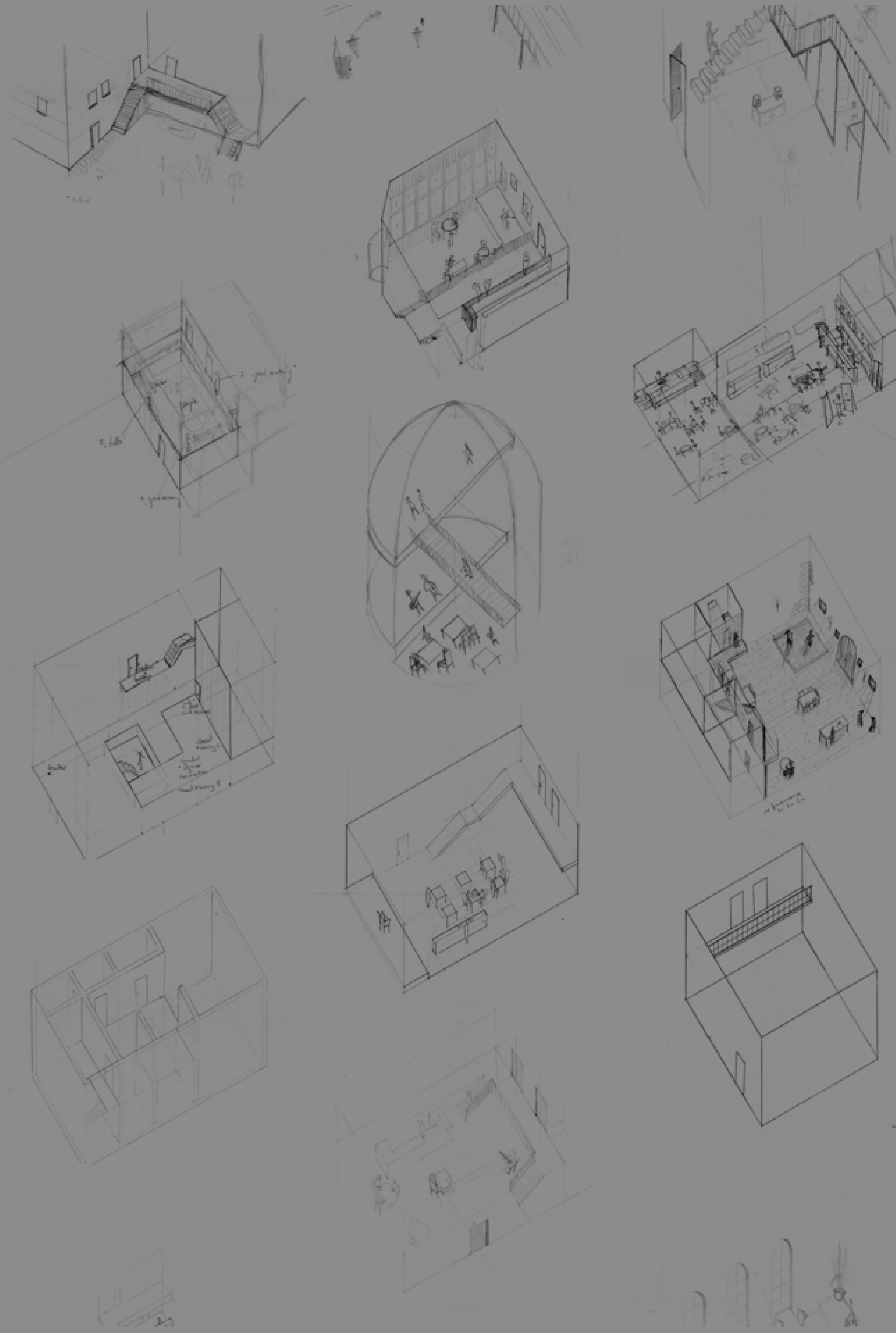
Fig. 12. All militar axonometries drawn by architecture students in the experiment.

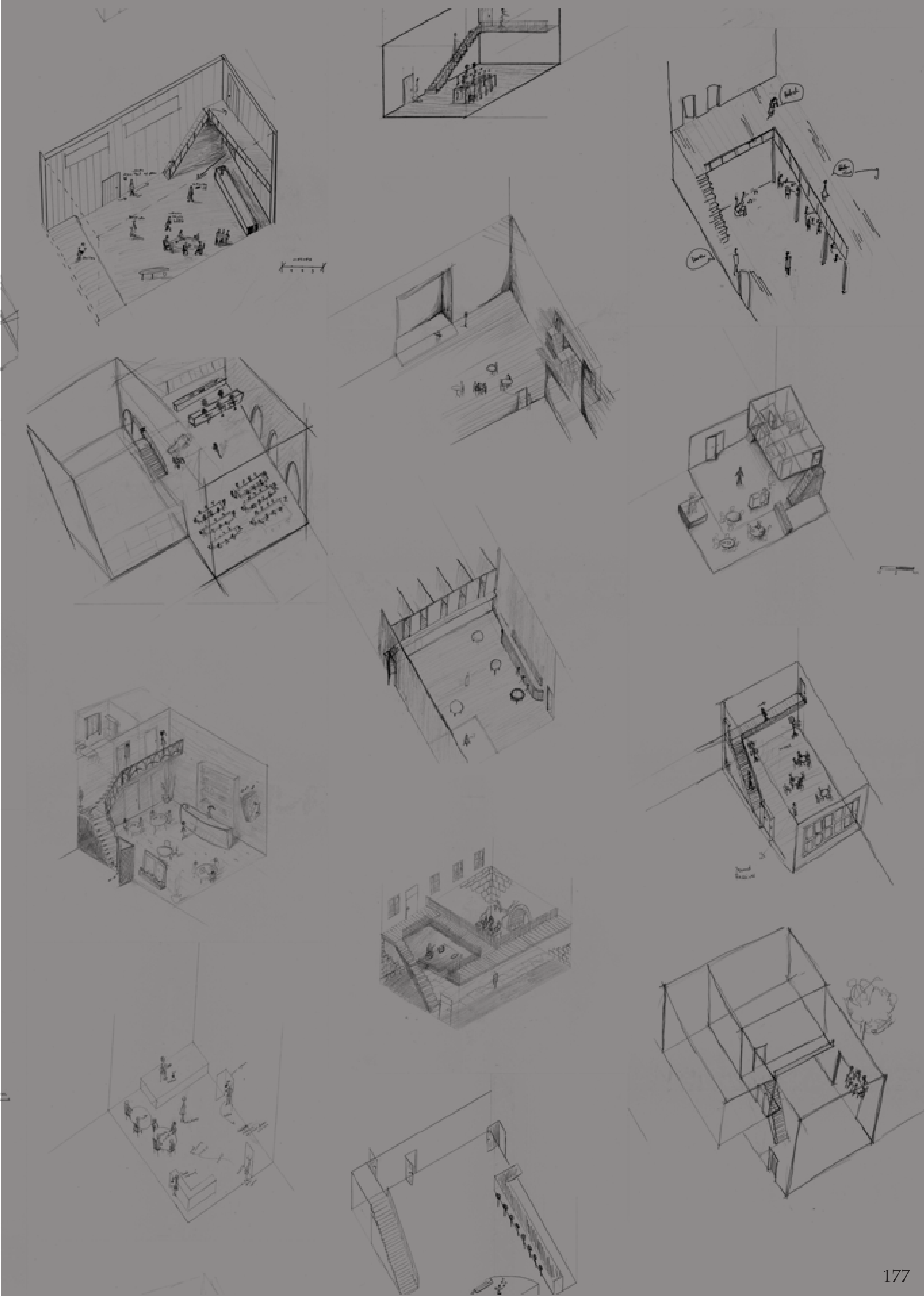
Fig. 13. Following pages: Details of the militar axonometries and final renders, plans and sections drawn by architecture students in the experiment.

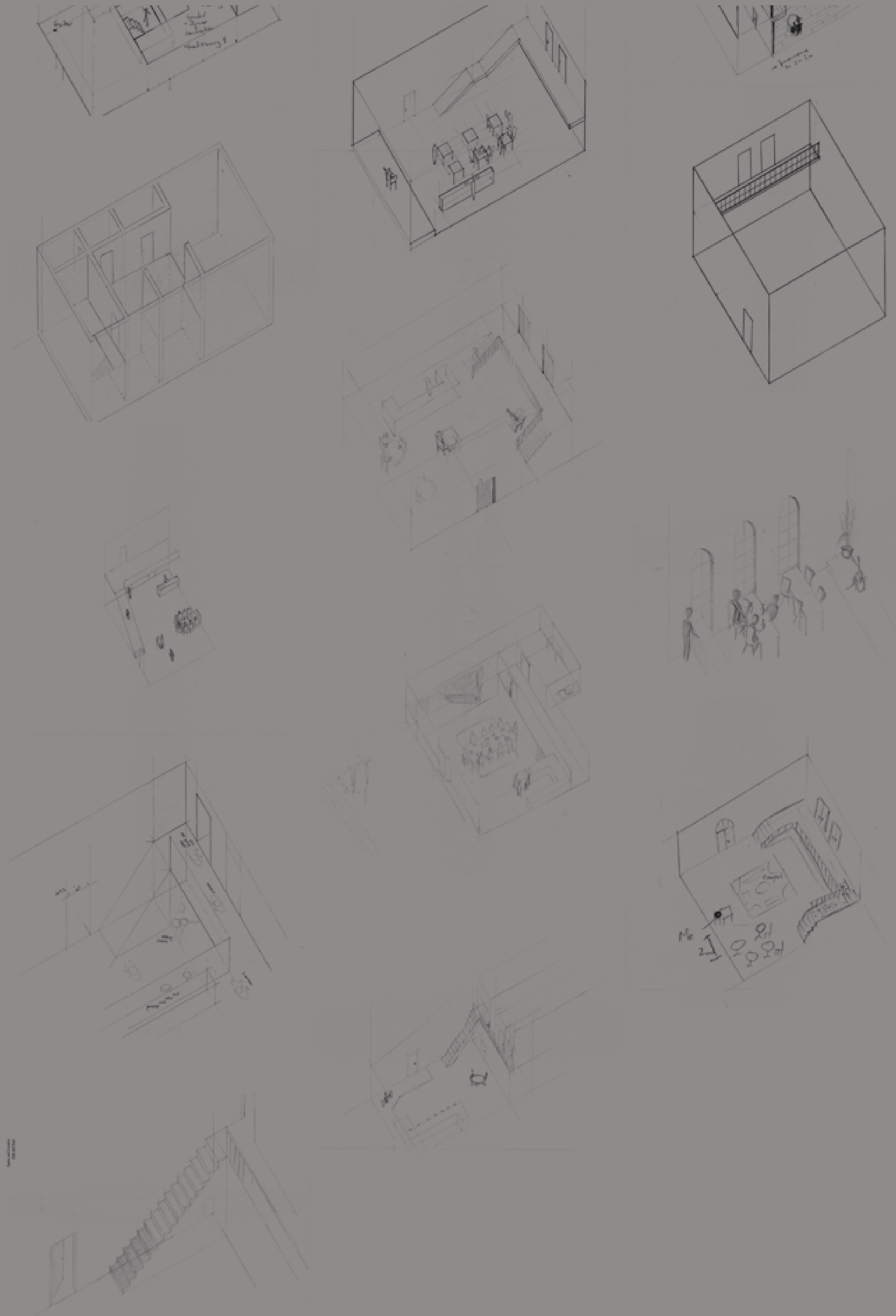


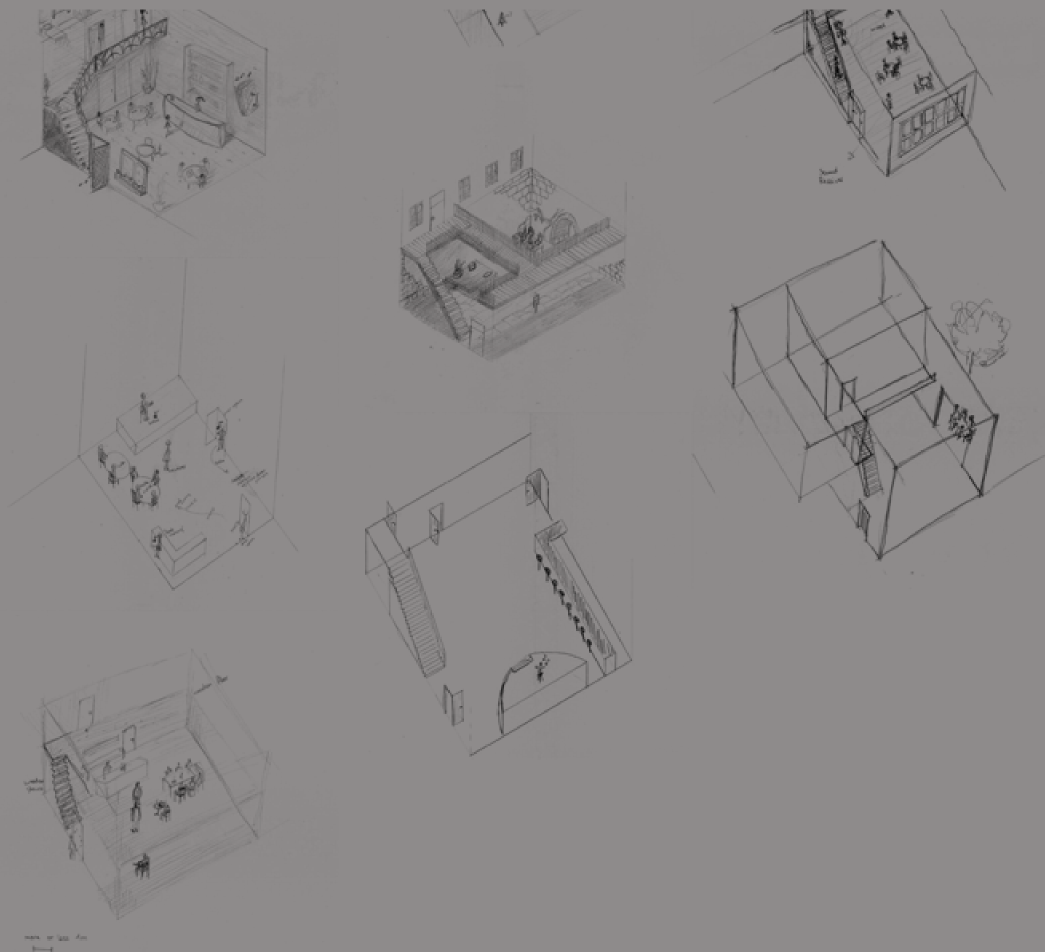


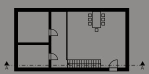












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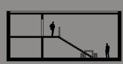

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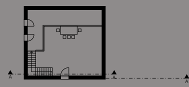

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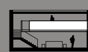

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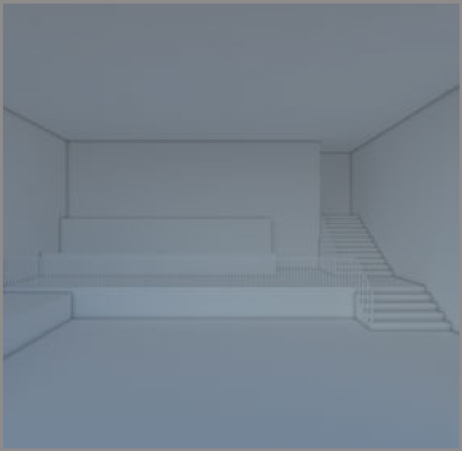

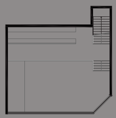

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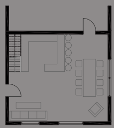

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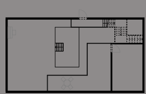

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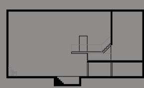

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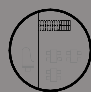

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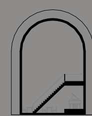

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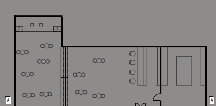

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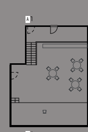

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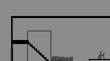

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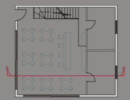

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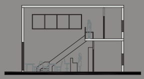

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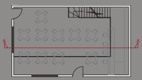

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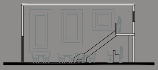

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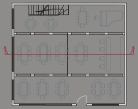

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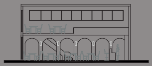

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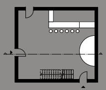

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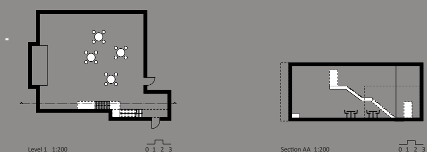

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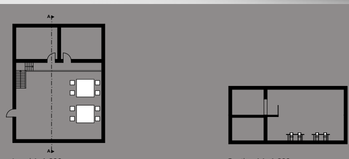
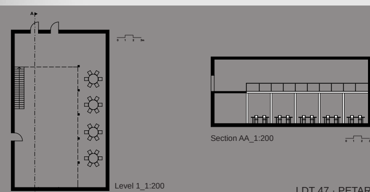
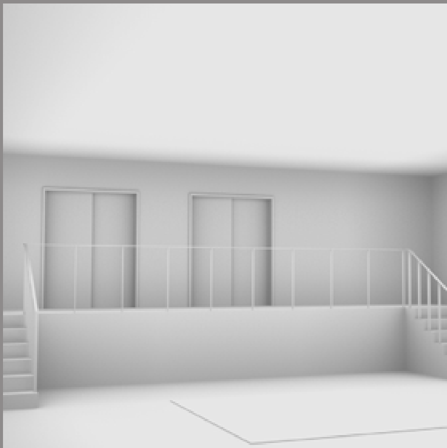
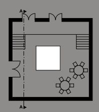


LDT 46 · PETAR TRASSIEV



LDT 47 · PETAR TRASSIEV





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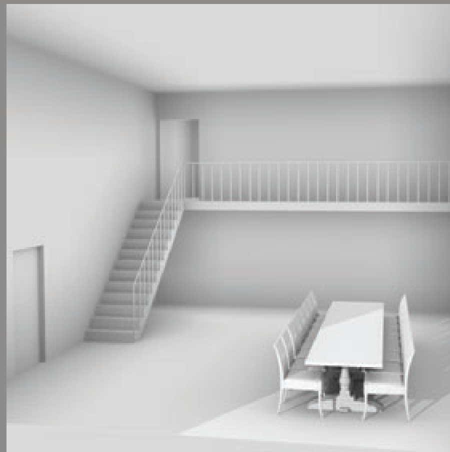
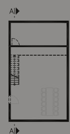
Section AA_1:200

LDT 48 · PETAR TRASSIEV





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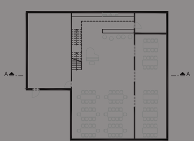
Section AA_1:200

LDT_50 · MARINA CHERNYSHOVA



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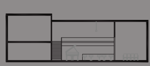

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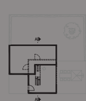

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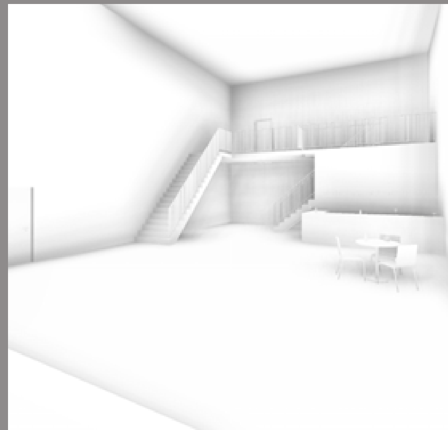
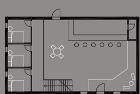
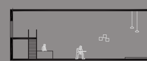
LDT_50 · MARINA CHERNYSHOVA





LDT_12 - TOBIAS WILKES



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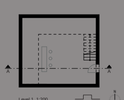
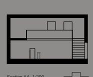
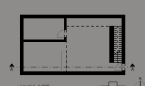
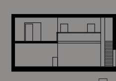




LDT_14 · CHRISTIANE BERLIN





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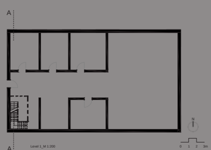
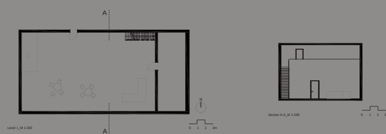
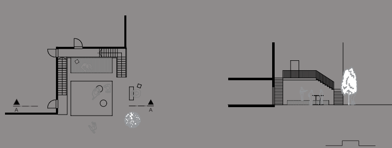
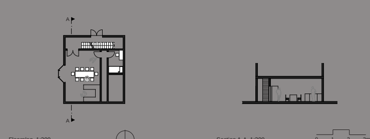




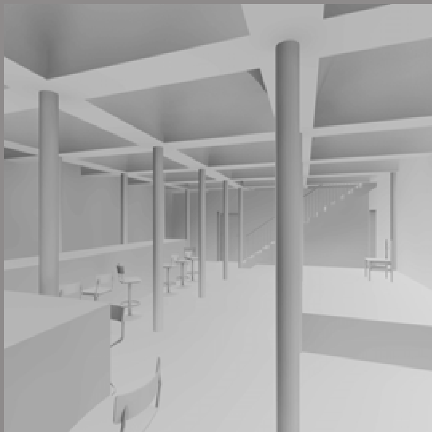
LDT_18 · Noemi Kremer

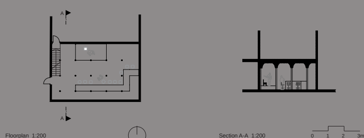
LDT_19 · Noemi Kremer





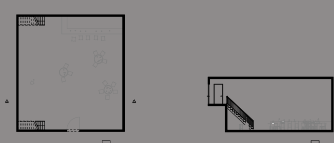
LDT_35 · LENA FAHRNER



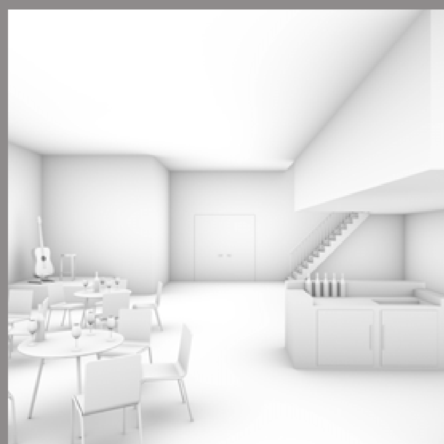


LDT_36 · LENA FAHRNER

DRAWING 37 · THOMAS KLINKHAMMER



DRAWING 38 · THOMAS KLINKHAMMER



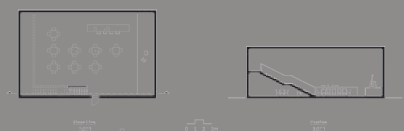
DRAWING 39 · THOMAS KLINKHAMMER

LDT_40 · MALTE PALMEN

LDT_41 · MALTE PALMEN

LDT_42 · MALTE PALMEN

DRAWING 16 · SAMILA SYDYQ



DRAWING 27 - CAMILA SYDIC

Chapter 3

Evaluation of generation

Soundscape for arhcitectural design:
a quasi-experimental study

Chapter 3

Evaluation of generation

Soundscape for architectural design:
a quasi-experimental study

The present chapter is derived from the work entitled *Soundscape for architectural design: a quasi-experimental study*. This work was presented by the author et al. as an research article in *The International Journal of Art & Design Education*.

3.1. Background

After the description of the problem, and its analysis by means of a detailed programme, the architectural design process enters upon a phase whose evocative technical description is "incubation" or *insight.*[1] As Gilbert Herbert said in 1965, here begins the vital creative phase of the design process, with inspiration, illumination, insight. Many classical authors have written about this process[2] and even today it is one of the main concerns of the architectural design process. In our research we try to present a different approach to this key point.

An important debate in the architectural design process is the use of external sources of inspiration to stimulate the generation of ideas, known as *design fixation*. [3] These external stimuli are introduced early in the design process and help designers produce new ideas that would otherwise be unlikely to emerge. Some studies highlight the benefits of using this method: the ideas generated are newer and of better quality. [4] However, the negative effects of this have also been discussed, highlighting the

1 Gilbert Herbert, 'The Architectural Design Process', T*he British Journal of Aesthetics*, 6.2 (1966), 152

2 George Frederick. Kneller, *The Art and Science of Creativity* (Holt, Rinehart and Winston, 1965); Brewster Ghiselin, *The Creative Process : A Symposium.* (University of California Press, 1985); E. F. O'Doherty, 'Psychological Aspects of the Creative Act', in *Conference on Design Methods* (London: Pergamon Press, 1963).

3 David G. Jansson and Steven M. Smith, 'Design Fixation', *Design Studies*, 12.1 (1991), 3–11

4 Ut Na Sio, Kenneth Kotovsky and Jonathan Cagan, 'Fixation or Inspiration? A Meta-Analytic Review of the Role of Examples on Design Processes', *Design Studies*, 39 (2015), 70–99 ; Luis A. Vasconcelos and Nathan Crilly, 'Inspiration and Fixation: Questions, Methods, Findings, and Challenges', *Design Studies*, 42 (2016), 1–32; Matti Perttula and Pekka Sipilä, 'The Idea Exposure Paradigm in Design Idea Generation', *Journal of Engineering Design*, 18.1 (2007), 93–102.

reduction in the variety of ideas generated.[5] In our research we decided to use *design fixation* to obtain better quality results knowing that the variety of these is restricted.

The ideation process of an architectural project is very varied. The place is the most important generator of ideas in architecture, expressing itself as views, climate[6], topography[7], etc. Other drivers can be cultural references related to the project such as popular festivals, regional colours, etc. There are also design generators external to the project, which are not related to the place or the use of the building, such as rubik cube or violin shaped projects.

Sound can be one of those architectural ideas generator. We can find some examples in the history of architecture where sound was the generator of architectural ideas. Iannis Xenakis designed the main façade of *La Tourette* monastery using stochastic methods in a similar way that he used them in his orchestra compositions [8] . Renzo Piano designed the architectural scenario of Luigi Nono musical piece with the acoustic and spatial requirements of it.[9] Stockhaussen and Fritz Bornemann designed a

Fig. 1. Façade of *La Tourette* monastery, by Iannix Xenakis.

5 Jansson and Smith; Lassi A. Liikkanen and Matti Perttula, 'Inspiring Design Idea Generation: Insights from a Memory-Search Perspective', *Journal of Engineering Design*, 21.5 (2010), 545–60 <https://doi.org/10.1080/09544820802353297>.

6 Victor Olgyay and others, *Design with Climate : Bioclimatic Approach to Architectural Regionalism*.

7 Norman K. Booth, *Basic Elements of Landscape Architectural Design* (Long Grove: Waveland Press, 1983).

8 Josep Llorca and Doménec Llorca, 'La Tourette Y Metastaseis : De Cómo Ordena El Material Un Arquitecto Y Un Músico.', *Circuito de Arquitectura*, 1.7 (2010), 5–16 <https://upcommons.upc.edu/handle/2117/85038> [accessed 8 March 2018]; Iannis Xenakis, *Music and Architecture : Architectural Projects, Texts, and Realizations* (Hillsdale: Pendragon Press, 2008).

9 Cristina; Palmese and José Luis Carles, 'Música Y Arquitectura', *Scherzo*, 193.1 (2005) <http://www.scherzo.es/hemeroteca/2005-01-193.pdf> [accessed 19 January 2018].

place where spatiality of music was the main topic.[1] Furthermore, some researchs have been done regarding the close relations between composers and architects.[2]

In recent years, the influence of acoustics on architecture students has been analyzed. Sheridan and Van Lengen[3] studied an educative study in which the students experienced the acoustic properties of different spaces in order to make an architectural design proposal. Michael Fowler teaches architectural students about the importance of sound in cities and encourages them to make urban design proposals to generate particular acoustic conditions.[4]

In our studio we propose another approach to architectural design based on sound. Space acoustic design and sound landscape design are not addressed, as it was done in the previous examples. Instead, we consider sound as a generator of architectural designs: students listen to a specific soundscape and they are asked to design the space that this suggests. As far as we know, no study has been published using this architectural design approach.

1 Michael Fowler, 'The Ephemeral Architecture of Stockhausen's Pole Für 2', *Organised Sound*, 15.3 (2010), 185–97 <https://doi.org/10.1017/S1355771810000269>.

2 Susana Moreno Soriano, *Arquitectura Y Música En El Siglo XX*, Fundación (Barcelona, 2008); Gastón Clerc González, *'La Arquitectura Es Música Congelada.'* Doctoral thesis, 2003; Emily Ann. Thompson, *The Soundscape of Modernity : Architectural Acoustics and the Culture of Listening in America*, 1900-1933 (MIT Press, 2002).

3 Ted Sheridan and Karen Van Lengen, 'Hearing Architecture', *Journal of Architectural Education*, 57.2 (2003), 37–44 <https://doi.org/10.1162/104648803770558978>.

4 Michael D. Fowler, 'Soundscape as a Design Strategy for Landscape Architectural Praxis', *Design Studies*, 34.1 (2013), 111–28 <https://doi.org/10.1016/j.destud.2012.06.001>.

3.2. Method

To analyse the possibilities of soundscape as a design generator, a design fixation model was used in architecture students. As it was explained before, this model consists of showing the student several completed works that have similar requirements to those required of the student. It was considered to use a Design fixation model to obtain less diverse results but with more quality and novelty[5].

A quasi-experimental approach was used with one-group pretest-posttest design in 3rd and 4th year architectural students of a six-year program at the Universitat Politècnica de Catalunya, Barcelona, Spain.

3.2.1. Data collection

Data was collected using an anonymous questionnaire (Appendix A). The questionnaire consisted of 11 questions included in 2 domains. The first domain values the architectural items (color, light, texture and sound) and the second values the usefulness of the method:

1. Do you feel "drawing the soundscape" useful for architectural design? [Effectivity]
2. Would you use it for your design projects? [Efficiency]
3. Do you feel comfortable with the method? [Satisfaction]

5 Ut Na Sio, Kenneth Kotovsky and Jonathan Cagan, 'Fixation or Inspiration? A Meta-Analytic Review of the Role of Examples on Design Processes', *Design Studies*, 39 (2015), 70–99 <https://doi.org/10.1016/J.DESTUD.2015.04.004>.

4. Is it easy to imagine architectural spaces from soundscapes? [Space Imagination]

5. Do you feel comfortable working with this method? [Comfortability]

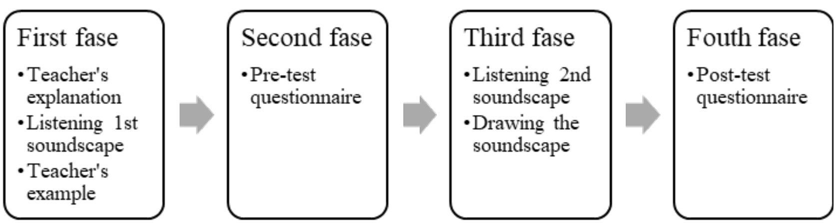
6. Does the method improve your imagination capacity? [Imagination improvement],

7. Does the method help you to the materialization of the architectural designs? [Materialization]

The questionnaire used a rating scale ranging from 1 point to 5 points.

3.2.2. Procedure

A four-phase design was conducted. In the first phase, which corresponds to design fixation, the teacher explained what the activity will consist of. The teacher reproduced a sequence of domestic sounds that had been recorded and assembled with the intention of describing a spatial sequence. Three examples of possible designs were shown.



In the second phase, a pre-test questionnaire with two domains was distributed to students and the results were collected. The first domain asked the student about the evaluation of the phenomenological elements of architecture corresponding to the senses most valued in western culture[1] (colour-light, sound and texture). Next, the second domain asked about the evaluation of the "drawing the soundscape" method, previously explained by the teacher in terms of effectiveness, efficiency, satisfaction, comfort, imagination and materialization. The results were then collected.

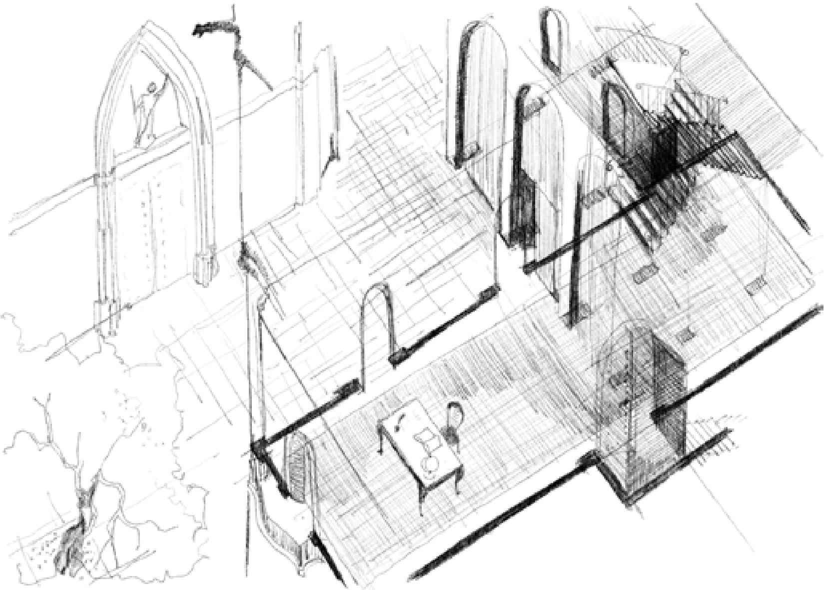
In the third phase, the teacher reproduced a second sequence of domestic sounds other than the first. Then, he asked students to draw the architectural space they imagined from that sequence. All students were asked to draw by hand with free technique, in military perspective and on an A3 din. At the end of the session, the exercises were collected.

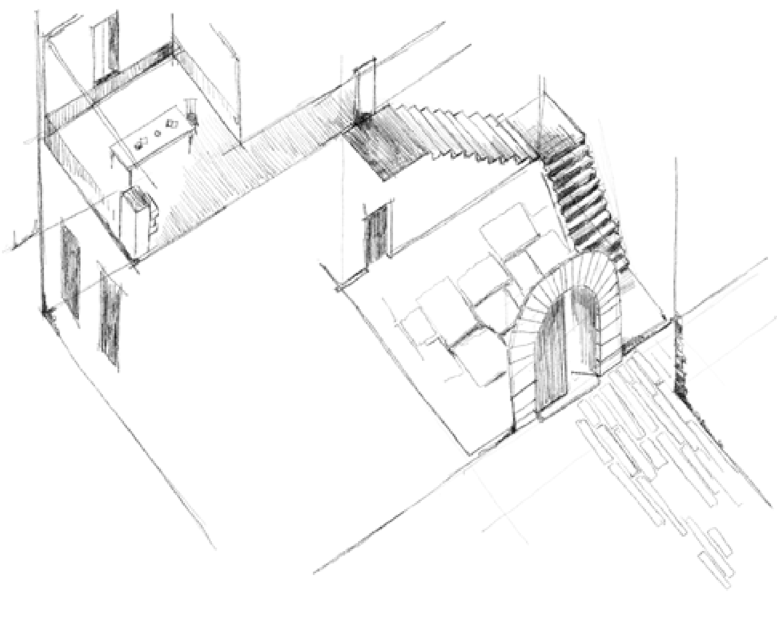
In the fourth phase, a post-test questionnaire, identical to the pre-test, was distributed to students and the results were collected.

3.2.3. Statistical analysis

Descriptive statistics of the results were computed as Median, Mean and Standard Deviation. The differences between pre and post test were evaluated using Wilcoxon test in the individual items and t-test in the total items. Spearman's correlation (rs) was used to explore the association of the musical level and the amount of change between pre and post test. A p-value less than 0.05 was defined as statistically significant. All computations were performed with use of SPSS-IBM (ver. 23) program.

1 Augusta Augusta McMahon, 'Space, Sound, and Light: Toward a Sensory Experience of Ancient Monumental Architecture', *American Journal of Archaeology*, 117.2 (2013), 163 <https://doi.org/10.3764/aja.117.2.0163>; Juhani. Pallasmaa, *The Eyes of the Skin : Architecture and the Senses* (Wiley, 2012).





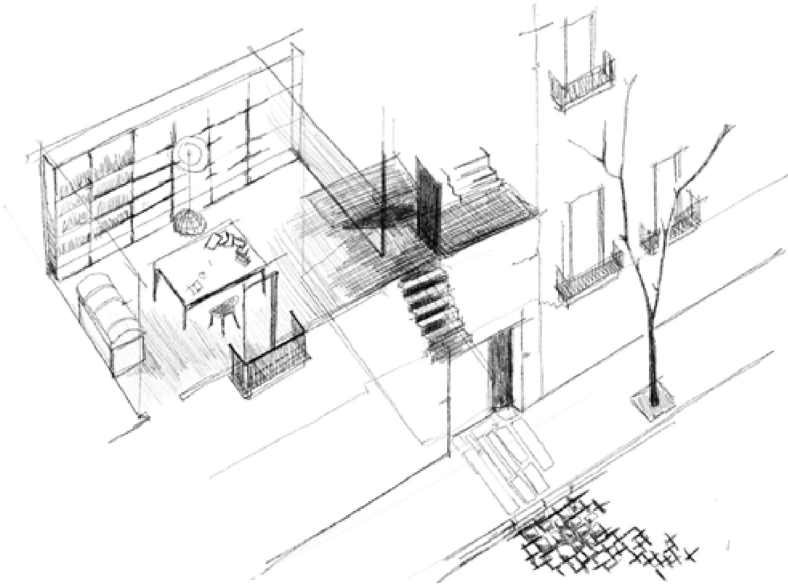


Fig. 2. The three examples shown by the teacher in the first phase

3.3. Results

A total of 70 students participated in the study – 37 females (52.9 per cent), 33 males (47.1 per cent)-.

3.3.1. Questionnaire results

Sixty-six volunteer students -34 females (51.5 per cent), 32 males (48,5 per cent)- answered the baseline questionnaire and 39 students -24 females (61.6 per cent), 15 males (38.4 per cent)- answered the follow-up questionnaire. Nevertheless, only 36 students -22 females (61.1 per cent), 14 males (38.9 per cent)- answered the two questionnaires and that data is used for the statistical analysis of the questionnaire and the correlations with musical level.

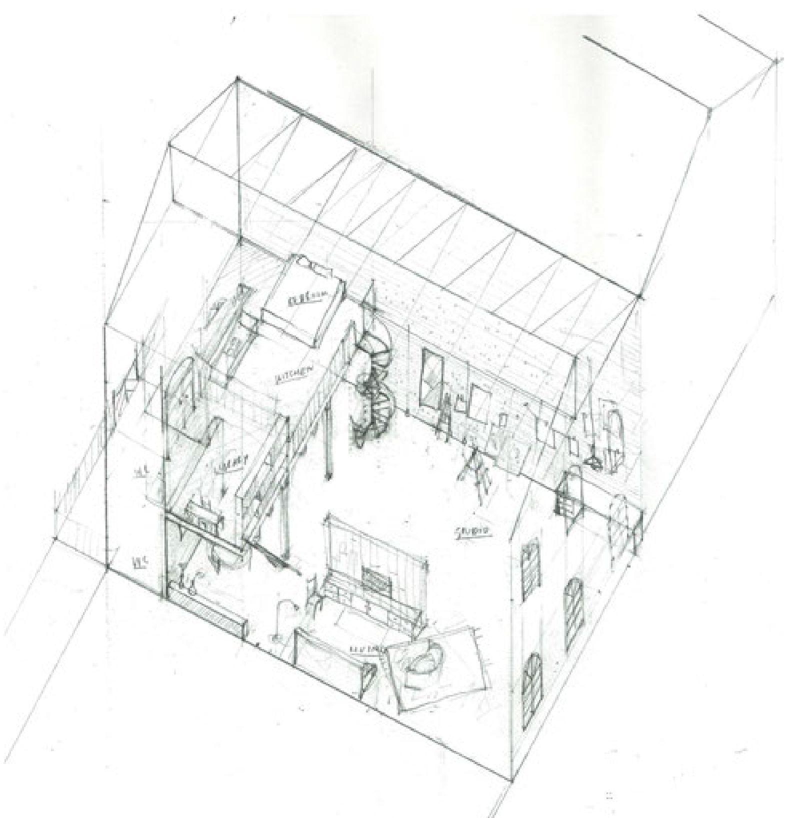
The architectural elements domain was influenced by the test changing the sound's valuation median from 3 to 4 point (p=0.009) but not the colour (p=0.702), light (p=0.655) and texture (p=0.225) medians. The total median from architectural elements assessment changed significantly from 16.50 to 17.50 points (p=0.033).

The "drawing the soundscape" assessment domain was influenced by the test improving one point in the median of effectivity (p=0.047), space imagination (p=0.004) and imagination improvement (p=0.011). The satisfaction's median was not changed, but the mean improved from 3.50 (SD=1.298) to 3.92 (SD=0.841) with significant difference (p=0.046). The total mean from that domain changed from 24 to 26 points (p=0.028).

Fig. 3. Opposite page. Design for the experiment, by Rebekah Tien Yi-Jo.

The total median was influenced by the test and changed from 40 to 43 with a statistical significant difference (p=0.012).

The influence of the previous musical level in the results of the questionnaire the students was classified depending on the previous musical education in three states: don't have musical studies (12 students, 33.4 per cent), elemental studies (15 students, 41.6 per cent) or medium-professional studies (9 students, 25 per cent). The correlation among musical level and the amount of change between pre and post test was significant only for light valuation (rs=0.366, p=0.028) and commodity (rs=0.488, p=0.003) but not for any of the other items evaluated.



QUESTIONNAIRE TABLE

	Pre (n= 36)			Post (n= 36)			
	Median	Mean	SD	Median	Mean	SD	p-value
ARCHITECTURAL ELEMENTS ASSESSMENT							
1) Color valuation	4.00	4.17	0.697	4.00	4.22	0.760	0.712
2) Light valuation	5.00	4.81	0.401	5.00	4.83	0.378	0.655
3) Texture valuation	4.00	4.31	0.668	5.00	4.44	0.652	0.225
4) Sound valuation	3.00	3.42	1.103	4.00	3.74	0.850	0.009*
Total architectural elements	16.50	16.55	1.918	17.50	17.19	1.801	0.033*
"DRAWING THE SOUNDSCAPE" ASSESSMENT							
1) Effectivity	3.00	3.17	1.231	4.00	3.61	0.838	0.047*
2) Efficiency	3.00	2.75	1.296	3.00	3.11	0.887	0.075
3) Satisfaction	4.00	3.50	1.298	4.00	3.92	0.841	0.046*
4) Space Imagination	3.00	3.00	1.042	4.00	3.64	0.867	0.004*
5) Comfortability	3.00	3.28	1.111	4.00	3.50	0.878	0.351
6) Imagination improvement	4.00	3.75	1.228	5.00	4.39	0.903	0.011*
7) Materialization	4.00	3.47	1.207	4.00	3.50	0.811	0.964
Total "drawing the soundscape"	24.00	22.91	7.216	26.00	25.66	4.616	0.028*
TOTAL	40.00	39.47	8.129	43.00	42.86	5.617	0.012*

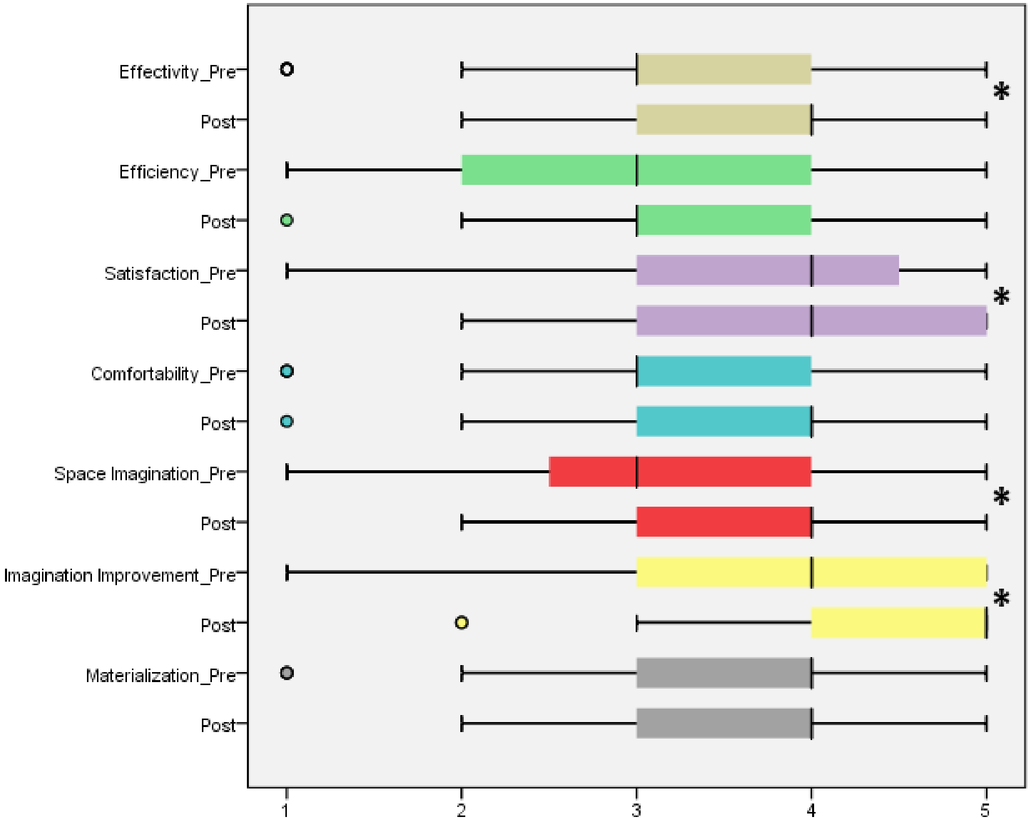


Fig. 4. The table on the left and the boxplot on the right show the results of the questionnaire. They are related to each of the analized domains in the Pre and Post test. * = statistically significant (p<0.05). In the domain of the "architectural elements" we observe a significant change in the sound valoration when modifying the whole valoration of the elements. In the "drawign the soundscape" domain we observe a significant change in the effectivity, satisfaction, space imagination and the improvement of imagination. The colour dots in the boxplot indicate the extreme values; people who answered that the domain was not useful for the method.

#. Soundscape sequence of the sonorous events.

3.3.2. Drawing the soundscape results

The elements contained in the student's drawings were detected in the Table III. The successive elements of the soundscape sequence are indentified in the horizontal axis. This sequence contains the following sonorous events: (A) Road, (B) Bycicle, (C) Exterior space, (D) Fence, (E) Door, (F) Interior space/steps, (G) Radio, (H) Steps/Interior space, (I) Sink/water, (J) Table/dishes, (K) Break, (L) Interior space/steps, (M) Radio off, (N) Interior space /steps, (O) Voices exterior, (P) Open door, (Q) Exterior space, (R) People shouting/Happy birthday. As it can be tested, the sequence contains both spatial elements (such as interior and exterior spaces) as well as objects (such as radio or shouting people). A first approach to the drawing consists of the comparison among the drawn spatial elements percentage.

It can be noted that architectural spaces correspond to the most drawn items: (A) 96 per cent, (C) 98.7 per cent, (D) 89.3 per cent, (E) 100 per cent, (F) 98.7 per cent, (H) 100 per cent, (L) 98.7 per cent, (N) 98.7 per cent, (P) 96 per cent, (Q) 92 per cent. On the contrary, non-architectural objects correspond to the less drawn items: (B) 61.3 per cent, (G) 66.7 per cent, (I) 76 per cent, (J) 77.3 per cent, (K)45.3 per cent, (M) 62.7 per cent, (O) 4 per cent, (R) 5.3 per cent.

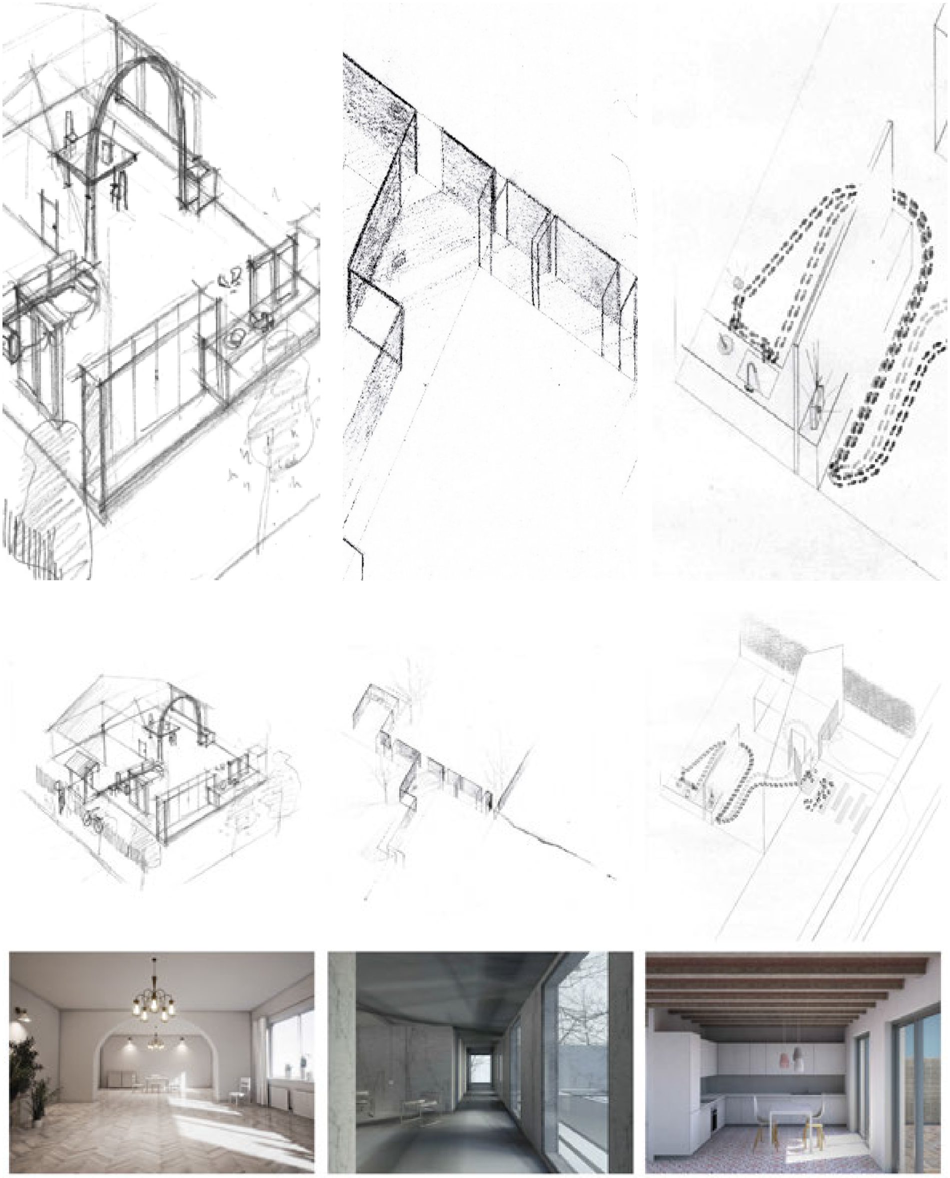
On the other hand, 54 of the 75 students that realized the experiment, that is a 72 per cent, finished the exercise by producing a photorealistic image of the interior space proposed in the first sketch. This photorealistic image introduces materiality in the architectural design process. However,

Audio	Timeline →																	
	Outdoors					Indoors							Outdoors					
Sound items	S. Road	T. Bicycle	U. Birdsong/Exterior space	V. Fence	W. Door	X. Steps/Interior space (1)	Y. Radio	Z. Steps/Interior space (2)	AA. Water	BB. Dishes	CC. Glass break	DD. Steps/Interior space (3)	EE. Radio off	FF. Steps/Intreior space (4)	GG. Voices	HH. Open door	II. Exterior space	JJ. People shouting
Num.	72	46	74	67	75	74	50	75	57	58	34	74	47	74	3	72	69	4
%	96	61.3	98.7	89.3	100	98,7	66.7	100	76	77.3	45.3	98.7	62.7	98.7	4	96	92	5.3

some students introduced already materiality in their hand drawing. To sum up, 84 per cent of the students treated materiality in their architectural designs, whether in initial drawings of in the photorealistic advanced image.

Finally, the interpretation that students presented over the acoustic route was evaluated. The acoustic route starts in an outdoor space, followed by an indoor space and ends in an outdoor space again. Even though there is no doubt that outdoor and indoor spaces can be distinguished, whether the first outdoor space corresponds to the last outdoors space can be freely interpreted by the student. This ambiguity leads to two kind of interpretations of the listened space: a circular route in which the starting space coincides with the final space, or a lineal route in which the beginning and the end are different. 78.6 per cent of the students imagined a circular route, whilst 21.3 per cent of them imagined a lineal route.

Fig. 5. Detailed and finished exercices by Killus, Millet and Llevadot.



3.4. Discussion

The architectural design process comprehends modifications of the original design, improving it and adjusting its measures. Therefore, the architectural design “cannot be created by starting at the beginning and going on in a ‘linear’ way to the end. On the contrary it is necessary to keep the totality in mind, and to go from the whole to the parts and back to the whole” [1] . Only in some cases “simplicity [is achieved] through elimination of the necessary, through lack of understanding of the complexities of the problem, through failing to see—or choosing to ignore—the real difficulties that must be met and solved” [2] . However, either following a lineal way or a more complex way, in the architectural design process, the initial powerful idea predominates. This idea is named “insight” at the beginning of the article: “if analysis is the exploration of the problem in terms of its potential for solution, then insight is the first, tentative, predication of that solution” [3] . The exercises shown in figure present clearly that an initial powerful idea is continued until the end, even though some accessory details change during the design process.

Now, not all students produced the photorealistic image as their first sketch pointed out, but modified their original design, up to the point that the final design was very different to the original. However, the fact that 72 per cent of the students ended up making a photorealistic image shows that this seed of architectural design containing the sound

1 Christian Norberg-Schulz, *Intentions in Architecture* (Cambridge: M. I. T. Press, 1965).

2 Herbert.

3 Ibid.

sequence was powerful enough to generate a finished architectural design in most students.

It has been seen that 84 per cent of the students imagined the materiality of their design and represented it in the drawings. However, drawing the materials is not necessary for a correct understanding of space. Thus, some examples of students can be found (Figure 3) in which they drew the geometry without using materials in their initial drawing. On the other hand, there are other students who, simply with the materials and a light sample of space, make the design understandable without having to make excessive use of the three-dimensionality (Figure 4).

Fig. 6. Space is defined and materiality is suggested. Authors: Christian, Corbacho and Casas.

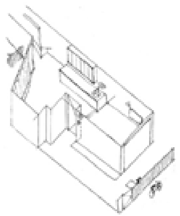
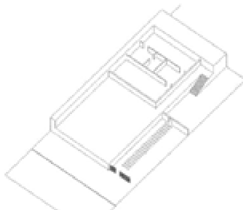
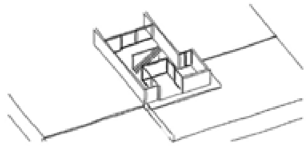
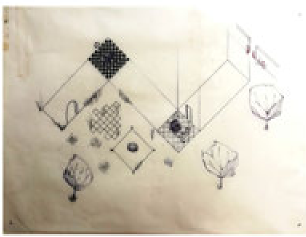
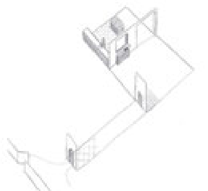
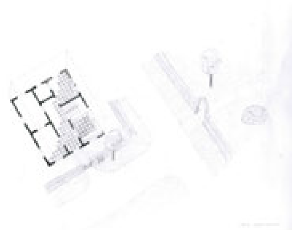
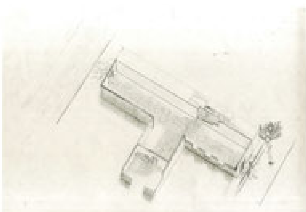
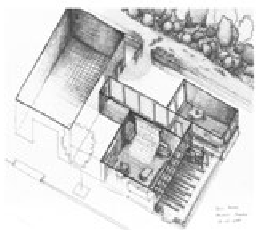
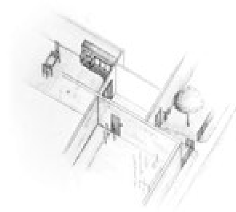
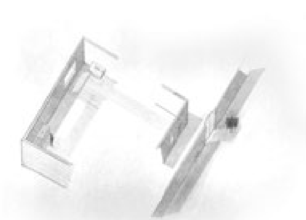
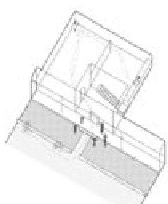
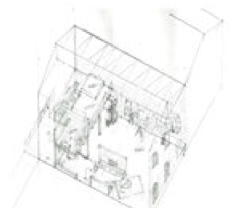
Finally, the fact that 78.6 per cent of the students imagined the spatial sequence to be circular (Figure 5), while 21.3 per cent imagined it to be linear (Figure 6), shows us that the architectural imagination to design a space from a sound landscape leaves some design questions open to the interpretation of the designer. This openness to personal interpretation is particularly useful for the pedagogy of the architectural project, in which, "while each design process may appear to be an isolated occurrence, it is essentially one event in a total creative situation and the solution to the one design problem forms part of the input to other problems, in a continuous evolutionary process of creativity"[1].

Fig. 7. Materiality is defined and space is suggested. Authors: Bruni, Mattis and Morey.

Fig. 8. Representation the sonic sequence as "lineal". Authors: Gómez, Aguado and Arranz Santa-Olalla.

Fig. 9. Representation of the sonic sequence as "circular". Authors: Ferrer, Costa and Tien.

1 Herbert.

3.5. Conclusion

This lesson has shown, through a teaching experience, the generative capacity of architectural designs from a soundscape. Following the design fixation model, the experience has been evaluated by the students themselves through questionnaires that were analysed statistically. In addition, a graphical evaluation of the obtained results has been carried out. The main findings of this study are that the soundscape can be used for architectural design, that there is no significant correlation with the students' previous musical knowledge and that this design method is very useful for teaching the architectural project.

On the one hand, there is a positive correlation with the previous musical knowledge of the students in the assessment of light and comfort, but these items do not show significant modification between the pre and post-test. On the other hand, the items that show pre-post differences (effectivity, satisfaction, space imagination and imagination improvement) are not modified by the musical level. This fact does not mean that it cannot be used in all types of students, but that those with previous musical knowledge feel more comfortable.

The study carried out implies that it can be applied perfectly as a methodology of architectural project design in architecture schools. What's more, it can result in a variety of design solutions without conditioning the student. However, it should be stressed that the study has some limitations: the spatial perception of students has not been taken into account and the questionnaire carried out needs to be improved. For this reason, a calibration of the spatial acoustic perception depending on the

Fig. 10. Final realistic image of the exercise by Valero.

individual and a study of the factors that favours this dependence for its generalization to the rest of the population remains open to future studies. Therefore, it is planned to carry out a spatial perception test related to conditioning factors by machine learning in the future.

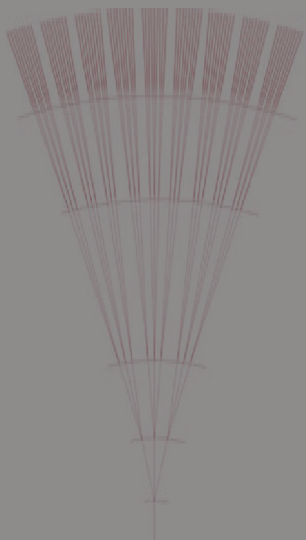
3.6. Appendix: pre and post test questionnaire

QUESTIONS (FROM 1: I DO NOT VALUE IT AT ALL; TO 5: I VALUE IT VERY MUCH)	1	2	3	4	5
ARCHITECTURAL ELEMENTS VALORATION					
1. ¿Do you value colour in architecture?					
2. ¿Do you value light in architecture?					
3. ¿Do you value texture in architecture?					
4. ¿Do you value sound in architecture?					
METHOD VALORATION					
1. Do you feel "drawing the soundscape" useful for architectural design? [Effectivity]					
2. Would you use it for your design projects? [Efficiency]					
3. Do you like working with this method? [Satisfaction]					
4. Is it easy to imagine architectural spaces from soundscapes? [Space Imagination]					
5. Do you feel comfortable working with this method? [Comfortability]					
6. Does the method improve your imagination capacity? [Imagination improvement]					
7. Does the method help you to the materialization of the architectural designs? [Materialization]					

Case study

The graphical data of the experiment

The graphical results of the second and fourth phase of the experiment of this chapter are not discussed in this section.



A total of 243 of the design possibilities could be derived from the designing process from the studied soundscape. If any suggested change of direction on the path of the walker is interpreted whether to the right, to the left or to the front, we must multiply by 3 each crossroad. This leads to a total of 243 possibilities of architectural designs. Students demonstrated this huge amount of possibilities. This fact can be identified in the graph on the right corner of the panel.

The architectural design process comprehends modifications of the original design, improving it and adjusting its measures. Therefore, the architectural design "cannot be created by starting at the beginning and going on in a "linear" way to the end. On the contrary, it is necessary to keep the totality in mind, and to go from the whole to the parts and back to the whole"[1]. Only in some cases "simplicity [is achieved] through elimination of the necessary, through lack of understanding of the complexities of the problem, through failing to see—or choosing to ignore—the real difficulties that must be met and solved"[2]. However, either following a lineal way or a more complex way, in the architectural design process, the initial powerful idea predominates. We have named this idea "insight" at the begining: "if analysis is the

Fig. 11. Diagram showing the 243 design possibilites from the studied soundscape.

Fig. 12. Some drawigns produced by the students in the experiment.

1 Christian Norberg-Schulz, Intentions in Architecture (Cambridge: M. I. T. Press, 1965).

2 Herbert.

#. Soundscape sequence of the sonorous events.

exploration of the problem in terms of its potential for solution, then insight is the first, tentative, predication of that solution." It can be observed in the panel that some of the students not only drew the initial sketch but also were able to finish the exercise producing a photorealistic image of the domestic space suggested by the soundscape.

To complete with this section, not all the elements present in the soundscape were drawn by the students. In the central area of the panel, one can find an identification of those elements drawn by each student. It is possible to note that architectural spaces correspond to the most drawn items.

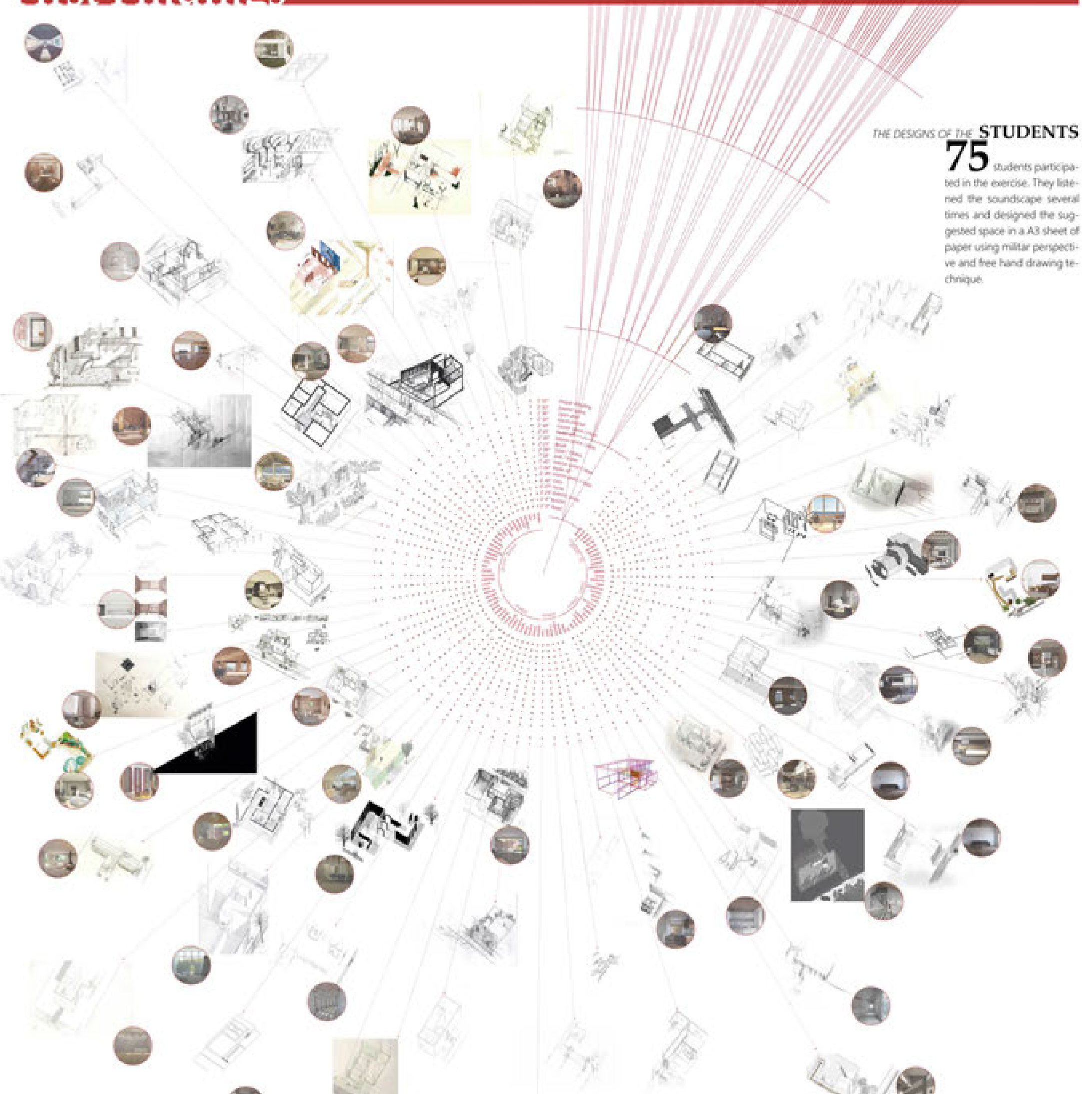
Fig. 13. Panel exposed in the DAGA Conference 2018, München (Germany).

Generation of Architectural Designs Using Soundscapes: First Findings

Architectural design process contains a crucial stage called "insight", in which the vital creative phase of the design process begins. Additionally, "design fixation", or simply designing from external stimuli, has been one of the most common methods to approach this phase. Sound as external stimuli for designing, has been used in many historical cases. However, it has never been considered as a design engine for inhabited interior environments.

THE **IMPACT** OF THE METHOD

A total of **243** of design possibilities could be derived from the designing process from the studied soundcape. If any suggested change of direction on the path of the walker is interpreted whether to the right, to the left or to the front we must multiply by 3 each crossroad. This leads to an total of 243 possibilities of architectural design. Students demonstrated this huge amount of possibilities.



THE DESIGNS OF THE **STUDENTS**

75 students participated in the exercise. They listened the soundscape several times and designed the suggested space in a A3 sheet of paper using militar perspective and free hand drawing technique.

THE DESCRIPTION OF THE **SOUNDSCAPE**

220 seconds of soundscape recorded in different environments to form a space-descriptive story.

You can find this **panel** and the soundscape **audio** in:

ETSAB

Chapter 4

Fundamentals on analysis

The plan and the score, the analytic drawings of architecture and music

Chapter 4

Fundamentals on analysis

The plan and the score, the analytic drawings of architecture and music

The present chapter is derived from the work entitled *The plan and the score: the analytic drawing on the elements of architecture and music*. This work was presented by the author as a conference article in EGA2016 and it can be found in the book *EGA2016: Architectural Draughtsmanship*.

4.1. Two precious carpets: Architecture and Music

Approximately between 1856 and 1859, the German theorist Gottfried Semper (1803–1879) writes his "Theory on the formal beauty" in which he defines that "tectonics constitutes the pure universal or cosmic art. The Greek word cosmos (κόrloς), that doesn't find an equivalence in none of the alive languages, means both universal order and ornament"[1]. Semper mentions with this definition the double nature of tectonic: a discipline that is able to create an ordered universe by controlling the nature by means of the delimitation of the space—or the formal elements—, and simultaneously a discipline that is able to embellish this universe by means of the technical arts—or the style elements.

But this statement is three paragraphs away from a second one in which he defends that "tectonics, as a cosmic art, constitutes a triad with music and dance because, each of them in its field, they are not imitation arts. Nevertheless, the three of them, with their own and different tools of representation, proceed in a similar way when they conceive cosmically their specific task: how to give to the material its ideal expression. In the music, it also guides the law that conforms and embellishes, in other words, the ornament made clear and remarked, as harmony of elemental forces that work simultaneously"[2]. From this moment, Semper is not going to place architecture besides painting and sculpture, as one of the plastic arts (imitatives),

1 Gottfried. Semper, Antonio Armesto and Manuel García Roig, *Escritos Fundamentales de Gottfried Semper : El Fuego y Su Protección* (Madrid: Fundación Arquia, 2014) <http://fundacion.arquia.es/es/ediciones/publicaciones/Colecciones/DetallePublicacion/111> [accessed 16 May 2018]. Pg. 233.

2 Semper, Armesto and García Roig. Pg. 234.

but, with the name of tectonics, is going to became one of the "cosmic arts", by the side of music and dance.

Architecture, music and dance are situated in a same level[3]. However, the high ideal of tectonics is the static cosmos, and that of music, the dynamic cosmos; this clear distinction will force Semper to relegate dance to a different level and although he began his theory with the three arts, he ends by giving priority to architecture and music over dance. With this definition, Semper mentions again the double nature of music: a discipline that is able to create an ordered universe delimiting the wild nature that is around it by means of the delimitation of time and sound—or the formal elements—and simultaneously a discipline that is able to embellish this universe by means of the technical arts—or the style elements. Therefore, a structural question is gathering us today: both of them conceive their specific task in a similar way: double but not contrary, bidirectional, like a fabric in which the two directions of threads are supporting each other and they are essential for the constitution of the carpet in which, "as it is known, the two threads that before of being weaved were equivalent, now they are not the same. Not because of their different material substance (wool, linen, silk), but because of the role they play in the constitution of the carpet: some of them play as warp (the longitudinal and parallel ones that you should tauten) and the others play as weft (in fact, there is only one, that goes and returns transversally between the threads of the warp, despite the fact you can cut it in order to change the colour, for instance, and then join the

3 Semper, Armesto and García Roig. Pg. 23

scraps for resuming the task) and other threads that they are not going to take place of the carpet but of the loom since fastened to the bars of the loom, they will be useful to separate those of the warp among them in order to the shuttle being able to weave with those of the weft. From the moment when the threads play a role in the loom, they are no more homogeneous and they belong to one of these three families"[1].

The analogy that we are pointing out between the carpet and the two disciplines is a sameness of reasons, which would be expressed in this way: the form elements are to the style elements in the two disciplines as, in the loom, the warp is to le weft. In architecture and music, we attend to the creation of the precious carpet that is constituted by form and style. Whereas, in the horizontal direction, the formal function system—the warp—looks after the basic elements out of the successive time on account of their condition of logical invariants (the hall, the enclosure, the roof, the note, the rhythm, the harmony) in the simultaneous order of the work, in the other direction, the structural phenomena system—the weft—has got the purpose of embodying these logical invariants till the point of turning them into concrete realities (colour, material, texture, timbre, dynamics). This begs the question: how does the man control the creation of this carpet? Which techniques does he makes use of for drawing the reality in a sheet of paper in order to control all the elements?

1 Semper, Armesto and García Roig. Pg. 31

4.2. The plan and the score

On one hand, the architect has got the plan as the main tool. The plane, in its more general mean, as a representation of the tectonic reality that is going to be built. By means of the ground plan, the elevation or the section, the plan is a document that prints the three-dimensional reality in a two-dimensional mean making a translation of the object being represented. In fact, the plan collects every feature of the building and projects them on the paper, recording every form of the walls, the position of the windows, the colour of the surfaces, the position of the furniture or the drawing of the tiles on the floor (Fig. 1). Obviously, the plan is an exact tracing of the reality and it doesn't permit of doubts about how it is going to be the building, what is more, there is the building. If we turn our sight to the definition of architecture as cosmic art made by Semper, we can distinguish in the plan the two axes of architecture—form and style—superimposed, because we find in a simultaneous way the form of architecture and its colour, texture, and material features.

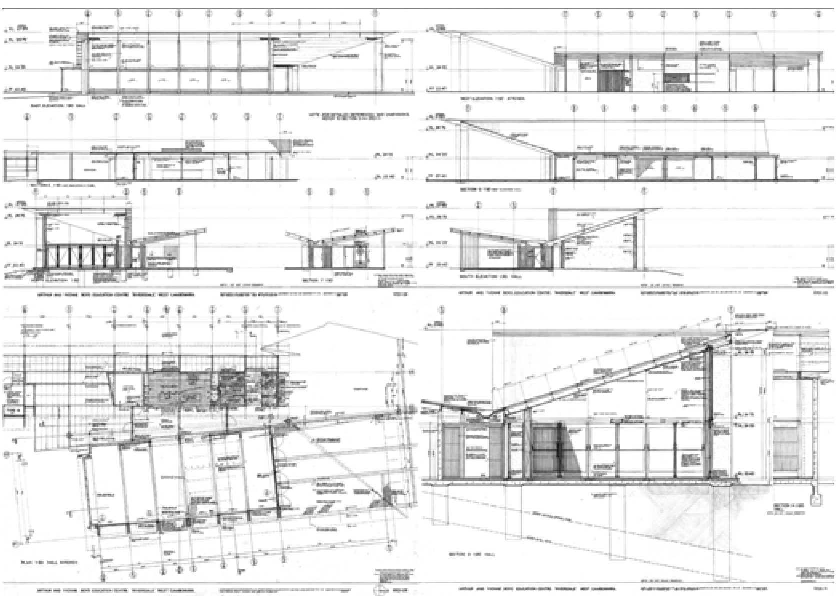


Fig. 1. Ground plans and sections of the Education Centre Riversdale by Glenn Murcutt. Note the great quantity of information contained in the sheet of paper.

#. Mahler's *Resurrection*: Symphony nº 2

By the other hand, the composer has got the score as the main tool. All over again, the score is understood as the representation of the acoustic reality that is going to be performed. The score is a document that prints the sonorous reality in a two-dimensional media by making a translation of the image of the object being represented. In fact, the score picks up every feature that constitutes the work and projects them to the paper, recording every note of instruments, main and secondary melodies, harmonies among voices, dynamics, timbres or the work's form (Fig. 2). Music as cosmic art is printed in the score when formal functions and its structural phenomena[1] —form and style—are weaved.

Fig. 2. First page of the 2nd Mahler symphony, "Resurrection". Note the great quantity of information contained in the sheet of paper. Source Universal Edition A. G.

1 Formal functions attend to the role played by each of the parts in the musical work. They constitute its form. In this context, there are the introductory function, the expositive, elaborative, transitive and conclusive in a big scale and the period, the phrase, the motive or the cell in successive lower scales. On the other hand, the structural phenomena embody these functions in concepts that we can get by sense such as timbre, dynamics, agogics, texture, or modulation. The changes in structural phenomena reveal the change from a function to another function. In this way, the two dimensions of music—the warp and the weft—are intimately related.

SYMPHONIE No 2

1. Satz

Gustav Mahler

Anmerkung für den Dirigenten. In den ersten Takten des Thema's sind die Bassfiguren schnell in heftigem Ansturm ungefähr ♩= 144, die Pausen jedoch im Hauptzeitmass ♩= 84 - 92 auszuführen. Der Halt im 4. Takte ist kurz — gleichsam ein Ausholen zu neuer Kraft.

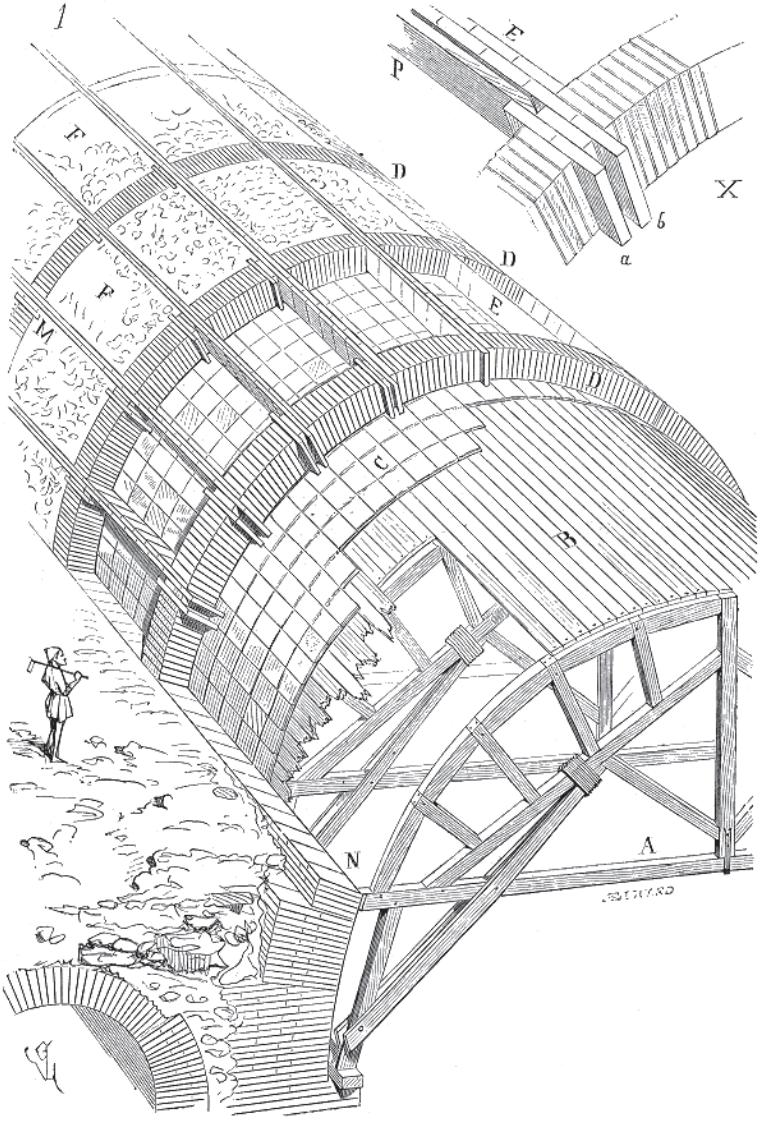
U. E. 13821

4.3. The representation of the warp or the strictness of form

The first of the features, and maybe the most important, expressed by the plan and the score is form, because form possesses an atemporal character. We understand form as the contrary of material: if material is what things are made of, form is what determines material in order things are what they actually are. Italo Calvino, in his *Invisible cities*, says by Marco Polo the following aphorism: "The bridge isn't held by this or that stone, but by the arch's line that they are forming". Therefore, if there is something that should inspire where things must be put, this is form. Accordingly, form is more similar to geometry than to construction. As a result, form analysis is understood, under this conception, in a more logical than phenomenological way.

This logical knowledge of the discipline points out the formal aspect, the warp of the carpet, understood as an insight of the internal structure of the work. Hence, we are interested in finding an analytical system of form representation in architecture that, starting from the basic features of the elements, could end in a symbolic notation and a tool for the project. In the research of this system we find other composition disciplines that count on a symbolic notation; the epitome is music, in which this notation system allows the composer writing music without the necessity of attending to the physic dimension attached to the acoustic phenomenon neither, the musical instruments or the interpretation. Conversely, we find in architecture the following paradox: he possesses a formal nature but, as a discipline, is very low formalized because it doesn't hold symbolic notation system in order to

Fig. 3. Oppostie page Each of the material elements that contribute to the construction of the roman vault follow the rules of the form of this vault: the formwork, the bricks and the archs.


1
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generate works in a deductive way and with a high control of its internal structure.

A representation system based only on form divests the work of every particular feature that attach it to the technique of the moment (constructive system or timbre), to the life (the architectural program or the lyrical program), and to the place (the topography or the thematic material). Geometry in architecture and harmony in music are what remain. They are few examples of representation at this level. But they hold the essential force of the elements represented in its nakedness.

A good example is offered by the Greek musician and architect Iannis Xenakis. In his years of work with Le Corbusier he composed his orchestral work *Meastaseis*. *Metastaseis* begins with a G played by the 46 strings by unison, pianissimo. It is G2, continuous and apparently eternal, immortal. After that, above all the first of the first glissandi rises up. Before of the entry of the viola it will have sounded a dry knock in the woods. And in this moment the incorporation of the other 43 string instruments into the glissandi takes place till opening the register in a huge 46 note chord: the seven pitches of the C major scale played at the same time and in different octaves. The high pitches have moved upwards and the lower ones downwards opening the fan and holding the chord during some seconds[1]. The author gets the inverse effect at the end of the work, in which a big volume of 55 strings deployed uniformly is going to fold over itself sliding from some notes to others without brusque changes, but

Fig. 4. Graphic score of the last 16 measures of Iannis Xenakis *Metastaseis*. There are only represented the pitches in time, without reference to timbre and dynamics.

1 Josep Llorca and Doménec Llorca, 'La Tourette y Metastaseis : De Cómo Ordena El Material Un Arquitecto y Un Músico.', *Circuito de Arquitectura*, 1.7 (2010), 5–16 <https://upcommons.upc.edu/handle/2117/85038> [accessed 8 March 2018].

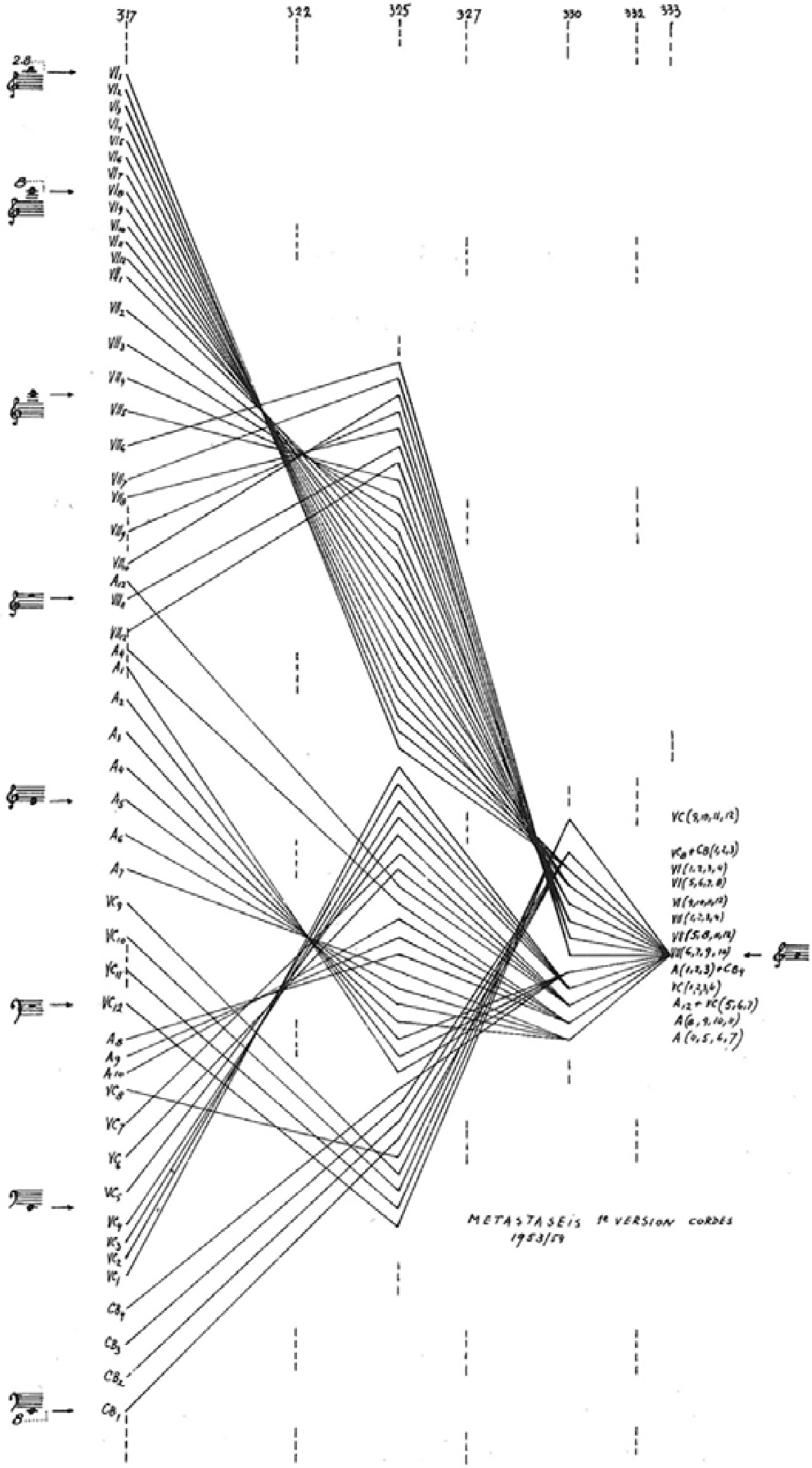
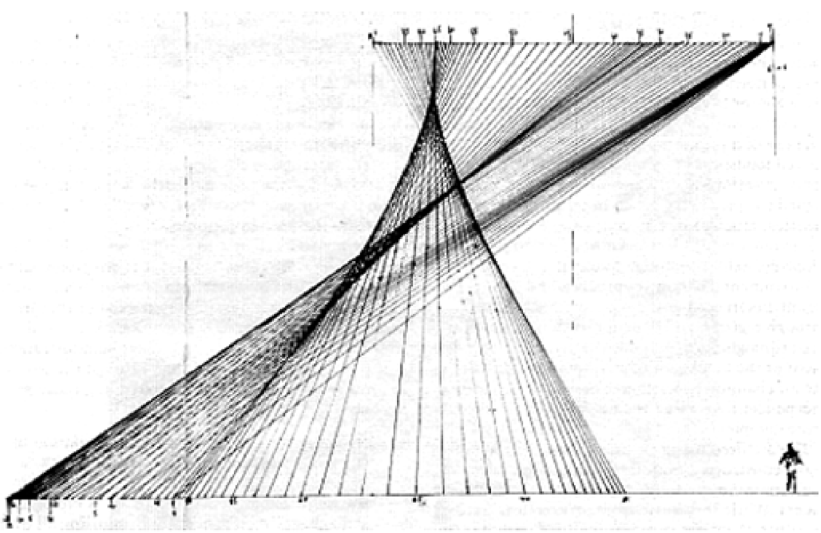

317
322
325
327
330
332
333
METASTASEIS 1re VERSION CORDES
1953/54

Fig. 5. Montreal *Politope* elevation, Iannis Xenakis' ephemeral pavilion. They are only represented the lines that constitute the ruled surface, without any reference to material and colour.

searching by means of glissandi the continuity in the acoustic result. This effect is revealed in the graphic score made for the study of the voice directions. The result is a net that points out only the pitch of the sounds and the continuous rhythm that they follow: The horizontal axis represents the time and the vertical represents the pitches of sounds; there is nothing more represented here: nor the timbre, nor the dynamics, nor the expression. Xenakis made an analogous procedure in the plans for his politopes, ephemeral buildings made of tense wires and under canvas. In particular, that of Montreal, where he only represented the ruled surface of the walls without any reference to materials and colours.

But Xenakis' example is situated in a place where the particularities of the work are relevant and it is not abstracted to the formal scheme, because, in the case of Metastaseis, the representation is attending to the particularity of each voice without clarifying that the whole work maintains a ternary form of the same nature as a sonata form; and, in the case of the Montreal Politope, the particular features of the ruled surfaces hide the fact that the work is a closed space, like any other hall. This kind



of representations are still so much similar to the plane and to the score.

The analytical notation introduced by Lerdhal and Jackendoff en their "Generative theory of the tonal music" is nearer to what we are searching for in the music. Here, they don't pay attention to the timbre, dynamics or even notes, but they show only the tension-resolution aspect of music, that corresponds directly to the formal aspect. Their tree schemes connect each unit (notes, cells, motives, phrases, periods, sections) with superior levels in a way that the whole work is branched in more concrete parts. A similar notation in architecture would help us

Fig. 6. Formal structure representation of the Johann Sebastian Bach *O Haupt* choral made by Lerdahl and Jackendoff. The tree scheme shows the more important events over those that are not so significant and it clarifies the structure of the work

#. Bach's *O Haupt*

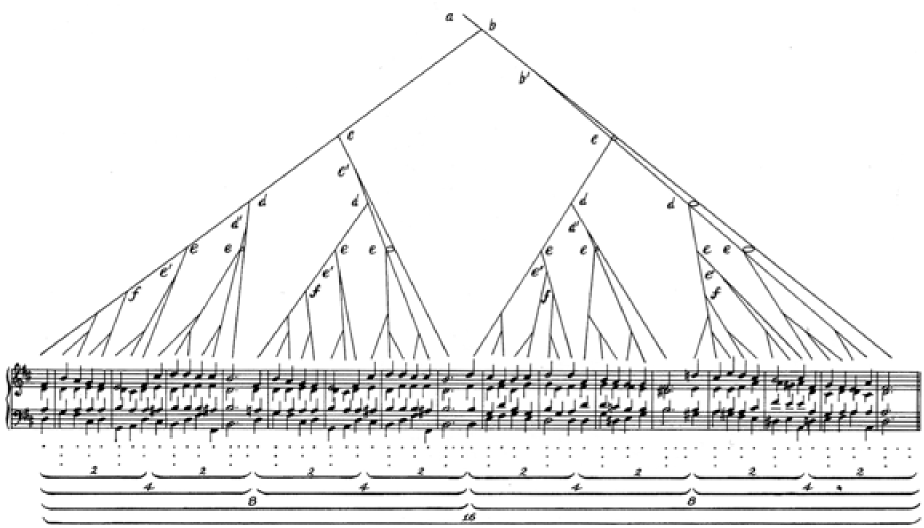
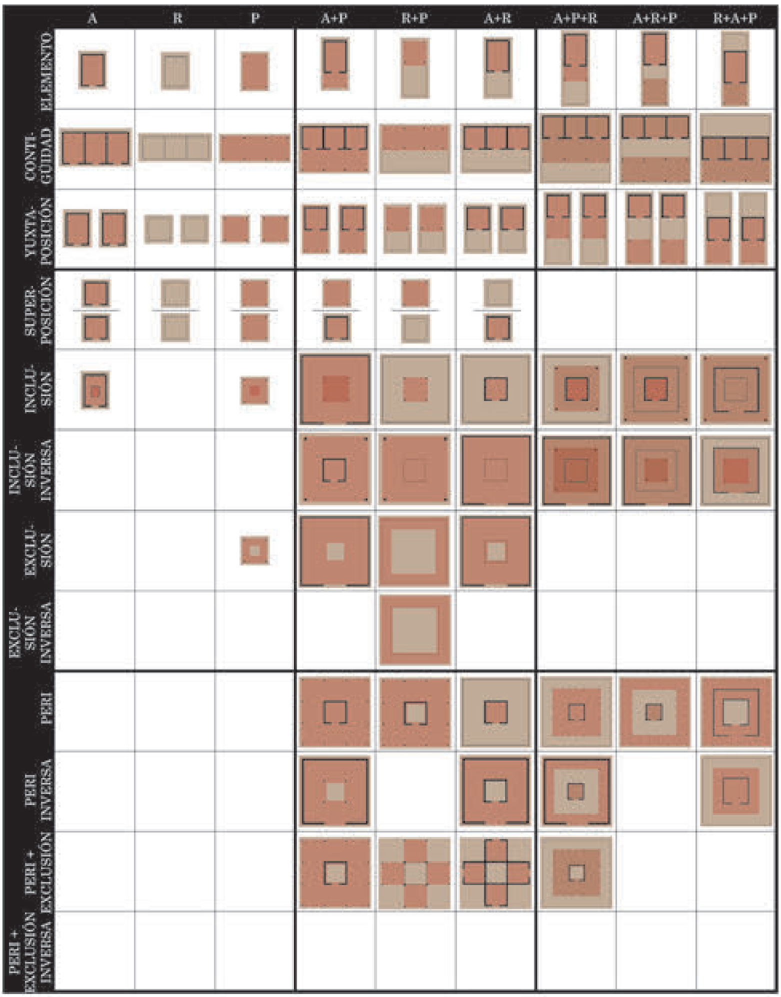


Fig. 7. Architecture Periodic Table of elements.

to understand it as a closed work, and we are not convinced at all of the benefit of this point of view.

But if we want to find a symbolic notation that expresses only form we must fall back to the scheme. In architecture this must be translated in a simple drawing containing the elements in an analytical way, that is, being independent among



them and at the same time, as a joint. For this purpose we have begun an attempt of drawing of these elements and their possible combinations in a kind of an Architecture Periodic Table. Here we can see in the horizontal axis the three basic elements from the others are combined and formed and, in the vertical axis, the formal operations that affect on these elements.

Fig. 8. Music Periodic Table with of examples.

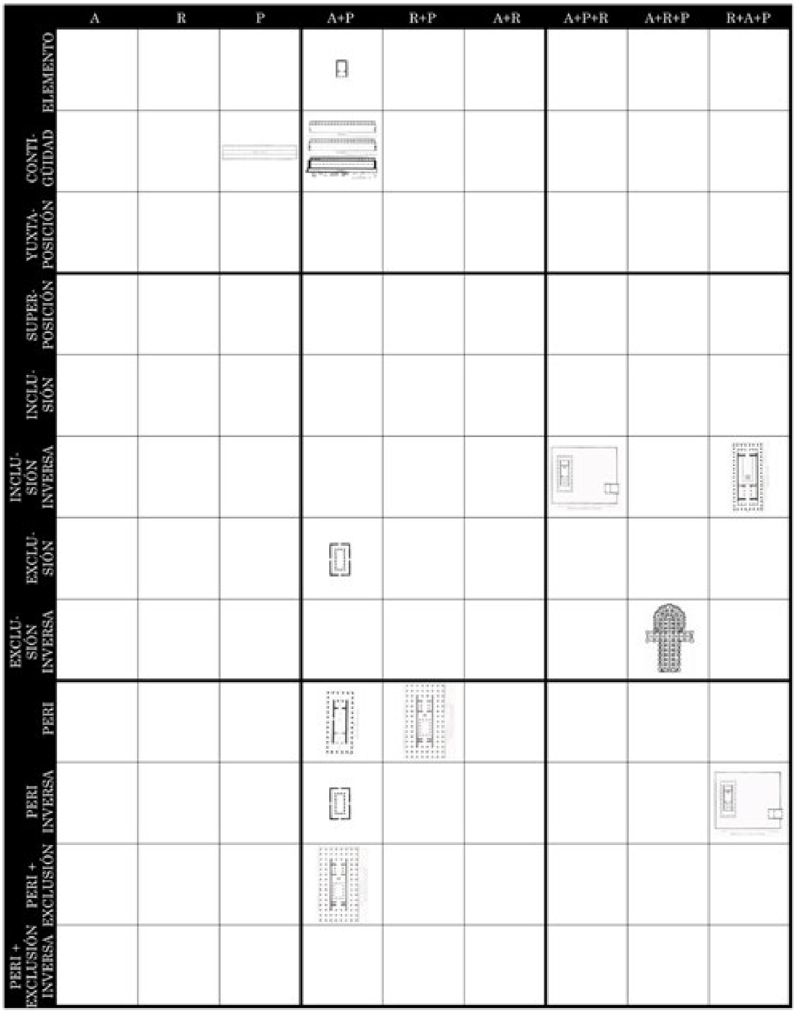
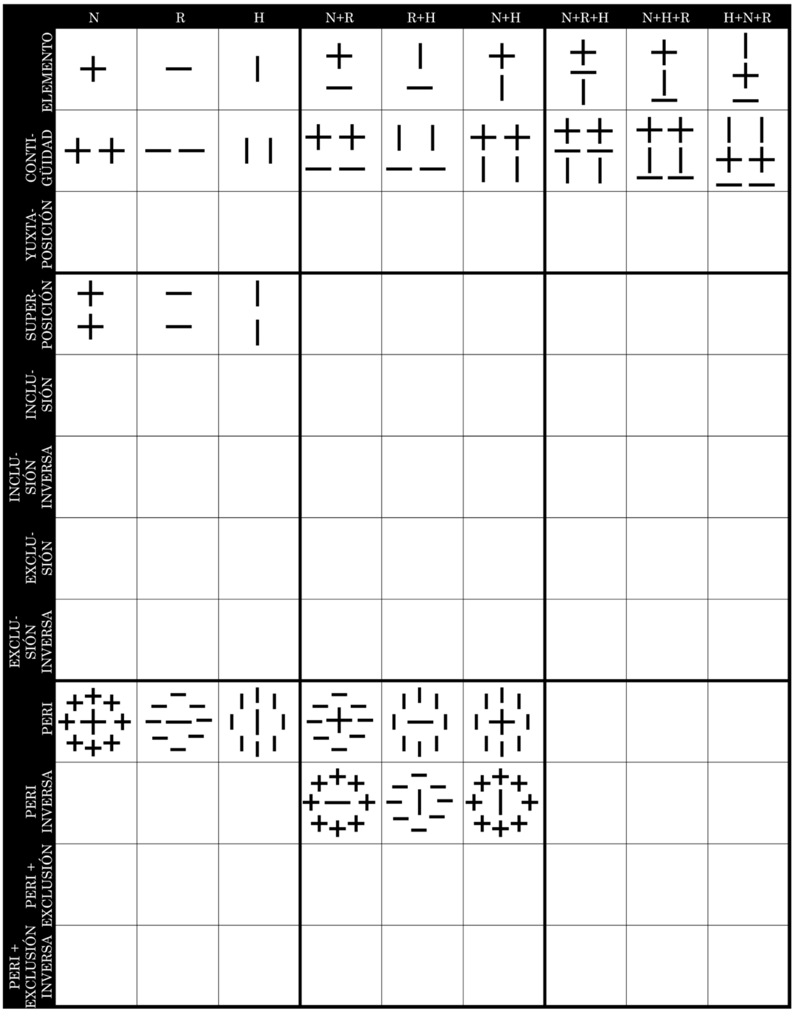


Fig. 9. Architecture Periodic Table of elements

The same way round in music when we want to explain it formally: we must resort to a scheme containing all the elements in an analytical way able to be combined. For this purpose, we have begun, again, a Music Periodic Table.

The first task when we make the Tables is to define the basic elements of each discipline. In both



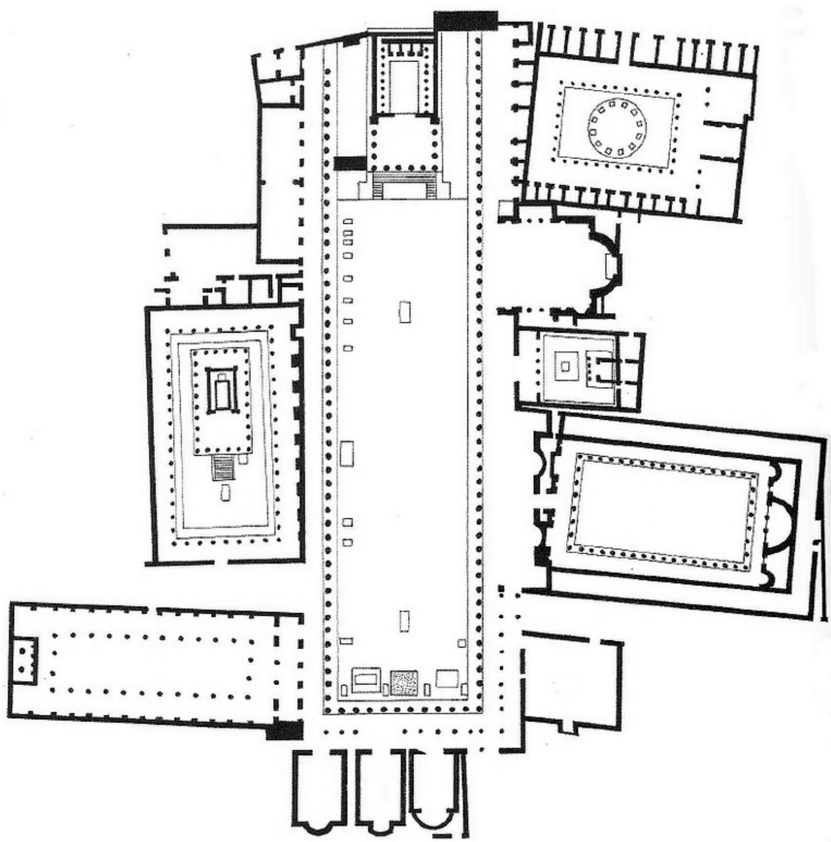
cases there are three elements. In architecture: the enclosure, combined with the roof gives rise to the hall. In music: the rhythm, combined with the sound gives rise to the note. Our aim is not to demonstrate the parallelism among the terms of one and another discipline, but the existence of a structural analogy. Both of them work in a similar way but each one

Fig. 10. Music Periodic Table of examples.

	N	R	H	N+R	R+H	N+H	N+R+H	N+H+R	H+N+R
ELEMENTO	NOTA LEITMOTIV	RITMO	HARMONÍA						
CONTI- GUIDAD	MELODÍA			MELODÍA ACOMPAÑADA POR RITMO *El pájaro de fuego*	HARMONÍA ACOMPAÑADA POR RITMO *Adoración* *de la Tierra*	MELODÍA ACOMPAÑADA POR HARMONÍA *Motete Ave Verum*			
YUXTA- POSICIÓN									
SUPER- POSICIÓN	MONODÍA *Canto gregoriano* *Salve Regina*		POLIFONÍA VERTIAL *Coral "O Haupt"* *Bach*						
INCLU- SIÓN									
INCLU- SIÓN INVERSA									
EXCLU- SIÓN									
EXCLU- SIÓN INVERSA									
PERI	RONDÓ *Yesterday*			TEMA CON VARIACIONES RÍTMICAS *Variaciones* *Mozart*		TEMA CON VARIACIONES HARMÓNICAS			
PERI INVERSA						TEMA CON VARIACIONES *Variaciones* *Goldberg*			
PERI + EXCLUSIÓN									
PERI + EXCLUSIÓN INVERSA									

Fig. 11. Pompeii Forum. The forum can be anlyzed as the logical inverse of the Greek temple (opposite page): in the forum, the wall surrounds the colonades.

from a specific place. For this reason, hall and note are the primary elements of both Tables and they are put in the first place from which the others can be developed. Architecture and music are shown to us as syntactic games, as an *ars combinatoria* in which the different elements of the Table find their place on the wide world and on the length history. These Tables are very useful in order to distinguish the nature of each of the architecture and music forms and, as a gift, to take account that there are some formal schemes that are similar in both disciplines,



proving Semper's hypothesis. As some examples we leave the following: we check that the forum (an enclosure that contains a four-sided portico in its interior) is the logical inverse of the periptero hyphaetros temple (an enclosure with a open-air hall rounded by a four-sided portico); similarly, in the music field, we can observe that a rondo (a main theme surrounded by secondary themes: ABACADA), is the logical inverse of the simple ternary form (a principal theme that surrounds the secondary theme: ABA).

Fig. 12. Most important Greek temples. The Greek temple can be analyzed as the logical inverse of the forum (opposite page): in the Greek temple the colonades surround the wall.

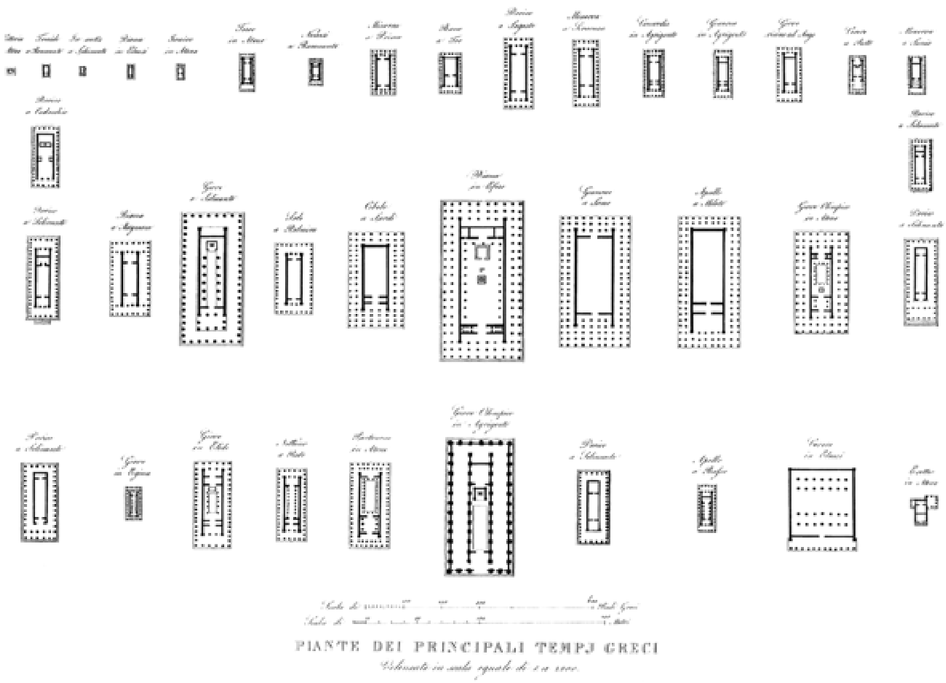


Fig. 13. Alessandro Anonelli's drawing of the San Gaudienzio's dome. The details of the frescos, the structure and the light through the openings describe the reality of the building.

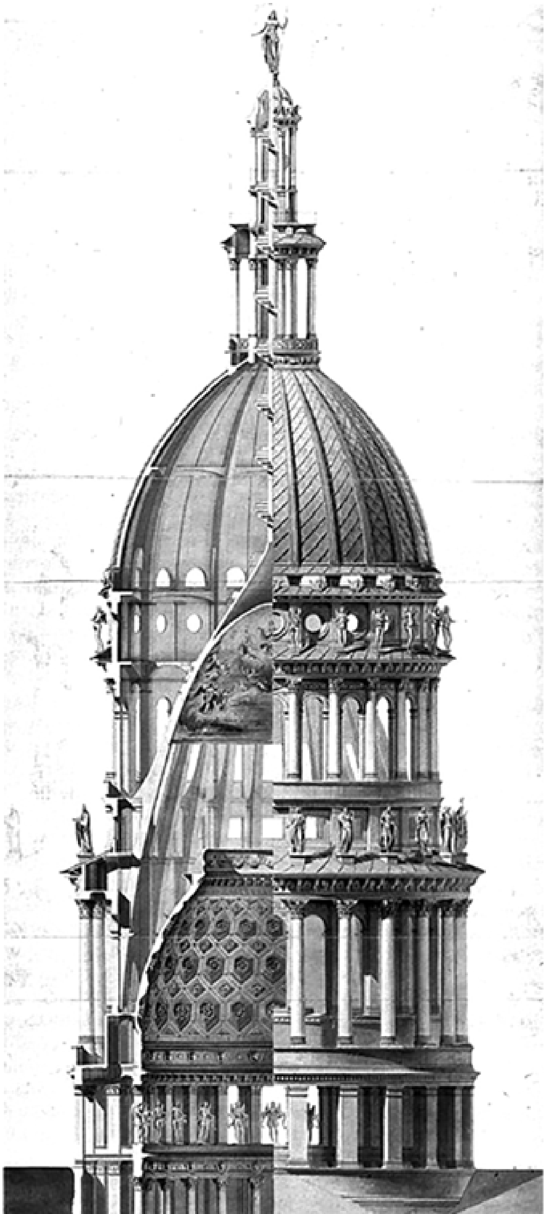
4.4. The representation of the weft or the splendour of style

Plan and score are able to express the other dimension of the carpet, the weft, the vertical axis. This axis, as Jakobson mentions, selects one specific way of representation of the formal elements in concrete realities[1]. This means that, in architecture, the element called enclosure—yet a logical creature— that goes before Aalto's Muuratsalo house is made of bricks in spite of concrete, stone or a hanged carpet. In this moment, the most important thing is how is it made, which is its appearance to our senses. In music, it happens something similar when Debussy begins his *Prelude a l'apres-midi* d'un faune with a chromatic descendent scale—that is, an abstract element—with a flute timbre filling the whole hall with a gloomy atmosphere that is distinguished all over the work.

#. Debussy's *Prelude àpres le midí d'un faune*

The plan is, again, in charge of representing the style in its splendour. It pictures the colours of the windows, the details of the work, the textures of the walls, the tilling of the floor, the shadows of the exteriors, the curtains that will cover the windows, the light illuminating the interiors, the cold steel where is going to catch the fire, the warm wood of the rail, the reflecting water in the patio, the creak of the wood under the grandfather's feet, the chirping of the door hinge… A great world of details that embodies architecture. The plane is in charge of indicating it in order to be built. The score is, as well, in charge of representing the style in all its splendour. It indicates the first silence, the

1 Roman Jakobson, *Fundamentos Del Lenguaje*, ed. by Ciencia Nueva, 1967 <https://books.google.de/books/about/Fundamentos_del_lenguaje.html?id=fokntwAACAAJ&redir_esc=y> [accessed 16 May 2018].



#. Stravinsky's *Chant du Rossignol*

violins pianissimo, the trombones sforzando with the main theme, the distance of the horn that is finishing the leitmotiv, the overwhelming sudden piano, the counterpoint between the oboe and the violoncello that flows into a crescendo, the choir voices retaking the main theme over a carpet played

by the woods, the contra subject that emerges from the double basses, the uninterrupted rattle of the Chinese box that dominates the orchestral volume, the held breathing of the white voices exhausting the last sight of the work… A great world of details that embodies the music. The score is in charge of indicating it in order to be interpreted.

Fig. 14. Two first pages of Stravinsky's *Chant du Rossignol*, orchestral work.

4.5. Ending

After having distinguished both values offered by a plane and a score our aim, finally, is to point out that architect and composer's task doesn't consist on treat favourably one instead of the other but, in the architect's case he uses initial sketches and schemes in order to puzzle out the form and, at the same time, he draws details that persuade him to a style: everything is offered to the author in a synchronic way, not synthetic, in a way that the work is formed as a totality. In a similar way Mozart described composition in a 1789 letter:

> All this fires my soul, and provided I am not disturbed, my subject enlarges itself, becomes methodised and defined, and the whole, though it be long, stands almost finished and complete in my mind, so that I can survey it like a fine picture or a beautiful statue at a glance. Nor do I hear in my imagination the parts successively, but I hear them as it were, all at once… What a delight this is I cannot tell! [1]

1 Edward Holmes, *The Life of Mozart* (Cosimo Classics, 2005) <https://books.google.de/books/about/The_Life_of_Mozart.html?id=V6dBeXZ3G-TwC&redir_esc=y> [accessed 16 May 2018]. Pg. 329.

Case study

The common complexity. About the architectural and musical composition

> "The "real" in the work of art, the surfaces and masses, the colours and materials, the sounds with their harmonic laws; all this has the character of an indication by which the artist agrees with the viewer on what he really wants. This is found in that unreal space that man manages to open through his gaze and imagination, and from which he puts himself in tension towards reality. Naturally, it cannot be separated from the real exterior, but it is linked to it, thus forming that characteristic unity which is precisely called "work of art". [1]

Trying to explain how one feels about a musical and architectural work and justifying one's point of view in this explanation is not an easy or perhaps useful task; it can help others who find themselves in the same situation to identify with it or, on the contrary, to brand one as crazy. This is exactly what comes to mind every time I return to this essay on two themes that, in my opinion, are closely linked: architectural composition and musical composition. However, I think it is important to talk about them insistently because they are not linked in a superficial way, but they share in their bases the same logic of operation: the succession and assembly of pieces to achieve an atmosphere. The way objects are organized - spatially or temporarily - is always "in relation to", that is, the objects are themselves in and through the others and therefore conclusions can be drawn and help to better understand both disciplines. The architects are constantly looking for ways to build an exquisite place that takes into account the complexity of human being and his relationship with the environment. The musicians, on their own, try to offer the man a carefully profiled piece of time in which human being identifies himself. They

1 Guardini, Romano, "Sobre la esencia de la obra de arte", in *Imagen de culto e imagen de devoción*; (Madrid, Guadarrama,1960), p. 67

both walk to the same place many times without knowing it. This can be revealing when it comes to resolving questions that concern the essence of both disciplines, always trying to find out what is authentic and peculiar to each of them.

The livable atmosphere

The idea oftenly spread is that music and architecture share aspects such as rhythm, harmony between the parts and the whole, the handling of proportions or contrasts. These ideas are not false, although they are not complete either, because they could be realized in comparison with many other disciplines without taking into account the hard core that unites them. What really sets them apart from the rest is that only music and architecture are capable of creating a habitat for humans to live in. Eugenio Trias expresses it with the following words in his *Lógica del límite*:

> In both, music and architecture, the dimension of inhabiting is in the foreground, unlike other arts (painting, sculpture, language arts). Music, like architecture, must be inhabited. This means that both have an immediate and spontaneous link with the habitat (Umwelt, environment). Music "envelops" us, as in general all the sonority-environment, in the same way as "it envelops" us in the field that determines architecture. It creates a second nature (already formed) in relation to the first, wild and uncultivated... [2]

Peter Zumthor has insisted on the term:

> And this second nature or habitat ends up forming what architects or musicians call atmosphere, the characteristic environment that each particular work offers to the individual. And we call it atmosphere because music and architecture do not have a semantic charge, they are abstract and, therefore, they constitute the boundary between man

2 Trías, Eugenio, *Lógica del límite*, (Ediciones Destino, S.A. 1991), p. 44x

> and the wild nature that surrounds him, intermediaries between the individual and culture. Both create a period of time or space in which the air becomes tense and the atmosphere becomes the fruit of it: either by tensioning the air with matter and light or by tensioning the air with sounds and silences. [1]

Peter Zumthor has insisted on the concept of atmosphere, defending that the architectural quality of a building can only come from whether it moves or not, from the atmosphere, and he exemplifies this fact with a musical work:

> In the first movement of Brahms' sonata for viola (sonata nº 2 in E flat major for viola and piano), when the viola enters, in a couple of seconds it is already there, and I don't know why. And something similar also happens in architecture. Not as powerfully as in the greatest of the arts, music, but it is also there. [2]

All other aspects that could relate to the two disciplines are submitted to this end, that of the creation of the atmosphere. For example, if we place ourselves in the process of gestation of a piece, we see that although architectural projects are handled by means of views, plans and models (all of them elements of approach to reality) and musical works are created in the score (also an element of approach to reality), both only make sense when they are executed, when they are put into practice. That is why the process of implementation is so important: the *litmus test* from which one atmosphere or another will result.

That is why I try to decipher how, in spite of their enormous differences in base material -space and time- they both manage to impress upon us

1 Zumthor, Peter. In *Atmósferas: entornos arquitectónicos, las cosas a mi alrededor*. Introducción a la charla. (Barcelona: Gustavo Gili, cop. 2006)

2 Íbid.

sensations of environments or atmospheres by means of mechanisms that can be classified as both structural and phenomenological, they are not at odds with each other. It is precisely in the brilliant articulation between the formal structures and the control of their perception in the person that the possibility lies in the fact that man finds himself in an atmosphere that satisfies his needs.

Formal functions

The structuralist thinking that Deleuze and his disciples promoted in the 1930s defended the existence of structures under the apparent chaos of things. This thought has had an enormous resonance in both architecture and music in the concepts of "type" or "formal structure" of works. In architecture, typological criticism [3] tries to discover the order between spaces, their articulation or hierarchy within the building throughout history. We speak of structure without referring only to the physical structure, but also to the logical relationship between spaces, which can be geometric or topological. In music, formal analysis also looks for the order between the formal functions, their articulations and their hierarchy within the work.

In this context, the work of Louis Kahn and that of Johann Sebastian Bach himself denote the importance of a robust structure that supports the discourse of the works. Although Kahn (1901-1975) offered 20th century architecture a distillation of historical typologies and Bach's work (1685-1750)

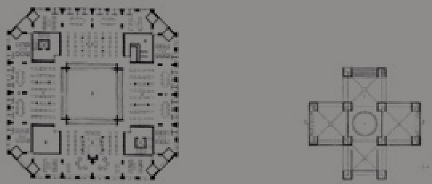
3 Term first coined by Manfredo Tafuri in *Theories and History of Architecture*, 1997 but previously analyzed in authors such as Rudolf Wittkower in *The Fundamentals of Architecture in the Age of Humanism*,1950.

culminated in the formal richness and expressive capacity of Baroque music, both based their works on the articulation and handling of the basic elements of formal structures. Kahn's projects demonstrate the ability to articulate pure forms - squares, triangles, circles - by means of logics or aggregation systems such as juxtaposition, repetition, axiality, simple and multiple symmetry, the inscription of figures within others, the articulation around a cloister or even the sum of heterogeneous buildings. These forms of articulation responded to the need to prioritize the spaces according to their functions, obeying the Kahntian distinction between "served spaces" and "server spaces". In the same way, the fugue, a jewel of Bach's legacy, consists of presenting a basic element - the subject - in its harmonic possibilities and articulating it with other secondary elements - contrasts and responses - by means of contrapuntal procedures such as direct, inverse or retrograde imitation, by augmentation, by reduction, canonical imitation, invertible counterpoint, stretto or episode. The articulations always respond to the need to prioritize the fragments of musical discourse in order to achieve the overall coherence of the work. [1] The result in both cases is a work of succession-and-assembly of primary forms in which the author's hand chooses which gesture or movement gives the optimal answer and, in this way, establishes a clear correspondence between form and function, which is expressed in the concept of "formal functions".

Fig. 15. Ways of articulating pieces to construct atmospheres in Kahn and Bach: 1: Multiple symmetry and invertible counterpoint in the Exeter library, the Trenton baths and the Crab Canon. 2: The repetition or aggregation of pieces in Richards laboratories and Prelude I of the Well-Tempered Clavier I. 3. The juxtaposition or intersection of simple figures in the convent of nuns, the Fisher house and the Fugue V of the Well-Tempered Clavier II. 4: Axiality, simple and multiple symmetry, inscription of figures within other juxtapositions in Dhaka's Assembly and the prelude and escape XX of the Well-Tempered Clavier II. Editing by the author of the article.

The atmosphere is directly linked to the perception that we have of the simple parts or "formal functions" with respect to the whole work, so it is essential to analyse how human perceives these

1 For a masterly analysis of the Art of Bach's escape see Donald Tovey's studies.



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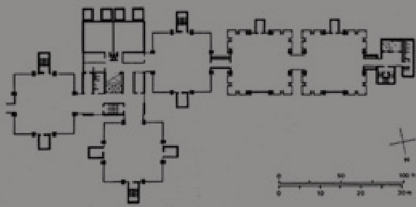

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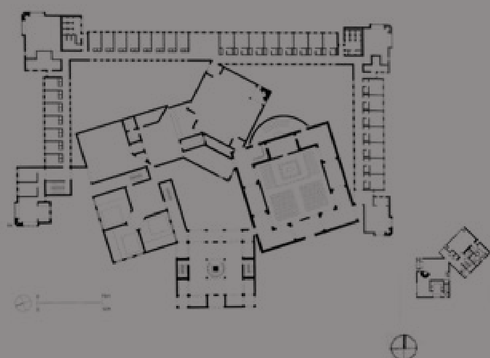

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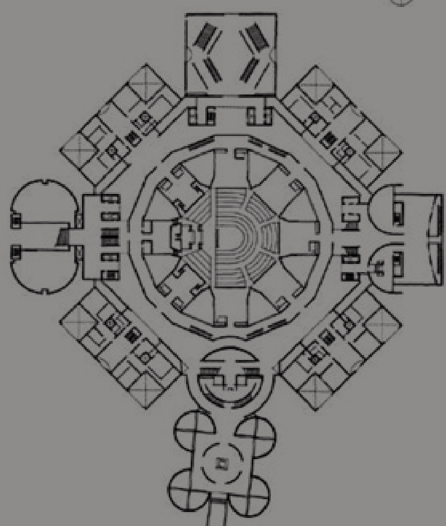
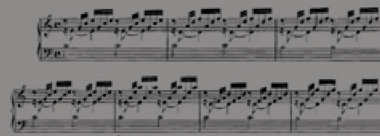
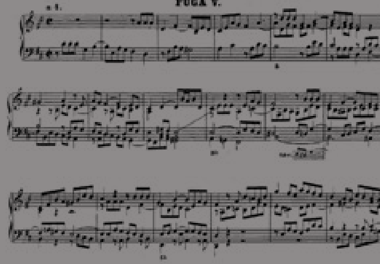


4

PRAELUDIUM I.



FUGA V.



PRAELUDIUM XX.

FUGA XX.

simple forms. The psychologists of Gestalt were the first to stress that we experience the environment as made up of objects and "totalities" by first applying it to the field of language and then to the other disciplines. As a result of his discoveries, the theory of perception was echoed in other fields of knowledge.

Christian Norberg-Schulz wrote a theory of architecture in 1967 in which he defended the coherence of the parts within the whole work as a starting point for its understanding:

> The meaning of an architectural element also consists in its relationships with other elements (and with its own parts, that is, with its internal organization), and the architectural form is a complex of such relationships. [1]

Likewise, Arnold Schoenberg, who in his mature work erased the classical relations between the heights of sounds in order to build a new musical language, kept alive, in 1975, the awareness that the work needs an intelligible discourse based on the relations between its parts:

> The fundamental requirements for the creation of an intelligible form are logic and coherence.The presentation, development and interconnection of ideas must be based on kinship or relationship. Ideas should be differentiated according to their importance and function. [2]

It might seem that structuralist thinking is stuck in concepts that have already been dealt with historically and that offer little novelty, but the strength of a robust structure makes the work fly over the tastes and fashions of a given period. It links it to history and at the same time makes it timeless.

1 Norberg-Schulz, Christian, *Intenciones en arquitectura*, (Gustavo Gili, Barcelona, 1979) p. 100.

2 Schönberg, Arnold, *Fundamentos de la composición musical*, (Real Musical, Madrid, 1979)

The modes of articulation that Bach investigated are the indications for the formation of the structural forms that the musical classicism (Mozart, Haydn, Weber, etc.) institutionalized and that today we know as sonata form, minuet form, round form, etc. These forms do not lose their validity because they have their roots in the world of logical structures and an attentive look at the musical panorama recognizes them without problems.

Structural phenomena

However, to value the work of Kahn or Bach solely for their structural ability is insufficient and does not allow us to understand its entirety. Therefore, other authors emphasize the role of the senses (sight, touch, hearing, smell and taste) in understanding the world rather than the mental structure. The atmosphere is, then, linked to the sensory perception that the work offers us. Gaston Bachelard defends that the only thing that remains in us of a place is the feeling we had of it:

> What good would it do to give the floor plan of the room that was really my room, to describe the small room at the back of a barn, to say that from the window, through the tearing of the roofs, you could see the hill? Alone, in my memories of another century, I can open the deep cupboard that still retains, for myself alone, the unique aroma, the smell of the grapes that dry on the wreath. [3]

Igor Stravinsky describes the musical phenomenon as an art of time, as a chrononomy and therefore defends the work with time as the basis of the sensations produced by music:

3 Bachelard, Gaston. *La poética del espacio*, (Fondo de cultura económica de España, 2000), p. 44.

> Who among us, when listening to jazz music, has not experienced a fun feeling close to dizziness, when he sees that a dancer or a soloist musician who stubbornly sets irregular accents cannot free his ear from the regular metric pulsation maintained by percussion? [1]

#. Stravinsky's *The Rite of Spring. Dance of the Earth.*

Stravinsky's entire work is an ode to polyrhythm, a demonstration of simultaneous rhythm control and its impact on the listener. When we heard the beginning of the *Dance of the Earth*, of the *Rite of the Spring* of 1913, we saw that power in us.

The phenomenological analysis [2] has placed the emphasis on all the sensory aspects of architecture by organizing them in layers: the texture of the materials, the color, the smell, the sound, the routes through the building and the geometry of the space. The music, which works on sound, has also described the elements that we perceive by the senses in the concepts of cadence, tonality, tempo, metric, rhythm, dynamics, density, timbre, register, texture and motif, among others, and has called them "structural phenomena".

The term "structural phenomena" perfectly includes the universe of perception within that of structure. And "the formal functions" take the form of textures, rhythms, colours, geometries, cadences, etc. Formal functions need structural phenomena to become concrete and there are no forms if they are not presented as phenomena. This awareness of complementarity gives the works the coherence and accessibility that are indispensable for the

1 Stravinsky, Ígor. *Poética musical*, (Taurus ediciones, Madrid 1981),p. 33.

2 I am referring to a broad phenomenological analysis, not particularly to the philosophical concept of phenomenology that Edmund Husserl establishes, although it has its roots there. For a recent overview of phenomenology in architecture see the essays by Juahanni Pallasmaa, in particular *The Eyes of the Skin*.

individual to live in. And only the art of space and the art of time can offer this gift to humanity.

Complexity enriches

So far we have understood that musical and architectural works create atmospheres thanks to all the real objects that make up "structural phenomena" and "formal functions". However, an attentive look at history reveals that there are authors who work on these real objects in a clear way and that the observer perceives them quickly and transparently, an atmosphere of serenity and order is breathed in. This is the case of the works of the architectural enlightenment period - the ordered buildings of Donald's school - or those of the classical musical period - brilliant cases are Haydn or Mozart. However, there are others who intermingle the limits between functions and phenomena and manage to create more ambiguous environments between their parts, the relationships are confused and overlapping, the complexity of the work increases and, at the same time, the richness of relationships increases. These atmospheres are characteristic of the aesthetics of musical romanticism and impressionism, the avant-gardes of Xenakis, Ligheti and Stockhaussen or the indeterminism of John Cage, where the sometimes contradictory complexities of the relationship between the parts of the work enrich the result. But they are also characteristic of the landscape architectures of Alvar Aalto or William Turnbull, the fragmentary strategies of Rem Koolhaas or the forms of chaos of Daniel Libeskind, where the sometimes contradictory - again contradictory - complexities of a project's environment enrich the relationships between the pieces. [1] The attractive power of an atmosphere can come as much from its serenity, order and inner balance as from its richness, contrast and complexity between its parts.[2]

Debussy's case in the *Prelude Aprés le Midi d'un Faune* perfectly illustrates the latter type of atmosphere. A languid descending scale of the flute breaks the silence of the room and for a few moments it remains dancing through the air until a trumpet accompanied by the orchestra responds to the dialogue. The flute plays the main theme a second time and, instead of finishing it alone, it lengthens the last note until it merges with the sound of the oboe that collects the same note and makes it the beginning of what will be the third motif of the work. This small fragment embodies the atmosphere of the whole work. And we can see it in the main motif, characterized by the fluidity of its stroke in the air, its rhythmic instability and its ability to adapt to any harmonic base. But we can also see it in the way in which the other secondary themes are related to the main one: the boundaries between them are never defined until they are fused; there are always second voices that mask the main voice by erasing all traces of a clear melody; neither can we discover a constant or repetitive rhythm, but rather a set of tempos that are deformed to make way for the next one.

1 See Montaner, Josep Maria, *Sistemas arquitectónicos contemporáneos*, (Gustavo Gili, Barcelona, 2009)

2 See Venturi, Robert, *Complejidad y Contradicción en Arquitectura*, (Gustavo Gili, Barcelona, 1978)

Fig. 16. The spaces and their functions merge into the Aalto's Villla Mairea. The observer can see the entrance, the living room on the left, the staircase and the garden in the background at a glance. Photography: Rauno Träskelin

#. Debussy's Prelude Aprés le Midi d'un Faune. Minute 1' 22"

Today's society is very conducive to valuing both architectural and musical works only on their surface, although much more precious pearls could be extracted from them. The formal analysis described above, is a way of approaching works that does not dry them, does not kill them, but rather decomposes them to discover their parts and recomposes them to admire their totality. However, the phenomenological gaze offers the range of subjective perception, the sensations that the works produce for each one of us. Both are necessary, but they are still insufficient if we are to understand the atmosphere. It is necessary to live them, to face reality and to be imbued with them in order to know the very Being of each work, of its essence, of all the depth of its message. Walking through the city, walking through the buildings, sleeping in the room, entering the hall, listening to the water, getting lost in the endless bells of an orchestra, getting caught in the hammer of the piano, feeling the scrubbing of the double bass string, waiting for the silence between two movements or immersing yourself in the disjointed rhythms of a piece by Jacques Loussier. The real experience of the works goes beyond any explanation and, therefore, capturing the atmosphere means living them.

> But he achieves this [the viewer] insofar as he makes an effort - and many people are unaware of this, that it is necessary to make an effort, to concentrate, to penetrate, to learn and to exercise, because they see in the work of art only one thing for hours of leisure, a "diversion", whereas, on the contrary, it belongs to the high order of things, which makes demands in order to be able to communicate. The Parthenon, in its kind, is as difficult to understand and requires as much effort as Plato's philosophy. [1]

1 Guardini, Romano, "Sobre la esencia de la obra de arte", en *Imagen de culto e imagen de devoción; Sobre la esencia de la obra de arte*, (Madrid, Guadarrama, 1960), p. 68.

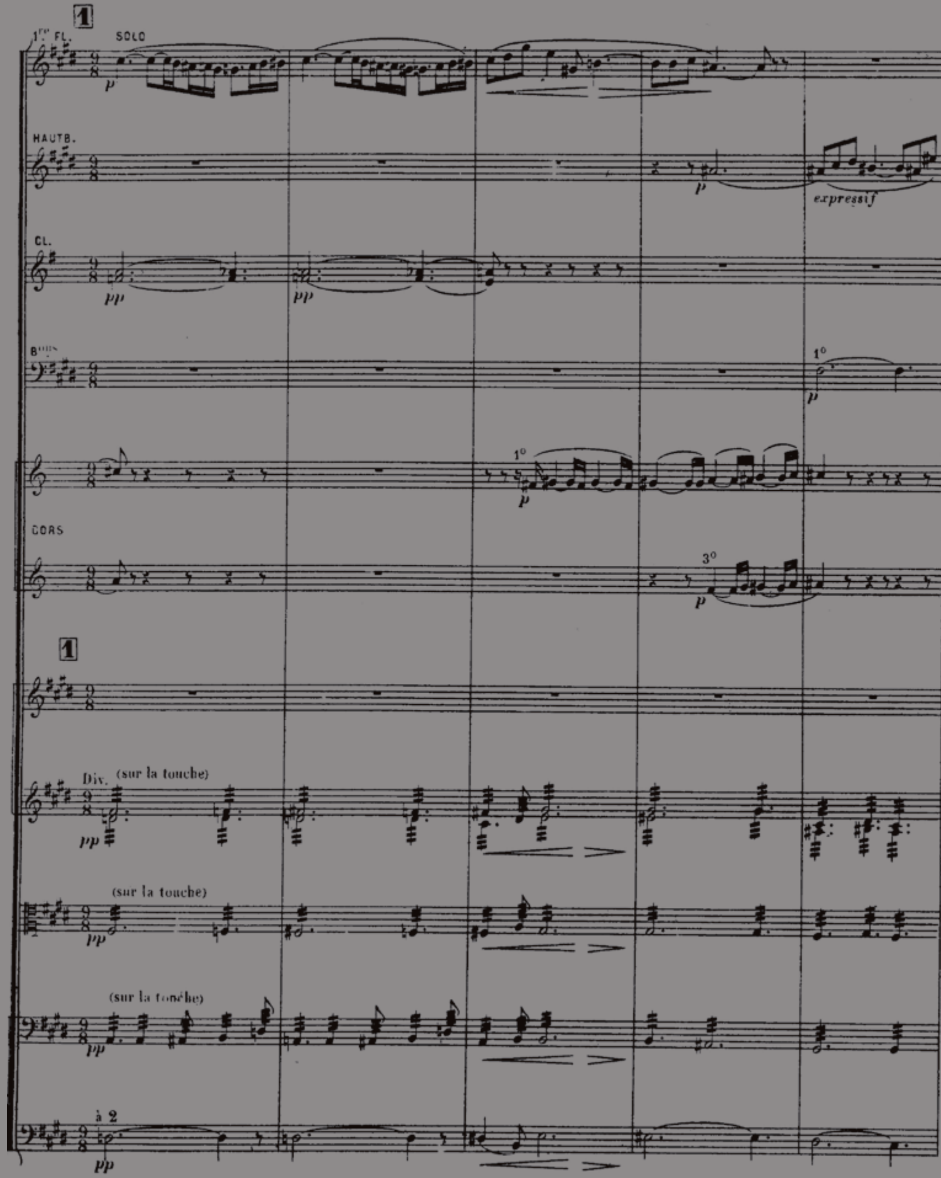


Fig. 17. Prelude aprés le midi d'un faune, where the motif of the flute and the oboe melt together. Web edition: www.ismlp.org

Chapter 5

Tools for analysis

Urban soundscapes
in Ciutat Vella, Barcelona

Chapter 5

Tools for analysis

Urban soundscapes
in Ciutat Vella, Barcelona

The present chapter is derived from the work entitled *Urban Soundscapes in Ciutat Vella, Barcelona: The Relationship between the Configuration of Public Space and Street Music*. This work was presented by Álvaro Clua, Josep Llorca and Sophia Psarra as an article in *Urban Design International*.

5.1. Introduction

After a long history of local governments treating "street music performance" and "busking" as an annoying or even dangerous practise, legislation has changed in the recent decades to express a more permissive view. Due to the fact that those activities play an important role in the public realm and "contribute to the "vitality of everyday life of the city" [1], a restriction of performance hours has been recently imposed. The purpose was to preserve the identity of busking as part of the public heritage [2]. Furthermore, recent studies conclude that in some cities contemporary busking laws are not only tolerated by buskers, but widely embraced by them [3]. Of course, not everyone is so enthusiastic about the contribution that buskers make to the streetscape. Some people still feel annoyed by the presence of these street actors [4], while others complain about the quality of the played music [5].

In the case of central Barcelona, most of the official buskers feel it is difficult to practise particularly

Fig. 1. Opposite page: concerts and buskers at the four studied environments: Plaça de Sant Felip Neri, the Corner between Carrer del Bisbe and Carrer Santa Llúcia, Plaça Sant Iu and Plaça del Rei.

1 Simpson, P. (2011) 'So, as you can see . . .': Some reflections on the utility video methodologies in the study of embodied practices'. *Area.* Advance online publication. doi:10.1111/j.1475-4762.2011.00998.x

2 Ajuntament de Barcelona, *Normativa Músics de Carrer. Proposta 2014* (Barcelona, 2014) <http://conventagusti.com/wp-content/uploads/Normativa-per-a-tocar-al-carrer_2014.pdf>.

3 Luke McNamara and Julia Quilter, 'Street Music and the Law in Australia: Busker Perspectives on the Impact of Local Council Rules and Regulations', *Journal of Musicological Research*, 35.2 (2016), 113–27 <https://doi.org/10.1080/01411896.2016.1161477>.

4 Nicole Hasham, 'Buskers Produce Plenty of Sound - and Some Fury', *The Sydney Morning Herald* (Sydney, 2012) <http://www.smh.com.au/entertainment/music/buskers-produce-plenty-of-sound--and-some-fury-20121229-2c07l.html> [accessed 27 September 2017].

5 Michael Koziol, 'Tuneless, Boring, Sometimes Scary: Too Many Buskers Lack the Wow Factor', *The Sydney Morning Herald* (Sydney, 2013) <http://www.smh.com.au/comment/tuneless-boring-sometimes-scary-too-many-buskers-lack-the-wow-factor-20130818-2s4wn.html> [accessed 27 September 2017]

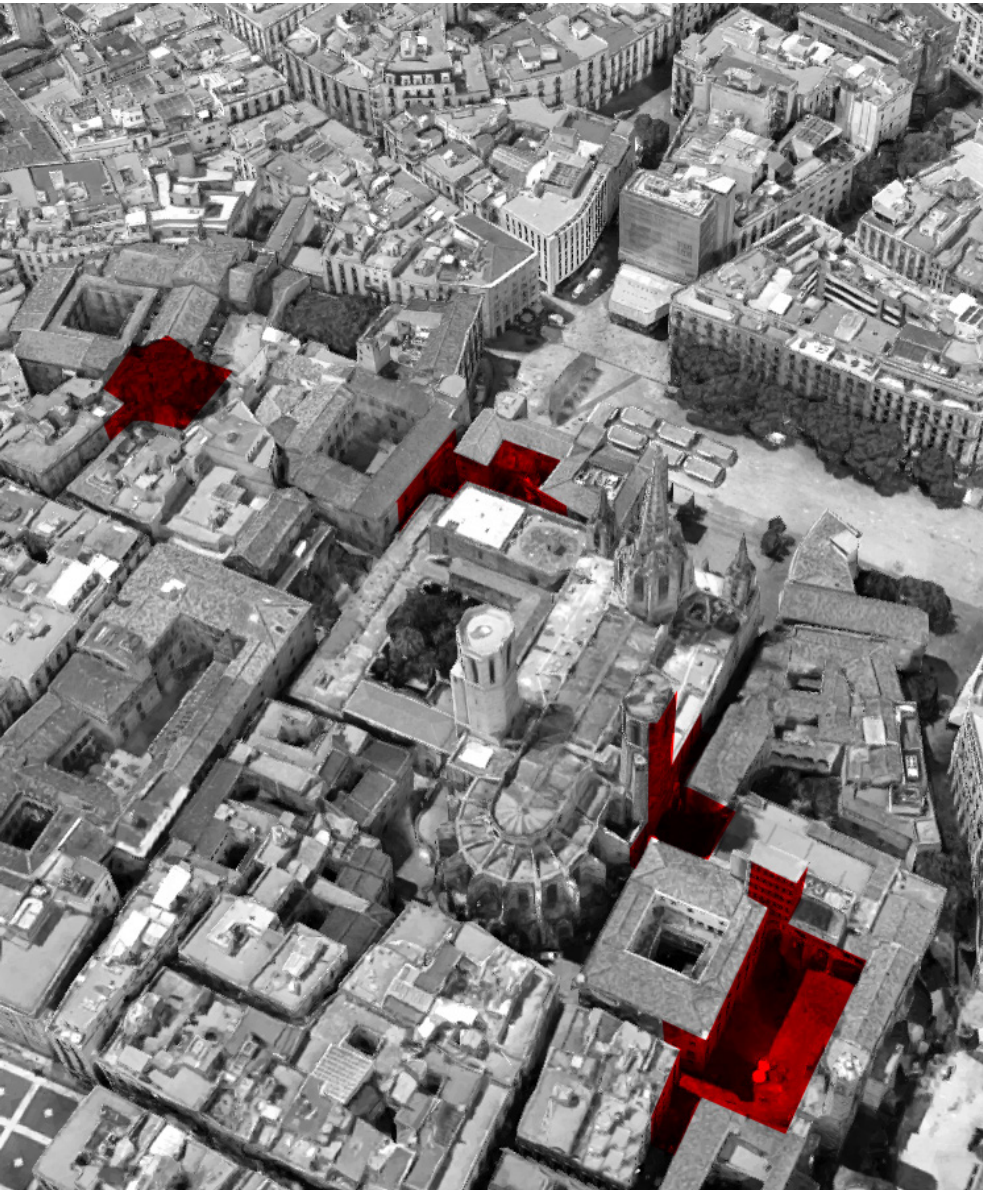
when they do not follow the council’s laws [6]. However, the sequencing of sounds and plays, of musicians and magicians, of painters and artists has definitively shaped the way citizens and tourists experience the central areas of the city. Street performers and, in particular, street musicians, far from being an undesirable interference, are really adding vitality to the life of public spaces, to the interactions between people and the built environment, to the centre’s retail activity and, in short, to its urbanity [7].

All these considerations might lead one to raise a range of research questions: Are those places which happened to be officially designated by the municipality of Barcelona, acoustically suitable and profitable for this type of musical performance? If so, which specific areas within those environments are more suitable for each kind of musical activity? And, more generally, what kind of relation exists between spatial configuration and the acoustic qualities of the open spaces? Is there a methodology that could help us understand and provide a greater and better functioning number of spaces for street music interpretation? This article aims to shed light on those questions through a comparative analysis of four of the main central performance environments located within the inner core of Ciutat Vella of Barcelona: Plaça Sant Felip Neri; the

6 Nando Cruz, ‘Los Músicos Callejeros de Barcelona Denuncian El Acoso Que Sufren Por El Ayuntamiento’, *El Periódico* (Barcelona, 2016) <https://www.elperiodico.com/es/sociedad/20160815/musicos-callejeros-denuncian-el-acoso-al-que-les-somete-el-ayuntamiento-de-barcelona-5325622> [accessed 27 September 2017].

7 Jan Gehl, *Life between Buildings: Using Public Space* (New York: Van Nostrand Reinhold, 1987); Jan Gehl, Cities for People (Washington, DC: Island Press, 2010).

corner between Carrer del Bisbe and Carrer Santa Llúcia; Plaça Sant Iu and Plaça del Rei.



5.2. Background research on configurational analysis and urban acoustics.

There are two strands of existing research informing this study: first, research using space syntax theory and method in urban settings and second, studies on urban acoustics.

The first group of studies explores the potential of space syntax graph-based theories and methods introduced by the work of Bill Hillier, Julienne Hanson and their colleagues at UCL in 1970s, to describe the spatial characteristics of buildings and cities by producing accessibility maps and measuring topological, metric and angular relationship between different elements of a given network. This approach has become a contrasted and widely used platform to explore interactions between the built environment and other fields of knowledge. Some researches has elucidated, for instance, strong links between social phenomena and the built environment: the causes of urban social segregation and ghettoes, the crystallization of pockets of poverty or crime in cities have been already analysed in terms of spatial configuration [1]. In the same line it would be worth pointing out

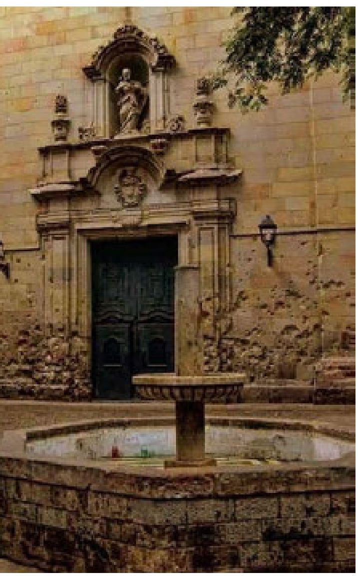
1 Bill Hillier, 'Against Enclosure', in *Rehumanizing Housing*, ed. by Necdet Teymur, Thomas A. Markus, and Tom Woolley (Elsevier Ltd., 1988), pp. 63–68; Laura Vaughan, 'The Relationship between Physical Segregation and Social Marginalisation in the Urban Environment', *World Architecture*, 185 (2005), 88–96; Linda Nubani and Jean Wineman, 'The Role of Space Syntax in Identifying the Relationship Between Space and Crime', *Proceedings of the 5th Space Syntax Symposium*, 2005 <http://spacesyntax.tudelft.nl/media/Long papers I/lindanubani.pdf> [accessed 28 September 2017]; Laura Vaughan, 'The Spatial Syntax of Urban Segregation', *Progress in Planning*, 67.3 (2007), 205–94 <https://doi.org/10.1016/j.progress.2007.03.001>; Lars Marcus, 'Social Housing and Segregation in Sweden: From Residential Segregation to Social Integration in Public Space', Progress in Planning, 67.3 (2007), 251–63; B Hillier and O Sahbaz, 'An Evidence Based Approach to Crime and Urban Design', in *Designing Sustainable Cities: Decision-Making Tools and Resources for Design*., ed. by Rachel Cooper, Graeme Evans, and Christopher Boyko, Wiley Blac (Hoboken:

Fig. 2. Opposite page: aerial view of the four studied environments. From left to right: Plaça de Sant Felip Neri, Carrer de Santa Llúcia, Plaça de Sant Iu, Plaça del Rei.

space syntax's inherent connection with culture, art, phenomenology and narrative [1], with tourism and sightseeing [2], or its great potential for a science-based assessment of the design process [3]. There has been also steps towards the understanding of the resonances of the spatial configuration in health and wellbeing [4] or in the quantitative and evidence-based understanding of lighting and perception in architecture [5].

For the aim of this chapter, two key specific contributions should be here listed: the theory of natural movement and the idea of visibility networks and affordances. The first one recalls to the seminal book *The Social Logic of Space* [6], in which the authors explained that different types of societies adopt fundamentally different spatial forms and, conversely, the build environment might influence social behaviour. Some years later,

Wiley Blackwell, 2009), pp. 163–86 <http://discovery.ucl.ac.uk/18540/> [accessed 12 March 2018].



1 David Seamon, 'A Lived Hermetic of People and Place: Phenomenology and Space Syntax', in *International Space Syntax Symposium* (6th: 2007: Istanbul, Turkey), 2007, p. iii-1-iii-16 <http://hdl.handle.net/2097/1689>.

2 Yuan Li and others, 'Understanding Tourist Space at a Historic Site through Space Syntax Analysis: The Case of Gulangyu, China', *Tourism Management*, 52 (2016), 30–43 <https://doi.org/10.1016/j.tourman.2015.06.008>.

3 Kayvan Karimi, 'A Configurational Approach to Analytical Urban Design: "Space Syntax" Methodology', *URBAN DESIGN International*, 17.4 (2012), 297–318 <https://doi.org/10.1057/udi.2012.19>.

4 Laura Vaughan and Rosica Pachilova, 'An Interdisciplinary Perspective on Health and Wellbeing in the Built Environment Report on the Bartlett Research Exchange on Health and Wellbeing in the Built Environment', *Bartlett Research Exchange on Health and Wellbeing in the Built Environment Summary Report*, 2017 <http://discovery.ucl.ac.uk/1554732/1/BREReport2017_PRINT.pdf> [accessed 28 September 2017].

5 Gianna Stavroulaki and John Peponis, 'Seen in a Different Light: Icons in Byzantine Museums and Churches', in *5th International Space Syntax Symposium*, 2005, pp. 251–63 <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Seen+in+a+different+light.+Icons+in+Byzantine+museums+and+churches#0>

6 Hillier & Hanson 1984

the article "Natural movement: or, configuration and attraction in urban pedestrian movement" [7] detailed how the spatial layout is more the "primary generator" of the patterns of movement rather than the presence of attractors. The so-called concept of "natural movement" refers to the "proportion of urban pedestrian movement determined by the grid configuration itself" [8]. According to the authors, most of the urban areas show how "retail land uses are then located to take advantage of the opportunities offered by the passing trade and may well act as multipliers on the basic pattern of 'natural movement' generated by the grid configuration" [9]. As a conclusion, cities could be regarded as "movement economies" [10] or, to put it in other words, as the result of the multiplying effects of movement patterns shaped by a particular urban grid. The present chapter is based on this particular interpretation of movement in cities, limiting its focus to a more abstract view of the potential of the urban space and leaving for further researches the influence of attractors and phenomenology in the analysis.

The second key contribution for this study is the research developed around the configurational understanding of visibility networks described in the paper "Making isovists syntactic: isovist integration analysis" [11] and latest publications

Fig. 3. Opposite page: Plaça de Sant Felip Neri. Barcelona.

Fig. 4. Plaça del Rei.

7 B Hillier and others, 'Natural Movement: Or, Configuration and Attraction in Urban Pedestrian Movement', *Environment and Planning B: Planning and Design*, 20.1 (1993), 29–66 <https://doi.org/10.1068/b200029>.

8 Hillier et al 1993: 32

9 Íbid.: 29

10 Bill Hillier and Alan Penn, 'Cities as Movement Economies', *Urban Design International*, 1 (1996), 49–60.

11 Alasdair Turner and Alan Penn, 'Making Isovists Syntactic: Isovist Integration Analysis', in *2nd International Symposium on Space Syntax 1999*, 1999, pp. 1–9.

such as “From isovists to visibility graphs” [1] . In those studies, the authors describe how a graph-based analysis of the viewsheds can illustrate the accessibility and visibility potential of a given space and their relationship with spatial perception attributes such as way-finding, focus of interests, patterns of flows or space use. A good number of researches have been using this approach to argue the detailed interaction between the spatial configuration and the displays in museum and galleries [2] or the performance of movement in workspaces [3] . However, the application of this methodology to the analysis of open spaces has received less consideration relative to the extensive body of visual-graph studies [4] and none of them has stablished the basis of the interaction with urban acoustics as its main focus of interest.

1 A. Turner and others, ‘From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space’, *Environment and Planning B: Planning and Design*, 28.1 (2001), 103–21 <https://doi.org/10.1068/b2684>.

2 Kali Tzortzi, ‘An Approach of the Microstructure of the Gallery Space. The Case of the Sainsbury Wing’, in *4th International Space Syntax Symposium*, ed. by Julienne Hanson (London: University College London, 2003); Kali Tzortzi, ‘Kroller-Muller vs Louisiana: Alternative Explorations of Museum Experience’, in *5th International Space Syntax Symposium, ed. by Akkelies Van Nes* (Delft: Technical University of Delft, 2005); John Peponis, Ruth Conroy-Dalton and Jean Wineman, ‘Measuring the Effects of Layout upon Visitors: Spatial Behaviors in Open Plan Exhibition Settings’, *Environment and Planning B: Planning and Design*, 31 (2004)

3 Alan Penn, Jake Desyllas and Laura Vaughan, ‘The Space of Innovation: Interaction and Communication in the Work Environment’, Environment and Planning B Planning and Design, 26.2 (1999), 193–218 <https://doi.org/10.1068/b260193>; Kerstin Sailer and Ian McCulloh, ‘Social Networks and Spatial Configuration. How Office Layouts Drive Social Interaction’, Social Networks, 34.1 (2012), 47–58 <https://doi.org/10.1016/j.socnet.2011.05.005>.

4 Maria Beatriz De Arruda Campos and Theresa Golka, ‘Public Spaces Revisted: A Study of the Relationship between Patterns of Stationary Activity and Visual Fields’, in *Proceedings of the 5th Space Syntax Symposium, ed. by Akkelies Van Nes* (Delft: Technical University of Delft, 2005), pp. 545–53; Y Bada and A Farhi, ‘Experiencing Urban Spaces: Isovist Properties and Spatial Use of Plazas’, *Courrier Du Savoir*, 9 (2009), 101–12; Maria Guerreiro and others, ‘Seeing, Standing and Sitting: The Architecture of Co-Presence in Small Urban Spaces Presence in Small Urban Spaces’, in *CITTA 8th Annual Conference on Planning Research* (Porto, 2015).

Urban acoustics has been approached from multiple perspectives. Some studies have been carried out on “urban soundscapes”, i.e., the user’s perception of outdoor sound where the role of the receiver and his or her personal perception is the main concern [5]. Other studies analyse the propagation of sound in semi-open environments such as streets and squares[6]. Different kind of studies go deep on methods of modelling sound fields that ride between the totally enclosed space and the open field, such as squares or urban environments [7] . In recent investigations, the role of sound in ancient civilisations [8] has been studied, cultures where music was considered as a social practice rather than an art [9].

Urban acoustic analysis normally concerns noise propagation in canyons, noise maps in cities or

5 Jian Kang and Brigitte Schulte-Fortkamp, *Soundscape and the Built Environment* (Boca Raton: CRC Press. Taylor & Francis Group, 2016).

6 Miguel Molerón and others, ‘Sound Propagation in Periodic Urban Areas’, *Journal of Applied Physics*, 111.11 (2012), 114906 <https://doi.org/10.1063/1.4725487>; J. Picaut, J. Hardy and L. Simon, ‘Sound Propagation in Urban Areas: A Periodic Disposition of Buildings’, *Physical Review E*, 60.4 (1999), 4851–59 <https://doi.org/10.1103/PhysRevE.60.4851>; Jian Kang, ‘Sound Propagation in Street Canyons: Comparison between Diffusely and Geometrically Reflecting Boundaries’, Http://Dx.Doi.Org/10.1121/1.428580, 2000 <https://doi.org/10.1121/1.428580>.

7 Wei Yang and Jian Kang, ‘Soundscape and Sound Preferences in Urban Squares: A Case Study in Sheffield’, *Journal of Urban Design*, 10.1 (2005), 61–80 <https://doi.org/10.1080/13574800500062395>; Mostafa Refat Ismail, ‘The Effect of Building Density and Size on the Propagation of Sound through the Urban Fabric’, in *Proceeding of the Institute of Acoustics (IOA)*, 2010.

8 Jeffrey Veitch, ‘Ear & Stone: Acoustics, Architecture and Art in Ostia, London Roman Art Seminar – Ancient Noise’, 2017 <https://jeffdveitch.me/2017/04/25/ear-stone-acoustics-architecture-and-art-in-ostia-london-roman-art-seminar/> [accessed 10 April 2018].

9 Alexandre Vincent, *Jouer Pour La Cité : Une Histoire Sociale et Politique Des Musiciens Professionnels de l’Occident Romain*, 2011 <http://www.publications.efrome.it/opencms/opencms/jouer_pour_la_citè_:_une_histoire_sociale_et_politique_des_musiciens_professionnels_de_l’occident_romain_231581e3-5607-11e5-b8eb-000c291eeace.html> [accessed 10 April 2018].

Fig. 5. Plaça de Sant Iu. Barcelona.

big areas, or traffic noise attenuation along the street network. Hence, it is easy to see that most of the acoustic investigations done in open air environments is focused on a rough description of sound behaviour rather than a detailed depiction of its propagation. On the contrary, indoor acoustic analysis has developed techniques and softwares with a high level of detail. Despite the multiplicity of studies on urban acoustics and the introduction of new noise policies in the EU [1] , it has been shown in some researches that some techniques and software could provide a general, macro-scale picture of urban areas. However, the study of the micro scale, such as streets or squares, may be more appropriate by using detailed acoustic simulation techniques, such as room acoustic measurement softwares [2] .

Finally, it should be noted the work developed on the relationship between sound and space syntax theories. Some themes have been mentioned exploring the built environment in conjunction with other fields of knowledge. In this context, studies such as Laurence's [3] show how city studies in the Roman era are shifting the focus from static architecture to activities and movement within urban spaces. This concern for mobile activities in the city, rather than for static constructions in it, expands not only into ancient civilizations, but increasingly numerous studies are investigating the subject in

1 European Union, 'Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 Relating to the Assessment and Management of Environmental Noise.', *EUR-Lex*, 2002 <http://eur-lex.europa.eu/legal-content/GA/TXT/?qid=1399875039336&uri=CELEX%3A32002L0049> [accessed 9 November 2017].

2 Kang, 'Sound Propagation in Street Canyons: Comparison between Diffusely and Geometrically Reflecting Boundaries'.

3 Ray Laurence and David Newsome, Rome, Ostia, and Pompeii : Movement and Space (Oxford University Press, 2011).

more contemporary cities [4] . The soundscape, in particular, can have positive or negative effects on comfort within a room [5] or a street or city square [6]. In this sense, the concern for the acoustic pollution of urban air urges the implementation of adequate strategies for the control of noise generated by traffic in cities. Space syntax can have potential in predicting traffic noise by improving noise simulation models [7]. In this sense, the work of Conor Black [8] investigates comparisons between space agents and the propagation of voice in enclosed spaces. In parallel, some investigations on the relationship between space and music, have been recently developed, ranging from a rhythm-based analysis of the Parthenon frieze [9] , understanding

Fig. 6. Corner between Carrer del Bisbe and Carrer Santa Llúcia.

4 Colin G. Pooley, 'Cities, Spaces and Movement: Everyday Experiences of Urban Travel in England c. 1840–1940', *Urban History*, 44.01 (2017), 91–109 <https://doi.org/10.1017/S0963926816000031>.

5 Brenda Soars, 'Driving Sales through Shoppers' Sense of Sound, Sight, Smell and Touch', *International Journal of Retail & Distribution Management*, 37.3 (2009), 286–98 <https://www-emeraldinsight-com.recursos.biblioteca.upc.edu/doi/pdfplus/10.1108/09590550910941535> [accessed 15 April 2018].

6 Kang and Schulte-Fortkamp.

7 Angel M. Dzhambov, Donka D. Dimitrova and Tanya H. Turnovska, 'Improving Traffic Noise Simulations Using Space Syntax: Preliminary Results from Two Roadway Systems', *Archives of Industrial Hygiene and Toxicology*, 65.3 (2014) <https://doi.org/10.2478/10004-1254-65-2014-2469>.

8 Conor Black, 'Comparisons with Space Syntax and "Sound Syntax" |', *Web Page*, 2013 <https://conorblack.wordpress.com/2013/07/30/comparison-with-space-syntax-and-sound-syntax/> [accessed 28 September 2017]; Conor Black, 'Comparisons with Agents Space Syntax Movement and Speech Propagation |', *Web Page*, 2013 <https://conorblack.wordpress.com/2013/07/04/comparisons-with-agents-space-syntax-movement-and-speech-propagation/> [accessed 28 September 2017]; Conor Black, 'Genetic Algorithms and Sound Propagation |', *Web Page*, 2013 <https://conorblack.wordpress.com/2013/07/25/genetic-algorithms-and-sound-propagation/> [accessed 28 September 2017].

9 Katerina Michalopoulou and Antonis Touloumis, 'Structural Correlations between Music, Architecture and Cinema: Rhythmical Description of the Parthenon Frieze', in *Proceeding of the 10th International Space Syntax Symposium*, 2015 <http://www.sss10.bartlett.ucl.ac.uk/wp-content/uploads/2015/07/SSS10_Proceedings_028.pdf> [accessed 28 September 2017].

the temporal perception of space [1] . However, no study addresses thoroughly the influence of the space syntax's urban configuration on the daily activity of street music performance.

1 Antonis Touloumis and Katerina Michalopoulou, 'Issues of Inscription in Temporal Experience. Re-Composing a Staircase', in *Proceedings of the 7th International Space Syntax Symposium* (Stockholm, 2009) <http://www.sss7.org/Proceedings/10 Architectural Research and Architectural Design/S112_Touloumis_Michalopoulou.pdf> [accessed 28 September 2017].

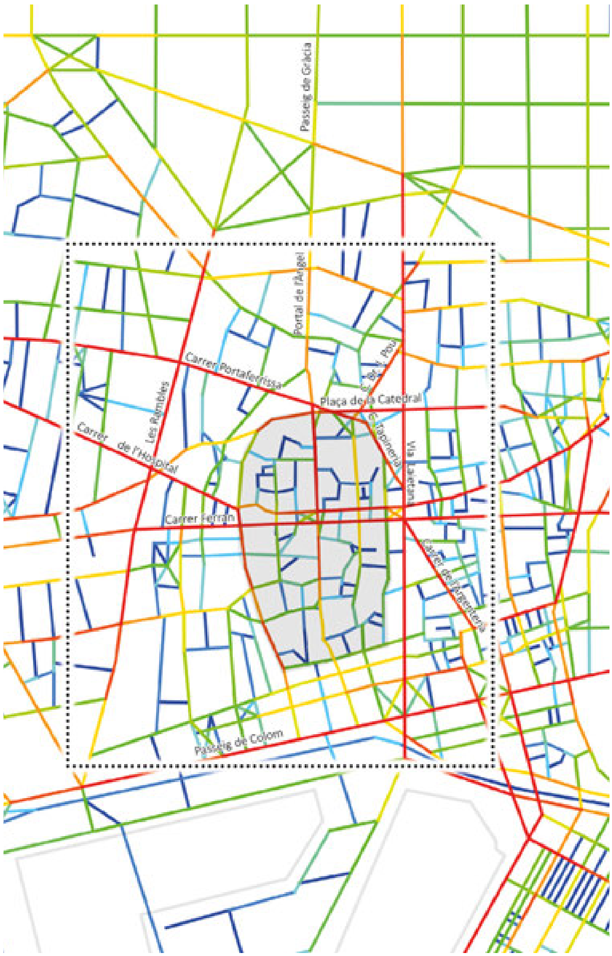


Fig. 7. Detail of the *Betweeness centrality* (choice) segment map of Ciutat Vella of Barcelona measured by *least angular choice* within a 1600m metric radius. The grey area is the former Roman city of *Barcino*.

5.3. Materials and methods

The spatial analysis has based its findings on the modelling of public space using space syntax's theories and methodology. The study has focused on the central area of Ciutat Vella, which is defined by the former Roman Walls of Barcelona (see grey area in next figure. The first step in the analysis has been carried out using the measure of betweenness centrality (or choice as is called in space-syntax terminology) in a street network consisting of segments which are defined by the intersections of lines of natural movement and sight that are drawn tangential to building surfaces. This measure captures the shortest paths that connect all pairs of origins and destinations or otherwise, the natural through-movement in the network. The value of betweenness centrality has been calculated based on the measure of *Normalised Angular Choice* [2] which considers angular distance, i.e. "the cumulative angles of turns taken between street segments in a city. This measure has shown to be a good predictor of pedestrian natural movement [3].

The analysis has been conducted in two stages. The first stage concerns the spatial analysis of Barcelona using the measure of betweenness centrality or choice. As it has been shown by previous studies of Barcelona [4] a space syntax analysis using choice at

2 NACH, Hillier et al 2012

3 Bill Hillier and Shinichi Lida, 'Network and Psychological Effects in Urban Movement', in *Spatial Information Theory. COSIT 2005. Lecture Notes in Computer Science*, ed. by Mark D.M. Cohn A.G. (Springer, Berlin, Heidelberg, 2005), pp. 475–90 <https://doi.org/10.1007/11556114_30>; Bill Hillier, Tao Yang and Alasdair Turner, 'Normalising Least Angle Choice in Depthmap and It Opens up New Perspectives on the Global and Local Analysis of City Space', *Journal of Space Syntax*, 3.2 (2012), 155–93.

4 Antonio Millán, Felipe Lazo and David López, 'Organic and Inorganic Overlapping in Old Barcelona', in *Eighth International Space Syntax Simposium*, 2012; K Al Sayed, A Turner and S Hanna, 'Cities as Emergent

various radii is essential, revealing the relationships between local and global structure of the city. For our scope, the algorithm has been applied at a metric radius of 1600m, i.e., the average distance of walkable and shopping areas in Barcelona. This radius corresponds to the length of Passeig de Gràcia, Rambla de Catalunya and Las Ramblas, and is also a commonly used distance for the spatial layout of urban shopping malls in the city.

In the second stage of the research, the study provides detailed analysis of the four selected public spaces in Ciutat Vella that nowadays work as 'open music halls'. The above-mentioned environments have been chosen according to the following criteria: firstly, they have been recently designated as official performance stages (see musica-carrer.tumblr.com); and secondly, despite all being located in pedestrian areas - far from noise by vehicular traffic - and having similar materiality, they have strong differences from each other in terms of geometry, size and daily-use patterns. Each of them appears to be unique and worth comparing with the others.

A second more detailed analysis is carried out by comparing the spatial and acoustical data. There are two layers in this analysis: the first one is based on *Visibility Graph Analysis* [1] of central Ciutat Vella. This methodology calculates spatial measures based on a graph of visibility connections of each point in a grid of locations (1 m), superimposed on the layout, to all other points in the layout. Key measures such as *Visual Integration (HH)* and *Clustering Coefficients*

Models: The Morphological Logic of Manhattan and Barcelona', in *7th International Space Syntax Symposium*, 2009 <http://eprints.ucl.ac.uk/16411/>.

1 Turner and Penn.

are used to describe the spatial structure of Ciutat Vella and the positioning of the 4 public spaces in this area. *Visual Integration (HH)* is a global measure that accounting for the mean shortest path from one point to all other points in the system [2]. The *Clustering Coefficient*, in turn, is a measure “potentially related to the decision-making process in way-finding and navigation and certainly marks out key decision points within complex configurations” [3]. Subsequently, the “clustering coefficient” might “indicate the potential for perceivable co-presence in a space and therefore the potential to form groups or to interact” [4] .

The second layer of analysis in stage two explores the acoustic features of urban space, specifically focusing on the selected squares. Five on-site measurements have been recorded in an empty room configuration with similar environmental conditions. The recordings have been made with a pair-matched omnidirectional microphones RODE NT 55 connected to a ZOOM H6 recorder placed on a stand. Once the recordings have been analysed, a bicubic spline interpolation has been generated in order to cover the same surface as the *VGA* analysis. The study finally combines each layer in a geolocated platform in order to find correlations and frictions between the spatial and acoustical values.

2 Turner & Penn 1999: 3

3 Turner et al. 2001: 111

4 Turner et al. 2001: 111

5.4. Analysis

5.4.1. Spatial configuration

After a long sequence of urban transformations over centuries, today's Ciutat Vella in Barcelona presents a complex and rich street configuration. As has been widely explained [1], the old city is no longer an old city. From its very initial Roman grid on top of the Mons Taber to the progressive densification and expansion of the city walls, and from its modernization in the 19th and 20th Century by means of new sventramenti, regular squares and markets to the last experiences of strategic openings, pedestrianizing and new public facilities, the Ciutat Vella of Barcelona offers a rich urban experience for pedestrians.

Nonetheless, in order to go beyond a historical reading on this palimpsest of interventions and understand its configurational properties a street-network analysis using space syntax is proposed. The results of this analysis are represented in figure 1 showing the preponderance of north-south streets in terms of integration, such as Las Ramblas, Rambla del Raval, Via Laietana and Portal de l'Àngel-Passeig de Gràcia. This pattern is complemented by a slightly perpendicular 'stave' of integrated streets like Carrer Ferran, Carrer de l'Hospital (former roman decumanus) and Carrer Portaferrissa-Plaça de la Catedral. Some diagonal streets can also be found in the central integrated core of Ciutat Vella. These are Carrer de l'Argenteria, leading to Santa Maria del Mar, Carrer Tapineria, stretching all along the former roman walls and Carrer del Dr.

1 Busquets 2003; De Solà-Morales 2008

Joaquim Pou which leads towards the Palau de la Música. This map also shows how the streets north of the Carrer Ferran between Les Rambles and Via Laietana are potentially more integrated that the southern ones: an evidence-based remark of the existing duality found in central Ciutat Vella.

This analysis is also important in providing a general picture of those streets that potentially enable a high degree of social co-presence, which in turn facilitates successful retail activity and, in our case, a profitable street performing culture. Although no consideration has been taken regarding the visual qualities and width of each street or the attractors and distribution of land-uses, many studies argue that spatial configuration, as such, is the "primary generator of pedestrian movement patterns" and "in general, attractors are either equalisable or work as multipliers on the basic pattern established by configuration" [2] . This argument leads to the understanding of "natural movement" as the proportion of movement that is directly influenced by the spatial layout. In an old city core like the city of London, studies reveal a normal correlation of 50-80% between the values of betweenness centrality (choice) and on-site movement rates [3]. For our scope, these results may be sufficiently relevant to justify the validity of the argument.

However, it would be worth exploring this general picture of central Barcelona taking into account the specific spatial attributes of the street network (width and geometry). To this end, the research has produced a Visibility Graph Analysis (Depthmap X, v. 0.5) on the basis of a 1.0m grid resolution,

2 Hillier and others.

3 Hillier and others.

Fig. 8. The *Betweeness centrality* (choice) segment map of Ciutat Vella of Barcelona measured by *least angular choice* within a 1600m metric radius. The grey area is the former Roman city of *Barcino*.

which is applied to the relevant pedestrian areas and shared surfaces within Ciutat Vella. The size of the area of analysis is 1000x1500m, thus providing with more accurate global values for the central area comprised by the former Roman Walls of Barcelona (300x500m), whilst producing a decrease in reliability in the surrounding area beyond Via Layetana and Rambla de Catalunya.

This produces at least two significant results:

(1) Figure 2 shows the distribution of Visual Integration (HH). This map should not be seen as an exact image of the current use, but only as the 'potential' movement capacity suggested by the street space configuration, thus strengthening the evidence shown in the previous segment analysis. Given the fact that the inner core of Ciutat Vella is quite uniform in terms of materiality, activity and uses, the hypothesis is that the spatial analysis can stand as a good proxy of movement rates, land uses, area density and attractors. This, though, may require further research, which extends beyond the scope of this paper. Some remarks could be here outlined:

First, it is worth noting the strong levels of integration of the western part of Carrer Ferran-Jaume I and its progressive shift towards Carrer de la Llibreteria (former decumanus). This is due to the transformation of the street section into a more car-oriented space towards the east side of Plaça de Sant Jaume, forcing pedestrians to use narrow sidewalks.

Secondly, Carrer Porta Ferrissa presents a high value of integration and draws a clear diagonal effect on the regular geometry of the Plaça/Avinguda de la

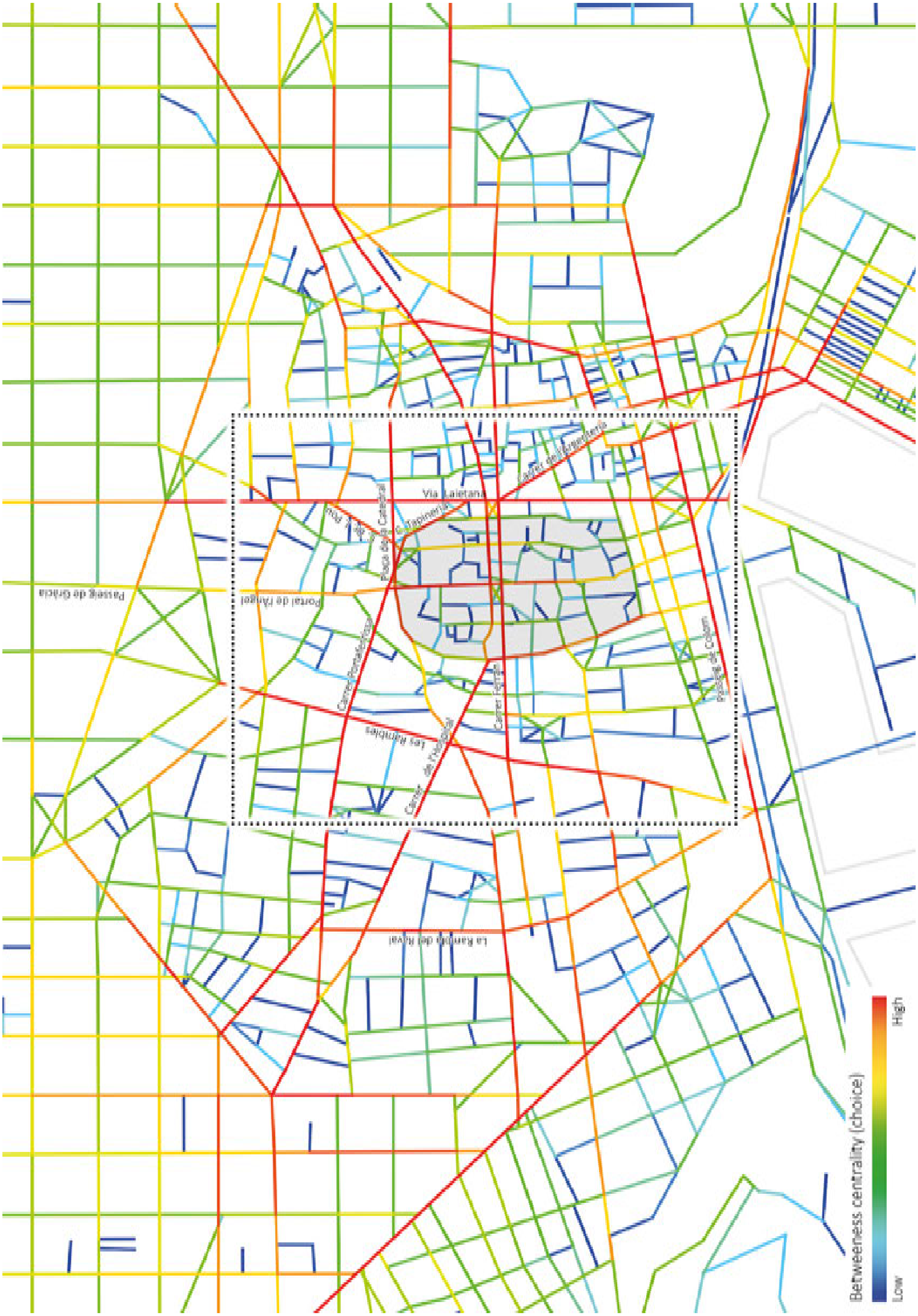

Via Laietana
Portal de l'Àngel
Passeig de Gràcia
Les Rambles
Carrer Ferran
La Rambla del Raval
Betweeness centrality (choice)
High
Low

Fig. 9. Visual Integration (HH) map of central Ciutat Vella, Barcelona. The colour ranges from high values indicating well integrated areas (red) to low values representing more secluded areas (blue).

Catedral. This might be a useful consideration when discussing ephemeral street markets and pavilions that often occupy the square resultantly blocking views and direct routes through their spaces.

Thirdly, the distribution of integration along Carrer Ciutat and its extension towards Carrer Bisbe not only confirms the role of the Roman cardus in the general structure of the city, but also shows a progressive decay towards the south. This pattern may be also recognized in the street parallel to Carrer Ciutat, Comtes-Freneria-Dagueria, thus producing an overall decrease of integration and, consequently, potential pedestrian flow, at the lower part of Ciutat Vella.

These considerations point out the existence of a grid-like structure made of these high integrated streets and an intricate system of streets and public spaces located in-between. This provides an interesting geography of less integrated squares and broad streets that might foster the emergence of 'open music halls', i.e., spaces of relative calmness close to the main structure. However, could all those spaces be suitable to become profitable street performance stages?

(2) The Visibility Graph Analysis provides us with another significant measure: the so-called Clustering Coefficient (figure 3). The application of this measure to central Ciutat Vella makes evident the sequencing of thresholds and urban corners, spaces which present a high-level of surprise and key places for route decision-making. It is worth noting, for example, the wide red area (less Clustering Coefficient) in the intersection of Carrer Ciutat and Plaça Nova, the characterization of Plaça Sant Jaume and its potential conflict with vehicular

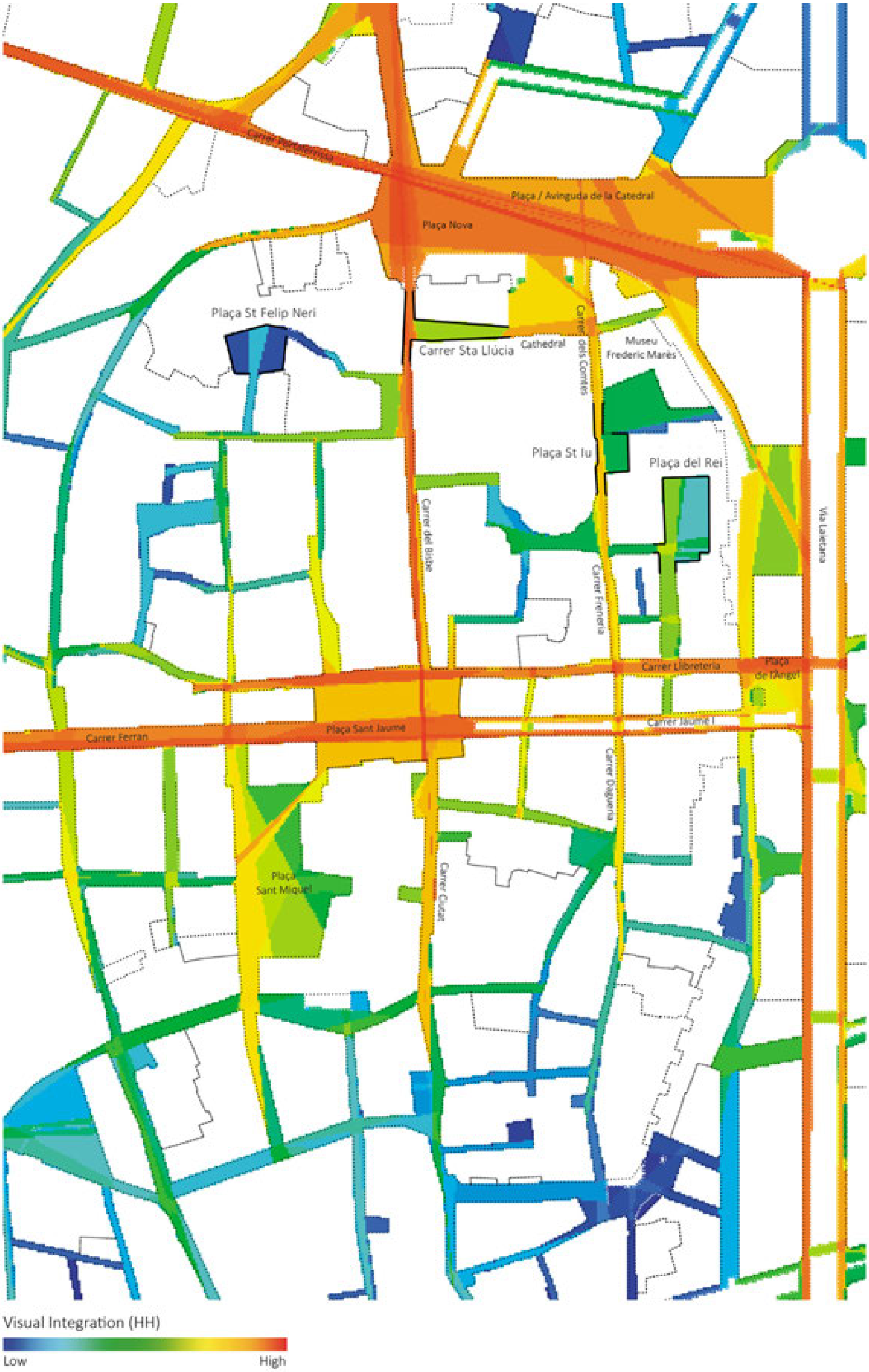

Plaça / Avinguda de la Catedral
Plaça Nova
Plaça St Felip Neri
Carrer Sta Llúcia
Cathedral
Carrer dels Comtes
Museu
Frederic Marès
Plaça St Iu
Plaça del Rei
Carrer del Bisbe
Carrer Freneria
Via Laietana
Carrer Llibreteria
Plaça
de l'Angel
Carrer Jaume I
Plaça Sant Jaume
Carrer Ferran
Carrer Daguería
Plaça
Sant Miquel
Carrer Ciutat
Visual Integration (HH)
Low
High

Fig. 10. Clustering Coefficient analysis of central Ciutat Vella, Barcelona. Within this framework the values range from 0.42 (red) to 0.98 (blue).

through-movement and, last but not least, the high level of interaction around the Plaça de l'Àngel.

If the highest 50% of values of Isovist integration (HH) are overlapped with the lowest half of the values of Clustering integration that highlight the intersection areas within Ciutat Vella, the result consists of a heatmap of those urban corners with a high potential level of pedestrian flow and decision-making (see fig. 4). At first glance, this would mean that those places could afford high levels of social interaction, surprise and, therefore, a profitable street performance. On the other hand, though, on-site everyday experiences reveal that musicians usually prefer to set up their stage more or less intuitively, either close to the main flow -see for example the long corridors in the underground system- whilst always trying to keep themselves out of flow in order to avoid conflicts in narrow streets or passageways. This suggests that good position for street musicians are areas of high values of clustering coefficient (shown in blue) close to a highly integrated street corner, thus enabling unexpected discovery of the busker by the pedestrians alongside and enough space for them to stop and listen.

Although the profitability of any busking activity is also linked to its strategic position within the field of view of potential consumers, musical performance obviously benefits from placement within an acoustically sensitive area for pedestrians. If it can be considered that the open field decay of sound is 6dB when doubling the distance to the speaker [1], then it can be reasoned that any calm area within a 40m radius from a high integrated corner might be

1 Leo L. Beranek, *Acoustics* (McGraw-Hill, 1945).

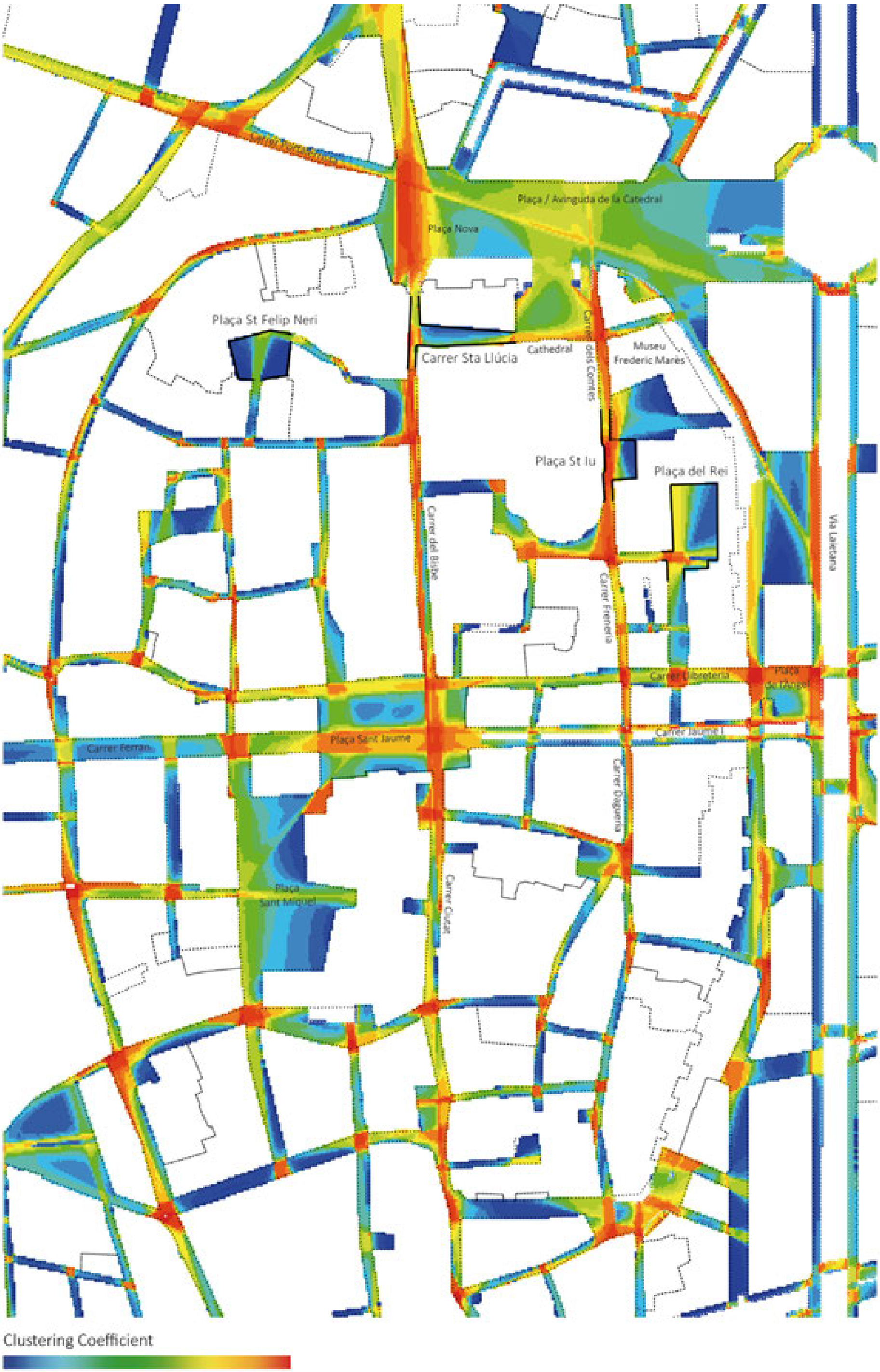
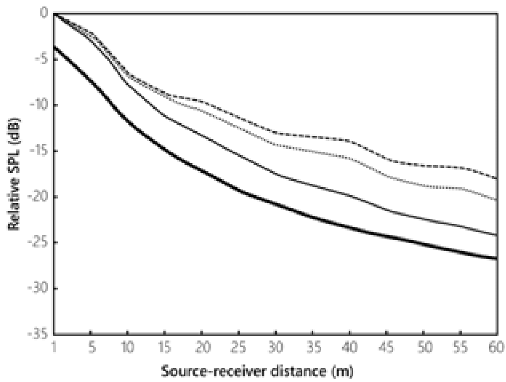

Carrer Comtal
Plaça / Avinguda de la Catedral
Plaça Nova
Plaça St Felip Neri
Carrer Sta Llúcia
Cathedral
Carrer dels Comtes
Museu
Frederic Marès
Plaça St Iu
Plaça del Rei
Carrer del Bisbe
Carrer Freneria
Via Laietana
Carrer Llibreteria
Plaça de l'Àngel
Carrer Jaume I
Carrer Ferran
Plaça Sant Jaume
Carrer d'Aguería
Carrer Ciutat
Plaça
Sant Miquel
Clustering Coefficient
High
Low

Fig. 11. Sound attenuation along a street canyon (20m) with diffusely reflecting boundaries. Black fine line, Z=6 m; dot line, Z=18 m; dash line, Z=30 m, black heavy line, free field. Redrawn from (Kang 2000b).

Fig. 12. Acoustical influence area (radius 10 to 40m) from high integrated corners (red to yellow) in central Ciutat Vella, Barcelona. The intensity of the red colour is the result of the division between *integration* and *clustering coefficient*. Blue areas are low integrated areas that might work as profitable 'open music halls' following the spatial City Council criteria.

suitable place for busking. Given that the average level of a street musician is 60dB when measured from a distance of 5m, it can be deduced that from a distance of 10m the level is 54dB, from a distance of 20m the level is 48dB, and from a distance of 40m

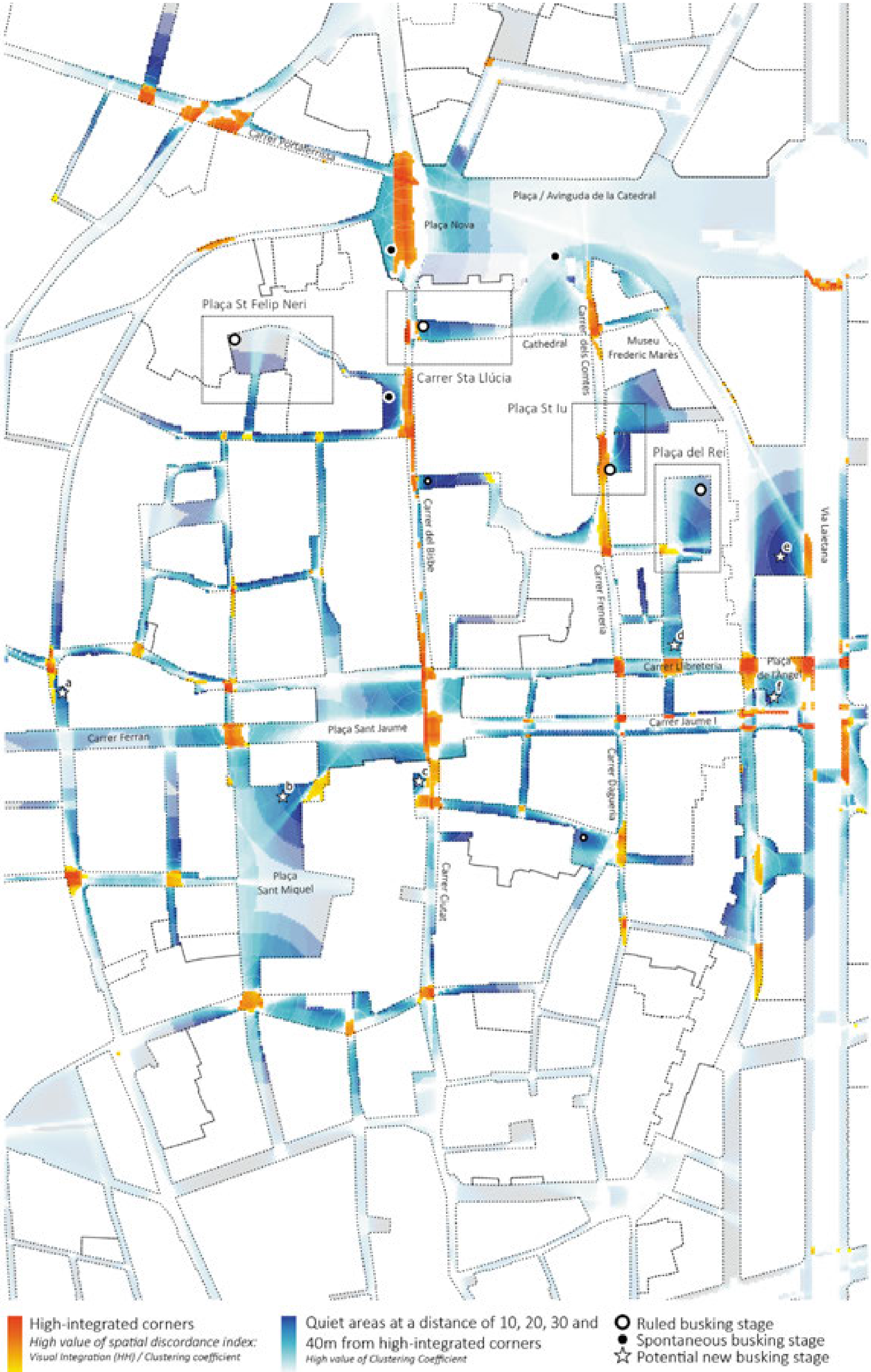


the level is 34dB, at which point it is a position that could be occupied by another busker (see figure 4).

Figure 5 shows a visual overlapping of the combined measures of *Visual Integration Clustering Coefficient*, and noise levels providing a synthetic cartography of streets and open spaces.

This deductive approach to the spatial configuration of central Ciutat Vella might be useful to understand the differences and similarities between the selected case studies. Some specific conclusions might be advanced here:

- Plaça de St. Felip Neri is a square located in a spatially and acoustically secluded area in comparison with the other case-studies. However, the internal configuration given by the Clustering Coefficient, which is similar


Carrer Portaferrissa
Plaça / Avinguda de la Catedral
Plaça Nova
Plaça St Felip Neri
Cathedral
Carrer Sta Llúcia
Carrer dels Comtes
Museu Frederic Marès
Plaça St Iu
Plaça del Rei
Via Laietana
Carrer del Bisbe
Carrer Freneria
Carrer Llibreteria
Plaça de l'Àngel
Carrer Jaume I
Carrer Ferran
Plaça Sant Jaume
Carrer d'Hogueria
Plaça Sant Miquel
Carrer Ciutat
a
b
c
d
e
f
High-integrated corners
High value of spatial discordance index: Visual Integration (HH) / Clustering coefficient
Quiet areas at a distance of 10, 20, 30 and 40m from high-integrated corners
High value of Clustering Coefficient
Ruled busking stage
Spontaneous busking stage
Potential new busking stage

to the distribution of the Visual Integration values, reveals a very suitable pattern of blue regions that could facilitate musical activity and listening areas. The reason busking is dramatically reduced here is because only those pedestrians that know of the existence of such a square or discover it by pure chance could become potential listeners.

- The corner between Carrer del Bisbe and Carrer Santa Llúcia is a wide street linking the entry of the Cathedral with the main street of central Ciutat Vella. Its centrality and profitability for busking is clearly confirmed by its close position to a highly integrated corner and by the size and geometry of the space available for listening (blue areas).

- Plaça Sant Iu is perhaps the most suitable 'open music hall' case-study in terms of spatial configuration. As in the previous case, it is located very close to a highly integrated corner but nevertheless presents a slightly more generous free space, sheltered from the main flow. While the stone bench located along the largest side of the square may contribute to its success, the access to the current Museu Frederic Marès might disrupt this general pattern during opening times.

- Plaça del Rei is located one step behind the main integrated streets but it is still well connected to them. The current busking position in the furthest corner of the square not only allows for a clear visual connection with the streets connected to the square, but also provides for a large quiet area in which to stay and enjoy the music.

5.4.2. Acoustical properties

Although the studied environments present some specific features due to their open-air condition, the study considered them using a closed concert hall acoustics method. This decision was taken after considering three factors. The first one deals with the openness of the places. Due to their three-dimensional geometric configuration, the four squares can be viewed as boxes where the floor and most of the walls are defined, while lacking a ceiling. This configuration can be understood as if the floor and the walls were made of stone while the ceiling of the box was made of the most absorbent material possible, because no audible sound is going to bounce back in the open air. The second consideration concerns the size of the four spaces. The smallest space, Santa Llúcia Street, holds an air volume of 1,800 m3, which makes it similar to a typical speech hall. On the other extreme, the largest space, the Plaça del Rei, which has a volume of 12,000 m3, does not exceed the volume of a large concert hall, such as the Berliner Philharmonie. Finally, the third consideration takes into account that in an open-air environment the sound sources change position constantly. This would be significant if the study of the soundscape of an everyday configuration was taken into account–with running children, singers, street vendors, or even police sirens. But the fact is that the recording was made of places in a street concert configuration. This means that there is only one player at a fixed point and that the audience stands quietly listening to them. Therefore, although the studied environments present unpredictable levels of noise as open-air places, the study analyzes them

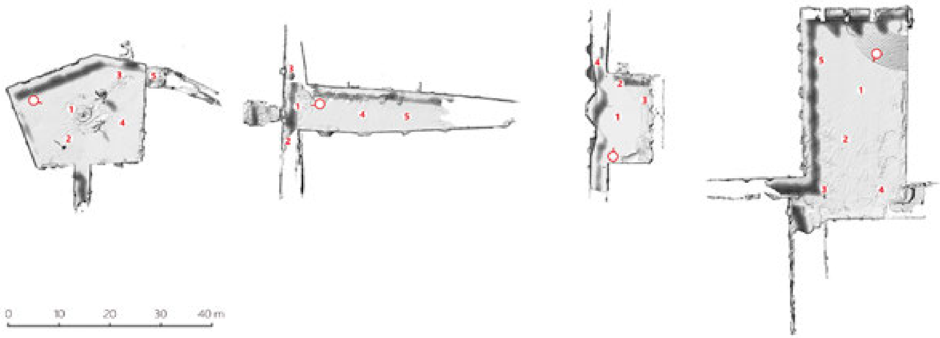


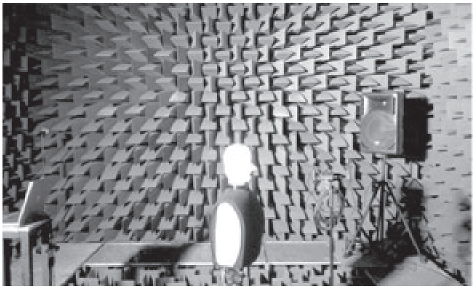
Fig. 13. Plans of the Plaça Sant Felip Neri, Carrer Santa Llúcia, Plaça Sant Iu and Plaça del Rei with the position of the musicians and the five recording points.

as closed concert hall stages and hence a concert hall acoustics analysis is provided here.

The four environments (figure 6) were acoustically studied under normalized parameters [1] using a reproduction-recording system. This system consists of an impulsive signal previously calibrated in the Anechoic Chamber of the Escuela Politécnica Superior de Gandia and recorded in a set of different xy locations for each case. As every recording point is subdivided in two channels: left (L) and right (R), the result is a double value for each point: 1_L, 1_R, 2_L, 2_R, etc.

Once the impulse responses of the different points recorded have been obtained, some of the parameters of acoustic quality have been extracted by means of signal processing. The resulting studied parameters are Reverberation Time, Early Decay Time, Speech Clarity, Definition, Musical Clarity, and Sonority.

1 AENOR, 'AENOR: Norma UNE-EN ISO 3382:2001', Http://Www.Aenor.Es/ <http://www.aenor.es/aenor/normas/normas/fichanorma.asp?tipo=N&codigo=N0024618#.WZ6SLChJaMo> [accessed 24 August 2017].



#. Mendelssohn oboe excerpt recorded in anechoic chamber.

#. The same Mendelssohn oboe excerpt reproduced and recorded in plaça Sant Felip Neri.

For this study the attention was focused on the most basic and direct parameter called Reverberation Time. When a sonorous source that is continually radiating suddenly stops in a determined enclosure, a listener in the hall will continue to hear the sound for a period of time during which its energy is being absorbed by the surfaces of the enclosure's limits [2]. The Rt value corresponds to the falling time of the sound associated with the angle for the first 60 dB decrease. Here, the different results of the Reverberation Time in the different environments and at different frequencies are shown:

2 Higini Arau Puchades, *ABC de La Acústica Arquitectónica* (Ediciones CEAC, 1999) <http://cataleg.upc.edu/search~S1*cat?/Xhigini+arau&searchscope=1&SORT=D/Xhigini+arau&searchscope=1&SORT=D&searchtype_aux=X&SUBKEY=higini+arau/1%2C4%2C4%2CB/frameset&FF=Xhigini+arau&searchscope=1&SORT=D&2%2C2%2C> [accessed 24 August 2017].

Fig. 14. Reproduction – recording system in the Anechoic Chamber of the EPSG and in Plaça de Sant Felip Neri

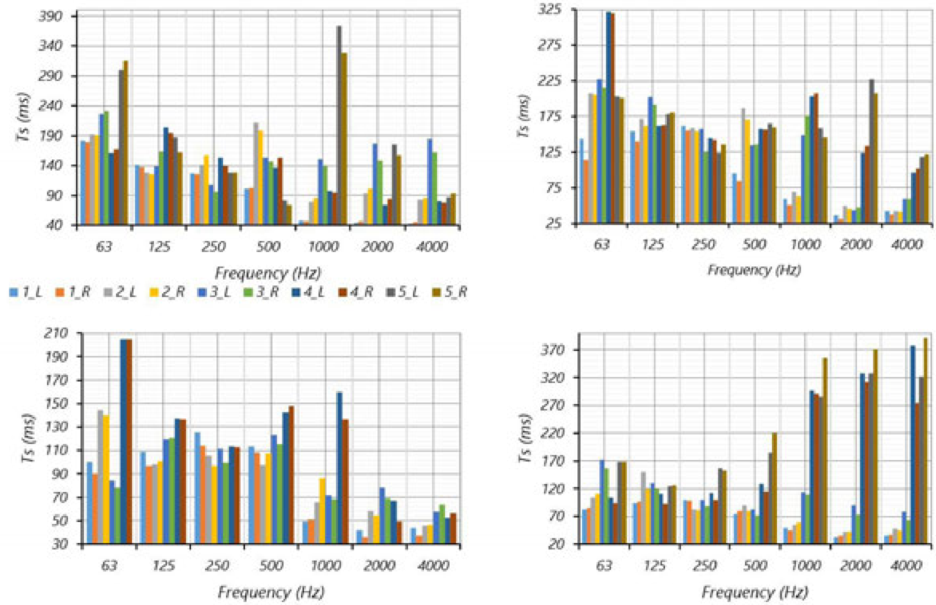


Fig. 15. Reverberation time in the four environments studied: Plaça de Sant Felip Neri (up and left), Plaça del Rei (up and right), Plaça de Sant Iu (down and left) and Carrer de Santa Llúcia-del Bisbe (down and right).

Fig. 16. Reverberation time map elaborated for each frequency: Plaça Sant Felip Neri, Carrer Santa Llúcia, Plaça Sant Iu and Plaça del Rei.

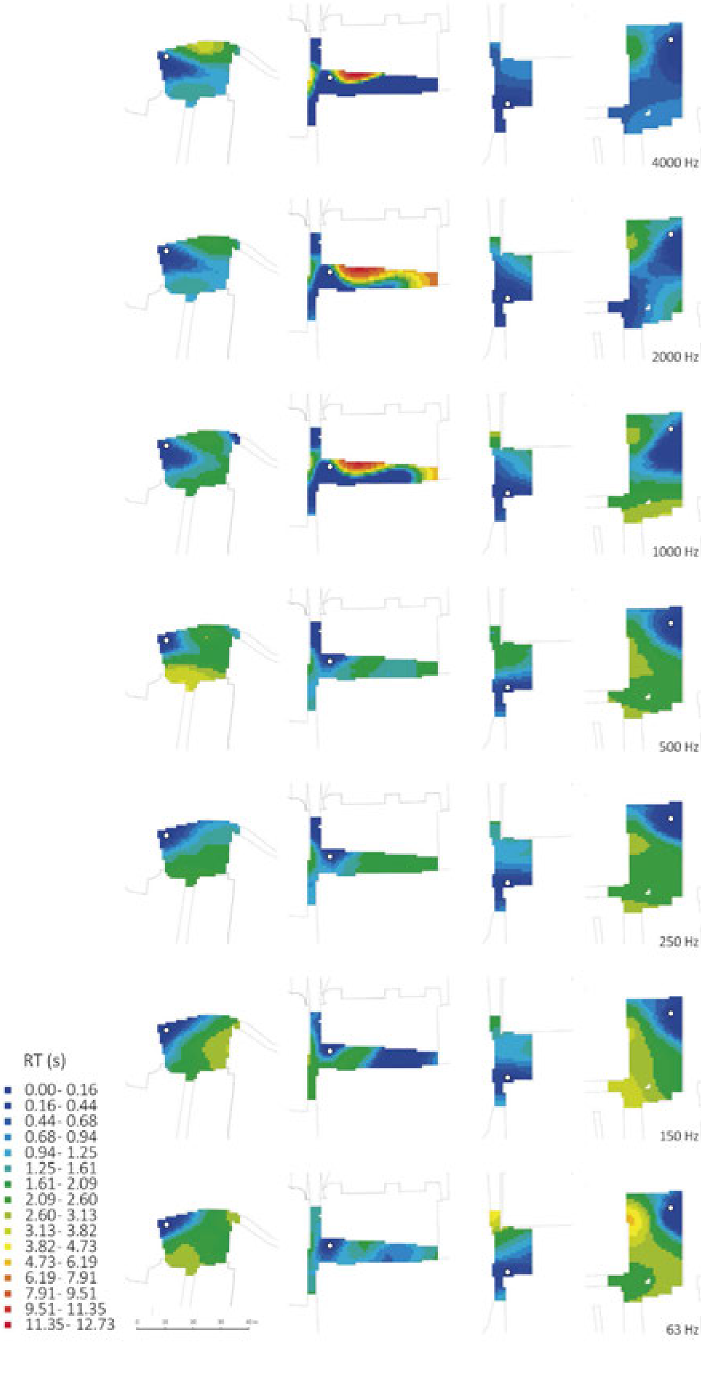
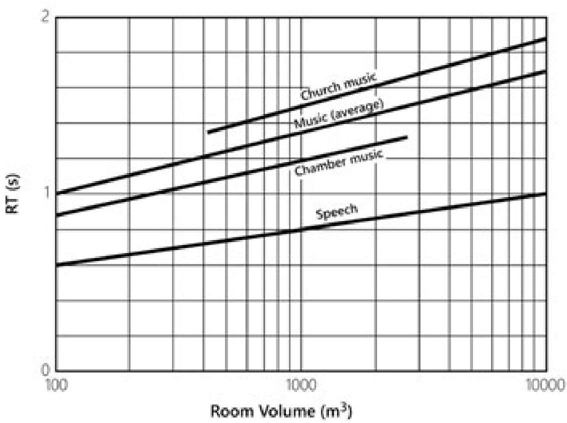

4000 Hz
2000 Hz
1000 Hz
500 Hz
250 Hz
150 Hz
63 Hz
RT (s)
0.00- 0.16
0.16- 0.44
0.44- 0.68
0.68- 0.94
0.94- 1.25
1.25- 1.61
1.61- 2.09
2.09- 2.60
2.60- 3.13
3.13- 3.82
3.82- 4.73
4.73- 6.19
6.19- 7.91
7.91- 9.51
9.51- 11.35
11.35- 12.73

Fig. 17. Optimum reverberation time according to the volume of the hall and its use. Redrawn from (Turner & Pretlove 1991).

Analysing the obtained results, some acoustic features of the environments can be highlighted. In Plaça de Sant Felip Neri, it can be observed that the Reverberation Time increases according to the distance from the emission point. Using the reference values stated in Carrión (1998), the first recorded point values are comparable to a speech hall (Ts 70ms – 100ms). The second point values are similar to an opera theatre (Ts = 120 – 150). The third and fourth points are similar to a chamber music hall (Ts = 130 -170). Finally, the fifth point, which is situated in an access road to the square, presents similar values to a symphonic hall (Ts = 180 – 200).



It can be deduced that the points that better approximate the current use of the square –i.e. chamber music- are the third and fourth recorded points. Looking at the plans on fig. 8, it can be understood that Reverberation Time values of this environment. The interpolated plans show us that, as the frequency is increased, a blue area corresponding to the lowest Reverberation Time zone increases also. At the same time, the green area decreases when the frequency increases. These two features explain why Sant Felip Neri square holds a wide range of reverberation time values in its low frequencies while it has a similar reverberation time in the high frequencies (1 sec. approx.). It is also noticeable in these drawings that the best place to hear the chamber music played in the stage corresponds to the half of the square that is not the same half with that of the musician. This is because the reverberant field is not yet active in the first half of the square and so, therefore, the spectator must move back fifteen meters from the player in order to get a proper spatial sensation of the music.

Carrer de Sant Llúcia-del Bisbe at the first, second and third recorded points presents Reverberation Time values that do not exceed the limit of an opera theatre, corresponding to the area usually used by the audience. Meanwhile, the fourth and fifth points, which are not occupied by the spectators, present similar features to a symphonic hall. Looking at the interpolated plans, the apparition of zones of high reverberation time values in frequencies 1000Hz, 2000Hz and 4000Hz is remarkable. These odd values could be ignored in this analysis because they are caused by the deformation of the interpolation generated from an accumulation set of disparate values of frequency in a very close distribution.

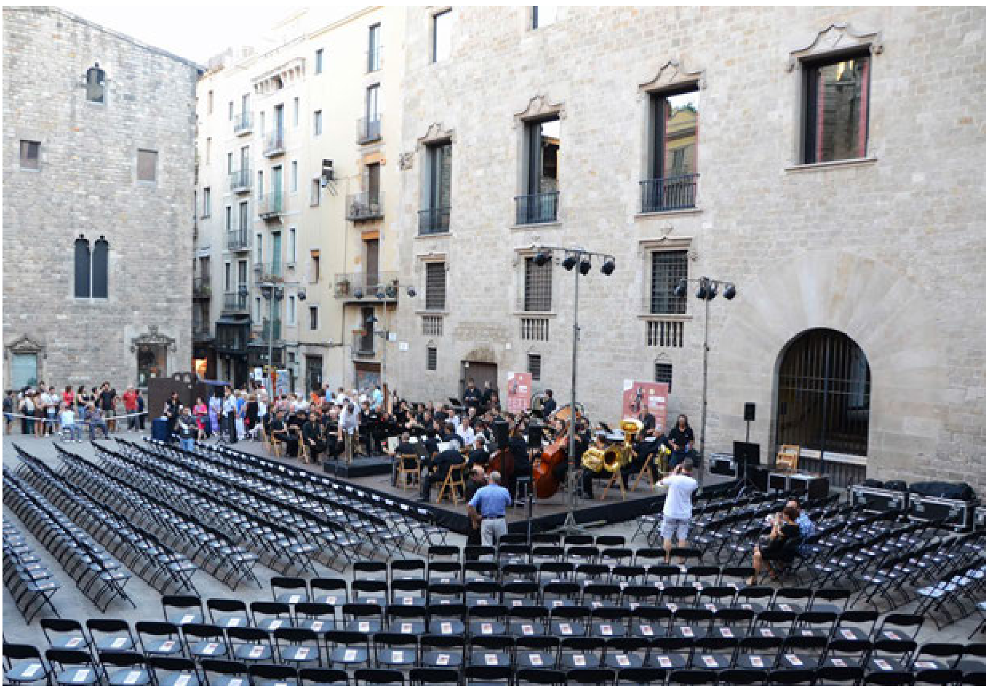
Beyond that, it is possible to notice that there is a good reverberation zone at the left of the emitter and that this zone coincides precisely with the area in which the public stands every Saturday night. This fact reveals to us that the acoustical properties of the spaces perfectly match their weekly musical use.

Plaça de Sant Iu presents Reverberation Time values that lie on the boundary of the speech and chamber hall domains (Ts = 70-170), except for the fourth point which behaves like a chamber music hall. Looking at the interpolated plans, it can be highlighted that this is the most homogeneous environment studied. It is also noticeable that its reverberation time values remain very low in high frequencies and that they increase at the distant points from the emitter once the frequencies decreases.

In Plaça del Rei it can be observed that the reverberation time reaches similar values to a symphonic hall as the receiver walks away from the emission point. Only the first and the second recording points are out of this domain because they are too near to the source. Again, the third, fourth and fifth points are the positions with values that approximate better the current musical use of the square –i.e. symphonic music-. Looking at the plans on last figrue, the Reverberation Time values of this environment are shown. The interpolated plans show us that there is a difference in reverberation time values between the different frequencies studied. While a blue area (low reverberation time) is always present near to the player, the green area decreases with the increase of the frequencies. This shows that at high frequencies the reverberation time remains at a low value, but in low frequencies the longer the distance away from the player is, the longer the reverberation time is. If the plans are carefully observed, it is possible to notice a stain in higher values at all the frequency ranges when located at the left of the emitter. The most probable explanation of this phenomenon is the parallelism and flatness of the longest walls of Plaça del Rei. This point receives a concentrated amount of waves provided from the front wall, which is totally flat and parallel to its back.

Fig. 18. A prepared concert in Plaça del Rei. The soundsource is here in a different position that the studied.

Bearing in mind the points that approximate better to the current use of the environment, now the correlation of this information with their spatial configuration is feasible.

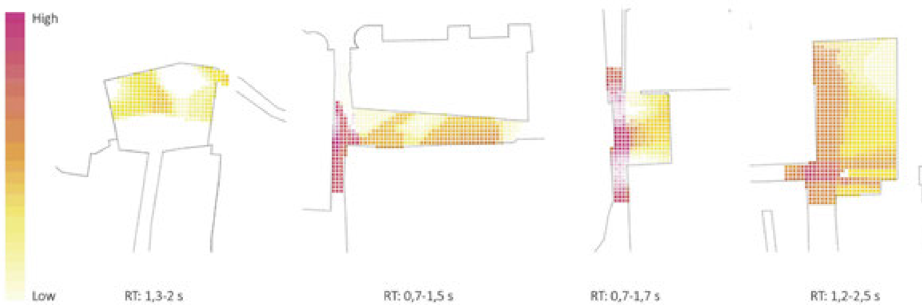


5.5. Results: correlations between space and acoustics

After referencing the spatial and acoustical data to the same 1.0m geo-located grid using a GIS platform, some findings could be highlighted in order to establish a set of correlations and mismatches between those two variables:

Regarding the spatial configuration, it has been argued that the best busking points are located within a 40m radius from a *high integrated corner* but, at the same time, a non-conflictive street performance should be surrounded by a quiet area so that people are able to stop and listen. To express this quantitatively, the most suitable spaces for both listeners and the musician are those which are placed in the vicinity of a corner with a higher value of *Visual Integration (HH) / Clustering Coefficient*. This factor could be defined as the Spatial Discordance Index, i.e., the higher the value, the more movement conflict that will be produced at that decision-making point.

If the spatial data is crossed with the *Reverberation Time* specific for each case-study - this analysis is framed to the most common frequency 500Hz -, an outstanding output could be found. It could be argued that it is not always the case that a high-quality acoustical area matches up with a proper spatial configuration. Indeed, as the analysed case-studies are to be considered “open music halls”, through-movement generated by the pedestrian flow often conflicts with the sound quality. The correlation between these two sets of values can, in turn, be used to clearly understand the *spatial-acoustic discordance* areas. This behaviour is visible in fig. 11 where a graduated colour sum of spatial and sound values has been produced for each case-study. The darker the colour range is, the higher level of natural movement and acoustical incompatibility is registered. The white colour indicates, in turn, which are those non-conflictive areas that either have bad acoustics, very low pedestrian flow or a combination of both. The middle values (orange) highlight those points with a good equilibrium in terms of acoustics and spatial attractiveness which provide suitable spaces for a profitable and calm listening environment.



The figure can also be analysed by setting a numerical correlation between the specific Rt Reverberation Time (s) in each place and the Spatial Discordance Index (Visual Integration (HH) / Clustering coefficient) ranging from 0 to 4.5 (cut-off value selected for this comparison). The results comparison may allow us to state some important findings in figure no. 12-15.

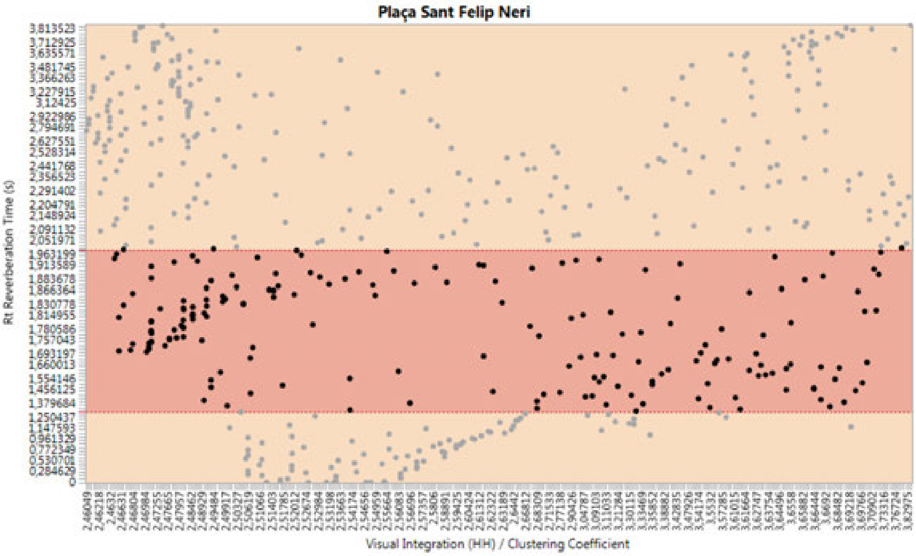
Fig. 19. Spatial-acoustic discordance: visual overlapping of the spatial and acoustical properties of the Plaça Sant Felip Neri, Carrer Santa Llúcia, Plaça Sant Iu and Plaça del Rei. This map is the result of a graduated colour sum of the Spatial Discordance Index and the best reverberation time for each environment for a 500Hz frequency. The areas with a dark colour are those specific points with good acoustics but with a conflictive position in the movement pattern.

Fig. 20. Spatial-acoustical discordance. Correlation between the Rt Reverberation Time (s) for Plaça Sant Felip Neri (red) and the Spatial Discordance Index (0 to 4.5, in orange).

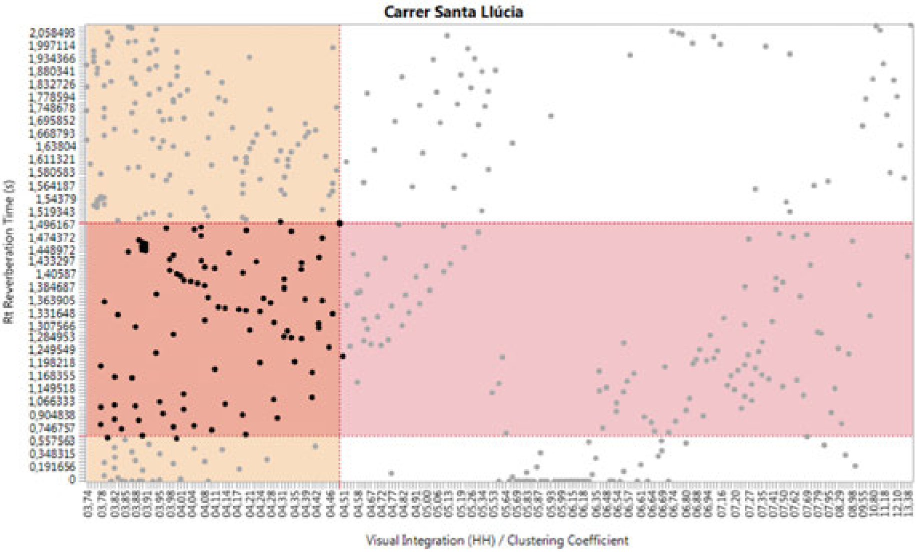
Fig. 21. Spatial-acoustical discordance. Correlation between the Rt Reverberation Time (s) for Carrer Santa Llúcia (red) and the Spatial Discordance Index (0 to 4.5, in orange).

Focusing on Plaça Sant Felip Neri, it is noticeable that the Spatial Discordance Index is very low at all points, because they do not surpass the 4.5 value that is meant to mark the threshold between a high integrated corner and a quiet area. The chart shows that it is a square in which the flow of pedestrians is broken up due to its step depth from the rest of the main streets. This exceptional condition means that as much as 185 sqm (185 points in the graph) possess an acceptable acoustic for musical purposes, particularly when the range between 1.3s and 2s was considered, which would fit inside both the chamber and symphonic acoustic categories. Despite of this, its secluded position in Ciutat Vella, definitely prevents it from becoming a profitable 'open music hall' for busking.

Carrer Santa Llúcia presents a very different picture. It is easy to identify two large point groupings in figure no. 12: those with a high index of spatial discordance and those with a low value. This division indicates the large disparity between the different spatial conditions of the analysed points: in a constrained domain of space the spatial discordance falls from a hyper-connected street to a secluded area. What is more, those values with low spatial discordance (less than 4.5) correlate with very dispersed reverberation time values; and those values with high spatial discordance (more than 4.5) match the low reverberation time values (around 1.19s) i.e. they are inside the optimum domain of reverberation. To be exact, only 98 sqm of the crossroad have both a good acoustic condition and do not coincide with spatial discordance areas. Interestingly enough, those points with high spatial discordance and with good Reverberation Time values, match those points where the audience is



Plaça Sant Felip Neri
Rt Reverberation Time (s)
Visual Integration (HH) / Clustering Coefficient



Carrer Santa Llúcia
Rt Reverberation Time (s)
Visual Integration (HH) / Clustering Coefficient

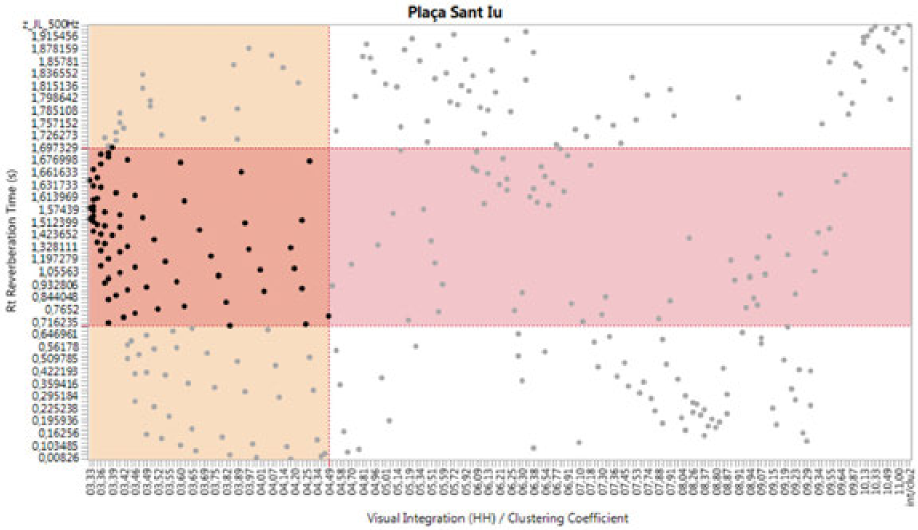
Fig. 22. Spatial-acoustical discordance. Correlation between the Rt Reverberation Time (s) for Plaça Sant Iu (red) and the Spatial Discordance Index (0 to 4.5, in orange).

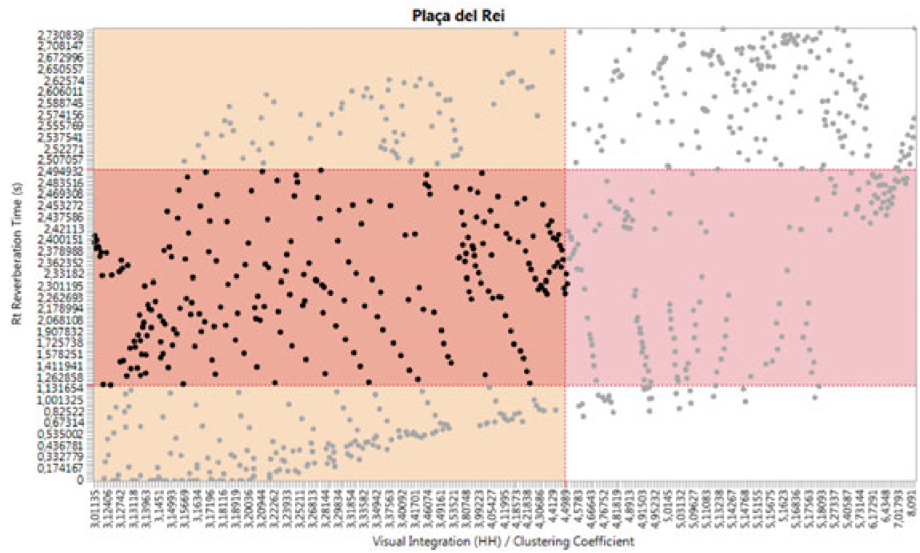
Fig. 23. Spatial-acoustical discordance. Correlation between the Rt Reverberation Time (s) for Plaça del Rei (red) and the Spatial Discordance Index (0 to 4.5, in orange).

normally placed. This phenomenon makes sense of the most common opinion listeners give of enjoyable busking activity: "to watch without being seen", which expresses the preference to be located in places with a good acoustics which, nevertheless, provide a sufficiently high level of pedestrian movement to preserve one's anonymity.

Plaça Sant Iu presents a different distribution of points of spatial and acoustic values (fig. 12). Firstly, the acoustically acceptable domain is highlighted in the dark pink area of the graph. On the other hand, a heavy concentration of areas with low Spatial Discordance index is found on the left of the graph. To the right of the chart, in turn, a smaller and more dispersed number of points shows a decrease in the Spatial Discordance index. It can be concluded that this square contains a great deal of good acoustic space (72 sqm, to be precise) which falls into an acceptable domain of Spatial Discordance.

Finally, Plaça del Rei registers a lineal relation between the Reverberation Time parameter and the Spatial Discordance Index. When the receiver moves away from the acoustic source (upper right-hand corner), which belongs to the area with less spatial discordance, the reverberation time increases in parallel with spatial discordance. Therefore, when maximum spatial discordance is also found in the place where maximum reverberation time occurs, the Reverberation Time is too high for optimal listening. Thus, it is clear that the central zone (240 sqm) of the square is the optimum acoustic area below the spatial discordance limit.


Plaça Sant Iu
Rt Reverberation Time (s)
Visual Integration (HH) / Clustering Coefficient


Plaça del Rei
Rt Reverberation Time (s)
Visual Integration (HH) / Clustering Coefficient

5.6. Conclusions

These analytic results help to conclude into some specific remarks. To start with, it would be worth noting that two different kind of spaces could be here categorised based on their spatial and acoustic affordances. The first type comprises environments that should be regarded as more appropriate for spontaneous music street performance, since this kind of activity accepts, encourages and is rooted on a high level of through-movement. The second might be more linked to organized musical events, because those are spaces that are not reliant on natural movement flow which, on the other hand, could host a larger audience. Having this in mind, it is fairly evident that both the Plaça Sant Iu and Carrer Santa Llúcia belong to the first type of places and, more specifically, that the first of these should be considered more ideal than the second one. Indeed, given the fact that both spaces are connected to streets of similar integration, it is notable that the geometry of Plaça Sant Iu is less conflictive in terms of Spatial-Acoustical Discordance than the corner of Carrer Santa Llúcia, despite the fact that the access to the Museum Frederic Marès in the former splits the square and reduces the area for listening. While Plaça Sant Iu's high-integrated street and decision-making point still leaves a generous and comfortable area for listening, Carrer Santa Llúcia has almost no area to do so next to Carrer Bisbe. The area close to the musician is often too difficult to reach because of the narrow size of this street. Conversely, the more secluded position of Plaça del Rei and, of course, Plaça Sant Felip Neri might be regarded as appropriate spaces for organized musical events due to their high capacity (800 sqm and 700 sqm, respectively) and lack of free-busking as such. The fact that these acoustics are very suitable for symphonic orchestras, bands and choral ensembles, only reaffirms this suitability.

Secondly, it is worth highlighting that, as stated at the beginning of the article, this methodology could also be useful in identifying other potential new busking places. As fig. 4 shows, the star-shaped points identify suitable spaces for busking because of their appropriate spatial configuration: (a) Carrer Avinyó; (b) Plaça Sant Miquel; (c) Carrer del Veguer; (d) Plaça Ramon Berenguer Gran; (f) Plaça de l'Àngel. While the first three can easily be converted into future busking stages, the latter two might be better understood as a potential part of an overall redesign of Via Laietana. Further acoustical studies should be developed in each of those areas in order to provide for a good results in the correlations explored in this article.

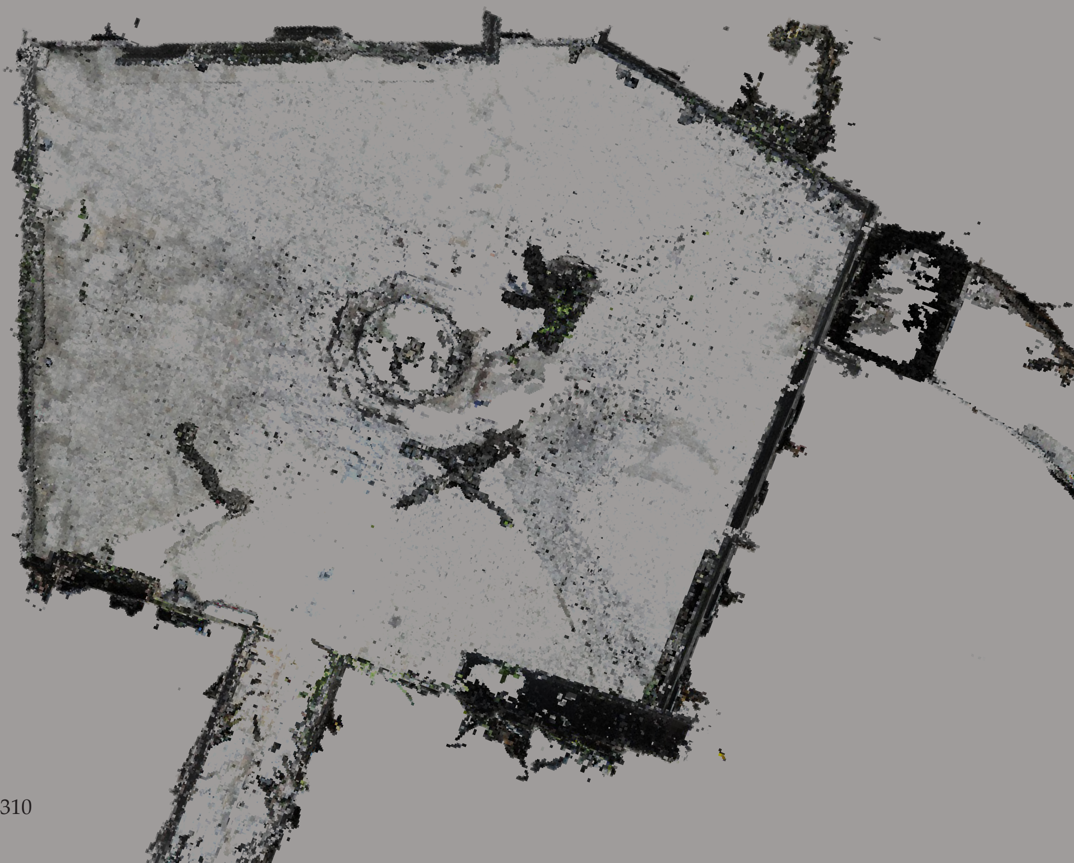
Thirdly, it must be acknowledged that although the obtained results and conclusions provide additional evidence to the existing literature on this topic, several limitations to this pilot study need to be indicated. Firstly, the reduced number of case studies in Ciutat Vella and the acoustic study's restriction to the 500Hz frequency band limit the conclusiveness of the results and it would therefore be worth expanding the study to other environments and to the entire musical spectrum -from 63 Hz to 4000 Hz- in order to develop a better account of which type of music might be more suitable for each space. Furthermore, regarding the spatial configuration, it is worth mentioning that the *VGA* space-syntax analysis used for this research uses the "natural movement" definition as its main argument [1] and, therefore, it does not take into account the spatial qualitative data such as ground-floor activities, materiality, minor obstacles, topography, climate and greenery or the existing peaks of accessibility in the underground accesses. The hypothesis already argued by the previous researches is that those attractor-based analysis could qualify yet not modify substantially the results [2] and, in any case, could give a strong picture of the potential spatial capacity of a given street network. Further research might be developed in order to calibrate the influence of this arguments in the specific urban layout of Ciutat Vella, Barcelona and, finally, this study could also be balanced by an on-site survey of the pedestrian movement within this area in order to give evidence-based of the configurational-based conclusions.

All in all, this study has provided a method of analysis of spatial configuration and acoustical properties for outdoor spaces in a compact public space network in Barcelona. But it would be worth concluding how this methodology could be also valuable to provide a wider view of the topic by extending the case study places beyond the limits of Ciutat Vella, to other districts in Barcelona or any other compact city. The methodology discussed in this paper could be also significantly applied to the understanding of the busking phenomena in other collective spaces with a different geometrical and movement pattern such as shopping malls, underground system or larger open areas. This forthcoming studies on urbanscapes could help to provide evidence-based understanding of the hidden patterns of these fluid activities which deeply shape the urbanity of our cities.

1 Hillier and others..

2 Hillier and Penn.

Case study



Plaça Sant Felip Neri

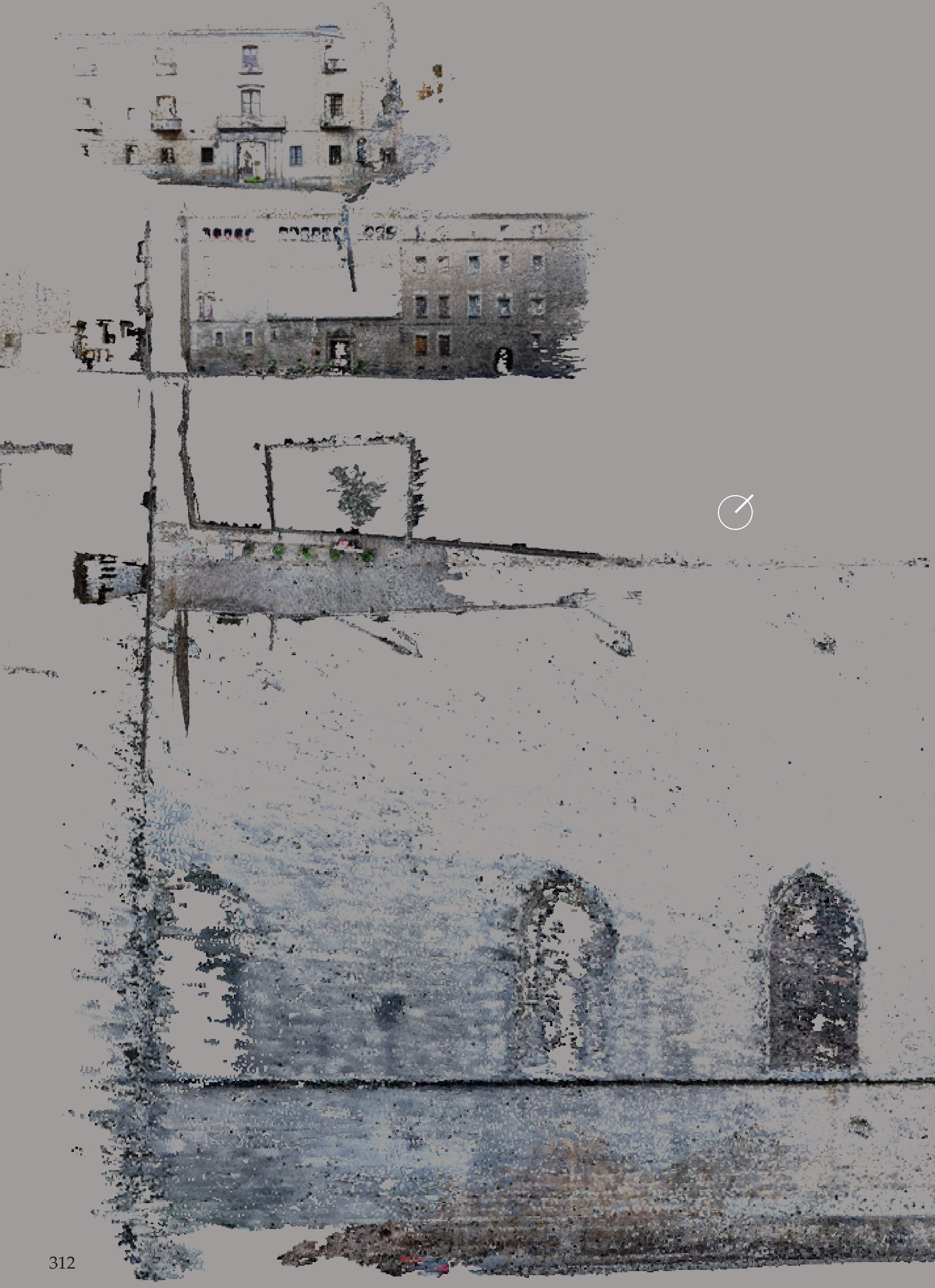
Fig. 24. Section and plan from a photogrammetric model of Plaça Sant Felip Neri.

Romantic and with a decadent twist, Sant Felip Neri Square is an essential corner of the walk through the Gothic Quarter. Presided over by the baroque church that baptizes it, the square has some historical elements that make it especially attractive, especially when one perceives the silence.

Small, labyrinthine streets in the Gothic Quarter flow into this unthinkable corner of the city. A small square dominated by a charming fountain and dominated by the baroque church of Sant Felip Neri. On the one hand, the buildings of the old guilds of the cauldrons and the shoemakers found a new location here after moving from their original location, in the streets of La Bòria and Corribia, respectively.

Next to the church is the school of Sant Felip Neri. When the children of the school do not play in the square and silence is heard, perhaps we will still hear the sound of the bombs that fell from the sky that fateful January 1938. We see the healed wounds on the main façade of the church; they still seem to be hurting. A plaque reminds us that the bombing of the fascist planes killed 42 people, many of whom were children, who had taken refuge in the air raid shelter underneath the church. Now, however, the children play in the shade of the acacias, unaware of this past in a square that acts as a gateway to the Jewish quarter of Barcelona

Translated from *http://www.barcelonaturisme.com/wv3/es/page/1247/placa-sant-felip-neri.html*



Carrer Santa Llúcia: The businessman who ended up singing opera in the street.

He is the author of the soundtrack of Santa Llúcia Street, behind the majestic cathedral of Barcelona. He succeeds in transporting those who stroll around to scenes from La Bohème or Tosca, both works by Puccini, but he is undoubtedly known for his particular Nessun Dorma, the aria par excellence of the opera Turandot. A risky masterpiece that dares to interpret as Luciano Pavarotti himself did at the time.

"I also like Led Zeppelin, don't believe it", explains to Crónica Global Enrique de Torres, the street tenor of the Catalan capital. But the lyric is the apple of his eye. He began to sing it at a family meal, encouraged by what was then his father-in-law, a Basque performer who discovered his potential and pushed him to educate his voice to sing opera.

And so he did. He hired several repertoire and vocalization teachers and learned to control the vocal ups and downs required by lyrics. "To let my voice always come out in the same glow." He invested a lot of money in his training, but then he was an entrepreneur and could afford it. He polished his voice and took part in several contests that offered him to go abroad, but he could not: "My life was a little convulsed, I had very serious back problems and some losses in the business".

Translated from *https://cronicaglobal.elespanol.com/vida/empresario-opera-catedral-barcelona_69494_102.html*

Fig. 25. Sections and plan from a photogrammetric model of Carrer Santa Llúcia

Fig. 26. Sections and plan from a photogrammetric model of Plaça Sant Iu.

Plaça de Sant Iu

The Porta de Sant Iu is the oldest door of the Cathedral of Barcelona. During its five hundred years, it will be the main entrance to the Cathedral. It is located under one of the bell towers. The Porta de Sant Iu will be built with marbre and Montjuïc stone in 1298. It is characterized by its pointed, degrading archivolts, which rest on ribs with floral capitals. On each side of the door there are two inscriptions with a text commemorating the beginning of the works of the Gothic cathedral on 1 May 1298, and also two relics representing the rain of the home against the beasts, which seem to come from the ancient Romanesque cathedral, since they date from the 12th century. The gateway, in the name of Sant Iu, has been the patron saint of lawyers since the 15th century.

Transalted from *https://catedralbcn.org/index.php?option=com_content&view=article&id=68%3Aporta-de-sant-iu&catid=4%3Ala-catedral&Itemid=82&lang=ca* Transalted from *https://catedralbcn.org/index.php?option=com_content&view=article&id=68%3Aporta-de-sant-iu&catid=4%3Ala-catedral&Itemid=82&lang=ca*

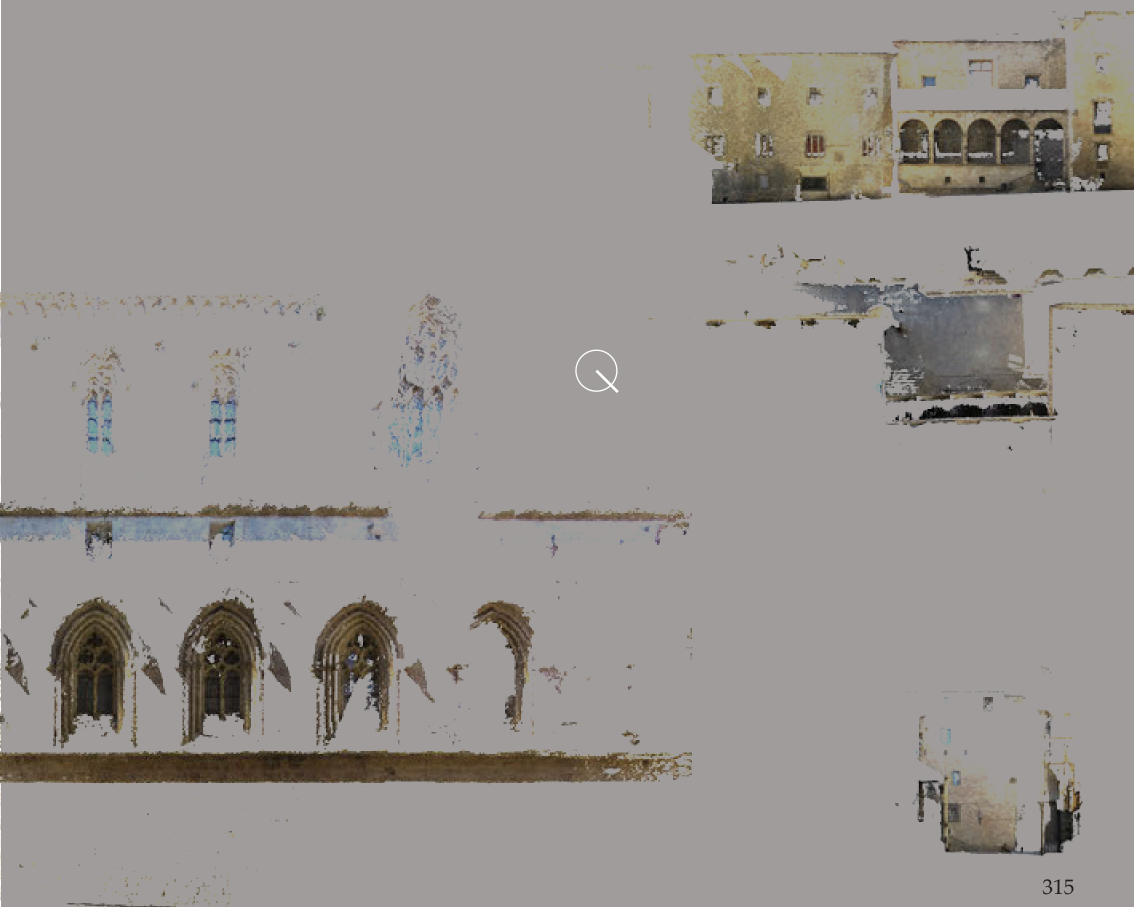
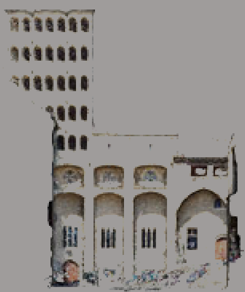


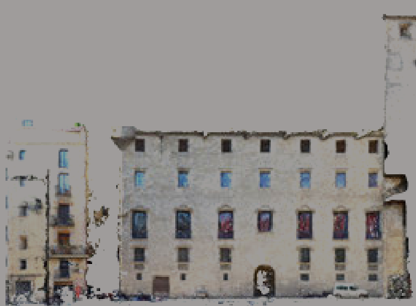
Fig. 27. Sections and plan from a photogrammetric model of Plaça del Rei.

Plaça del Rei

The monumental complex of Barcelona's Plaça del Rei is probably the Gothic corner that best exemplifies the city's medieval past. The Palau Reial Major and the surrounding rooms close a harmonious and quiet square where it seems that it still breathes the glorious past of Barcelona in the Middle Ages.

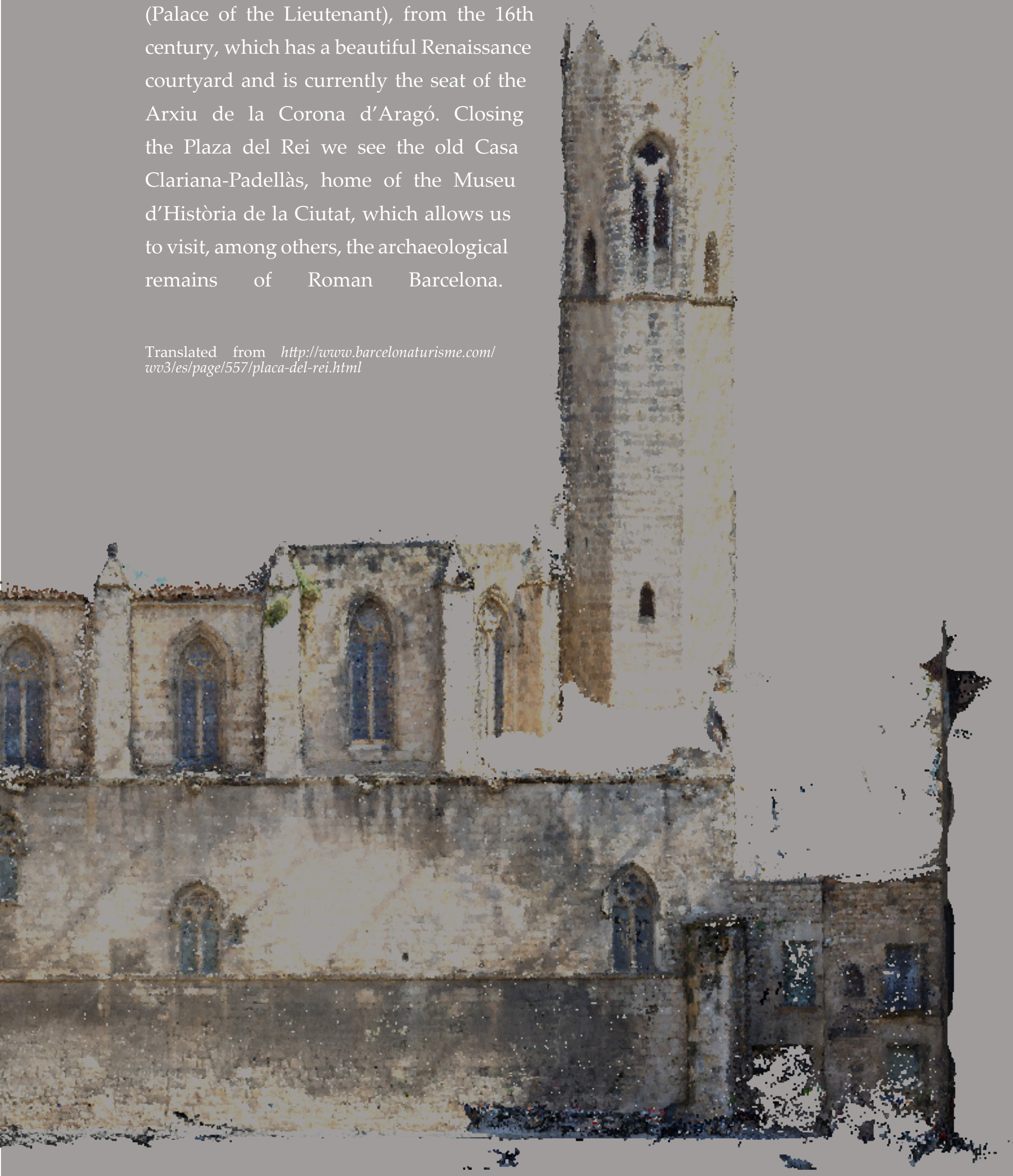


The Plaça del Rei in Barcelona is dominated by the Palau Reial Major, the building we see rising in the background, with King Martí's lookout tower on the side. A residence of the Catalan Counts from the 13th to the beginning of the 15th century, the history of the building dates back to the 11th century, although the present appearance belongs to the remodelling work carried out during the 13th century. Gothic is, therefore, the predominant style, although at the base of the building are Visigothic and Roman remains. Inside, the Saló del Tinell, organised in a series of semicircular arches, is the most emblematic and beautiful room in the Palau Reial Major.



On one side of this building, and built on the ancient Roman wall, we can see the royal chapel of Santa Àgata, from the fourteenth century, the interior of which hides the valuable altarpiece of the Condestable, by Jaume Huguet. The building in front is the Palau del Lloctintent (Palace of the Lieutenant), from the 16th century, which has a beautiful Renaissance courtyard and is currently the seat of the Arxiu de la Corona d'Aragó. Closing the Plaza del Rei we see the old Casa Clariana-Padellàs, home of the Museu d'Història de la Ciutat, which allows us to visit, among others, the archaeological remains of Roman Barcelona.

Translated from *http://www.barcelonaturisme.com/wv3/es/page/557/placa-del-rei.html*



Chapter 6

Evaluation of analysis

A short review on evaluation methods
on subjective-objective acoustics

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Evaluation of analysis

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of subjective-objective acoustics

6.1. Introduction

When Tapio Lokki compares the acoustic evaluation of a concert hall to a wine taste task [1] , some features of this procedure come into the mind. Actitudes such as comparison between the wines, attention to the details, good taste for the flavour or subjective judgements are always present. Paralelly, the chemical composition of the liquid, the oil content in the wine, or the alcohol grade present in the sample are also strong determining factors for the judjment. This clear distinction between the world of the sujbective perception and the filed of the objective facts seems to be very useful when approaching to the evaluation of such an intangible reality.

Room acoustics is the target of discussion of many concert-goers, amateurs or professional musicians when comparing different halls where they played, or assisted to. Comments on the best seat position into a concert hall, or the preference among different auditoriums are usually heard in conversations on the foyer before starting an opera or a symphonic performance. Taking into account that the architect design plays a crucial role on the final result of the acoustics of each concert hall, it seems reasonable an evaluation of the subjective perception of users on these architectural spaces. This chapter presents a review on the most recent and relevant methods for evaluation of architectural spaces. The different studies reviewed are compared under different aspects such as method of evaluation, hypothesis, indoor-outdoor, experiments used and design methodologies.

1 Lokki, Tapio, 'Tasting Music like Wine: Sensory Evaluation of Concert Halls', *Physics Today*, 67 (2014), 27–32 <https://doi.org/10.1063/PT.3.2242>

6.2. The studies reviewed

The bibliographic search was taken in databases under the keywords such as "evaluation acoustics" or "subjective and objective acoustics". This basic idea which searches for the link between the subjective judjements of acoustics and the objective parameters of it is in the core basis of the collection of studies here reviewed.

As Gade defends [2] , like in many other aspects of life, the real world is so complex that it is needed to simplify the problem, reduce the degrees of freedom, through definition of abstract, well-formulated and meaningful concepts and parameters in the domains of architecture, objective and subjective. The solution of the problem starts trying to define a vocabulary to describe the subjective acoustic impression: we will isolate a set of subjective acoustic parameters that are valid to most people's listening experiene, then it seems reasonable to try to deduce those properties from the sound fileds that are responsible for our experience of each of the subjective aspects: to define a set of objective, measurable parameters that correlate well with the subjective parameters; and finally, we must find out which aspects of the design govern the important objective that in turn the subjective parameters, so we can asseist in building halls meeting the specific needs of their users.

2 Gade, A., 'Acoustics in Ha 9. Acoustics in Halls for Speech and Music', in *Handbook of Acoustics* (Springer, 2007), pp. 301–50 <https://ccrma.stanford.edu/courses/318/mini-courses/papers/rooms/Gade - Handbook Ch9.pdf> [accessed 10 April 2018]

Different methods of evaluation of the acoustic parameters in indoor and outdoor environments. One of the most common methods of evaluation is *Differential Semantics*. This method uses bipolar adjectives, presented in a Likert format, which are used in the form of “scales“ for the purpose of gaining responses to a concept or object [1] . In (Galiana et al. 2016) it used as a questionnaire that considered three parts. Block 1 included objective information on the subject (gender, age, concerts attended per year, kind of music mostly listenend to at the concert hall and usual location in the venue. Block 2 and 3 assessed by means of 27 acoustic adjectives and 26 architecture expressions respectively may comprised 162 acoustic adjectives and 259 adjectives. Similarly, in (Kuwano et al. 2001), a 7-point semantic differential scale was used with 14 pairs of adjectives on the basis of former suties to assess participants perceptions of the environment depicted. To reduce possible order effect, four sequences of adjective scales were utilized. However, *Differential Semantics* has some disadvantages, in particular, the mental schme of non-experts is not taken into account when designing some questionnaires. This is the reason why in (Galiana et al. 2012) they establish a methodology to define valid evaluation scales for different collectives. Therefore, the *Differential Semantics* method within the frame of Knasei Engineerign was used to achieve this purpose.

1 Polizzi, Kenneth G., and Jean A. Steitz, ‘EXAMINING THE AGING SEMANTIC DIFFERENTIAL: SUGGESTIONS FOR REFINEMENT’, *Educational Gerontology*, 24 (1998), 207–23 <https://doi.org/10.1080/0360127980240302>

Another method used to evaluate the subjective acoustics of halls is *Double-blind paired comparisons*. In (Soulodre and Bradley 1995) this method was used with eight separate listening tests. For example, for the loudness experiment, subjects listened to pairs of sound fields and identified the one which they perceived to be louder. Similarly, (Lokki et al. 2016) used AB paried comparison and AAB triplet with hidden reference. In this case, 3 listening sessions were arranged: 1) 18 samples (6 halls x 3 positions) ramdomly presented. The hearing of the assessors was screened with the audiometry and the first listening session was ended with the attribute elicitation. 2) The second listening session started again witha brief familiarization of all samples. Then the assessors rated the samples with their own two to four attributes, one attribute at a time. 3) Third and foruth sessions repeated the whole process (without audiometry) with another music excerpt, thus new preference ratings and new set of attributes were collected. To balance the dependecy of music, half of the assessors started with Bruckner and the other half with Beethoven.

The third common method is *Individual Vocabulary Profiling*. In (Kuusinen et al. 2014) individual preferences are regressed onto a latent three-dimensional sensory space obtained by multiple factor analysis of descriptive sensory data. Subjective evaluations were performed with individual vocabulary profiling (IVP), where each test subject devlops his or her own set of descriptive attirbutes for the comparison and evaluation of the stimuli. A total of 60 attributes were reliaby used in the evaluation. First, multi factor analysis (MFA) was performed on the descriptive data of all 60 atributes. MFA revealed that there were three latent facotrs, each explaining a significant amount of the total variance in the data. Second, a clustering with Euclideand distances and Ward's minimum variance method of the 60 attributes was performed in this latent 3D space using transformed sample scores of each attribute on the three factors. Third, cluster anlysis was also performed on the preference ratings. This clustering revealed two groups of assessors: who tend to like louder enveloping and reverberant sound, and those who like more proximate and clear sound. Finally, proximity was identified as the main driver of preference and it was argued that none of the standaridized room acoustical parameters were associated with either proximity or overall preference.

5.2.2. Outdoor-Indoor evaluation

Despite the fact that most of the studies were realized for concert halls, some of them tackled the problem in outodoor enviroments. In the studie of (Cerwén 2016) the concern remained in how urban soundscapes can be altered through design of outdoor space. (Fowler 2013) examined the pedagogical aspects of teaching soundscape to design students ant eh implications of such methodologies for the field of design in the built environment.

Other environements different from concert halls were classrooms (Astolfi and Prellery 2007), offices (Kaarlela-Tuomaala et al. 2009) and (Jensenand Arens 2005), churches (Alonso et al. 2013), indoor tonal noise environments (Ryher and Wang 2008) and general indoor environments (Frontezak and Wrgocki 2010).

5.2.3 Experiment setups

Differnt kinds of purposes in the studies derived into different experiment setups. In the studies or (Lokki 2014), (Lokki et al. 2011), (Kuusinen et al. 2014) a 34 loudspeaker orchestra was used to record the soundfield in the each concert hall. Excerpts of symphonic music recorded in anechoic chamber was reproduced with the loudspeaker orchestra with separate channels for each group of instruments. The reason for this setting is that no auralization procedure reaches the quality of a real distribution of sound in real scenarios. In other cases, such as (Soulodre and Bradley 1995), (Lokki et al 2016), (Kuusinen and Lokki 2015), (Tervo et al. 2014), (Ando et al. 1979) or (Lokki et al. 2012) the anechoic signals were convolved with the impulse response of the halls. Other kind of experiments involving questionnaires were taken directly in or near the concert hall when a performance was taken place. It is the case of the studies of Galiana et al. (2012, 2014, 2016)

5.3. Conclusion

The 22 studies collected here show different methods ffor the evaluation of the subjective and objective parameters of concert hall acoustics. It is possible to conclude that objective parameters can be assessed by standarized concepts and units. However, the evaluation of the subjective acousitcs needs a different approach. From methods such as Vocabulary Profiling or Differential Semantics are more useful to the subjective ratings.

In the following pages the information of each of the studies is shown in tables.

Year	Author/s	Paper Title	doi	Type of publication	Coverage	Sample Type	Sample Size
2016	Galiana et al.	*Impact of architectural variables on acoustic perception in concert halls*	10.1016/J.JENVP.2016.09.003	Journal paper	Region of Valencia (Spain)	74 experts and 236 non-experts	310
2016	Lokki et al.	*Concert hall acoustics: repertoire, listening, position and individual taste of the listeners influence the qualitative attributes and preferences*	10.1121/1.4958686	Journal paper	Finland	10 professional musicians, 10 amateur musicians, 8 concert goers.	28 (14m+14f)
2016	Cerwén	*Urban soundscapes: a quasi-experiment in landscape architecture*	10.1080/01426397.2015.1117062	Journal paper	Sweden	General users	198
2015	Kuusinen and Lokki	*Investigation of auditory distance perception and preferences in concert halls by using virtual acoustics*	10.1121/1.4935388	Journal paper	-	Critical listeners. Two listeners practiced an instrument.	8 (6m+2f)

Aim	Objective parameters	Subjective parameters	Methods	Stimuli	Exp. setup	Findings
To analyze whether architectural variables (visual component) affect acoustic percpection in concert halls and quantify this influence.			Semantic differential. Affinity diagram. ANOVA.	In situ. Orchestra. 17 concert halls.	Survey during and after the concert.	Acoustic perception was influenced by the visual component, and vice-versa. Experts differentiate between acoustics and visuals.
1) Six concert halls compared 2) Influence of music style and instrumentation on the acoustic perception 3) Sensory evaluation	Volume, Number of seats, Strength, EDT.	Preference tests.	AB paired comparison and AAB tripet with hidden reference.	Short excerpts convolved with the SDM spatial IR.	Stimuli were playback in semianechoic chamber.	Listeners can be categorized into two different preference classes: some listeners prefer claity over reverberance, others love strong , reverberant and wide sound.
The present study aims to further our understanding of how urban soudscapes can be altered through design of outdoor space	SPL	Questionnaires.	Design an arbour on the square. The intention was for the arbour to change the soundscape by screening the noise and by adding forst sounds	Outside and inside the arbour. Group A with no added sound, group B with loudspeaker sounds added.	In situ, questionnaires.	The intervention put in place on the square generally influecned the experience of the sound environment in a positive manner. The construction of good sound environements involves aspects that go beyond what can be measured through SPL. This supports that the intorudction of new sound may be a relevant step to take, provided the sound pressure level is below 65-70 dBA.
To search differences in auditory distance perception in different concert halls and find that acoustic proximity or "intimacy" is a shared preferred quality among listeners, while taste manifest in other factors.	Real distance.	Abstolute distance estimation.	Pairwise comparisons	2 anechoic sound materials played in halls as loudspeaker orchestra. 4 concert halls, five distances from 10 to 26.	Listening room semianechoic: 24 loudspeakers	Perception of distance is dependent on the hall acoustics. The G factor and direct-to-reverberant energy ratio can covary in relationto perceptual distances in these halls. Additionally, overestimation of short distances may contine up to and further than 10 m from the sound sources.

Year	Author/s	Paper Title	doi	Type of publication	Coverage	Sample Type	Sample Size
2014	Kuusinen et al.	*Relationships between preference ratings, sensory profiles, and acoustical measurements in concert halls*	10.1121/1.4836335	Journal paper	-	-	23
2014	Giménez et al.	*Mismatches between objective parameters and measured perception assessment in room acoustics: a holistic approach*	10.1016/J.BUILDENV.2013.12.022	Journal paper	Region of Valencia and Andalucía (Spain)	Music experts (not in room acoustics) and general public.	1284
2014	Lokki	*Tasting music like wine*	10.1063/PT.3.2242	Journal paper	Finland	Finnish listeners. "Assessors".	-
2013	Alonso et al.	*Acoustic evaluation of the cathedral of Seville as a concert hall and proposals for improving the acoustic quality perceived by listeners*	10.1080/19401493.2013.848937	Journal paper	-	-	-

Aim	Objective parameters	Subjective parameters	Methods	Stimuli	Exp. setup	Findings
In this paper, the preference of critical listening environments among sound engineers is studied with listening tests.	Acoustic parameters of the environment	Preferences.	Preference tests. ANOVA	Twelve secons from three songs	Anechoic chamber: loudspeakers in 3d disposition	Correlations: EDT and LEF correlate negatively with preference. Sound engineers tend to prefer rooms with short reverberation time and high clarity. Mastering engineers preferred a room with more reverberation. Clarity was not as important.
To study the relationships between objective acoustic parameters measured in the room with the survey responses, which measure the quality of perceived acousics of that room.	Tmid, ETDmid, Br, BR, ITDG, C50, C80, LEV, IACCe3, IACCi3, G 125, Gmid, Glate, Lj4 (late lateral sound level), Jlf3 (early lateral energy fraction), Jlf4 (early lateral energy fraction), Jlfc4 (lateral energy fraction)	Questionnaire	Correlation analyses and multidimensional scaling	In situ, orchestra	In situ, orchestra	Correlation between objective parameters and users' responses show that transversality exists between them. Although the results show the mismatch between objective parameters and subjective responses, a model of subjective global evaluation of the acoustics of the room from data of three orthogonal acoustic parameters is implemented, revealing a reasonably good fit.
Learn how do acoustics affect a concertgoer's experience by asking listeners.	-	102-60 attributes	Sensory evaluation. 20 European concert halls. 3 Finnish concert halls.	2-4 minutes of symphonic music convolved with the RIR of each concert hall.	Build an ourchestra out of ludspeakers: 24 calibrated loudspeakers. Listening room	Halls that produced quiet, distant sound were rated poorly by the listeners. Halls with their loud, reverberant sound, were preferred by some listeners but not all. The favorite halls were the ones that offered the greatest subjective proximity.
1) To carry out an acoustic evaluation of the cathedral as a concert hall in tis current condition 2) To provide a series of proposals for the improvement of audience sound perception in these concerts.	T30, DDT, C80, Ts, G, jLF (Early lateral energy fraction)	Reverberance, musical clarity, perceived sound level, spatial sensation	Acoustic simulation analysis	-	-	The cathedral and its transept can provide acoustic conditions suitable for concerts with a large audience. However, adequate acoustic requierements are not obtained from cert

Year	Author/s	Paper Title	doi	Type of publication	Coverage	Sample Type	Sample Size
2013	Flowler	*Soundscape as a design strategy for landscape architectural praxis*	10.1016/j.destud.2012.06.001	Journal paper	Australia	Architectural students	-
2012	Lokki et al.	*Disentangling preference ratings of concert hall acoustics usign subjective sensory profiles*	10.1121/1.4756826	Journal paper	-	Participants with a musical background and between ages 19 and 75 years	23
2012	Galiana et al.	*Subjective evaluation of music hall acoustics: reponse of expert and non-expert users*	10.1016/j.buildenv.2012.06.008	Journal paper	-	Non-experts users and expert users.	310

Aim	Objective parameters	Subjective parameters	Methods	Stimuli	Exp. setup	Findings
To examine important theroretical concepts of soundscape studies and how these concepts were used to guide a number of design projects of the studios. To reflect on the pedagogical aspects of teaching soundscape to desgin students and the implications of such methodologies for the field of design in the built environment.	-	-	1) Sound diary 2) Sound-walking 3) Field recordings 4) Sounds-cape composi-tion	-	-	Students experience an overwhelming desire to create auditory simulations that match the levels of detail achievable in current modelling and illustration softwares.
1) Nine concert halls are measured for comparison with a loudspeaker orchestra, such that the lisnte-ning poisition is the same in all halls 2) Signal processing in stimuli creation is utilized to render high quality spatial sound samples for listening test 3) the data analysis is further developed by including the mapping of individual elicited attributes, objective parameters and sub-jective preferences of the nine concert halls studied	Stregnth (G), Early Decay Time (EDT), Clarity (C80), Early Lateral Energy Frac-tion (Jlf) and Lateral Sound Level (Lf)	Elicitation of attributes	Indibudual voca-bulary profiling	3 musical excerpts: mozart, Beetho-ven and Bruckner.	9 spatial sound repreo-duction int eh la-boratory: B-format IR were first processed with the spatial impulse response rendering algorithm. Convolu-tion with anechoic music.	The preference judg-ments were divided into two groups of assessors, the first preferring concert halls with loud, enveloping and reverberant sound. The second group preferred concert halls that render intimate and close sound with high definition and clear sound. All assessors dislike the concert halls with weak and distant sound. The best co-rrelation with average preference ratings of all assessors was found to be with subjective proximity. None of the standardized objective room acoustical para-meters could explain the proximity and preference data.
To stablish a metho-dology to define valid evaulation scales for different collectives and determine evalua-tion criteria related to the overall assessment of music hall acoustics. To detect and try to improve emotional response, link to phy-sical parameters and finally translate it into design elements that improve the overall quality of music halls	-	Questionnaire in 5 point-Liker scale.	Differential Semantics within the frame of Knasei Eginee-ring . ANOVA	17 concert halls in situ	No lab conditions because they cannot repre-sent real settings with 100% reliability.	The identification of these independent attributes is very important in order to be able to relate, in a subsequent phase, the perceptions with the physical parameters that detenrmine them, SD is the first step in the Kansei methodology whose ultimate objective is to understand the relationships between physical variables and perceived music.

Year	Author/s	Paper Title	doi	Type of publication	Coverage	Sample Type	Sample Size
2011	Lokki et al.	Concert hall acoustics assessment with indifviddually elicited attributes	10.1016/j.buildenv.2012.06.008	Journal paper	-	-	20
2010	Frontzak and Wargocki	*Literature survey on how different factors influence human comfort in indoor environments*	10.1016/J.BUILDENV.2010.10.021	Journal paper	-	-	-
2009	Kaarlela-Tuomaala et al.	*Effects of acoustic environment on work in private office rooms and open-plan offices. Longitudinal study during relocation*	10.1080/001 40130903154579	Journal paper	-	-	31
2008	Ryher and Wang	*Indications of human performance and perception under tonal noise conditions on indoor noise criteria*	10.1121/1.2932075	Journal paper	-	-	30

Aim	Objective parameters	Subjective parameters	Methods	Stimuli	Exp. setup	Findings
To obtain sensory profiles fof three concert halls by eliciting perceptual attributes for evaluation and comparison of the halls.	-	Questionnaire	Descriptive analysis. Individual vocabulary tecniques include: Free-choice profiling, the Repertory grid Technique, the Flash profile and Individual vocabulary profiling.	Playing back anechoic symphony musuic from 34 loudspeakers on stage in each concert hall.	Spatial sound reproduction in dark anechoic chamber: 16 loudspeakers in a 3D array.	At least five perceptual dimensions were identified. They are reverberance related to the size of the space, enveloping reverberance, width of sound, loudness/distance, and definition. Neither TS nor C80 could predict well the judjed definitio or clarity for the used samples.
How the indoor environment in buildings affects human comfort.	-	-	-	-		The acoustic comfort is affected by the country of origin.
To determine how the perceived work environment, especially acoustic environemtn, and its effects idfferend in private office rooms and in open-plan offices.	Long-term SPL; speech propagation	Bakground questions concerned age, gender, level of education, job title, etc. Also, questions regarding typical strss-induction factors were asked, e.g. possibilites of influence, support from others, etc.	Statistical analysis of questionnaires	-	Questionnaires 2 months before the relocation of the new office.	Negative effects of acoustic environemnt increased significantly, including increased distraction, reduced privacy, increased concentration difficulties and increased use of coping strategies. Self´rated loss of work performance because of noise doubled. The open plan office is not recommended for professional workers.
To investigate the differences in task performance and perception under six non-time-varying ventilation -type background noise spectra with differing tonality.	Objective measures of tonality	Subjects completed three types of performance tasks (typing, reasoning, and math) and answered questions about their perception of the indoor environment under each noise concition	Six sessions of 55 minutes at the same time all days if possible.		Six tonalities ventilation systems	Performance socres did not change significantly across the six noise conditions, but there were differnces in subjective perception, perception trends for tonality, annoyance, and distraction changed based on the frequency and prominence of discrete tones in noise.

Year	Author/s	Paper Title	doi	Type of publication	Coverage	Sample Type	Sample Size
2007	Astolfi and Pellery	*Subjective and objective assessment of acoustical and overall environmental quality in secondary school classrooms*	10.1121/1.2816563	JOURNAL PAPER	-	-	1006
2005	Jensen and Arens	*Acoustic quality in office workstations, as assessed by occupant surveys*	10.1080/00140 130903154579	Journal paper	-	-	23450
2003	Sheridan van Lengen	*Hearing architecture. Exploring and designing the aural environment*	https://doi.org/10.1162/1046488037705 58978	Journal paper	USA	Architectural students, in fall of 2000. University of Virginia	-
2001	Kuwano et al.	*Auditory and visual interaction int he aesthetic evaluation of environment*	10.2190/MDF0-1CNE-Y4UW-VNQN	Journal paper	-	-	52

Aim	Objective parameters	Subjective parameters	Methods	Stimuli	Exp. setup	Findings
Correlation between speech comprehension and acoustical quality	LspaA1, L, RT, RTu, LspA, SNR, SNRa, STI	Quesionnaire: general information and environmental quality, acoustical quality, thermal quality according EN ISO, visual quality, overall quality.	Subjective survey	-	-	It was confirmed that sound-absorption treatments are necessary also in small occupied classrooms in order to obtain optimal RT. Acoustical satisfaction was lower in nonrenovated classrooms, and one of the most important consequences of poor acoustics was the decrease in concentration.
To analyze acoustic satisfaction in office environmnets in buildings	The Occupant IEQ survey asks those respondents who have indicated dissatisfaction with noise level or speech privacy to identify problems contributing to this dissatisfaction.	The subjective analysis correlates the distribution of noise level or speech privacy votes with a particular aspect of the office environment.	-	-	-	People are significantly more dissatisfied with speech privacy than noise level. Occumpants in private offices are significantly more satisfied with the acoustics than occupants in cubicles. Occupants in open office environemnts are significantly more satisfied than the occupants of either type of cubilce with noise and speech privacy.
Historic revision of sound and architectural design. Architecture schools often teach acoustic design as part of a core curreiculum, but to our knowledge, very little exploration has been done in the studio using sound as a generative thesis for design.	-	-	Introduce students to the mechanical and cultural aspects of soudn, and apply to design.	-	Historical overview, spaces evoking a personal memory, soudn inventories, recording, design.	The most challenging aspects of this kind of studio is to effectively present an intended acoustical result.
The effect of visual scenery on the subjective impression of environmental soudns was investigated.	-	7-point semantic differential scale was used.	Two contidions, Participants were then asked to judge the impression of the auditory stimuli.	Motion pictures recorded together with sounds.	Screen	The impression of environmental sounds, especially in the aesthetic sense, is dependent on the perceiver's knowledge of sound sources. Scenery that included green plants contriubtte to the improvement of the environment even when the plants were only visual image.

Year	Author/s	Paper Title	doi	Type of publication	Coverage	Sample Type	Sample Size
1995	Soulodre & Bradley	*Subjective evalua-tion of new room acoustic measures*	10.1121/1.411951	Journal paper	North America	Extensive musical training and all had previous expe-rience in critical listening experi-ments.	10
1991	Ando	*A theory for indivi-dual preference of desingin the sound field in a concert hall.*	10.1121/1.401566	Journal paper	-	-	-
1979	Ando et al.	*Subjective preferen-ce tests for sound fields in concert halls simulated by the aid of a computer*	10.1016/0022-460X(79)90516-9	Journal paper	-	-	10-15

Aim	Objective parameters	Subjective parameters	Methods	Stimuli	Exp. setup	Findings
The present paper reports the results of a series of experi-ments desgnied to examine the suitability of various objective measures as predictor of subjective ratings.	RT, EDT, C80, G, LF, IACC	Loudness, clarity, reverberance, bass, treble, envelpment, apparent source width and overall preference	Dou-ble-blind paired compa-risonss. Eight separate listning tests.	15s pas-sage from over-ture of Mozart's "Le Nozze di Figaro". Convlou-tion of the music with the IR from halls	Omnidi-rectional (dodeca-hedron) sound source for IR mea-surement. Head and torso simulator.	Correlation between clarity and treble. Importance of EDT as a predictor of sub-jective reverberance. Loudness significantly related to overall G va-lues. Clarity was found to correlate well with midfrequency values of both C80 and TS.
-	-	-	-	-	-	For the majority of listeners, probability index (PI) is defined by PI = P(B < A)/P(B > A), 0<PI < 1.0. If P(B > A) = 0.5, then PI=1.0, which implies the most preferred condition.
-	-	Subjects jud-ging which of the sound files they preferred to hear. Prefe-rence scores were obtained for each pair by givin scores +1 and -1 correponding to positive and negative judgments, repectively.	Paired compari-son tests of the sound fileds were conduc-ted for changes in the ACT of the music motifs.	Simula-tions of sound fields. Rever-beration free music signals were fed into the digital computer.	Louds-peakers	The most preferred initial time delay betweenthe direct sound and the first reflection has been found to be related tot the autocorrela-tion fuction of sound source signals and the total amplitude of both early refections and the subsequent reverberation.

Case study

Evaluating instruction in architecture design trhough sound. A pilot study

Introduction

Even after decades of research, space perception effects on architectural design remains the subject of active investigation, indicating that it is a challenging problem. Visual perception distance, as an example of those multiple research lines in the topic, is still far from a fully understanding of some fundamental issues, such as the mapping between physical and visual perceived space. Another approach to the same problem has focused in colour and light as affecting the spatial perception). Therefore, it is very common to find a wide range of experiments comparing between visual perception form real to simulated environments, perceived walking perception or even the subject's experience depending on visual perception. Still more focused on the big problem of its effect on architectural design, some authors studied how the form perception revealed the mechanism of creating emotional response associated with semantic capacity of design object and special features of its visual organization.

However, there may be a different approach to this hard topic if the focus is not just on the visual aspects of architectural designing. Acoustic spatial perception presents some advantages in front of visual spatial perception that may help in the research. The main advantage is the wide range of design possibilities that sound and soundscape can suggest. Due to the spatial ambiguities that sound can create, the spatial precision concluded by sound is not as high as the visual one. This fact fosters the range of spatial dimensions that each subject can perceive acoustically.

In recent years, the influence of acoustics on architecture students has been studied. Sheridan and Van Lengen conducted an educative study in which the students experienced the acoustic properties of different spaces in order to make an architectural design proposal. Michael Fowler teaches architectural students about the importance of sound in cities and encourages them to make urban design proposals to generate particular acoustic conditions. Cerwén explores how urban soundscapes can be altered through the design of outdoor space by students. These investigations reveal the potential of sound in architectural education but none of them deepens into the question of how this sound influences the way architects can design.

This research aims to answer the following question in the architectural design framework: does their acoustic spatial perception influences in the way architects design architectural acoustic environments? This issue can be divided into two separate problems. One is the question whether are there different kinds of acoustic spatial perception: spatial acoustic perception is not the same for everybody and this may lead into different patterns of acoustic spatial perception. The second problem, that follows the first one, is whether these patterns of acoustic spatial perception influence the way they design an architectural environment. The present paper addresses both questions in an experiment done to architectural students.

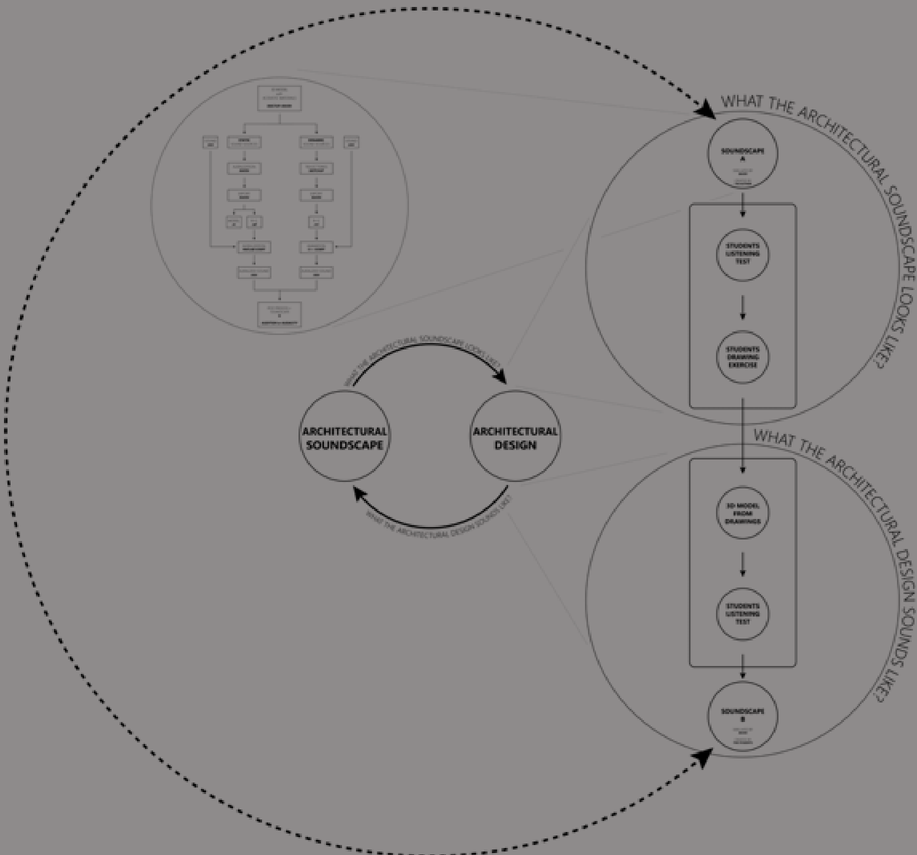


Fig. 1. In the general overview of the experiment, the two directions of the main question can be identified: Are there different kinds of acoustic spatial perception (up-right circle)? Do they influence the way architectural environments are designed (bottom-right circle)?

Background

Acoustic spatial perception

Acoustical spatial perception is rooted in the individual acoustic perception of spaces. Spatial sound perception is an important research topic in the field of acoustics. To address this topic, objective and subjective methods are commonly employed. Objective metrics to characterize acoustic spatial properties of spaces have been developed during the last decades (Lateral energy, etc.), but they are far away from the individual perception of spatiality of sound. Subjective evaluation methods are therefore a common option in such cases. Different perceptual evaluation methods can be considered in practice, e.g. preference tests to assess the individual tendencies in evaluating hall acoustics; attribute elicitation to assess the acoustic differences between seats in one hall; adjective characterization to analyse whether architectural variables affect acoustic perception in concert halls.

Descriptive analysis techniques such as the Quantitative Descriptive Analysis (QDA) methodology (reference 4 from Lorho 2005), the Spectrum Method (reference 5 from Lorho 2005) and the Free Choice Profiling method (FCP) (reference 6 from Lorho 2005) are commonly used for sensory profiling of food products. In the recent years, they have been used also for sensory profiling of architectural acoustics. These three methods are based on the same idea of quantitative description of a set of stimuli, but they differ considerably in terms of attribute development process. In the QDA case for instance, a panel of assessors develops a set of common perceptual attributes to describe the sensory properties of the stimuli under investigation. Standard methodologies have been developed for this type of consensus vocabulary development process and this method has proved to be successful in the food industry and also in acoustics preferences. In the FCP, each assessor develops his or her own set of attributes, which removes the need for construct alignment between the assesors and this method has proved to be successful in the acoustics preferences. Other methods such as Multifactor Analysis (search for reference) has been also used for correlation between objective parameters and subjective perceptions in concert halls acoustics As it can be proven, the tendency of the last studies regarding the subjective perception of architectural acoustics, is weighted towards the elicitation of attributes: different items (such as different concert halls or different seats in the same concert hall) are evaluated by the listeners in the same conditions (e.g. the same sample of music recorded for different receiver positions). The research question of this study, however, is not focused in the differences between the subjective acoustic taste perception, but in the differences between the subjective acoustic space perception. As such, drawing the perceived acoustical space consists on the first stage of the questionnaire, which will be followed by the characterization of the subjective acoustic parameters.

The spatiality of an architectural environment has got acoustic repercussions. We can acoustically perceive an architectural environment as very spacious or as not very spacious. To perceive this spatiality we have two ears separated by a distance of about twenty centimetres. Just as the separation between the two eyes allows for a three-dimensional view of reality, so the separation between the ears allows for the perception of the three-dimensional reality of sound. It is the difference between the sound that reaches the left ear and the one that reaches the right ear that allows us to reconstruct the spatiality of the environment. For example, if you listen to two sound sources that are located in front of the listener separated by only a few millimeters, you will not perceive a spatiality between them. On the other hand, if the two sound sources are located on either side of the head, we will perceive a clear spatiality between them.

In this context, in front of a single sound source, architecture will reinforce the sense of spatiality if it distributes the sound rays so that the left ear has significantly different information than the right ear. Conversely, architecture can also cancel out the sense of spatiality if it distributes the sound rays so that both the left and right ear have the same information at the same time. Some studies have shown that spatiality is closely related to the lateral faces of the room (reference). Therefore, and as can be assumed, acoustic spatiality is closely linked to the geometry and materials of architecture. This is the fact that makes it possible to relate acoustic spatiality with geometric or spatial spatiality.

The objective parameters that measure the spatiality of the room are IACC and LF. In particular, Lateral Energy Fraction (LF) is defined as the ratio of sound energy arriving laterally and sound energy arriving from all directions. This objective parameter characterizes the room for a receiver point and a transmitter point.

In our experiment, spatiality has been analyzed in three aspects:

1. the spatiality of the basic architectural environment has been extracted, which all the students listened to. That is a target value for each sound source for the same listener who does not move, that is, who is subdivided into four different values.
2. The spatiality perceived by each student before each sound source has been extracted by means of a questionnaire asking for "spatiality" and evaluating it from 1 to 7 on the following scale:
3. The spatiality of each environment drawn by the students for each of the four sound sources has been extracted. Spatiality has been extracted both acoustically and spatially.

The necessary correlations are: 1) the correlation between the spatiality perceived by each student in the questionnaire, with the acoustic spatiality drawn by each student; 2) the spatiality perceived by each student in the questionnaire, with the geometric spatiality drawn by each student.

Architectural features

In a correlation between the subjective acoustic parameters and architectural features was done. Thirteen architectural parameters were used such as absorption, area, height, length, volume and width. These parameters are very useful for acoustic characterization of the studied environments. Nevertheless, they do not provide a clear definition of the spatial distribution of architectural environments. Following this line, in recent studies were subjective and objective parameters were correlated, subjective expressions characterizing architectural environments were used (Galiana et al. 2016). Adjectives like versatile, good interior circulation, formal or wide were used. However, these last adjectives do not address an objective quantification of spatial properties.

The spatial configuration of the drawings of the students was analyzed using space syntax analysis. For this purpose, space syntax analysis provides an objective and space-based characterization of architectural designs. Space syntax is a graph-based theory and method describing the spatial characteristics of buildings, cities and spaces by producing accessibility maps and measuring topological, metric and angular relationship between different elements of the spatial network.

Methods

Study participants

42 subjects participate into the experiment. They are aged between 19 and 35 years old with a SD of 3,28. 45,2% of the participants were men. All participants are architecture students, so they are considered trained participants. 45,2% of the students work during their architectural studies.

Regarding their background education, 26,2% of them have no musical education; 61,3% of them have elementary musical education and 9,5% have professional musical education. Their everyday architectural drawing techniques can be explained as follows: their frequency of use of "axonometric perspectives" has a median of 3 (once a semester); their frequency of use of "conic perspectives" has a median of 3 (once a semester); their frequency of use of "plans, elevations and sections" has a median of 7 (everyday); their frequency of use of "hand-made drawings" has a median of 6 (once a week); their frequency of use of "computer drawings (CAD)" has a median of 7 (everyday); the frequency of use of "photorealistic computer render" has a median of 4 (once a trimester).

The students were also categorized by their referents when designing an architectural environment in the following way:

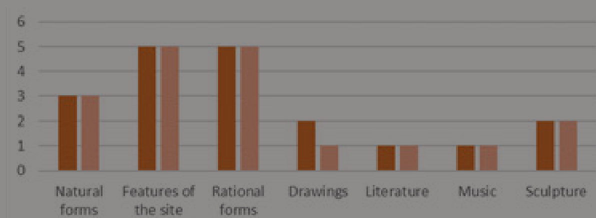


Fig. 2. References from features of the site and rational forms have the biggest median and mode, compared to references from drawings, literature and music.

Listening-Design test procedure

The first step in the test was an individual audiometry. All participants in the test had normal hearing.

The second step in the test consisted of a headphone calibration.

The third and main part of the test consisted in the so-called Listening-Design Test. This was done by the architectural students under the following conditions: a short duration soundtrack could be individually reproduced as many times as desired by the student. During the duration of the test (total: 45 minutes) they were allowed to sketch and draw the suggested architectural environment by the soundtrack on A4 and A3 sheets of paper. On the A4 sheet, a ground plan and a section of the

#. Soundscape track listened by the students in this experiment.

listened environemt was required. They could draw them with a pencil and a ruler on a grid of 1 x 1 meter. This task lasted 15 minutes. On the A3 sheet, an axonometric military perspective of the listened environment was required. They could draw it with a pencil, a straight ruler and a square ruler. They could include in the drawing geometry, materials, shadows, people, objects, vegetation, etc. They should include in the drawing a graphical scale, soundsource and listener positions. This task lasted 30 minutes. The soundtrack consisted of a sequence of sounds lasting 1 minute and 49 seconds. It contained the recording from a receiver point in a hall. The environment where the sound sources and the receiver point were situated was modelled in 3 dimensions in Sketchup and subsequently auralized () in RAVEN (). The soundtrack contained four sound sources plus one fixed receiver. Two of the four sound sources (the guitar and the people talking and driking) were static and the other two were dynamic (the steps on the staircase and the squeezing woman). Fig. 1 shows the auralization process.

The fourth step was a distance-perception test. It consisted of comparing two sounds of the same melody played from two different distances to the listener. The first melody was played at 2 meters from the listener, whereas the second melody was played at a distance that the listener should perceive and mark in a slider on the screen of a laptop. There were 3 groups of 7 samples each, that is a total of 21 samples with 20 second pause between the three groups to avoid fatigue.

The fifth step consisted of a space-perception test. It consisted of comparing two sounds of the same melody played in two different places. The firs melody was played at 2 meters in a fixed environment, whereas the second melody was played at a distance that the listener should perceive and write on the screen of a laptop. Additionally, the second melody was played in a different environment that the listener should perceive and mark in the seven options that were given to him (bathroom, living room, foyer, classroom, concert hall, cathedral and canyon). There were 3 groups of 7 samples each, that is a total of 21 samples with 20 second pause between the three groups to avoid fatigue.

The sixth step consisted of an architectural knowledge test. The questions regarded the frequency of use of "axonometric perspectives", "conic perspectives", "plans, elevations and sections", "hand-made drawings", "computer drawings (CAD)", "photorealistic computer drawings (render)". They also asked about the frequency of taking references for their architectural designs "from natural forms", "from features of the site", "from rational forms", "from drawings", "from literature art", "from music". One last question was about the frequency of reading books and the frequency of imagination of the spaces described in the read book. All questions were evaluated in a 7 Likert scale (1. Never, 2. Once a year, 3. Once a semester, 4. Once a trimester, 5. Once a month, 6. Once a week, 7. Everyday)

The seventh step consisted of a personality test. It followed the lines of the Sixteen Personality Factor Questionnaire (16PF) developed by Catell in 1946 (13, 14). It analyzed the following parameters in a 7 differential semantic scale: warmth (impersonal –

attentive to the others), reasoning (concrete thinking – abstract thinking), emotional stability (affected by feelings – emotionally stable), dominance (submissive – dominant), liveliness (taciturn – animated), rule-consciousness (diregard rules – rule conscious), sensitivity (objective – sentimental), vigilance (trusting – suspicious), abstractedness (practical – imaginative), apprehension (self-assured – worried), openness to change (traditional – experimental), self-reliance (group-oriented – solitary), perfectionism (unexacting – perfectionistic), tension (relaxed – high energy).

The eight and last part of the test was the subjective acoustics test. The four sound sources contained in the studied soundscape were separately presented to the subject to evaluate nine subjective acoustic parameters on a 7 Likert scale: loudness (1. Imperceptible, 2. Very quiet, 3. Quiet, 4. Neutral, 5. Loud, 6. Very loud, 7. Harmful), clarity (unintelligible, 2. Very unclear, 3. Unclear, 4. Neutral, 5. Clear, 6. Very clear, 7. Extremely clear)

Further research

The statistical results of this pilot study will be presented in a journal when finished. The graphical results of the study can be seen in chapter 2 of this dissertation.

Chapter 7

Fundamentals on instruction

The urban luthier

Chapter 7

Fundamentals on instruction

The urban luthier

he present chapter is derived from the work entitled *The urban luthier*. This work was presented by the author as a lecture at the *Academia de las ciencas, las artes y las letras, Jakiunde*, on October the 2nd 2017.

7.1. Introduction

When music is played in an architectural space, what acousticians call "reverberation" is automatically produced, an effect in which music puts the voices and architecture responds with the echoes [1] . Technically, reverberation is the acoustic phenomenon of reflection that occurs in a room when a wave front or direct field hits the walls, floor and ceiling of the room [2] . This phenomenon is clearly perceived by the listener as a small tail of reflected sound that is added after the direct sound and is summarised in a quantifiable parameter: the "reverberation time". Thus, a room with a large "reverberation time" will give a large reverberation impression, and vice versa.

Acoustics have developed precise methods for quantifying the "Reverberation Time". The simplest method, historically used, uses sound impulses in the room, such as a gunshot or a balloon burst. Other methods include the generation of pink or white noise with a loudspeaker and its subsequent sudden cessation [3] . Despite the notable differences between the different methods, they all have one basic principle in common: to generate a loud sound and then to stop producing it and sink into silence. Therefore, two distinct phases can be revealed in this process: the first, when the sound generated is calibrated in all frequency bands, i.e. that it contains a controlled sample of all of them. In this way, the

1 Joaquín Arnau, 'Las Voces y Los Ecos: Sobre Música y Arquitectura', *Palimpsesto*, 2015.

2 'QUE ES REVERBERACION ? | ACONDICIONAMIENTO ACUSTICO | ACUSTICA INTEGRAL' <http://www.acusticaintegral.com/reverberacion.htm> [accessed 30 May 2018].

3 Kristian Jambrosic, Marko Horvat and Hrvoje Domitrovic, 'Reverberation Time Measuring Methods', *The Journal of the Acoustical Society of America*, 123.5 (2008), 3617–3617.

excitement of the enclosure is assured in each and every one of the possible frequencies that the music could produce there. In other words: all the music is represented in the noise in one fell swoop. The second phase occurs when this noise is followed by a great silence. It is usually silent for about twenty seconds. During this time the bounces of the sound emitted in the enclosure still travel through space and reach the listener. This silence, therefore, is not empty, it is not a mute silence. On the contrary, it is the architecture that speaks in this second phase of the measurement.

The history of architecture has seen architects who have known how to perceive this elementary principle. They understood that architecture was a powerful weapon to reinforce and prolong the sound produced in their spaces.

> Capturing and preserving the tissue of living sound was an old ambition. In Babylonian mythology there is a special room in one of the ziggurats in which the whispers remained forever. There is a similar room in the Ali Qapu palace in Isfahan, however, its dilapidated and abandoned state today barely allows us to imagine how it worked. Apparently, its strictly burnished walls and floors gave the sounds an anomalous time of reverberation. An ancient Chinese legend tells that a king had a secret black box inside which he pronounced his orders, then sent them around his kingdom for his subjects to follow. [4]

Then, the mime Schaffer says:

> With the invention of the telephone by Bell in 1876 and the phonograph by Charles Cros and Thomas Edison in 1877, the era of schizophony was introduced. [5]

4 R. Murray Schafer, *The Soundscape: Our Sonic Environment and the Tuning of the World* (Rochester, Vermont: Destiny Books, 1977) Pages 134-135.

5 Schafer.

This elementary principle that we announced earlier could be understood as the natural response to a possible common origin of architecture and music. On the other hand, the era of schizophony, in which the dissociation between what is seen and what is heard was analyzed, put an end to this elementary principle that we have just stated. From then on, music and architecture would no longer meet so naturally in that silence that was not empty. Now there would be a mute silence in its place.

7.2. The genuine origin of architecture and music: the formality of the utensil

7.1.1. The question of the origin of architecture and music

When it comes to dealing with the origin of the different arts, anyone encounters the difficulty of finding historical documents that support a possible theory. Either because the known documents already support some of the theories of the origin of the artistic discipline; or because no document, however old it may be, could consider the first origin of that discipline as settled, since it precedes any desire to document it. In a way, the primitive origin of these disciplines is forbidden to the researcher and there are always two possible attitudes: to trust existing documents or to postulate possible origins.

The first attitude was appropriated by archaeology and massive research on the remote past. The second, thinkers on art. It will not be offered here a detailed overview of what archaeology has contributed to revealing the origin of artistic disciplines. The problem of the origin of art is more anthropological than historical [1] and, without devaluing the contributions that history offers to this field, we emphasize what art thinkers have come to postulate about its origin.

Architecture, in particular, has generated many reflections throughout history. One of the most

1 Francesco Pellizzi, 'Art Historical and Anthropological Translation: Some Notes and Recollections', *Art in Translation*, 4.1 (2012), 9–15; Charlotte Townsend-Gault, 'At the Margin or the Center?—The Anthropological Study of Art', *Reviews in Anthropology*, 27.4 (1998), 425–39 ; Peter Stupples, 'Art History as Anthropology', *Australian and New Zealand Journal of Art*, 2.1 (2001), 147–54.

famous postulates on the origin of architecture was published by Vitruvio in *De Architectura* [1] , where he opted for a mythical origin of the Corinthian capital, the predecessor of all classical architectural orders. In 1755, Abbé Marc Antoine Laugier in his *Essai sur l'Architecture* [2] proposed a change in the conception of the possible origin: a primitive hut that transferred the vegetable language from nature to architecture. Later, in 1860, Gottfried Semper published another postulate for the origin of architecture in his great work, *The Style* [3] , in 1860: his own primitive hut, which was based on textile art.

Jean-Jacques Rousseau was also a theorist who, at the end of the 18th century, sketched one of the first theories on the origin of music, according to which it had been derived from the inflections that the recitation imposed on speech. The music was, therefore, for Rousseau, a direct daughter of the emotion that poetry imposed on language [4] . Darwin, on the other hand, in the 19th century, referred the origins of music to the loving invitation among birds [5] .

Despite the light shed by these theories, the origin of architecture and music remains impenetrable and even makes some questions jump out. By focusing now on the realm of music, we skip the

1 Marcus Vitruvius Pollio, *The Ten Books on Architecture: De Architectura*, 20 aC.

2 Laugier, *Essai Sur l'Architecture*.. 1753.

3 Gottfried Semper, *Style in the Technical and Tectonic Arts, or, Practical Aesthetics*, ed. by Harry Francis. Mallgrave and Michael. Robinson (Los Angeles: Getty Research Institute, 2004).

4 Jacques Rousseau, *Essay on the Origin of Languages and Writings Related to Music*, ed. by T. Scott and T. Scott (Hanover: Darmouth College Press, 2000

5 Peter Kivy, 'Charles Darwin on Music', *Journal of the American Musicological Society*, 12.1 (1959), 42–48.

following: what came before, the need to create music or to experience its joy? Or is it before you know it rather than want to produce it? But who will make music if they don't know it first? Because, knowing the music, you can easily make it. Shall not music, rather, be manifested to be known? But how will they manifest what they have never heard of? And how will they hear if it is not manifested to them? Certainly those who want to make music will make music, because those who seek it will find it and those who find it will produce it [6] .

In a similar way, the same questions arise with regard to the origin of architecture: what came first, the need to create architecture or experience it? Or is it before you know it rather than want to produce it? But who will make architecture if he does not know it first? Because, knowing the architecture, you can easily do it. Is it not rather the case that architecture [7] has to be manifested in order to be known? But how will they manifest what they have never seen before? And how will they see if it is not manifested to them? Certainly those who want to make architecture will make architecture, because those who seek it will find it and those who find it will produce it.

All of this goes some way towards reflecting on the primacy of the origins of artistic disciplines. Something makes us decide that the human being has the primacy as creator and not the disciplines themselves as manifestation, although we must keep to some considerations before launching this

6 From the method of questions of St. Augustine at the beginning of his *Confessions*, I, 1

7 José Ángel Hidalgo Arellano, 'Arquifanía: La Arquitectura Como Manifestación' (E.T.S. Arquitectura (UPM), 2015)

postulate. In fact, the primacy cannot be given to the manifestation of the artistic disciplines themselves, since they need someone to create them. In this context, the notion of culture against nature (seeking reference) makes sense, according to which it is defended that everything created by man -culture- is opposed to what is created naturally -nature-. Therefore, man seems to have primacy as long as he has known some property in natural things that has served as a model to produce cultural things. If man only has nature given to him to produce the invented culture, he needs to extract some property from nature that serves him to create something new, as well as to differentiate himself from what already existed naturally. And if nature is distinguished from the culture in which the former is given while the latter is produced by man, the only thing that can be common to both is their capacity to conform as entities. In other words, man will only be able to make the qualitative leap from nature to culture if he is able to extract from nature what he does not define as natural even though he is always in it, that is, his capacity to be shaped by a creator, independently of his matter, that is, his form. (We already discussed the form in the first chapter of this dissertation)

But before going into this concept, it is necessary to observe an intermediate element between nature and culture, an element that rides between what is given as a cavity in the rock -the cave- and what man creates to protect his family from the wind -the house-. It's about the utensil.

7.1.2. The utensil as a common origin

Professor Antonio Armesto, in his lessons on Project Theory, defended the following:

> A very archaic form (of a granary), of enormous interest from the point of view of the theory of architecture, persists. These are "cabazos" , which are large baskets lifted from the floor on a table, pillar or pedestal and protected by a cover or lid. This type of barn, an agricultural utensil, is an exemplary model for architecture, founding some of its characters. In particular, the tripartite order has never shown its raison d'être more clearly than in any of these modest Galician-Portuguese or African "cabazos": between the base and the attic is the empty space for life to take root, for its protection and conservation. (...) We postulate the "cabazo" as a genuine primitive hut. [1]

But not only Antonio Armesto refers to the origin of architecture from the tool. The well-known myth of Calimachus inventing the Corinthian capital does not fail to show an origin from a useless tool: the basket. According to this myth, Calimachus (Calimachus), known by the nickname of Catatechnos (first architect) for the delicacy with which he carved the marble, was looking for inspiration for a commission of columns that the city of Corinth had made him. Calimachus was fascinated by the beauty of the new shape produced by acanthus leaves that wrapped a basket deposited on the tomb of a maiden. The acanthus leaves climbed up from the base of the basket, which was covered with a brick, forcing the leaves to curve. The design was very much to the liking of the Corinthians, who began to incorporate it into their capitals. The legendary attribution of the origin of the Corinthian capital to the sculptor Calimachus,

1 Antonio Armesto, 'Los Hórreos de La Península Ibérica. Breve Ensayo Sobre El Ethymon de Lo Monumental En La Arquitectura' (CSI-CSIF Sevilla)

collected by Vitruvius in his *Ten books on architecture* [1] , was repeated by later writers. Leon Battista Alberti in *De Re Edificatoria* [2] . He takes up again that the Corinthians came to bring the third order at the initiative of Calimachus. Vignola also welcomes the theory of the origin of the Corinthian capitel as a basket entangled in acanthus leaves [3] . Vitruvio's multiple translations repeated over and over again the belief in the myth of Daniele Barbaro in 1556, illustrated by Palladio. However, the delicacy and, above all, the ease with which the work was carried out made one think of a primitive work of metal work embedded in the stone. Choisy [4] and Chipiez [5] observed that it could have been derived from a previous work of forging and embossing of a crown of leaves attached to the capital. This interpretation is not new; in the seventeenth and eighteenth centuries it was also opposed by several writers; Caramuel was critical of Vitruvius because in his texts those who could not differentiate between the Corinthian and Ionian order could be based [6] ; however, Ortiz and Sanz commented that the Corinthian order never had credit among the Greeks for not finding a single capital of this order in Corinth [7] .

Fig. 1. Representation of the Calimacus mith. Roland de Chambray, *Parallele*, 1650.

Fig. 2. Representation of Calimacus mith. Edward Francis Burney (1760-1848).

1 Vitruvius Pollio.

2 Leon Battista Alberti, *On the Art of Building in Ten Books* (London: MIT Press, 1988).

3 Vignola, *Regola Delli Cinque Ordini d'architettura* (Rome, 1562).

4 Auguste Choisy, *Histoire de l'architecture*, 1898.

5 Chipiez, *Critical History of the Greek Orders* (Paris, 1876).

6 Juan Caramuel, *Architectura Civil Recta y Obliqua* (Vigevano, Italy: Emprenta obispal por Camillo Corrado, 1678).

7 Francisco José León Tello and María Virginia Sanz Sanz, *Estética y Teoría de La Arquitectura En Los Tratados Españoles Del Siglo XVIII* (Madrid: Consejo Superior de Investigaciones Científicas, 1994). Page 900.

Pierre Schaeffer, in his *Treatise on Musical Objects*, willingly bet that the utensil and the musical instrument

> they didn't really distinguish themselves and that the same pumpkin must have served indifferently for soup and music.
>
> One pumpkin certainly shouldn't have been enough, but what about two or three? The signal that was sent to the utensil, in the form of a pleonasm, is cancelled by repetition. Only "sound objects" are left that are selflessly perceived and "jump into the ear" as something totally useless, whose existence is nevertheless imposed and sufficient to transform the chef into an experimental musician. [8]

But not only Schaeffer refers to the origin of music from the utensil. Pythagoras' well-known success in the blacksmith's shop does not fail to show the origin of a utensil: the hammer. According to this event, Pythagoras found the basic musical proportions and the tunes derived from them by weighing four of the five hammers that the blacksmiths were using in the forge and obtaining the numbers 12, 9, 8 and 6. In fact, the existing relations between them belong to the basic intervals: 12/6 = octave, 12/8 = just fifth, 12/9 = just fourth, 8/6 = diatessaron consonance, 9/6 = diapent consonance, 9/8 = major tone. Robert Fludd explains in his *Temple Musicae* [9] that the inventor of music before the flood was Tubal; now, why Tubal, if in Genesis chapter 4 Jubal appears instead? In this regard, this chapter is very clear: «And Lamech took two wives for himself; the name of the one was Ada, and the name of the other, Zila. And Ada bare Jabal, or Jabel, who was the father of them that dwell in tents, and bare cattle. And his brother's name was Jubal, who was the father of all who play the harp

Fig. 3. African pumpkins prepared for drum production.

8 Pierre Schaeffer, *Treatise on Musical Objects : An Essay across Disciplines*, 1966th edn (Oakland: Univertisy of California Press, 2017). Page 34.

9 Robert Fludd, *Utriusque Cosmi Historia. Templum Musicae*, 1618.

and flute. And Zilah also gave birth to Tubal-Cain, the maker of every work of brass and iron; and the sister of Tubal-Cain was Naamah» [1] . Already in the book of *Etymologiae* [2] , Saint Isidore says that it was Tubal, thus beginning to develop an endless number of elaborations on the biblical text that give rise to the appropriation by Christian mythology of the Pythagorean event. As proof of this, we will mention only a dozen authors, chosen almost at random and with no intention of going into detail on the subject, from the end of the 15th century to the 18th century. In an anonymous Sevillian manuscript [3] we read that Tubal was the inventor of music and that he had two brothers: Jubal, "the eldest of all shepherds" and "Tubal cayn", the first blacksmith. The confusion, as we can see, is complete; however, he then refers in detail and with complete fidelity to the invention carried out after the Flood by Pythagoras. Bermudo [4] tells us that "Tubal found the musical proportions to the sound of his brother Tubalcayn", to state categorically later on that it was not Pythagoras who was the author of this fact. Hernando de Cabezón, in the introduction to his father's Works [5] , says only that the inventor of music was Jubal. Similarly Marín Gómez de Herrera [6] believes. Francisco de Montanos [7] opt for

1 Genesis 4:19-22.

2 Isidoro de Sevilla, *Etymologiae*, 625.

3 Anonymous, *Tratado de Canto Llano, Contrapunto y Canto de Órgano* (Sevilla, 1480).

4 Fray Juan Bermudo, *Decralaración de Instrumentos Musicales* (Osuna, 1555).

5 Hernando de Cabezón, *Obras de Música Para Tecla, Arpa y Vihuela de Antonio de Cabeçon...* (Madrid, 1578).

6 Marín Gómez de Herrera, *Advertencias Sobre La Canturia Eclesiástica*, 1580.

7 Francisco De Montanos, *Arte de Música Teórica y Práctica* (Valladolid, 1592).

Tubal. Fernando de Escalante [8] refers that Tubal, delighted by the sound of his brother Tubalcaín working with iron, deduced from the weights the proportions and musical tunes. Cerone [9] places special emphasis on the fact that it was Jubal and not Tubal who invented music: "The way, he says, how Iubal found the proportions was this one, entering one day in the forge of Thubal Cayn his brother, first inventor of the forge...", and then he explains in detail what we already know about Pythagoras; but later he repeats exactly the same story applying it to this one and affirms that both could very well find the same tunes by the same procedure (Jubal and Pythagoras), although at different times. The identification is now complete. Kepler [10] offers us another variant: for him Jubal is Apollo, who with the zither, whose string he has obtained from his brother Blacksmith Tubal-Cain (Vulcan), defeats or another brother Jabel (Pan), a shepherd who plays the "fistula agrestis". Independently of this he mentions Pythagoras and his hammers. Mersenne [11] , denies that he was the inventor of the music, a task he transferred to Jubal, who heard and weighed the hammers of Tubal-Caín, etc. Salvador de Arellano [12] says that "it was the old Iubal, or Tubal (that everything is one)..." who invented it; and, later on, that he had another brother, Tubal-Caín, "inventor of the tools of the blacksmith's shop and the art of melting bells and all the other metal things, to the sound of which Tubal, his elder brother, was delighted to extract from his blows..." He tells us

8 Fernando De Escalante, *Clypeu Concionatorum Verbi Dei* (Sevilla, 1612).

9 Cerone, *El Melopeo y El Maestro* (Naples, 1613).

10 Johannes Kepler, *The Harmony of the World*, Universal (Frankfurt, 1619).

11 Marin Mersene, *Quaestiones Celeberrimae in Genesim* (Paris, 1623).

12 Hermano Joan Salvador De Arellano, *El Psalterio de David* (Jerez de la Frontera, 1632).

the story of Pythagoras. Juan Ruiz de Robledo [1] establishes perfectly, however, the difference between Jubal and Tubal-Caín, adhering briefly to Genesis. In Kircher [2] we find Jubal, on the one hand, and Pythagoras with his blacksmith shop, on the other. Nassarre [3] , after saying that Pythagoras was the first to find the musical proportions by the sound of hammers in the forge, etc., he gathers the two currents of opinion according to which he makes himself the inventor of these proportions to Jubal or Tubal-Cain, and concludes by saying that, although the Holy Scripture proves that it was Jubal, it is easy to suppose that he entered the blacksmith's shop of his brother Tubal-Cain and, on hearing the sound of the hammers, made the same test as Pythagoras with the same result. An anonymous testimony [4] assures that chapter 4 of Genesis makes Tubal "the inventor of those who sang with zither and organ: and even from his name (according to the Latin language) it can be inferred that he was of those who make it with clarion or trumpet, because the trumpet is called tuva in Latin and he is called Tubal" [5] .

In both cases, in architecture and in music, attention is paid to the formality of the utensils, disassociating them from their useful fatigue. In the case of the pumpkin, the useful fatigue of hitting it, opening it and feeding it is eliminated. In the case of the basket, the useful fatigue of transporting and storing it is

1 Juan Ruiz de Robledo, *Laura de Música Eclesiástica*, 1644.

2 Athanasius Kircher, *Musurgia Universalis* (Rome, 1650).

3 Pablo Nassarre, *Escuela Música Según La Práctica Moderna* (Zaragoza, 1724).

4 Anonymous, *Historia y Origen de La Música y Canto Llano*, 1764.

5 Robert. Fludd and Luis Robledo, *Escritos Sobre Música* (Madrid: Editora Nacional, 1979). Pages 37-42.

eliminated. A universe of relationships without matter, which we call form, is then revealed. This universe dispenses with the material, leaving naked only that which sustains that matter. Formality, therefore, will be the noun that designates the capacity of things to manifest their form [6] .

And once the usefulness of them has been eliminated, that useless formality will create the aesthetic enjoyment. When the formality remains useless, the fatigue disappears, giving rise to a wide range of possibilities: the rubbing of the burnish gives way to the stringed instruments, the blowing of the glass gives way to the wind instruments, the pounding of the anvil gives way to the percussion, to name but a few actions of the musical world.

Seen in this way, the origin of architecture and music lies in a formality operation.

6 Antonio Armesto, 'Entre Dos Intemperies. Apuntes Sobre Las Relaciones Entre El Foro y El Mercado.', *REVISTA Proyecto, Progreso, Arquitectura*, 15.2 (2010), 14–23.

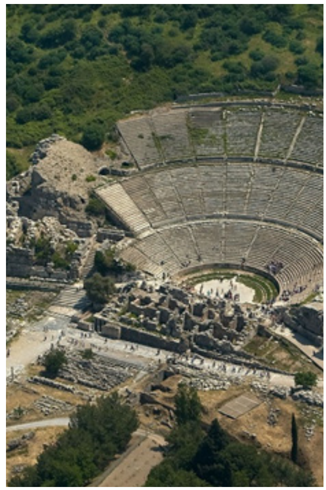
7.3. The progressive split between architecture and music.

This util-i-form origin that we have just shown, far from being a historical reading of reality, aims to emphasize the formal character of the origin of both architecture and music. It is, therefore, the extraction of the shape of the utensils that allows architecture and music to originate. In this way, both disciplines participate not from a mythical or imaginary historical origin, but from an origin that predisposes them to develop as what they really are: constructors of form - one spatial and the other temporal. The story contains numerous examples of situations, times, characters and places where this conception, if not consciously present, does at least intuit an awareness of their common origin and complementarity. However, we are currently seeing a change in this paradigm. Such awareness no longer exists and, more seriously, it has been suppressed in pursuit of a technological current that has come to replace the role of architecture in music and, vice versa. Next, we review the history of architecture and music to show the progressive split between them.

For the Greeks, measure and balance were what every citizen of the polis had to look for, in contrast to what was known about the barbarians. Therefore, in the moral application of this concept, the excess, the "lack of measure", is the "hybris" ("disproportion"), the greatest and most horrendous sin that could be committed [1] . In this sense, and according to Theophrastus, and recovering the arguments given by Pythagoras, "the principles of forms (geometric) are the numbers, insofar as they

1 Gastón Clerc González, 'La Arquitectura Es Música Congelada.'

determine the symmetries that we call "harmonies" [2] . Therefore, everything harmonious, i.e. not subject to any'hyperbolé', is governed by the'just measure' ('metron') and the'arithmetic ratio' ('arithmos symetros'). In this way, music as a discipline that imitates inner emotions (Plato) by interpreting the inner rhythm of the Soul offers its "harmony" in the right measure between sounds. Architecture, on the other hand, as a discipline that composes the "right proportions" for buildings, seeks the "harmony" in the right measure between the forms. In this way, a disciplinary vision was fostered in which both arts contributed to the promotion of that harmony sought by the citizen of the polis: one giving form to sound and time and the other giving form to matter and space. In addition, the Greeks were among the first to examine the phenomenon of sound, considering how it spread through space and questioning why it behaved differently in different types of spaces. The remains of his works remain as witnesses of an architecture that precisely controlled the functioning of sound. Thus, the ruins of theatres such as Epidaurus or Ephesus never cease to amaze by the precision and quality of the sound produced on stage, even to the spectator. Vitrubius, a first century B.C. scholar. In his treatise *De architectura* [3] he wrote references and concepts about the study of the acoustics of open-air theatres. This initial knowledge was applied mainly to promote the efficiency of voice transmission to the public and to seek the appropriate intelligibility of it [4] .



2 Edgar de Bruyne, *Historia de La Estética*. (Editorial Católica, 1963). Page 13.

3 Vitruvius Pollio.

4 Cristina Palmese and José Luis Carles, 'Música y Arquitectura', *Scherzo: Revista de Música*, 20.193 (1985), 113–33.

Fig. 4. Theatre of Epidaurus.

Fig. 5. Theatre of Efesus.

Following the tradition of Hellenism, the Romanesque took up the same concept of harmony as equilibrium. In the Romanesque church the cosmogonic vision of the unity of the universe is understood. "The Romanesque church, as a mirror of God and Creation, teaches the knowledge of itself and of the Universe. Man learns how to respond to his vocation as man, and the essential gesture is taught not only by symbolic images, but by the Art of building itself (that is, by Architecture). Here, in the Romanesque church, this Art is related to Mathematics, Music and Poetry, everything is Rhythm" [1] . Thus, the task of the musician in measured polyphony ("música mensurabilis") is to "compose" or "ordinare" a voice that already exists (the tenor) with its melodic structure applying a rhythmic organization of modes and orders. The construction of the polyphonic structure proceeds like the construction of a building: first the main parts and the choice of forms, and then the secondary parts. The meaning of the construction is expressed by the comparison of the'tenor' with'the foundations on which all the other parts of a building rest' [2] . In Gothic times, the relationship between music and cathedrals was not only acoustic, since both were an expression of the concept of cosmic order typical of the Middle Ages. Once again, the Pythagorean relationship linked to the musical consonances, the first known studies on sound, was taken up again. Pythagoras, who studied the relationship between the length of a vibrating body and the height of sound, and thinking that a body moving at a certain speed produces a sound, developed the

1 Marie-Madeleine Davy, *Initiation À La Symbolique Romane XIIe Siècle* (Flammarion, 2008).

2 AAVV, *De La Antigüedad Al Siglo XIII*, ed. by Andrés Ruiz Tarazona.

concept of harmony of the spheres, which would inspire many authors in architecture and music. According to Nicolás de Cusa, in *De docta Ignorantia* [3] "Thus, the elements have been constituted in an admirable order by God, who created all things in Number, Weight and Measure: The number refers to the Arithmetic, the Weight to the Music (it is remembered the legend that relates Pythagoras with the different weights of the hammers and the harmonic sound that they produce when hitting the blacksmith's anvil or the bronze bell, represented by Atanasius Kircher in his *Musurgia Universalis*), the measurement to the Geometry" [4] .

3 Nicolás De Cusa, *De Docta Ignorantia*. Book II, cp. XIV. (Basel, 1565).

4 Fludd and Robledo. Page 189.

Fig. 6. Robert Fludd. *Musurgia Universalis*.

This cosmic vision that we have been observing since the beginning of what we can know as the history of Western music and architecture, had its maximum expression in the treatises of the late Middle Ages and early Renaissance. Numerous writings on cosmogony, theodicy, geometry, music and arithmetic were written by philosophers, theologians, mathematicians and thinkers, including those of Johannes Kepler [1] , Atanasius Kircher [2] , Marin Mersenne [3] , Pietro Cerone [4] in the field of music. In architecture, works such as those of Sebastiano Serlio [5] , León Battista Alberti [6] , Iacome de Vignola [7] , Ioan de Arphe and Villafañe [8] , to name but a few. Many of them bring together different disciplines in the same volume, each of them treating music and architecture as sister arts, often under the umbrella of arithmetic. In this sense, he highlights a text, not so well known, that offers a theory of music in the light of a hypothetical architectural construction. This is Robert Fludd's *Temple of Music*. While Fludd (1574-1637) has been overlooked by musicologists mainly for having been written in Latin and for his immersion in his monumental history of the macrocosm and microcosm, his writings came into controversy with two prominent naturalist philosophers, Johannes Kepler (1571-1630) and Marin Mersenne (1588-1648). Kepler and Mersenne - like Flanders -

1 Kepler.

2 Kircher.

3 Marin Mersene, *Traité de l'harmonie Universelle*, 1627.

4 Cerone.

5 Sebastiano Serlio, *Seven Books of Architecture* (Paris, 1537).

6 Leon Battista Alberti, *De Re Aedificatoria* (Florencia, 1485).

7 Vignola.

8 Juan De Arphe y Villafañe, *De Varia Conmesuración de La Escultura y La Arquitectura*, 1585.

understood the universe as a harmonic construction. But the critics considered Fludd's opinion to be false and his adherence to the Pythagorean view of the monochord was considered obsolete. This view soon became orthodox, and while all three had become icons of the Scientific Revolution, Fludd was typified and belittled as a defender of a magical and mystical thought that the Enlightenment eventually swept away [9] . This appreciation was further reinforced by the Enlightenment music historian John Hawkins, who discovered that much

9 Peter J. Ammann, 'The Musical Theory and Philosophy of Robert Fludd', *Journal of the Warburg and Courtauld Institutes*, 30 (1967); Robert S. Westman, 'Nature, Art, and Psyche: Jung, Pauli, and the Kepler–Fludd Polemic', in *Occult and Scientific Mentalities in the Renaissance*, ed. by Brian Vickers (Cambridge: Cambridge University Press, 1984), pp. 177–230.

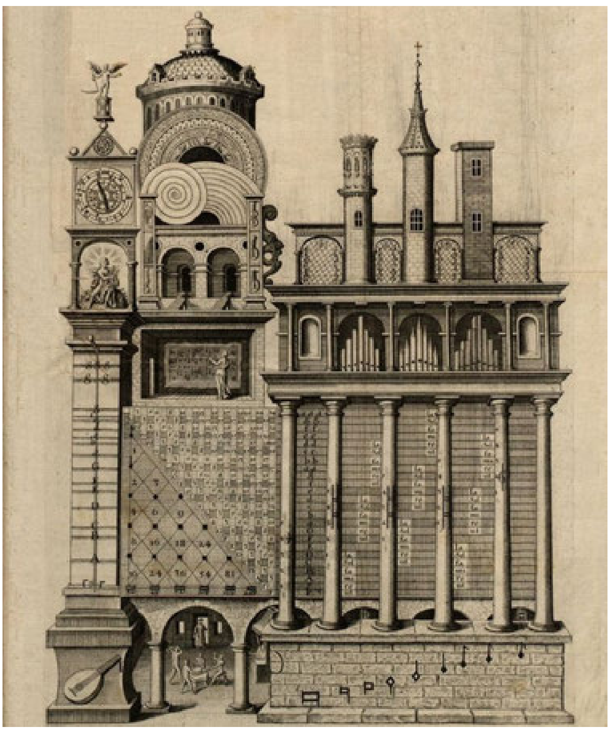


Fig. 7. Robert Fludd. *Temple of Music*.

#. Wolfgang Amadeus Mozart. Symphony n. 40.

of the "Temple" was copied from the English 14th century "Quatuor principalia musicae" .

With Classicism "the idea of formal perfection of reality tends to be expressed with the most absolute force; that is to say, the world tends to be expressed as a beautiful, perfect being and to give through Art the sense of perfection, of tranquility, of the ideal. That is why there is a tendency to give more shape to things, which is what reflects perfection" [1] .In fact, the architectural forms of architectural neoclassicism (17th-18th century) responded to the search for serenity where the parts of the whole were well differentiated from each other. The independence of the compositional elements guaranteed clarity between the parts: this was true of both architecture and music.

In Romanticism, Art "represented, coded and symbolically, the infinite in the finite" [2] , the metrialization of the Cosmic Order and the Music of the Spheres, thus establishing a "new metaphysical dimension" [3] . Perhaps the most important characteristic is the 'constant dissolution of boundaries' between and within the various Arts [4] . In fact, "instead of the classical idea of form, as an interaction between well-defined units (as Vitruvius and Alberti already pointed out) and functionally differentiated ones (thematic, transitional, developmental, cadential, etc.) a new romantic ideal of form emerged as a musical process, as a continuous uninterrupted growth and evolution"

1 Clerc González.

2 Christoph. Jamme, *El Movimiento Romántico* (Akal, 1998). Page 8.

3 Jamme; Antoine Fabre d'Olivet, *Histoire Philosophique Du Genre Humain : Précédée d'une Dissertation Introductive Sur Les Motifs et l'objet de Cet Ouvrage* (Editions traditionnelles, 1991).

4 Jamme. Page 10.

[5] ; which, in a way, is close to the creative process that takes place during the construction of a Gothic cathedral or when approaching the architecture of French Art Nouveau, Spanish Modernism, German Jugendstyl or English Arts and Crafts, all of them belonging to the 19th century [6] . In this way, the sounds of the last beethovens, bruckners and shuberts and wagners, pursued the grandiose materialization of a symphonic and constructive project of architectural dimensions: “to develop, starting from an elementary cell, a structure of ever-increasing dimensions” [7] . For his part, the wagners (Otto), morris, gaudís, muntaners and hortas did not move away from the same idea when they worked on the detailing materialization of projects where

#. Wagner. *Prelude to Tristan und Isolde.*

5 Robert P. Morgan, *Twentieth-Century Music : A History of Musical Style in Modern Europe and America* (New York: Norton & Company, 1991)

6 Clerc González. Page 484.

7 Jordi Ribera Bergós, *Anton Bruckner* (Barcelona: Ediciones Daimon, 1985).

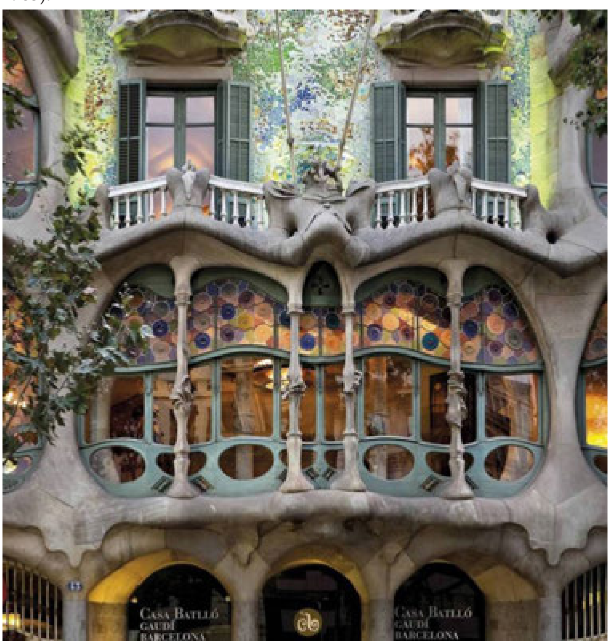


Fig. 8. Antoni Gaudí. *Casa Batlló.* The column transforms in linteln, and again in column, and in balustrade, etc.

the distinction between the constructive elements vanished, offering the image of an indivisible organic whole.

However, the arrival of the twentieth century completely changed the course that had been set so far. As Emily Thompson says in her book The Sound Landscape of Modernity, in the first quarter of the 20th century, the sounds of modernity were the increased result of technological mediation [1] . Scientists and engineers discovered ways to manipulate traditional architectural building materials to control the behavior of sound in space. New types of materials specifically designed to control sound were developed, and were quickly followed by new electro-acoustic devices that gave never before achieved results and converted sounds into electrical signals. Some of the sounds that resulted from these mediations were objects of scientific scrutiny; others were unintended consequences - the noises - of an increasingly mechanized society; others such as music concerts, radio programmes, soundtracks of moving images, were comforts consumed by an acoustically voracious audience. The framework for change was the same for everyone.

Emily Thomson argues that perhaps the most significant result of these physical and cultural changes was the reformulation of the relationship between sound and space. Indeed, as the new sound landscape was forged, sound was gradually dissociated from space until the relationship between the two ceased to exist. The dissociation

1 Emily Ann. Thompson, *The Soundscape of Modernity : Architectural Acoustics and the Culture of Listening in America, 1900-1933* (MIT Press, 2002). Page 2.

began with the technological manipulations of the sound absorbing materials in the construction, and the rupture was completed when the electro-acoustic devices claimed ownership of the sound. As scientists and engineers increasingly engaged in the electrical representations of the acoustic phenomenon, sounds became part of the circuits that produced them without distinction. When electro-acoustic instruments such as microphones and loudspeakers left the laboratory and entered the world, this new way of thinking migrated with them, and the result was that the sounds were re-conceived as signals.

At this point and thanks to the conversion of sound into signals, a new criterion emerged by which to evaluate these sounds, a criterion whose origins, like sounds themselves, were in new electrical technologies. Electrical systems were evaluated by measuring the strength of their signals against the inevitable invasions of electrical noise, and this measure now became the means by which to judge all sounds. The desire for clear, controlled, signal-like sound became pervasive, and any interference with this objective was now manipulated to remove it from existence.

Reverberation, that persistent residue of sound in a space, had always been a result of the architecture that created it. He always occupied that Silence after the music when it stopped playing in a space. It was always a function of both the size of a room and the material that made up its surfaces. As such, it made that signature of each particular place sound, representing the only characteristic (for better or worse) of the space in which it was heard. With the enlargement of the modern sound landscape this was no longer going to happen. Reverberation would now become another type of noise, of the many, unnecessary and better if it were eliminated.

As new, non-reverberant criteria grew, and as the technologies in architecture and electro-acoustic designed to achieve them developed more and more, the sound that those technologies now produced prevailed. The result was that many different places where the modern sound landscape was produced began to sound similar. From concert halls to corporate offices, from acoustic labs to television studio stages, the new sound resonated with everyone. Clear, direct, and not reverberant, this modern sound was easy to understand, but had little to say about the places where it was produced and consumed. Now the Silence that followed the music no longer spoke of the architecture in which it was performed: it was a *Mute Silence*.

7.4. The city as a stage for reconciliation between architecture and music

This phenomenon has been growing to this day. Proof of this are the multiple regulations on acoustics in the building where a type of non-reverberant sound is standardized to all the spaces of daily use, restricting reverberation times or, even, condemning them, “limiting the reverberant noise of the enclosures” [1] . However, despite this restriction of recent decades, music has always developed the concept of sound spatialization, which seems to offer an escape route to this phenomenon linked to *Mute Silence*.

Sound spatialization, or spatial music, tries to explore the possibilities offered by the location of sound sources, even making them a way of composing. As its main objective is the use of spatial properties, it seems to annul, by default, this Silent Mute and to offer, by default, varied games with sound locations and spatial reverberations... This method is not new in our century, although it has had much application in contemporary composition. The composer Giovanni Gabrieli (1554-1612) used the technique of polychorality by placing various choirs inside the Basilica of Saint Mark in Venice. Gustav Mahler, in his second, and eighth, symphonies placed trumpets for the announcement fanfares of the resurrection and endings on balconies far from the audience. This tradition of placing instruments, singers or groups scattered throughout the envelope of the concert hall turned the hall into a place of sound immersion, where the spectator was called upon to attend to the various calls coming from different directions. Peter

#. Gustav Mahler. *Eighth Symphony Finale.*

1 Article 14 of the CTE’s HR-BD.

#. Johann Sebastian Bach. *St. Mathew's Passion* at the Berlin Philharmonic.

Sellars' stagings of oratorios and operas accentuate the spatial character of musical interpretation today. In stagings such as that of the Passion of St. Matthew at the Berlin Philharmonic, singers move around the stage and points outside it as naturally as if it were an opera.

Other composers went further. They have treated sound spatialization not only as a field of action on the location of the sound source, but also paying special attention to that Silence that is not Mute. Indeed, this second group of composers looked at the reverberation of architecture to take it as a compositional excuse in their works. For them, the reverberation of the room allowed them to develop a type of music that would not have been possible without such a room. It is very likely that Johann Sebastian Bach himself (1685-1750) would not have been able to compose the counterpoint of his organ works without an architectural enclosure that allowed him, with a tight reverberation time, to pile up many notes in a short period of time.

However, there remains a third group of composers who consider the reverberation time not only as an excuse to compose in their own style, but also compose with the same reverberation time. These composers make tails sound that emulate impossible reverberations. In this way, his music acquires a spatial dimension that transports musical interpretation to remote places. Bernat Vivancos has shown in his recent choral works a masterful use of the reverberation time, emulating reverberation times impossible for the place where the piece is being performed. Since the phenomenon consists of keeping the notes playing for a period of time, the harmonies that are produced intermingle the melody in a reverberant aura that no room could produce.

All these samples of work with sound spatialization have contributed to renewing the union of architecture and music over and over again. But there is always a desire to maximize the possibilities: in the location there is a desire not to be locked up in a confined room; in the treatment of reverberation there is a desire to explore reverberations that go beyond what is plausible. What scenario could offer such possibilities? The city can be a new stage for the reconciliation of architecture and music. Below are some of the most remarkable possibilities in which the city could contribute to this reconciliation:

(1) In the city, the stage is not only defined by a unidirectional audience, but also by the multiplicity of sound sources. (2) The use of the third dimension is encouraged as the exploration of the vertical dimension in a concert hall is limited by its free height. (3) Squares, streets, passageways, galleries, courtyards or porches are elements with acoustic properties of masking, coupling or distant echoes that are hardly found inside concert halls. (4) Given the much larger dimensions of the city's open spaces compared to the enclosed spaces of concert halls, it is possible to count on echo and not just reverberation.

The city, however, requires specific instruments for it to truly function as a musical stage. To name the obvious, it is necessary to count on electroacoustic, to rely on the amplified reproduction of sound, since the city sometimes offers spaces so large that it would be difficult to fill them with a single violin. In this context, the union of the sound technician with the composer and the architect would be necessary.

Among the architects there has always remained the will to control and make use of the sound that would sound in their spaces. Likewise, composers have always been concerned about how their music would sound in the space where it would be performed. That's how we saw it from the beginning. Different circumstances, however, have sometimes led to a split between architecture and music. But in spite of this fact, the always clear and reciprocal will that we must remember remains: to fill this Mute Silence with music and architecture.

Case study

Metastaseis and the tourette

> A world of sound masses, vast groups of sound events, clouds and galaxies governed by new characteristics such as density, degree of order, level of change, which require definitions and realizations using probability theory. [1]

Introduction

There's been so much talk and writing about Tourette's that pencils know everything. It seems impossible to say anything else and all his words have already been consumed. There's only one thing left: listen. Listening to understand and quietly penetrate the messages that the place prepared for us a few years ago: the pencil writes better when you listen.

The building is anchored on the top of the slope, recessed and firm on the horizon. to never move. His gaze protects all the corners preserved since its construction and devoted forever to architecture. There, too, there is collected access, hidden, others would have made him great: he wouldn't. As you enter, you step into infinity: to cross the threshold of the Tourette is to walk on the line that separates the sky from the earth and -without leave the mortal world - set foot on the immensity. In the immensity he speaks Oh, God. No doubt he had to listen to put the monastery there.

Someone's walking by. It's been a while since he left the train station. Speed up the pace in the long shadows of the morning still half awakened. On the ground, a tapestry of leaf litter wood color covers the asphalt that the cars have cleaned as they pass by. He makes another furrow the roadside because

Fig. 9. Tourette. West view from the valley.

1 Iannis Xenakis, *Music, Architecture.*

it lifts up loose leaves as you walk, so that if you walk along the road, you will the afternoon doesn't blow the wind, you can come back and make your way back to the train.

Suddenly the convent appears again in the vegetation without shine, it is a mass of skin.

smooth and cold, stone coloured. At times it seems to fade between the trapped glass cloths between the concrete. He stops his march and contemplates: he does not want to miss the speech that pronounces because the Tourette speaks of the site and explains everything.

In the bottom of his backpack he finds the pencil and rushes to write down what he has seen without understanding. since he started walking up. He wants to catch his words, they're fugitive voices in his hasty mind and gaze prevents him from doing so faster than thought. Only if you expect a little more can freeze on paper the traces of memory that explain everything. If he listens, then he finds out he knows everything because silence tells him.

Fig. 10. Dominique monks in La Tourette monastery.

The 1950s were already a time for Le Corbusier when he was carrying out

large projects such as Chandigarh or Tourette itself. During those years it was and in the afternoons he went to his studio in the Rue de Sèvres to work as a painter. see the progress of the projects. It was in 1948 when a musician settled down in Paris who had just obtained his engineering and mathematics degree: Iannis Xenakis. He left his country for political reasons and joined Le Corbusier's studio as a calculator for the big boys. projects in Nantes, Chandigarh and Baghdad.

In 1953 Le Corbusier personally entrusted him with the management of the Tourette's project. and later, in 1958, from the Philips Pavilion. It was in these works that two artists coincided without a single word. know it on the road to beauty, one for the music and the other for the architecture. They shared on the same project table the discourse of proportion, the power of composing without control of materials, revolutionary construction....

The Tourette and Philips Pavilion projects were decisive contributions to architecture of the moment. La Tourette's talks about how to compose an almost closed box containing passageways with enclosures, with closed panels that are placed in a randomly controlled manner with golden proportions. The Philips pavilion ends up being an exhibition of the capabilities of post-tensioned concrete, the latest in construction of the moment.

Fig. 11. Le Corbusier and Xenakis in the Rue de Sèvres, 35, attelier.

During the years 1953 and 1954, Xenakis managed to turn the sum of all his research into paper.

musicals in Metastaseis B, a work for orchestra by 61 performers. This gigantic musical discourse leaves us as a legacy the study of how to structure two parts by means of a silence. In addition, Metastaseis is the direct application of composing mass sounds in a way that is controlled by the golden ratio, and finally, the use of glissando [1] as the melodic motif will be the glory for the string orchestra.

1 Continuous sound that varies in frequency progressively. It is used in Metastaseis by rubbed stringed instruments although there are other ways to produce it.

The five meters silence. How the project material makes up the structure of the work

Le Corbusier thought of the Tourette because he had listened. In the silence of his travels he learned the geometry of the spaces that would house about a hundred Dominican monks. In 1907 Le Corbusier visited the Carthusian monastery of Galutzo near Florence, a modern 15th century place full of architectural content: interior space protected by the programme, cloister crowned by the bell tower, cells open to the horizon.... There Le Corbusier listened and learned about the project for the Dominican order. For this reason, the new convent is immediately equipped with a square surrounded by rooms that are open to the outside world, watchtowers of the valley able to speak to the landscape.

A line of shade runs through the entire courtyard, underneath another. These are the gaps that hide the corridor for the individual cells. At the end of the corridor, the views to the outside are obstructed in order to reinforce the horizontal line. From time to time, small solid blocks give rhythm to the The façade, protruding inside and out, casts long, undeformable shadows on the wall: are actually the visible part of the pillars between floors. Underneath the sprayed concrete the real structure is hidden: concrete pillars and ceramic accessories. Now it's just we see the open edge in the concrete. I'm sure that during its construction someone placed there were the prisms as they were shaking, just at the very moment when the two parts. This is how we better understand its gravity, sober and silent; the glass trapped between the concrete cloths are witness to this.

Fig. 12. West façade of the monastery.

Fig. 13. View of the cloister volumes and windows.

The other piece is closed, airtight... a blunt northern volume that starts from the ground for the Eucharistic celebration. You can see the exhausted soil, it will still have to withstand for years, tons of concrete until the end of time. The weight is so great that from far away threatens to sink into the rock. But no. As it turns, the building rests on a forest of The slender pillars that receive as much as possible the two floors above. And it is here, after of turning, where the cut takes place. Noisy separation between the church and the rest of the building, so that the enclosure is open five metres at full height, while below, on the ground, they are collected the foundations that could be chasms.

Interruption is everything. The efforts practiced in the church would be of no use. Low strength would now have the volume of the north, the sobriety of the textures, the commitment to the facades. The two sides compete better because they separate. Here too, architecture needs of silence and thanks to him the strength of his intentions is evident. The volumes have been silent and then they sound louder again because of the silence. While the Tourette's project was being developed in the Paris studio, Metastaseis became a reality. Xenaquis' radical departure from the prevailing tendencies of the avant-garde of the time dominated by serialism:

> [...] as a result of the stalemate in serial music, as well as other reasons, in 1954 I originated a music built on the principle of indeterminacy [...] [1]

Metastaseis contains in the introduction a system of organizing the project material similar to that of the monastery of the Tourette. It is not strange to

1 Iannis Xenakis, 'La Crise de la Musique Sérielle', *Gravesaner Blätter*, 1, 1956.

#. Xenakis. *Metastaseis*

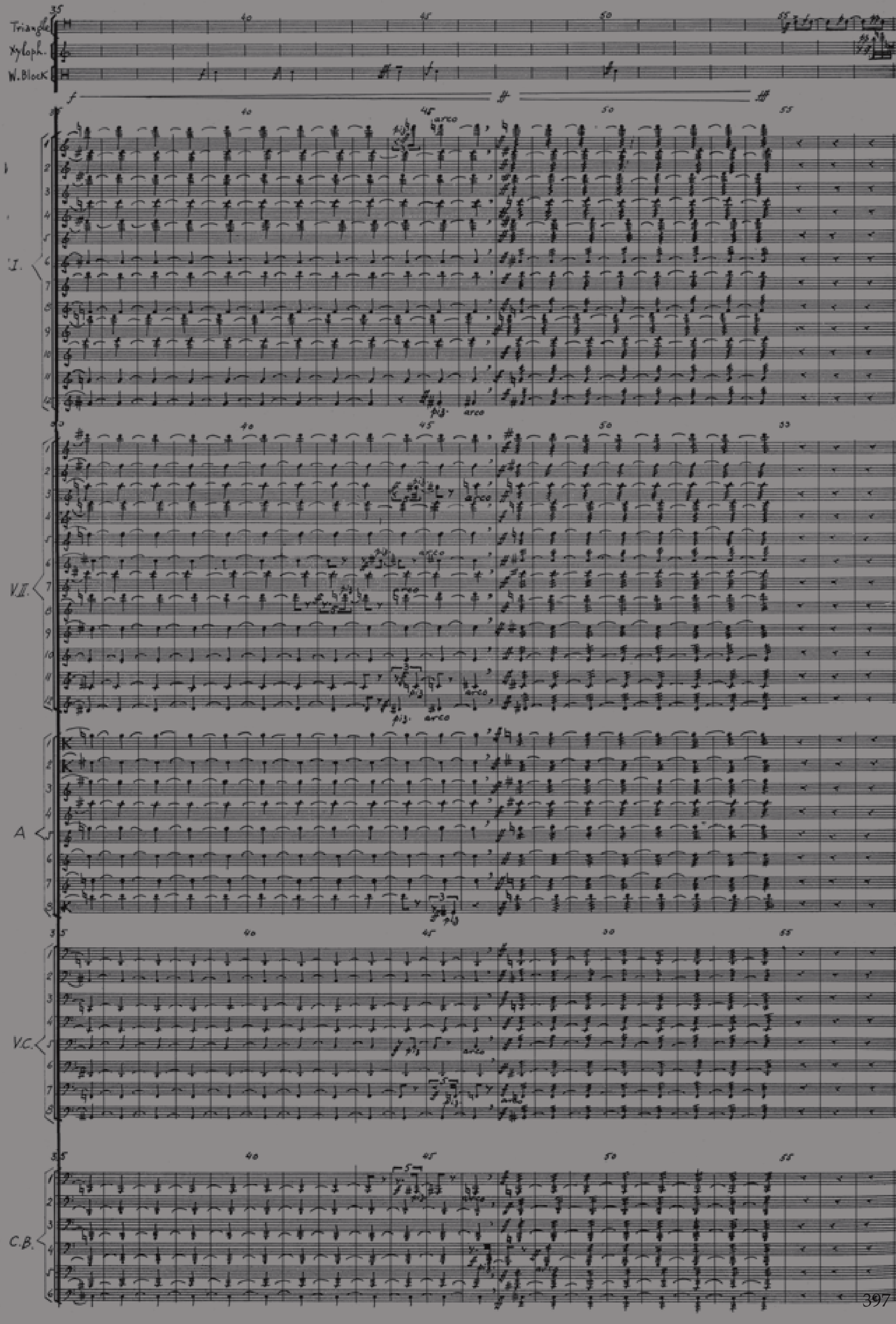
find in the two works of art the same compositional and formal mechanisms, evident parallels between written matter and sound. Start Metastaseis with a natural sun that plays the 46 strings in unison, pianissimo. It is the Sun2, continuous and seemingly eternal, immortal. Then the first of the glissandos, the first of the violins, rises firmly and stealthily above them all. Before the first viola comes in, there'll be a wooden knock on the door. And then the other 43 stringed instruments with their respective glissandos are slowly and progressively incorporated. Until you open the register to a huge chord of 46 notes: the seven notes of the C major scale played at the same time and in different octaves. The highs have been shifted up and the lows down, opening the fan to the maximum and holding the chord for a few seconds.

At this moment, as Alex Ross says, "silence is sometimes more terrible than the bellowing around it" [1] . Indeed, the enormous mass of sound gradually opens up until it reaches a sublime atmosphere that fades into the void. Instantly, it is in the ears of the overwhelming memory of the rope submerged in silence.

It is a unique moment: we have been led by the glissandos to such an extent that we rejoice. scrutinizing that huge mass when it suddenly vanished. It's exactly in measure number 47. But only for a few moments, because then they come back. the chords like a whip in the back, and they keep on playing, transporting us back down the line. a glissando that ends in two just quarters juxtaposed: Re#-Sol# and Mi-La.

Fig. 14. Metastaseis. Silence.

1 Alex Ross, *El Ruido Eterno: Escuchar el Siglo XX a través de su Música.* (Barcelona, Seix Barral, 2010)


Triangle
Xyloph.
W. Block
V.I.
V.II.
A
V.C.
C.B.
arco
pizz.

In the end, interruption is everything. The efforts practiced in the glissando would be of no use. the strung string strikes in vain as it adjusts the notes of the glissando in unison and with precision on the mast, little force would now have the sobriety of the second texture, the commitment to the metal in the next section.... better compete the two parties because they separate. Here too, music needs silence, and thanks to it the power of silence is evident. of his intentions. The volumes have gone quiet and then sound louder again, thanks to the silence.

THE EXACT PROPORTION. How the material requires measurements and proportions

The arrangement of the compositional material could not be left to the fate of the creative stroke and so, once again, Le Corbusier used his "Modulor" measurement system to control the dimensions and proportions of the work. Xenakis also awarded his entire work a system of proportions based on the golden number. This need for proportion is inherent to man since we can observe numerous cases throughout history in which proportion governs the measurements of works. In architecture, it has been proven that many of the traces of classicism are supported by the golden section, as in the façade of Brunelleschi's Santa Maria dei Fiore, where the rectangles of various marbles are governed by the number of gold. Also, the eyes of Velázquez's meninas continue to give order to the whole painting under this rule. Here, in the Tourette and many other works, Le Corbusier already used the Modulor in his studio as a rule for all measurements: from the large traces to the height, width of the cells, of the

Fig. 15. Metastaseis. Begining. Graphical score.

tables, chairs, cupboards and each of the elements that served the monk. Mozart also composes using the golden number to structure time in some of his works, although it was Bartók who consciously used the golden section in his works.

compositions. Xenakis acted in a radical way: the first part that we see here graphically is then governed exactly in the score if we do the calculations with the

number of bars of each fragment:

a/b=b/c/c=c/d=d/e=Ø=1.62

a/b=54/34=1,58~1,62

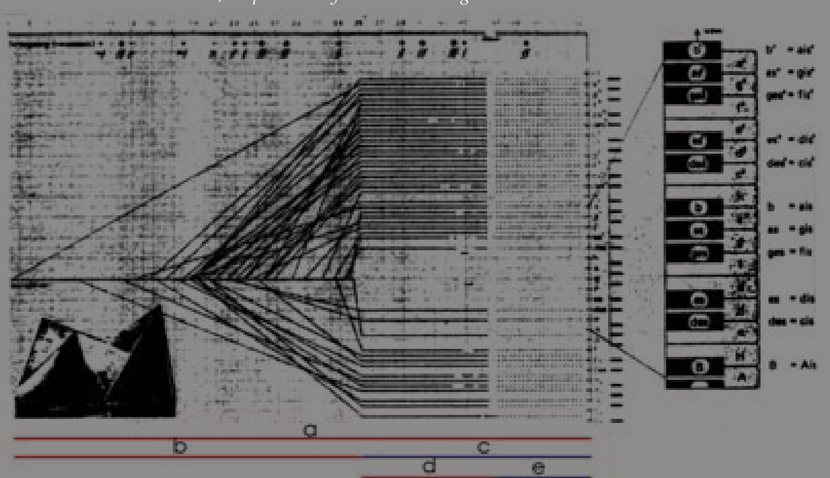
b/c=34/20/20=1.7~1.62

c/d=20/14=1.42~1.62

d/e=14/8=1,75~1,62

> The common ground that unites the two authors is their interest in using mathematics as an instrument of control in architecture and music.[1]

1 Susana Moreno Soriano, *Arquitectura y Música en el Siglo XX.*



The building line. How the project material is also construction material.

Two years after the completion of the convent, Le Corbusier commissioned Xenakis to design the Pavilion for the Philips company to be installed at the 1958 International Exposition. This project will be for Xenakis one of the ones that confirms his theory that tries to analog his music with his architecture: both based on the basic elements of space and perceptible only as a whole, as complete masses.

> My own musical search for sounds of continuous variation over time (see Le Corbusier, Modulor nº2, last pages) inclined me towards geometric structures based on lines: surfaces drawn with rulers. [1]

To this end, Xenakis explains in his book Music-Architecture that the point is equivalent to the chopped note, the line to a succession of points or, in other words, a note held or a glissando; the plane as a succession of lines or, in other words, a chord had; and the hyperbolic paraboloid a succession of non-coplanar lines, or in other words, a succession of glissandos sounding at the same time. Thus, reaching the plane and the hyperbolic paraboloid Xenakis had already reached the discovery of what the basic elements of composition of the new pavilion should be: a set of hyperbolic paraboloids cut by the horizontal plane of the ground.

> In the Philips Pavilion I applied the same basic ideas as in Metastaseis: as in music, I was interested in the problem of going from one point to another without interrupting continuity. In Metastaseis, the solution took me to the

1 Iannis Xenakis, *Música-Arquitectura, (*Antoni Bosch, Barcleona, 1982)

> glissandos; in the Pavilion the answer was given to me by the hyperbolic paraboloids. [2]

The pavilion houses the slide show while the "Electronic Poem", a concrete music composed by Edgar Varèse for the event, plays. It consists of six minutes of images projected on the curved walls that, according to Le Corbusier, were intended to show, in the midst of an anguished tumult, our civilization to the conquest of modern times. "Architecture is frozen music" in this case could already be fulfilled, because both in the As in Metastaseis, the glissando is the element that literally builds the work: in one case it forms ordered space and in the other it forms ordered sound. So how should the works be heard from this point of view? Looking at the whole thing, or with words from Xenakis himself, listening to the masses of sounds that make them up listen to the paraboloids that are built in Metastaseis. When Xenakis reaches this point he is the father of a new sonority that has replaced melody with glissando, harmony with mass and polyphony with punctual sounds.

> Just as in Metastasis, the linear universe is replaced by the "mass" universe, in the Philips Pavilion the flat architecture is replaced by the volumetric structure.[3]

Volumetric architecture is the term that Xenakis adopts for architecture that will become truly abstract, bearing in mind that abstract architecture is for Xenakis that which truly uses the three dimensions of space and includes time in it. For Xenakis the old architecture does not belong to this new group:

2 Ibid. page. 145

3 Aulestia Gotzon, *Técnicas Compositivas del Siglo XX, Tomo II.* (Alpuerto, Madrid, 1998)

> Never, since the earliest antiquity, has architecture been a manifestation
>
> really spatial. It's essentially two-dimensional, it's essentially flat. The square, rectangular, trapezoidal, circular figures of temples, rooms, palaces, churches, theatres, etc., are flat. The third dimension is penetrated by parallel translation, following the direction of the plumb bob. [1]

On the other hand, the new architecture that he proposes has the following characteristics:

> These forms (the warped ones) mean for the architect the passage from a translational conception of volume (the elevation resulting from the vertical translation of the plane) to a new conception of volume, of three true, different and not homomorphic dimensions.[2]

All this reflection carried out by Xenakis does not end or stop at the Philips Pavilion. In the future, it will seek to reflect the same logical formal rigour in all its projects and will take the as a paradigm that will serve as an outline for other similar applications that will be called Politopes, ephemeral architectures that practice this theory and of which the Politopo of Montreal and the Diatopo de Beaubourg for the

1 Iannis Xenakis, *Música de la arquitecutra* (Madrid, Akal, 2009)

2 Ibid. pp. 153-154.

Fig. 16. Philpip's pavillion. Cables on the roof.

inauguration of the Pompidou Centre are the most important ones. outstanding.

One for all and all for one

How elements can be grouped into stochastically controlled masses.

A final linking element in the Le Corbusier-Xenakis conjunction is the treatment of the masses. The west elevation of the Tourette's contains what is called the glass cloths or the ondulateurs, which are the vertical windows that correspond to the library, refectory and rooms common. Its result must be observed from a distance and as a whole, that is to say, considering it as a whole as a mass of vertical and horizontal elements.

In the same way there are moments of Metastaseis in which the pizzicatos or notes are also treated as masses. In both cases the individual element only makes sense if the mass is observed on a large scale, and this mass is stochastically controlled. According to the author, taken from the preface of his book "Formalized Music: Thought and Mathematics in Composition":

> As a result of the deadlock in serial music, as well as other reasons, in 1954 I originated a music built on the principle of indeterminacy; two years later I called it "stochastic music". The laws of probability calculation came into composition out of pure musical necessity. But other roads also led to the same crossroads, the most important one: natural events, such as the collision of hail or rain on hard surfaces, or the singing of cicadas in a summer field. These sound events are made up of thousands of isolated sounds; this multitude of sounds, seen as a whole, is a new sound event. This massive event is articulated and forms a flexible temporal mold, which in itself follows random and stochastic laws. If someone wants to form a large mass from punctual notes, such as with pizzicati of strings, he must know these mathematical laws, which, in any case, are nothing more than a strict and concise expression of chains of logical reasoning. Everyone has observed the sound phenomena of a political crowd of tens

Fig. 17. La Tourette's ondulateurs.

or hundreds of thousands of people. The human river shouts a slogan with a uniform rhythm. Then another motto emerges from the head of the demonstration; it extends towards the tail, replacing the first one. A transition wave passes from the head to the tail. The clamour fills the city and the inhibiting force of the voice and the rhythm reaches a climax. It is an event of great power and beauty in its ferocity. Then, the impact between the protesters and the enemy occurs. The perfect rhythm of the last motto is broken in a large group of chaotic screams, which also extends to the tail. Imagine, moreover, the bursts of the machine guns and the whistling of the bullets interspersed in this total disorder. The crowd disperses quickly, and after the sonorous and visual hell only silence remains, full of despair, dust and death. The statistical laws of these events, separated from their political or moral context, are the same as those of cicadas or rain. They are the laws of transition from absolute order to total disorder in a continuous or explosive manner. They are stochastic laws. [1]

For Xenakis, stochastic music will serve two purposes. The first will be to create a music which can be found in the second part of Metastaseis (Compases 151 to 174; minutes 2,3-5,1). You must listen to the different atmospheres he creates with point clouds, of pizzicatos and short notes. This

1 Iannis Xenakis, *Música-Arquitectura.*

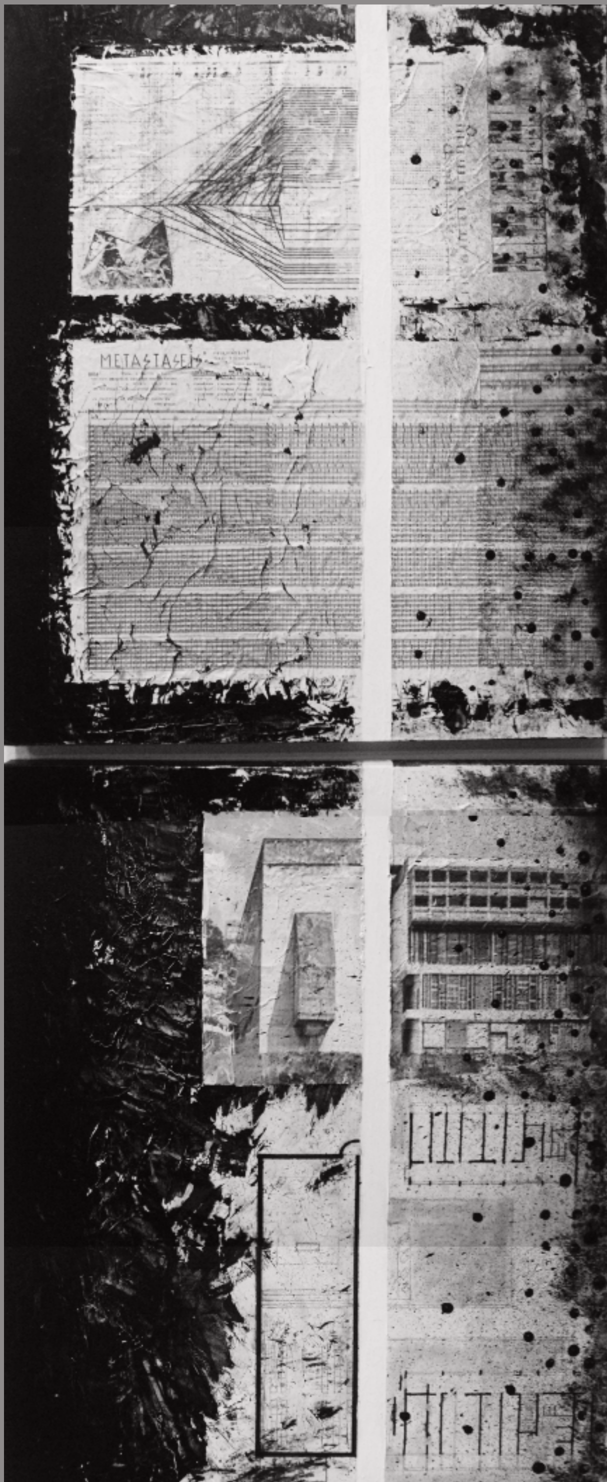
mass music has a clear parallelism with architecture of masses in the glass cloths or the ondulateurs: one for all and all for one.

The second goal is of great importance because it is a path of musical abstraction. Serialism had begun this path by de-hierarchizing the twelve notes of the tempered scale, but now the stochastic one overcomes it considering it as a particular case of this one. And to conclude the abstraction, it will be necessary to introduce space into music through the concept of "dynamic stereophony", which is nothing more than conceiving sounds that move in space forming more or less complex sound surfaces. Of this type were the shows already announced as Diatopos, whose first essay is the Philips Pavilion, finally reaching the abstraction in music and architecture that Xenakis was looking for.

> Since the music of Schoenberg's time had liberated the tones of his tonal or modal servitude, it was not to be limited again by a deterministic rule (the serial principle) but, on the contrary, to be left free, that is, to introduce a principle of uncertainty that included determinism as a particular case and to resort to logic and probabilistic reasoning.[1]

Fig. 18. A comparison between Metastaseis and La Tourette showing the common silence.

1 íbid. p. 23.


METASTASEIS

The reddish sun on the horizon casts long shadows on the slopes of Éveux. Now cross over

the threshold of the Tourette's a figure upright, purposefully passing through, and walks away among the oaks lined up in the path. It is accompanied by echoes of Vespers in the valley and undoubtedly the memory fixed in the memory of a few days between architecture and mystery. The path descends and pushes the feet down marking the path and stops to look at the building. He's been there for several days. He has lived in one of the cells, eating in the refectory, walking along the hillsides and the cloister, and attending the services in the box torn by two lines and a skylight. We are not sure if he knew about Metastaseis or if he heard it during those days on some gramophone in the library of the Dominicans. In any case, there is no doubt that the Tourette's has spoken to him about it, a multitude of corners silently explain features of a place devoted to beauty. Like Metastaseis, Tourette's does not need to make sounds, words are solidly written in its architecture over the years. In the same way, Metastaseis does not use matter to clearly construct the same discourse. All it takes is a brief, empty moment without matter to teach everything. La Tourette's, in the silence also explains everything.

And he will have understood that the work of art is discourse, whether it is images, sounds or words. And the discourse needs a structure to be intelligible. And every work of art has a layout decipherable and necessary. Who understands the structure, albeit unconsciously, understands the speech of the play, and with it the the work.

Chapter 8

Tools of instruction

The study of the acoustic urban heritage as a tool

Chapter 8

Tools for instruction

The study of the acoustic urban heritage as a tool

The present chapter is derived from the work entitled *Evaluation between virtual acoustic model and real acoustic scenarios for urban representation*. This work was presented by the author et al. as a chapter in the book *From Natural to Artificial Intelligence - A Chaotic View*, Intech Open.

1. Introduction

The current chapter is based on the answers to two basic questions arising in evaluation and instruction of digital cultural resources, and more specifically, sonic cultural heritage: “what” and “how”. Firstly, what are we evaluating when we refer to digital cultural resources? Is it a tangible issue or an intangible perception? Does it consist of a series of personal impressions or can we establish an objective parameter? The United Nations’ Millennium Ecosystem Assessment was carried out from 2003 to 2005, and the subcategory of cultural heritage in Cultural Ecosystem Services (CES) was introduced over a decade later. Yet there is a lack of consensus about what cultural heritage refers to within the Ecosystem Services (ES) context [1]. Secondly, how should cultural heritage be evaluated: through abstract concepts or immersive experience? Is this practice a good tool for instruction? It seems practically impossible to imagine an evaluation of cultural resources that is only based on abstract concepts. However, the evaluation also requires a common basis to enable comparisons of the results. This second answer supports the immersive experience as a powerful method for cultural resources evaluation.

An explanation is required to understand the methodology used in this chapter. In general, people know very little about decibels of sound, and much less about sound roughness, musical clarity or speech intelligibility. Only a small group of scientists understand the operation of acoustic

1 Herdis Hølleland, Joar Skrede and Sanne Bech Holmgaard, ‘Cultural Heritage and Ecosystem Services: A Literature Review’, *Conservation and Management of Archaeological Sites*, 19.3 (2017), 210–37

science. Therefore, when urban acoustic heritage is evaluated and teached, why are ordinary people forced to refer to numbers and graphs? Surely the instruction would be more reasonable if it were made using real sound samples? In this context, Virtual Reality (VR) provides an easy, interactive framework for ordinary people to learn about urban acoustic heritage.

The interest in conservation of tangible and intangible cultural heritage has been rising notably in recent years. Apart from its own value, cultural heritage fosters economic and social growth. The Heritage Research National Plan, drawn up by the Spanish Cultural Heritage Institute, highlights the importance of cultural heritage as a local development engine and a stimulus for tourism, and its relevance as a generator of culture and knowledge. However, the Plan also stresses the complexity of research in this field, due to a range of characteristics and problems, and because of the high number of factors involved that make it necessary to apply human and experimental sciences in interdisciplinary teams.

1.1 Evaluation of acoustic quality in outdoor spaces

The evaluation of the acoustic quality of a space is fundamental to determine possible interventions in it and the suitability of its future uses. Several studies have established optimal indexes and ranges for the various measurable parameters [2]. Nevertheless, as in current regulations, the focus

2 [2,3]

has been concert halls, which have different features and requirements from outdoor spaces.

Very few objective and subjective tests have been undertaken in these kinds of spaces, due to the difficulty in installing measuring instruments and the variable conditions of the environments. In this study, four outdoor spaces were tested and a great effort was made to find the best environmental conditions. Preliminary work was done in the studied environments [1].

The application of new technologies in cultural heritage is a practice that has become increasingly widespread. The construction of virtual models allows us to reproduce environments for their study, avoiding direct intervention in these spaces and encouraging their conservation. After some data collection in the actual place, a model is designed and calibrated in which the environment can be recreated as many times as desired, without the need to travel there. This methodology could overcome the major difficulty that an in-place test might present.

Some authors have attempted to investigate urban sound propagation. They have centred on the complexity of the medium: irregular faces, interconnection with adjacent canyons, and a large variety of materials and boundary conditions. Moreover, a predominant characteristic of the urban environment is that it is open to the sky, and induces large radiative losses [2]. Much of the

1 Miguel Molerón and others, ‘Sound Propagation in Periodic Urban Areas’, *Journal of Applied Physics*, 111.11 (2012).

2 Jian Kang, ‘Sound Propagation in Street Canyons: Comparison between Diffusely and Geometrically Reflecting Boundaries’; Adrien Pelat, Simon Félix and Vincent Pagneux, ‘On the Use of Leaky Modes in Open Waveguides for the Sound Propagation Modeling in Street Canyons’, *The*

literature is focused on propagation in a single urban canyon [3]. A few authors attempted to model wave propagation in parallel or intersecting streets[4], or in larger urban areas, but often limited to 2D geometries. Others have used a coupled modal-finite elements method to address the problem, while others have introduced the frontier finite elements method.

1.2 Spatial audio in architectural representation

Spatial audio in virtual reality has received increasing attention in recent years, due to its impact on the immersive experience. Spatial audio is the representation of audio features of reality that intentionally exploit sound localization. It has many possible uses in the gaming industry, entertainment or military applications. Most of these uses rely on

Journal of the Acoustical Society of America, 126.6 (2009), 2864–72; Richoux and others, 'Effect of the Open Roof on Low Frequency Acoustic Propagation in Street Canyons', *Applied Acoustics*, 71.8 (2010), 731–38.

3 Picaut, 'Numerical Modeling of Urban Sound Fields by a Diffusion Process', *Applied Acoustics*, 63.9 (2002), 965–91; Bullen and Fricke, 'Sound Propagation at a Street Intersection in an Urban Environment', *Journal of Sound and Vibration*, 54.1 (1977), 123–29; T. Van Renterghem, El. Salomons and D. Botteldooren, 'Parameter Study of Sound Propagation between City Canyons with a Coupled FDTD-PE Model', *Applied Acoustics*, 67.6 (2006), 487–510; A. Can and others, 'Traffic Noise Spectrum Analysis: Dynamic Modeling vs. Experimental Observations', *Applied Acoustics*, 71.8 (2010), 764–70; Maarten Hornikx and Jens Forssén, 'The 2.5-Dimensional Equivalent Sources Method for Directly Exposed and Shielded Urban Canyons', *The Journal of the Acoustical Society of America*, 122.5 (2007), 2532; Maarten Hornikx, 'Acoustic Modelling for Indoor and Outdoor Spaces', *Journal of Building Performance Simulation*, 8.1 (2015), 1–2.

4 J. Picaut, J. Hardy and L. Simon, 'Sound Propagation in Urban Areas: A Periodic Disposition of Buildings', *Physical Review E*, 60.4 (1999), 4851–59; Donald G. Albert, Lanbo Liu and Mark L. Moran, 'Time Reversal Processing for Source Location in an Urban Environment', *The Journal of the Acoustical Society of America*, 118.2 (2005), 616–19; Donald G. Albert and Lanbo Liu, 'The Effect of Buildings on Acoustic Pulse Propagation in an Urban Environment', *The Journal of the Acoustical Society of America*, 127.3 (2010), 1335–46; Dietrich Heimann, 'Three-Dimensional Linearised Euler Model Simulations of Sound Propagation in Idealised Urban Situations with Wind Effects', *Applied Acoustics*, 68.2 (2007), 217–37..

both acoustic and spatial information about the sound. However, although spatial information is addressed, architectural design representation does not currently pay much attention to spatial audio as a factor in spatial representation.

Many other factors that have been considered in architectural design representation are linked to visual features [1]. Natural light modelling and rendering [2], artificial light control [3], texture cognition and representation [4], colour discernment [5] or material visualization are some of the countless details that an architect must manage when they represent a building. However, although the effect of sound on spatial cognition is recognisable [6],

1 Juhani. Pallasmaa, *The Eyes of the Skin : Architecture and the Senses* (Wiley, 2012).

2 R. Perez, R. Seals and J. Michalsky, 'All-Weather Model for Sky Luminance Distribution—Preliminary Configuration and Validation', *Solar Energy*, 50.3 (1993), 235–45; Richard Kittler, Miroslav Kocifaj and Stanislav Darula, *Daylight Science and Daylighting Technology* (New York, NY: Springer New York, 2012).

3 Franklin C. Crow, 'Shadow Algorithms for Computer Graphics', in *Proceedings of the 4th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH '77* (New York, New York, USA: ACM Press, 1977), XI, 242–48; Channing P. Verbeck and Donald P. Greenberg, 'A Comprehensive Light-Source Description for Computer Graphics', *IEEE Computer Graphics and Applications*, 4.7 (1984), 66–75.

4 Sidney M. Newhall, Dorothy Nickerson and Deane B. Judd, 'Final Report of the OSA Subcommittee on the Spacing of the Munsell Colors*', *Journal of the Optical Society of America*, 33.7 (1943), 385 ; Bela. Julesz, *Foundations of Cyclopean Perception* (MIT Press, 2006) <https://mitpress.mit.edu/books/foundations-cyclopean-perception> [accessed 3 October 2017].

5 Eric P. F. Lafortune and others, 'Non-Linear Approximation of Reflectance Functions', in *Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH '97* (New York, New York, USA: ACM Press, 1997), pp. 117–26; Michael Ashikhmin and Peter Shirley, 'An Anisotropic Phong BRDF Model', *Journal of Graphics Tools*, 5.2 (2000), 25–32.

6 W. Todd Nelson and others, 'Spatial Audio Displays for Speech Communications: A Comparison of Free Field and Virtual Acoustic Environments', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 43.22 (1999), 1202–5; Paul M. Hofman, Jos G.A. Van Riswick and John Van Opstal, 'Relearning Sound Localization with New Ears', *Nature Neuroscience*, 1.5 (1998); J. D. Warren and T. D. Griffiths, 'Neural Mechanisms Underlying Melodic Perception and Memory for Pitch.', *The Jour-*

it has received little attention in architectural representation.

In 2003, Kang et al. highlighted the introduction of new EU noise policies [7] and noted that noise-mapping software/techniques are being widely used in European cities [8]. Nevertheless, they noted that these techniques can provide an overall picture for macro-scale urban areas, but the study of the micro-scale, for example an urban street or a square, could be more appropriate with the use of detailed acoustic simulation techniques. In addition, applications that predict and measure micro-scale environments [9] are still not sufficiently user-friendly, and the computation time is rather long. Kang et al. presented two computer models based on the radiosity and image source methods in an attempt to present to urban designers an interface that could be useful in the design stage, using simple formulae that can estimate sound propagation in micro-scale urban areas.

This chapter presents a set of criteria for implementing 3D audio in virtual urban environments. The study is based on the definition of a new virtual audio format, generated from the combination of objects and ambisonic formats. This

nal of Neuroscience : The Official Journal of the Society for Neuroscience, 14.4 (1994), 1908–19 [accessed 3 October 2017]; Benedikt Grothe, Michael Pecka and David McAlpine, 'Mechanisms of Sound Localization in Mammals.', *Physiological Reviews*, 90.3 (2010), 983–1012; Christopher J. Plack, *The Sense of Hearing*, 2nd edn (London: Taylor & Francis Group, 2014) [accessed 3 October 2017]; Lulwah Al-barrak, Eiman Kanjo and Eman M. G. Younis, 'NeuroPlace: Categorizing Urban Places According to Mental States', ed. by Boris Podobnik, *PLOS ONE*, 12.9 (2017).

7 European Union, 'Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 Relating to the Assessment and Management of Environmental Noise.', *EUR-Lex*, 2002.

8 'Welcome to Schal' <http://www.tpsconsult.co.uk/schal.aspx> [accessed 9 November 2017].

9 Molerón and others.

new audio format was explained in 2017 by Llorca et al. [1]. Using these criteria, we then describe the preparation of a set of experiments with architecture students. The results of the experiments confirm that the implementation of 3D audio enhances the immersive experience in the environments.

1 Josep Llorca, Ernesto Redondo, and others, 'Acoustic Filter', in *Learning and Collaboration Technologies. Novel Learning Ecosystems* (Springer, Cham, 2017), pp. 22–33.

2. The case study environments

Four main performance environments located within the heart of the Ciutat Vella of Barcelona, the area surrounded by the former Roman Walls, were studied: Plaça Sant Felip Neri, the corner between Carrer del Bisbe and Carrer Santa Llúcia, Plaça Sant Iu, and Plaça del Rei.

Plaça Sant Felip Neri

This quiet and secluded public square, located at the end of Montjuïc del Bisbe street, is one of a set of closed squares in the Ciutat Vella of Barcelona. Its floor plan shows an irregular pentagon boundary figure with a central fountain. The 505 sqm plan presents a uniform stone floor material and is completed by five façades made of stone material as well. Of the five façades, one is Sant Felip Neri church, while the others house a school, a hotel, some dwellings and the parish stances. Three big, old trees with an asymmetric distribution in plan cover the square with their foliage. Their trunks serve as irregular columns that support the green ceiling, enclosing the square and preventing people from seeing the open sky. No sound of traffic is heard, because the Plaça is far from main roads. However, the noise of shouting children fills the square every morning, when a group play during breaktime in their beautiful schoolyard: Plaça Sant Felip Neri. During the rest of the day, a few groups of tourists arrive and look to the pockmarked stones on the church façade; marks that remind us of the Spanish Civil War. At any time of day, a street musician may use the square to play the guitar or violin in the most distant corner or near the central fountain, accompanying with music couples who are out walking, in a romantic scene.

Carrer del Bisbe-Carrer de Santa Llúcia

This little crossroads near the cathedral square seems an ordinary place. Nevertheless, a closer examination reveals that some factors come together in this single crossing. Geometrically, the floorplan forms a T pattern in which the crossing point coincides with the bishop's palace door. This door, when opened, reveals an interior courtyard that enlarges Carrer de Santa Llúcia, leading into this peaceful enclosure. The façade of Santa Llúcia chapel in the same corner gives a monumental and ceremonial character to the place. On the opposite side, the entrance to the Casa de La Ardiaca museum is prolonged by a ramp. During the day, some street vendors invade the corner and try to sell their products in front of Santa Llúcia chapel or at the beginning of the ramp. However, the Bishop's palace door is always fully clear, because of the presence of a guard when the door is open, or even on account of the large number of people who circulate through Carrer del Bisbe. Only at night, and particularly on Saturday nights, people tend to fill the area in front of the closed door of the bishop's palace standing up and looking in the opposite direction. There, an old man sings opera arias and recitatives over an amplified orchestral base. His voice invades the corner and goes beyond those limits, turning the old streets into an urban opera theatre.

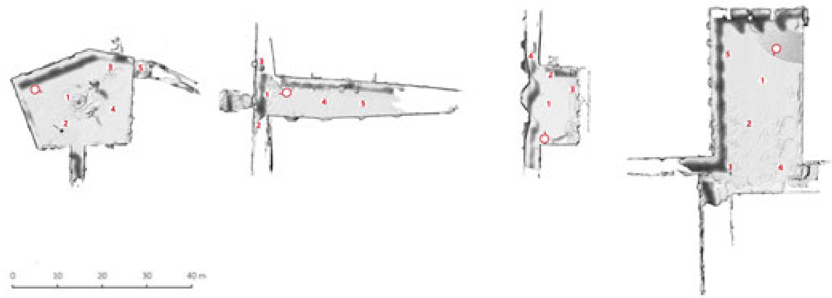
Plaça de Sant Iu

Like a widening of the street, Plaça de Sant Iu is located in front of the eastern door of the cathedral. A gigantic gothic door crowned by an octagonal bell tower constitutes the west façade of this little square. On the opposite façade, a gallery formed by five stone arches closes the square. The north façade is formed by the classic-style entrance of Frederic Marès museum, whilst the south façade presents a flat wall without any door that serves as a perfect backstage for street musicians. This is the preferred point for buskers in Plaça de Sant Iu, not only because of the presence of the big wall behind them, but also because of a long stone bench on the east façade that allows listeners to sit down. In this privileged environment, groups of one, two or three musicians sing or play their instruments. A unique stone material covers the four façades of the square and the floor and gives it a uniform appearance.

Plaça del Rei

Some meters behind Plaça de Sant Iu is Plaça del Rei, a totally different environment both in size and proportions. There are no trees in this 745 sqm area of stone pavement, whilst its four façades enclose the square up to a height of 20 meters. In the north corner of the square, a monumental staircase rises from the floor to the Museu de la Ciutat door. Usually, street musicians enliven the atmosphere with their instruments every day, and crowds of tourists occupy the entire square looking at the real shields on the walls, the pointed arches of the windows, or the tower of Santa Àgata chapel. The everyday life of the square is always very busy, and total silence only occurs when the square transforms into a concert hall for choir, orchestra or band performances. At these times, the players are usually situated on the corner stairs and the public occupy the rest of the square. When this happens, the sound of the musicians can be heard bouncing on the hard stone of the rear walls creating a sense of spatiality that envelopes the audience.

Fig. 1. The plans of the four environments: Plaça de Sant Felip Neri, Carrer de Santa Llúcia, Plaça de Sant Iu, Plaça del Rei. The recording points are marked with a number. The source point is marked with a circle.



3. The methodology used for the in-site measurements

The four environments have some features of open-air places. However, bearing in mind studies on the evaluation of outdoor space acoustics [1], we analysed them using a closed concert hall acoustic method. This decision was taken after considering three factors. The first one, concerns the openness of the places: the four environments can be seen as boxes in which the floor and walls are made of stone, and the ceiling of the most absorbent material that ever existed, because no sound will bounce in the open air. The second consideration for the decision concerns size: the smallest environment, the Carrer de Santa Llúcia, holds an air volume of 1,800 m3, which makes it similar to a typical hall for speeches; the largest environment, the Plaça del Rei with a volume of 12,000 m3, does not exceed the volume of a big concert hall such as the Berlin Philharmonic Concert Hall. Finally, the third consideration explains that in an open-air environment, the sound sources change their position every moment. This situation could be definitive if we were studying the soundscape of an everyday configuration, with running children, singers, street vendors or even police sirens. However, we are recording the place in a street concert configuration, and this means that there is one player at a fixed point and the listeners stand up in the quietest mode.

The measurement methodology was *previous controlled reproduction*. This method consists of the previous recording of an acoustic signal in an anechoic chamber and the following recording of the same signal in the environment. Subsequently,

1 Molerón and others.

the two signals are compared. The first of the recordings in the anechoic chamber were made with a calibrated reproduction system and a calibrated recording system. The reproduction system consisted of a directional speaker LD 90W connected to a 230V power supply. It was positioned in one of the corners of the anechoic chamber. The recording system consisted of RODE NT-55 pair-matched microphones connected to a ZOOM H6 handy recorder on a stand. This recording system was positioned in the middle of the chamber, which was 2.5 meters from the speaker. Additionally, the anechoic measurements were recorded with a HATS system connected to a laptop.

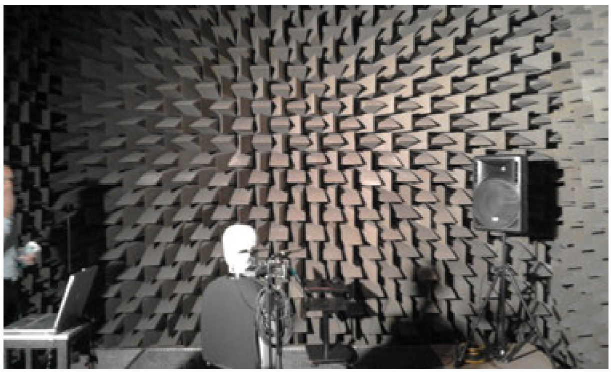


Fig. 2. Recordings in the anechoic chamber of the Universitat Politècnica de València, Gandia.

Fig. 3. Recordings in Plaça de Sant Felip Neri, Barcelona.

The in-site measurements were performed with the same equipment as the anechoic chamber measurements, except the HATS system. The distance of the measurements varied in each environment, as shown in the following floorplans:

To ensure uniform measurements, some were repeated in the four environments, while others were recorded in specific places, considering the normal musical use of the environments. Tracks 1-13 were repeated in the four environments. However, tracks 17 (the final part of Stravinsky's Firebird Suite) and 18 (a solo harp piece by Lucien) were reproduced only in Plaça de Sant Felip. Track 16 (the initial measures of Puccini's Nessum Dorma) was reproduced in Carrer de Santa Llúcia due to the usual type of music played in this environment. Tracks 14 (initial measures of Victoria's choral work O sacrum convivium) and 15 (a flute-guitar piece by Dvorak) were played in Plaça de Sant Iu. Finally, track 19 (initial measures of Orff's Carmina Burana) was recorded in Plaça del Rei. The dates of the recording are as follows (Table 1):

Fig. 4. Relation of tracks played and recordings at the environments.

Track		Plaça de Sant Felip Neri	Carrer de Santa Llúcia	Plaça de Sant Iu	Plaça del Rei
1.	La oboe	30/3/2017	24/04/2017	07/04/2017	06/04/2017
2.	Brahms	30/3/2017	24/04/2017	07/04/2017	06/04/2017
3.	Mendelssohn	30/3/2017	24/04/2017	07/04/2017	06/04/2017
4.	Tchaikovsky	30/3/2017	24/04/2017	07/04/2017	06/04/2017
5.	63 Hz	30/3/2017	24/04/2017	07/04/2017	06/04/2017
6.	160 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
7.	400 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
8.	1000 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
9.	2000 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
10.	4000 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
11.	White noise	30/3/2017	24/04/2017	07/04/2017	06/04/2017
12.	Pink noise	30/3/2017	24/04/2017	07/04/2017	06/04/2017
13.	Shotgun	30/3/2017	24/04/2017	07/04/2017	06/04/2017
14.	Victoria			07/04/2017	
15.	Dvorak			07/04/2017	
16.	Puccini		24/04/2017		
17.	Stravinsky	30/3/2017			
18.	Lucien	30/3/2017			
19.	Orff				06/04/2017

4. What is evaluated and learned?

The four environments were studied using a reproduction-recording system. In this system, an impulse signal previously calibrated in the Anechoic Chamber was emitted in the environment. This signal was captured in different positions in each environment, as already mentioned. Fig () shows the measured positions. Each of the recording points was subdivided into two channels corresponding to left (L) and right (R). Therefore, the naming of each recording consists of the number of the recording point, followed by an underscore and capital letter L or R: 1_L, 1_R, 2_L, 2_R, etc.

Acoustic framework

Once the recordings had been made, different parameters of acoustic quality were obtained by signal processing. The following parameters were studied:

Reverberation time (T60): when a sonorous source that is continually radiating suddenly stops in a determined enclosure, a listener in the hall will continue to hear the sound for a period of time in which its energy is being absorbed by the surfaces of the enclosure's limits [1]. The T60 value corresponds to the falling time of the sound associated with the angle for the first 60 dB decrease. The T60 for an empty hall varies with the frequency. Generally, for music halls, the Ts is higher for low frequencies and decreases when the frequency increases. This typical spectrum of reverberation is known as the tonal curve.

1 Higini Arau Puchades, *ABC de La Acústica Arquitectónica* (Ediciones CEAC, 1999).

Early Decay Time (EDT): this considers the reverberation time for the first 10 dB of decrease. EDT is more closely related to the subjective impression of the reverberation in an enclosure than T60 [1]. To ensure good diffusion of sound in a hall, it is imperative that EDT corresponding to 500 Hz and 1kHz is in the same order as T60[2].

Speech clarity (C50): registered C50 values vary with the listening point. According to Carrión Isbert [3], the recommended value of C50 associated with each point in an occupied hall must fulfil C50 > 2 dB. The higher the value, the greater is the speech intelligibility and sonority in the considered point.

Definition (D50): if the definition increases, the hall is better prepared for speech, as may be the case in theatres or conference halls. Thus, a D50 value that is over 65% is an appropriate value for this kind of hall. A concert hall with good acoustics has a definition index lower than 50% in central frequencies of 500 and 1000 Hz. In concert halls, the higher the definition index is, the worse quality the acoustics .

Musical clarity (C80): registered C80 values vary with the listening point. Beranek [4] recommends an average of -4≤C80≤0 dB for C80 in the 500 Hz, 1kHz and 2kHz frequencies for an empty hall. Values over +1 dB should be avoided.

Strength (G): G values remain similar at each of the measurement points. They approximately

1 Arau Puchades.

2 Arau Puchades.

3 Antoni. Carrión Isbert, *Diseño Acústico de Espacios Arquitectónicos* (Edicions UPC, 1998)

4 Beranek.

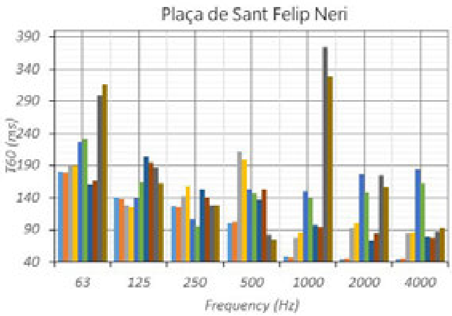
correspond to a decreasing line from low frequencies (G=30) to high frequencies (G=10). UNE-EN ISO 3382 [5] recommends G values between 4 and 5.5.

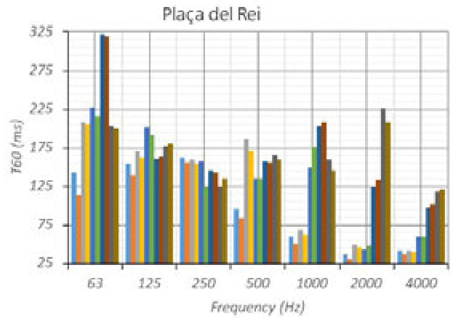
5 AENOR, 'AENOR: Norma UNE-EN ISO 3382:2001', Http://Www.Aenor.Es/ <http://www.aenor.es/aenor/normas/normas/fichanorma.asp?tipo=N&codigo=N0024618#.WZ6SLChJaMo> [accessed 24 August 2017].

Reverberation Time (T60)

In Sant Felip Neri square (top left from Figure 5) we can observe an increase in reverberation time when we step away from the source. The Ts values vary from a conference hall (T60 = 0.7–1.9: point 1), an opera theatre (T60 = 1.2–1.5: point 2), a chamber music concert hall (T60 = 1.3–1.7: points 3 and 4) and a symphonic concert hall (T60 = 1.8–2.0), according to the recommended values of Carrión [1]. Plaça del Rei (top right) presents typical values of a symphonic hall when we step away from the source. Meanwhile, Plaça Sant Iu (bottom left) shows a typical curve of a speech hall in all the interior points of the square, except for the point in the alley, which presents Ts values like a chamber music hall. Carrer de Santa Llúcia (bottom right) presents some features of an opera theatre for points 1, 2 and 3, that is, in the frontal points to the source, whilst in the rear part to the source, some symphonic hall features are presented.

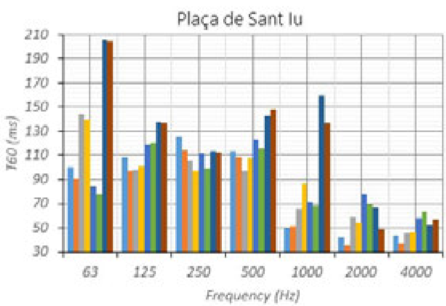
1 Carrión Isbert.

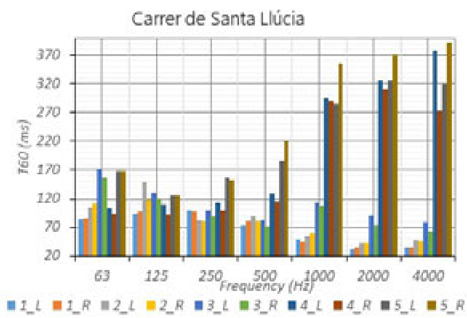




#. Mendels-sohn excerpt at Plaça de Sant Felip Neri.

#. Mendels-sohn excerpt at Plaça del Rei.





#. Mendel-ssohn excerpt at Plaça de sant Iu.

#. Mendels-sohn excerpt at Carrer de Santa Llúcia.

Fig. 5. Reverberation Time (T60) of the different environments: Sant Felip Neri (top left), Plaça del Rei (top right), Plaça Sant Iu (bottom left) and Carrer santa Llúcia (bottom right).

Speech clarity (C50)

In Plaça de Sant Felip Neri (top left from Figure 6) only the recordings at points 1, 2 and 3 exceed 2 dB of C50 for high frequencies. Note that Points 1, 2 and 3 are the nearest points to the source and it is natural that clarity is better near the speaker. Thus, we can deduce that this is not a square with clear acoustics for speech in most of the recording locations and frequencies. In Plaça del Rei (top right) we find a similar situation at first glance. However, clarity is very appropriate at point 1 for mid-high frequencies. Moreover, as we step away from the source, that is, at points 1, 2 and 3, clarity is restricted only to high frequencies, whilst in lateral points, the clarity is below accepted levels. Plaça de Sant Iu (bottom left) presents a similar scheme to those seen above: a lack of clarity for low-mid frequencies and better clarity for high frequencies. Note that point 4 is the only one that does not follow the typical curve of the other points. This is due to its position in the access alley to the square rather than inside the enclosure. Thus, its behaviour is different from the others. In Carrer de Santa Llúcia (bottom right) we can observe a progressive decrease in speech clarity from point 1 to point 5 for mid-high frequencies. This knowledge indicates that speech clarity at points 1 and 2 is only acceptable for mid-high frequencies. Considering that this environment is generally used by opera singers, and that most of the audience occupies the zone in points 1 and 2, we can say that the acoustics of this space are extremely favourable to its use.

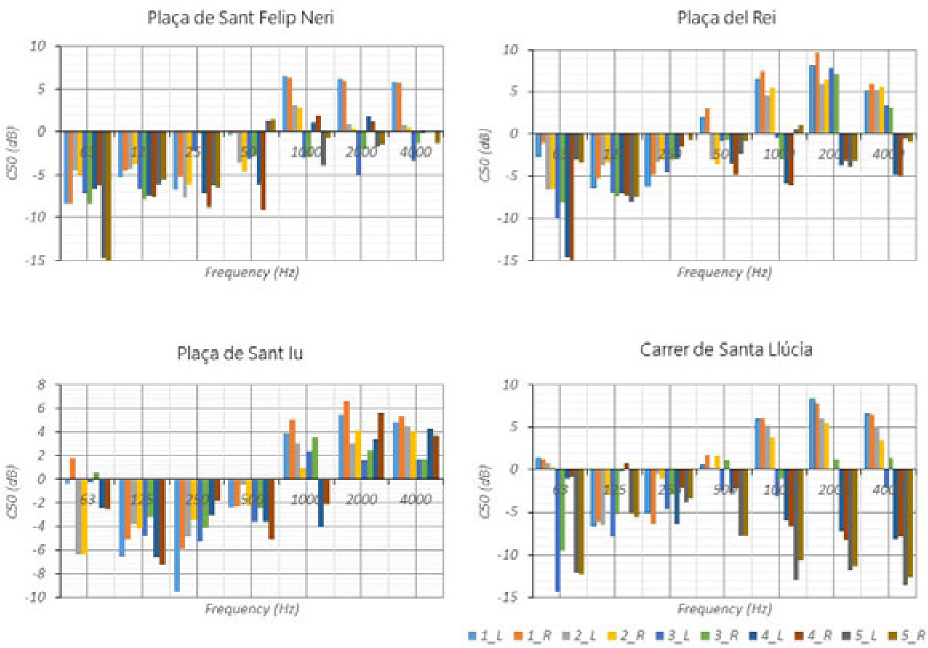


Fig. 6. Speech clarity (C50) of the different environments: Sant Felip Neri (top left), Plaça del Rei (top right), Plaça Sant Iu (bottom left) and Carrer santa Llúcia (bottom right).

Musical Clarity (C80)

In Sant Felip Neri Square (top left from Figure 7) we can see that all the C80 values remain above -4 Db, but they are higher than +1 dB from 2 kHz at points 1, 2 and 4. If we compare C50 and C80 values, we can deduce that this square is clearer for music than for speech. In Plaça del Rei (top right), C80 values at points 2, 4 and 5 are within the desired limits. However, at points 1 and 2, C80 values exceed +1 dB, thus those points are not optimum for musical clarity. This square holds good musical clarity at the points furthest from the source, that is to say, points that belong to the reverberant field and not to the direct field. In contrast, Plaça de Sant Iu (bottom left) only shows C80 values within the desired limit when we consider low and mid frequencies. These recommended frequencies hold C80 values exceeding the +1 dB criteria. These data, compared with C50, make us think that the square is more appropriate for speech than for music. It is a square in which the spoken word is correctly understood, although music is not underprivileged. Finally, Carrer de Santa Llúcia (bottom right) has better musical clarity at points 3, 4 and 5. Curiously enough, these points are the same that held the aforementioned bad speech clarity (C50). This fact suggests that the points with better qualities for speech are not the optimum ones for music, and vice-versa.

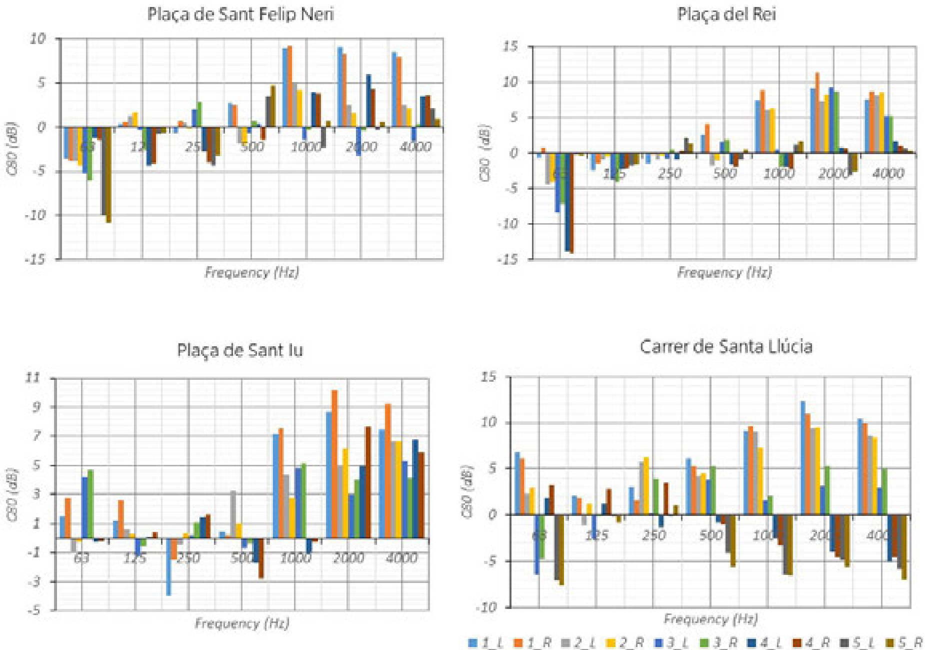


Fig. 7. Music clarity (C80) of the different environments: Sant Felip Neri (top left), Plaça del Rei (top right), Plaça Sant Iu (bottom left) and Carrer santa Llúcia (bottom right).

Definition (D50)

In Plaça Sant Felip Neri (top left from Figure 8), we can see that D50 values were below 50% for low frequencies, but above 50% for high frequencies (from 500Hz). This was true particularly at points 1, 2 and 4. Thus, this square is very appropriate for music at points 3 and 5 (lateral and distant from the source) and better for speech at points 1, 2 and 4 (points near to or centred with the source). Similarly, the Plaça del Rei (top right) had D50 parameters that exceeded 50% for high frequencies at points 1, 2 and 3 (these points were aligned frontally with the source). The lateral points maintained D50 values under 50%. Thus, these lateral points are appropriate for music. These data, together with those revised about C50 and C80, again indicate that this square has good acoustics for music and worse acoustics for speech. Conversely, Plaça Sant Iu (bottom left) had a similar tendency for almost all the measured points, except for the point measured in the alley. In particular, D50 was above 65% for high frequencies and under 50% for mid and low frequencies. Therefore, we restate that this square works better for speech and has too much definition for music. Perhaps for this reason, and because of its size, the square is ideal for solo singers or those accompanied with chamber instruments. Finally, Carrer de Santa Llúcia (bottom right) has an inherent tendency to lower definition when we move away from the source or we are behind it. Particularly, points 1 and 2 are more suitable for speech or opera, whilst points 3, 4 and 5 have better features for music. Again, we can note that the audience zone belongs to points 1 and 2.

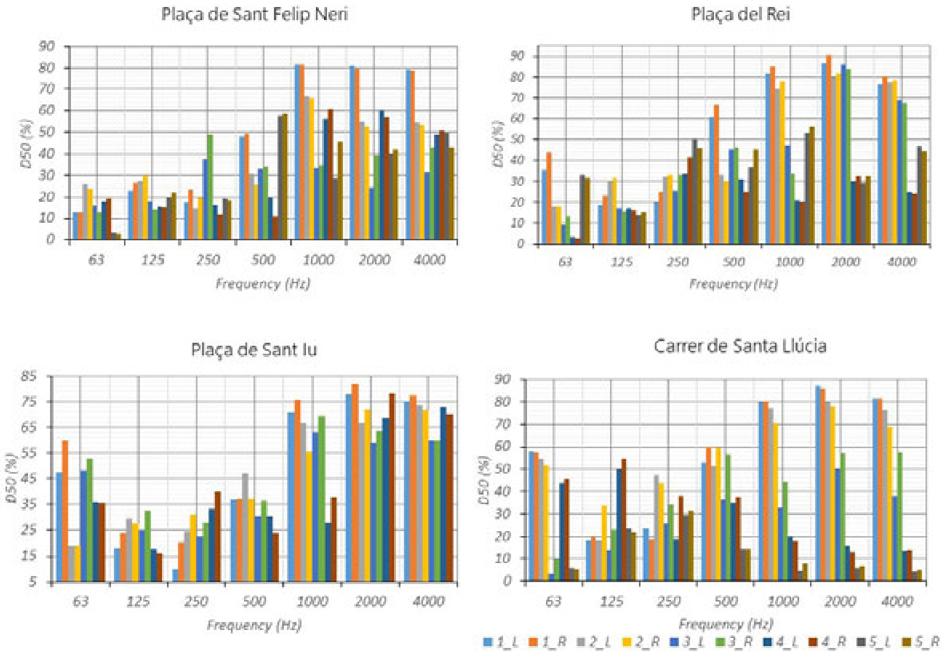


Fig. 8. Definition (D50) of the different environments: Sant Felip Neri (top left), Plaça del Rei (top right), Plaça Sant Iu (bottom left) and Carrer santa Llúcia (bottom right).

Early Decay Time (EDT)

In Plaça de Sant Felip Neri (top left from Figure 9) we can see that EDT values for 500 Hz and 1 kHz are similar to Ts values, except for the Ts peak at point 5, which is the result of a measurement error due to the high amount of background noise at that time. Similarly, in Plaza del Rei (top right), Sant Felip Neri (bottom left) and Carrer Santa Llúcia (bottom right), the EDT levels are very similar to the Ts levels, which indicates that there is a good sound diffusion in these environments.

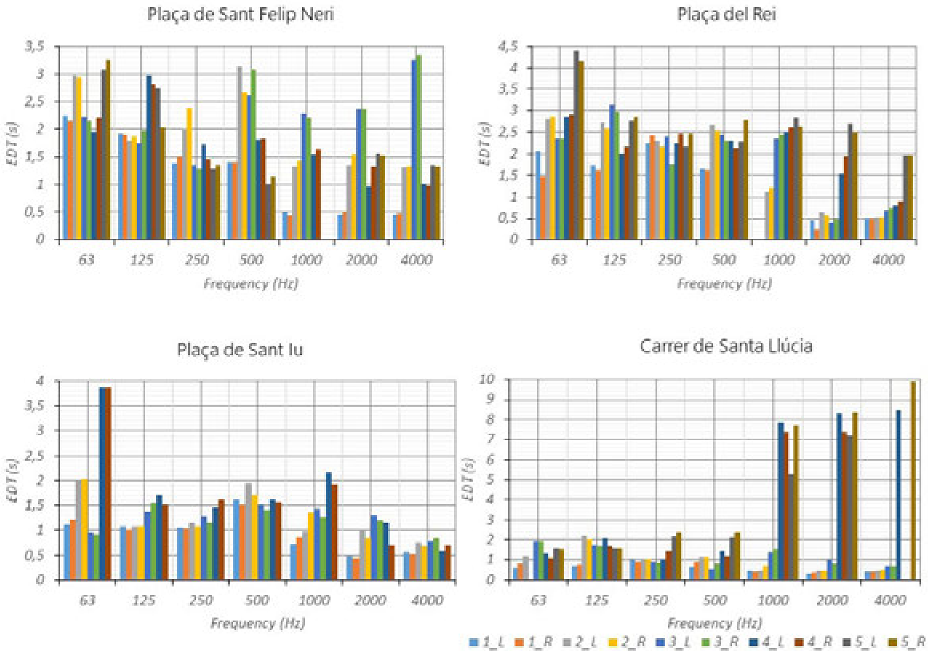


Fig. 9. Early Decay Time (EDT) of the different environments: Sant Felip Neri (top left), Plaça del Rei (top right), Plaça Sant Iu (bottom left) and Carrer santa Llúcia (bottom right).

5. How is it evaluated and instructed?

Quantitative approaches are the main methods of scientific research. They focus on analysing the degree of association between quantified variables, promulgated by logical positivism. Therefore, possible answers need to be constrained in order to evaluate results objectively [1]. Some evaluation investigations have already been done with architecture students [2].

Qualitative research is less common in education areas, because it focuses on detecting and processing intentions. Unlike quantitative methods, qualitative approaches require deduction to interpret the results. The qualitative approach is subjective, because it is assumed that reality is multifaceted and cannot be reduced to a universal parameter. Interviewers are passive observers, they take notes and classify them [3]. These methods have traditionally been related with social sciences, due to their association with human factors and the user's experience. In fact, User Experience, UX, is a discipline focused on the study of behavioural patterns in working environments. Our case study is framed in teaching

1 Miguel Ángel Conde and others, 'The Implementation, Deployment and Evaluation of a Mobile Personal Learning Environment', *Journal of Universal Computer Science*, 19.7 (2013) <https://doi.org/10.3217/jucs-019-07-0854>.

2 Josep Llorca, Héctor Zapata, and others, 'Bipolar Laddering Assessments Applied to Urban Acoustics Education', in *WorldCIST'18 2018: Trends and Advances in Information Systems and Technologies* (Springer, Cham, 2018), pp. 287–97 <https://doi.org/10.1007/978-3-319-77700-9_29>; Carles Campanyà and others, 'Identification of Significant Variables for the Parameterization of Structures Learning in Architecture Students', in *WorldCIST'18 2018: Trends and Advances in Information Systems and Technologies* (Springer, Cham, 2018), pp. 298–306 <https://doi.org/10.1007/978-3-319-77700-9_30>.

3 Marc Hassenzahl and Noam Tractinsky, 'User Experience - a Research Agenda', *Behaviour & Information Technology*, 25.2 (2006), 91–97 <https://doi.org/10.1080/01449290500330331>.

process usability [4]. Thus, a brief discussion of what usability means is mandatory.

Usability evaluation

We could define usability as a general quality that indicates the suitability for a specific purpose of a particular artefact (appropriateness for a purpose) [5].

This term is linked with the development of products (which could be systems, technologies, tools, applications or devices) that can be easy to learn, effective and enjoyable in the user's experience. Nevertheless, usability can be considered another factor in a wider process called the acceptability of a system. Thus, acceptability defines whether a system is good enough to meet all a user's needs [6].

In ISO/IEC 9126, usability is defined as "software product capability to be understood, learned, used and attractive for the user, when it is used under specific conditions". However, usability is not limited to computer systems. It is a concept that can be applied to any element in which an interaction between a human and an artefact occurs.

In addition, in ISO/IEC 9241-11, the guidelines for the usability of a particular product are described. Here, usability is defined as "the level in which a

4 Jakob Nielsen and Jakob, *Usability Engineering* (Academic Press, 1993) <https://dl.acm.org/citation.cfm?id=529793> [accessed 31 October 2017].

5 J. Brooke, 'SUS - A Quick and Dirty Usability Scale - WebSM', in *Usability Evaluation in Industry*, ed. by I. L. M. P. W. Jordan, A. Weerdmeester, and A. Thomas, 1996, pp. 189–94 <http://www.websm.org/db/12/16455/Web Survey Bibliography/SUS__A_quick_and_dirty_usability_scale/> [accessed 31 October 2017].

6 Jorge Martín Gutiérrez, 'Estudio y Evaluación de Contenidos Didácticos En El Desarrollo de Las Habilidades Espaciales En El Ámbito de La Ingeniería', *Riunet* (Universitat Politècnica de València, 2010) <https://doi.org/10.4995/Thesis/10251/7527>.

product can be used by particular users in order to reach specified goals with effectivity, efficiency and satisfaction in a particular context of use". In our research, the effectivity of a system is related with its goals, efficiency is related with the performance of the used resources to reach the goals, and satisfaction is related with its acceptability and commodity [1]. This definition is based on the concept of quality in use, and describes how the user does particular tasks in particular environments in an effective way [2]. For Bevan, the quality of use, measured in terms of efficiency, efficacy and satisfaction, is not only determined by the product, but also by the context (kind of users, tasks of the users and physical environment). Therefore, the usability, understood as the quality in use of a product is the interaction between a user and a product while a task is being accomplished in a technical, physical, social and organizational environment.

In our study, usability defines the general quality, indicating the suitability for educational purposes of an immersive scenario. In a similar line as Fonseca et al. [3], the goal is to evaluate the student motivation before and after the use of such technologies. Users are asked to evaluate the quality of the soundscape representation in this scenario. Both visual and acoustic data have a direct impact on the perception of the space and the realism of this representation is the focus of the evaluation.

1 Nigel Bevan and Nigel, 'Practical Issues in Usability Measurement', *Interactions*, 13.6 (2006), 42 <https://doi.org/10.1145/1167948.1167976>.

2 David Fonseca and others, 'Student Motivation Assessment Using and Learning Virtual and Gamified Urban Environments', in *Proceedings of the 5th International Conference on Technological Ecosystems for Enhancing Multiculturality - TEEM 2017* (New York, New York, USA: ACM Press, 2017), pp. 1–7 <https://doi.org/10.1145/3144826.3145422>.

3 David Fonseca and others. Ibid.

Two kinds of experiments were carried out with architecture students. The first group of experiments considered a quantitative approach to the evaluation, whereas the second group was performed according to a qualitative approach.

The quantitative test

A set of multiple choice questions about several audio sequences were administered to a group of people (17 in total). In this test, some urban acoustic features were analysed. This first test, as shown in Table 2, was given once the recordings and acoustic analysis had been carried out. The test had two objectives: to characterize people's perception and knowledge of acoustic and sonic features of the outdoor space, and to obtain feedback on the most relevant aspects of street music.

The results should allow for an initial approximation of whether people are aware of the nuances and differences between a street music recording and a concert hall music recording. Above all, it should be possible to test people on the big differences between the acoustics of the different public spaces. Therefore, different recordings of the same music but from different spatial points were compared. A total of six questions, each with a new melody, covered the following topics: speech intelligibility, sense of space, reverberation time, timbre modification, EDT and bass amplification.

The first dataset (Tables 2 and 3) shows the description of the analysed elements and the individual responses of the different users.

E. Code	*Description*	*Option A*	*Mention index MI (%) for option A*	*Option B*	*Mention index MI (%) for Option B*
1. I	Speech clarity (C50)	C50 (500Hz) = 2dB (from Figure 5: Carrer Santa Llúcia, recording point 1, Puccini track)	**100**	C50 (500Hz) = -7.5dB (from Figure 5: Carrer Santa Llúcia, recording point 3: Puccini track)	**0**
2.S	Sense of space	(Plaça de Sant Iu, recording point 3, Tchaikovsky track)	**82.4**	(Plaça del Rei, recording point 1, Tchaikovsky track)	**17.6**
3.EDT	Early decay time	EDT (500Hz) = 1.3 s (from Figure 8: Plaça Sant Felip Neri, recording point 1, Mendelssohn track)	**29.4**	EDT (500Hz) = 2.3s (from Figure 8: Plaça del Rei, recording point 4, Mendelssohn track)	**70.6**
4.Br	Brightness	(Plaça Sant Iu, recording point 1, Dvorak track)	**58.8**	(Plaça Sant Iu, recording point 4, Dvorak track)	**41.2**
5.T60	Reverberation time	T60 (500Hz) = 0.65s (from Figure 4, Plaça del Rei, recording point 1, Orff track)	**88.2**	T60 (500Hz) = 1.75s (from Figure 4, Plaça del Rei, recording point 4, Orff track)	**11.8**
6.BR	Bass ratio	(Plaça Sant Felip Neri, recording point 1, Lucien track)	**82.4**	(Plaça Sant Felip Neri, recording point 4, Lucien track)	**17.6**

E. Code	*Male*											*Female*					
USERS	**U 1**	**U 2 (M)**	**U 3 (M)**	**U 4**	**U 5**	**U 6**	**U 7**	**U 8**	**U 9**	**U 10 (M)**	**U 11**	**U 12**	**U 13 (M)**	**U 14**	**U 15 (M)**	**U 16**	**U 17**
1.I	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2.S	A	A	B	B	A	A	A	A	A	A	A	A	A	A	B	A	A
3.EDT	B	B	B	B	B	B	B	B	A	B	B	A	B	A	B	A	A
4.Br	B	A	B	A	A	B	A	B	B	A	B	B	A	A	A	A	A
5.RT	A	A	A	A	A	B	A	A	A	A	A	A	A	A	B	A	A
6.BR	B	B	B	B	B	B	A	B	B	B	B	B	B	B	A	A	B

Fig. 10. Table 2. Description and definition of the options in the quantitative test

Fig. 11. Table 3. Individual options for the quantitative test

After an analysis of the survey results, we can highlight some important findings. First, all the questions in Table 2 are balanced to A or B over 70%, except the fourth question, which is more ambiguous. This shows the high consensus about the acoustic features that were being evaluated. Second, we highlight the presence of users who had professional or higher music qualifications in

Table 3. These users agreed unanimously, or almost unanimously (except one) in their decisions. The only question on which they disagreed with each other concerns the sense of space.

The qualitative test

In this context, the analysis of some typical street music locations in Ciutat Vella of Barcelona was included in this soundscape evaluation. One of the environments studied here was the Plaça Sant Felip Neri. Various recordings were made in the environment according to different positions of the listeners. For the current study, one recording was selected: The Fountain by Marcel Lucien was reproduced in Plaça de Sant Felip Neri in five positions. Fig. 1 shows the emitting point with the enumeration of the different recording points in each square.

To create the test conditions, Plaça Sant Felip Neri needed to be reproduced as faithfully as possible, in terms of visual and auditory aspects.

First, a 3D model was created using photogrammetric processing of digital images to generate 3D spatial data. This method is relatively fast to implement, does not require specialized hardware like laser scanning and, if performed correctly, produces high quality results that are not as precise as other techniques, but more than enough to transport the user to a faithful 3D recreation of the square.

The next goal was to recreate the soundscape. Two options were developed and presented to the test subjects. The first option was to use the original concert hall recording and present it to the users

Fig. 12. Three students in the experiment.

as it is, without any distortion, reverberation or additional ambient sounds from the square.

The second option was more difficult to create. As stated, five recordings of the song were made from different locations in the square. These recordings captured the subtleties a user would experience listening in the real square. The challenge was to allow the test subjects to move freely around the square and still be able to listen to the song in conditions as close as possible to the real conditions at any point in the square, not only the five recording points.

To extend the experience to any given point, a mixing algorithm was used to perform a logarithmic interpolation between the nearest recordings, to provide an experience that was identical to the original when the user was exactly at the recording point, and faded seamlessly as they moved closer to the next one.

Finally, a head mounted display needed to be used to show the virtual reality to the test subjects. The Oculus Rift was selected for this task due to its compact size, high quality display and integrated headphones. This provided a fully immersive

environment with a great sense of presence for the users (Figure 12)

The Oculus Rift allows for room scale tracking. This means that the user can move around the real space, and that movement translates to the virtual world. This greatly amplifies the sense of presence and makes the experience a lot more realistic and comfortable. However, it has limitations: the length of the cable and the resolution of the tracking cameras only allow the user to move around a space 3 meters long and 2 meters wide, approximately.

To improve this aspect, a teleport system was created. Using the Oculus Rift touch controllers, the user could point to any location in the square, and instantly teleport to that location. This provided the necessary freedom to move around the square, while maintaining all the benefits of room tracking.

The result of this process was an experience that allowed free movement around a realistic 3D recreation of the original square. Users perceived two distinctly different audio environments: one that recreated concert hall conditions, and a second one to experience as closely as possible the square's sound conditions (Figure 13).

Fig. 13. Two screenshots of what students can see with the glasses.

For the qualitative study, a sample of 18 students (11 men and 8 women) who agreed to participate was selected.

The BLA method works on positive and negative poles to define the strengths and weaknesses of the product. Once the element is obtained, the laddering technique can be applied to define the relevant details of the product. The object of a laddering interview was to uncover how product attributes, usage consequences, and personal values are linked in a person's mind. The characteristics obtained through the laddering application will define which specific factor contributes to the consideration of an element as either a strength or a weakness. The BLA process consisted of three steps, following a similar method to Fonseca, Redondo and Villagrasa :

1. Elicitation of elements. The implementation of the test started with a blank template for the positive (most favourable) and negative (least favourable) elements. The interviewer (in this case the professor) asked the users (the student) to mention a positive and a negative aspect of the two types of music that could be heard (Option A and Option B). Thus, we obtained two positive aspects and two negative aspects.

2. Marking of elements. Once the list of positive and negative elements has been completed, the interviewer asked the user to mark each one from 0 (lowest possible level of satisfaction) to 10 (maximum level of satisfaction).

3. Element definition. Once the elements had been assessed, the qualitative phase started. The interviewer asked for justification of each one of the elements by performing the laddering

technique. Questions were asked such as "Why is it a positive element?" "Why did you give it this mark?" The answers had to be specific explanations of the exact characteristics that made the mentioned element a strength or weakness of the product.

From the results obtained, the next step was to polarize the elements based on two criteria:

1. Positive (Px)/Negative (Nx): the student had to differentiate between elements perceived as strong points of the experience that helped them to consider the music as satisfactory, compared to negative aspects that were not satisfactory or simply needed to be modified to be satisfactory.

2. Common Elements (xC)/Particular (xP): finally, the positive and negative elements that were repeated in the students' answers (common points) and the responses that were only given by one of the students (particular points) were separated according to the coding scheme shown in Tables 1, 2 and 3.

The common elements that were mentioned at a higher rate were the most important aspects to use, improve or modify (according to their positive or negative sign). Particular elements, which were mentioned by only one user, could be ruled out or treated in later stages for development.

The individual values obtained for positive and negative indicators are shown in Table 2. Once the features mentioned by the students were identified and given values, the third step defined by the BLA initiated the qualitative stage in which the students described and provided solutions or improvements

Fig. 14. Table 4. Positive common (PC), particular (PP), negative common (NC) and negative particular (NP) elements for Option A (concert hall) and Option B (public square)

for each of their contributions in the format of an open interview.

E. Code	Description	Av. Score (Av)	Mention Index (MI) (%)
1PC (A)	Clarity of music	7.7	44.4
2PC (A)	Guiding thread for music	8.3	16.6
3PC (A)	Quality of sound	8.3	16.6
4PC (A)	Focused on the music	9	11.1
1PP (A)	Peaceful music	9	5.6
1NC (A)	Not realistic	3	33.3
2NC (A)	No sense of space	4	22.2
3NC (A)	No background	4.5	11.1
4NC (A)	Movement too fast	4	11.1
1NP (A)	No variance of echo	4	5.6
2NP (A)	Like a television	4	5.6
3NP (A)	Too loud	4	5.6
1PC (B)	Realistic	8.4	50
2PC (B)	Sense of the place	8.7	33.3
1PP (B)	Alive	9	5.6
2PP (B)	Softer and modulated	7	5.6
3PP (B)	More natural	7	5.6
1NC (B)	No clarity of music	3.8	22.2
2NC (B)	Relation between background and vision	4.7	16.7
3NC (B)	Disturbing background	3.7	16.7
4NC (B)	Problems with volume	3.7	16.7
5NC (B)	It is not real enough	3.5	11.1
1NP (B)	Quality of hardware	5	5.56
2NP (B)	Sudden changes in sound	3	5.56

Fig. 15. Table 5. Individual scores for PC, PP, NC and PC elements for Option A (concert hall) and Option B (public square)

E. Code	*Male*											*Female*						
USERS	**U 1**	**U 2**	**U 3**	**U 4**	**U 5**	**U 6**	**U 7**	**U 8**	**U 9**	**U 10**	**U 11**	**U 12**	**U 13**	**U 14**	**U 15**	**U 16**	**U 17**	**U 18**
1PC (A)	-	-	-	9	8	-	8	-	7	7	8	-	8	-	-	-	7	-
2PC (A)	9	-	-	-	-	-	-	8	-	-	-	-	-	-	-	8	-	-
3PC (A)	-	8	-	-	-	7	-	-	-	-	-	-	-	9	-	-	-	8
4PC (A)	-	-	8	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
1PP (A)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-
1NC (A)	2	-	-	-	3	4	-	-	-	-	-	-	-	3	-	5	-	1
2NC (A)	-	2	4	-	-	-	-	5	-	-	-	-	-	-	-	-	5	-
3NC (A)	-	-	-	-	-	-	5	-	-	-	-	-	4	-	-	-	-	-
4NC (A)	-	-	-	5	-	-	-	-	3	-	-	-	-	-	-	-	-	-
1NP (A)	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
2NP (A)	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-
3NP (A)	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-
1PC (B)	-	9	-	-	10	9	7	-	5	9	-	10	-	-	-	8	-	9
2PC (B)	10	-	-	9	-	-	-	9	-	-	4	-	-	10	-	-	10	-
1PP (B)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-
2PP (B)	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3PP (B)	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-
1NC (B)	-	-	-	-	-	-	4	3	-	4	4	-	-	-	-	-	-	-
2NC (B)	-	5	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3NC (B)	-	-	-	-	-	4	-	-	-	-	-	3	-	-	4	-	-	-
4NC (B)	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3	-
5NC (B)	-	-	-	-	3	-	-	-	2	-	-	-	-	-	-	-	-	-
1NP (B)	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
2NP (B)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3

E. Code	Description	Mention Index (MI) (%)
1CI (A)	Improve the relation with the environment	66.7
2CI (A)	Improve the background sound	22.2
3CI (A)	Change the position of the sounds	11.1
2PI (A)	Decrease the volume of the sound	5.7
3PI (A)	Improve the relation with the musician	5.7
4PI (A)	Improve the quality of the sound	5.7
1CI (B)	Improve sound quality	27.8
2CI (B)	The changes between position could be softer	22.2
3CI (B)	Balance the volume levels between different points	11.1
4CI (B)	Improve the relation between vision and sound	11.1
5CI (B)	Decrease the background noise	11.1
1PI (B)	Improve the clarity of sound	5.7
1PI (B)	Improve the relation with the place	5.7

Fig. 16. Table 6. Proposed common improvements (CI) and particular improvements (PI) for both positive and negative elements for common and particular items in A recording (concert hall) and B recording (public square)

At this point, we can identify the most relevant items obtained from the BLA, which had high rates of citation, high scores or a combination of both. It is important to separate the types of results obtained. The first group belongs to option A (concert hall recording), and the second group to option B (public square recording). After the elicitation of the most relevant features of each of them, we are going to end by comparing them.

Option A (concert hall recording). We can highlight that this kind of recording has good clarity of music (MI: 44.4%, Av: 7.8), it favours the guidance of the thread for music (MI: 16.6%, Av: 8.3), and the quality of the sound is valued (MI: 16.6%, Av: 8.3). In terms of the main negative comments, students clearly identified a lack of realism in this kind of experience (MI: 33.3%, Av: 3), that was related to the lack of sense of space (MI: 22.2%, Av: 4) and they missed the background noise (MI: 11.1, Av: 4.5), aspects that were directly related to the design of the application.

Option B (public square recording). Two main positive aspects were highlighted by students: the high degree of realism of the application both in visual and acoustic terms (MI: 50%, Av: 8.4), and the good relation between sound and place (MI: 33.3%, Av: 8.7). Conversely, some negative comments were pointed out: a lack of clarity in the music (MI: 22.2%, Av: 3.8), a bad relation between background and vision (MI: 16.7%, Av: 4.7), which could be solved with the position of different visual avatars, and the presence of some disturbing background (MI: 16.7%, Av: 3.7), due to the different times of the original recordings. Technically, these would be the main aspects to modify in future iterations of the proposed method.

In summary, two clear opinions about the experiment were shown, which confirm the first question of the survey: Which recording do you prefer, A or B? Most people (61.1%) agreed that option B was better than option A (38.9%). The reasons for this answer were clearly explained in the rest of the survey. Although there was a high valuation of the realism of the application both in visual and acoustic terms in option B (MI: 50%, Av: 8.4), it was also certain that clarity of music in option B was not as good as in option A, as we can see if we compare 1PC (A) with 1NC (B). This confirms that the street music recording implies a decrease of quality in the music played. This loss could be a drawback for musicians who want to perform in the middle of the city. However, the survey reveals another feature that must be taken into account: a third of the students (MI: 33.3%) evaluated option B with an almost excellent score (Av: 8.7) for the sense of space quality (2PC [B]). This shows the hidden potential of spatial sound, that is, sound spatialization. Several attempts can be found in the history of music in which composers wrote their music bearing in mind the spatial features of the places in which it was going to be played. However, all these compositions tend to be limited to closed spaces, and the spatial possibilities are limited to the specific space. A wide range of possibilities arise when a closed concert hall is replaced by the openness of squares and public spaces. Coupled volumes, streets, galleries, balconies or even stairs now belong to this new stage for music that can be explored in infinite ways.

6. Conclusions

The study aimed to highlight the questions of What is going to be evaluated and How is it going to be evaluated within the context of cultural heritage evaluation. In this case study of a higher education evaluation, we have explained that both questions can be answered in three words: objectivity through subjectivity. In fact, what was evaluated with the quantitative and qualitative tests was not far from what was studied with the acoustic parameters. Furthermore, the subjective opinions were based on the objective parameters. This built a bridge over the big gap between these two poles, and helped us to understand that no objective parameters can be evaluated without subjective insight. For the cultural evaluation, a scientific basis must be established to achieve reliable results. Nevertheless, a unilateral evaluation that only relies on these scientific data would overlook the valuable opinions of users. What is more, without the user's insight, the analysis would neglect the term "cultural", because no culture is possible without the action of humans, that is, the users. Here, cultural is defined as the opposite of natural, as a synonym of artificial, as something that is evaluated by a human.

However, some limitations of the study need to be addressed in further research. The number of participants in the surveys should be increased, and a pre- and post-test evaluation of satisfaction with the process introduced. Similarly, the immersive experiment should be extended to other outdoor environments (Carrer Santa Llúcia, Plaça de Sant Iu and Plaça del Rei) so that the objective parameters can be compared with the subjective users' opinions.

Further research must also be carried out on the implementation of these representation techniques in the higher education system, especially in Architectural Degree courses, in which spatial understanding is crucial. In this context, it is clear that architecture students should be able to deal with spatial representations that not only cover visual features, but also sonic or even thermic components of architecture. Today's technology has reached such a high level of representation capabilities, that a vague idea of what an environment looks like is no longer acceptable. An architect should manage these tools when they present a new building, and protect existing constructions that are regarded as cultural heritage.

Case study

Acoustic Filter

Virtual Reality (VR) has received much attention in the last decades due to its multiple applications in a broad range of fields: conductor training (look for references), military strategies, entertainment, blind rehabilitation, neurological testing, surgery training, etc. VR is an environment generated in the computer, which the user can operate and interact with in real time. [1] It has also many applications in the architectural field such as designer training [2] or citizen participation in urban design process [3] . But a remarkable feature is that the majority of architectural applications of VR rely only on the visual aspects and doesn't pay much attention to the acoustic ones, although other architectural-related fields use images combined with sound, such as computer games. The lack of attention to the acoustic aspects in VR architectural representations presents big interest to those who search for an immersive architecture experience.

There are several ways to include audio in VR and there has been extensive research regarding the development of these formats. The three

1 Michael Vorländer, *Auralization : Fundamentals of Acoustics, Modelling, Simulation, Algorithms and Acoustic Virtual Reality* (Berlin: Springer, 2008).

2 D. Henry and T. Furness, 'Spatial Perception in Virtual Environments: Evaluating an Architectural Application', in *Proceedings of IEEE Virtual Reality Annual International Symposium (IEEE, 1993)*, pp. 33–40 <https://doi.org/10.1109/VRAIS.1993.380801>; Lluís Vicent Safont and others, 'Virtual Learning Scenarios for Qualitative Assessment in Higher Education 3D Arts', *Journal of Universal Computer Science*, 21.8 (2015), 1086–1105 <https://doi.org/10.3217/jucs-021-08-1086>.

3 Huayi Wu, Zhengwei He and Jianya Gong, 'A Virtual Globe-Based 3D Visualization and Interactive Framework for Public Participation in Urban Planning Processes', *Computers, Environment and Urban Systems*, 34.4 (2010), 291–98 <https://doi.org/10.1016/j.compenvurbsys.2009.12.001>; David Fonseca and others, 'Informal Interactions in 3D Education: Citizenship Participation and Assessment of Virtual Urban Proposals', *Computers in Human Behavior*, 55 (2016), 504–18 <https://doi.org/10.1016/j.chb.2015.05.032>.

most common and successful ones are named Multi-Channel audio, Object-Based audio [4] and Ambisonics [5] . Although each of these technologies present their own advantages over the others, none of them is capable of containing the soundscape of the place and allowing the free movement of the listener without a big array of speakers, a huge use of CPU power, or a multiple path recording, respectively. Firstly, not everybody has the chance for a big array of speakers. Secondly, the average of personal computer's power cannot be big enough for the support of a game as that presented, Finally, a multiple path recording would be too expensive and tedious for an architectural VR study.

This section presents a set of criteria for the generation of a new VR audio format that can fulfil the lacks that the other formats have. This new format is based on the creation of a filter which contains the place information. On the basis of these criteria it then describes the preparation of a set of study cases where the filter can be tested.

The last step in the experimental process will consist of the evaluation of this acoustic filter by architecture students and by generic users. This evaluation will show us the satisfaction grade of both students and users in a similar way that some studies made before [6] . The intention of these studies

4 Robert Bleidt and others, 'Object-Based Audio: Opportunities for Improved Listening Experience and Increased Listener Involvement', *SMPTE Motion Imaging Journal*, 2014 <https://doi.org/10.5594/M001546>.

5 MA. Gerzon, 'Multidirectional Sound Reproduction Systems' (UK-Patent no. 3 997 725, 1976).

6 Ernesto Redondo Domínguez, Alberto Sánchez Riera and Joaquim Moya Sala, 'La Ciudad Como Aula Digital: Enseñando Urbanismo y Arquitectura Mediante Mobile Learning y La Realidad Aumentada: Un Estudio de Viabilidad y de Caso', *ACE: Architecture, City and Environment*, 0.19 (2012).

was to understand the city as a digital educational environment and use it as an experimental frame for the implementation of the new technologies both in academic curriculum and in informal education.

Background

Architecture necessarily deals with use, place and technique [1] . The three basic components contain the questions that architecture must answer: how do you live in this architecture, where is this architecture located, and how is this architecture made. The study of these three components leads to the architectural discipline. It seems to be logical that if a representation of an architectural ambience pretends to be immersive, it must represent the three basic components with success. This means that the representation (and more exactly VR) must explain how do you live there, where is this located and how is that made.

The first component (how do you live in this architecture) has always been represented by a wide range of methods commonly known as geometry. These methods consist on showing the facilities of the space to the user: the comfortable measures of the rooms, the suitable position of furniture or the convenient disposition of the walls between rooms. VR representations have developed ways for the visualization of these features by representing the geometry of a place in a perspective in a convincing way. It was also shown that viewing a graph in a virtual reality display is three times as good as 2D diagram [2] .

The second component (where is this architecture located) can be firstly found in the science of place called geography. This science is able to define the

1 Antonio Armesto, 'Arquitectura y Naturaleza: Tres Sospechas Sobre El Próximo Milenio', *DPA: Documents de Projectes d'arquitectura*, 2000

2 C. Ware and G. Franck, 'Viewing a Graph in a Virtual Reality Display Is Three Times as Good as a 2D Diagram', in *Proceedings of 1994 IEEE Symposium on Visual Languages (IEEE Comput. Soc. Press)*, pp. 182–83 <https://doi.org/10.1109/VL.1994.363621>.

physical characters of place and represent them through cartographic drawings. VR representations have developed ways for the visualization and navigation through these spaces not only by a desktop but also by a head-mounted display [1] . What is more, architectural models need to include landscape elements such as trees, mountains and other buildings in order to locate the represented architecture in an exact environment.

The third component (how is this architecture made) representation counts with a long tradition of drawing techniques that are able to explain the nature of the construction: materials, textures, colours, brightness, transparency or blurriness are some of the large number of the characteristics of the built environment. VR representations have also developed ways for the visualization of these features by representing the qualities of an object under the effect of natural or artificial light.

As we can see, the three components need to be convincing in order to achieve an immersive environment. Nevertheless, we have presented architecture as a discipline only dealing with visual data. While use, place and technique embrace also haptic, tactile or acoustic factors [2] . In fact, some critiques from within the discipline of architecture itself argue the importance of the other senses, apart from sight, for the discipline of architecture. Juhani Pallasmaa [3] , Ted Sheridan and Karen Van

1 Beatriz Sousa Santos and others, 'Head-Mounted Display versus Desktop for 3D Navigation in Virtual Reality: A User Study', *Multimedia Tools and Applications*, 41.1 (2009), 161–81 <https://doi.org/10.1007/s11042-008-0223-2>.

2 Vorländer.

3 Juhani. Pallasmaa, *The Eyes of the Skin : Architecture and the Senses* (Wiley, 2012).

Lengen [4] , Björn Hellstrom [5] , Stephen Holl and Rafael Pizarro [6] are some of the architects who have noted what the discipline of architecture may profit from considering the hidden realm of the auditory and the multisensory [7] .

These reasons conduce our attention to the acoustic representation in VR. As Vorländer says, if the behaviour of an acoustic object or system is shown in a more complex way than numerically, including the creation of acoustic signals in time or frequency domain, we talk about "simulation" and "auralization" [8] .

The implementation of audio information from the surroundings is what is needed for an enhanced immersive experience of the represented architecture. For this purpose, several VR audio formats for auralization have been developed during the last decades: Multi-channel audio, Object-Based audio and Ambisonics. In this part of the article we are going to explain the main features of these audio formats and to point out the main strengths and weaknesses of each of them.

4 Ted Sheridan and Karen Van Lengen, 'Hearing Architecture: Exploring and Designing the Aural Environment', Journal of Architectural Education, 57.2 (2003), 37–44 <http://www.jstor.org/stable/1425798> [accessed 27 December 2016].

5 Björn. Hellström, *Noise Design : Architectural Modelling and the Aesthetics of Urban Acoustic Space* (Göteborg: Ejeby Förlag, 2003).

6 Rafael E. Pizarro, 'Teaching to Understand the Urban Sensorium in the Digital Age: Lessons from the Studio', *Design Studies,* 30.3 (2009), 272–86 <https://doi.org/10.1016/j.destud.2008.09.002>.

7 Michael Fowler, 'Sound, Aurality and Critical Listening: Disruptions at the Boundaries of Architecture', *Architecture and Culture,* 1.1 (2013), 162–80 <https://doi.org/10.2752/175145213X13756908698766>.

8 Vorländer.

Multi-channel Audio

In the Multi-channel audio representation, the listener is located in the centre of the scene and an array of speakers surround them. The unit of information is the loudspeaker, where each channel is associated to a loudspeaker. Here, the sound reproduction is made by mixing the various channels on several speakers. In Multi-channel audio, the more channels, the more spatial sound capabilities. This method has been the traditional sound representation used for the past 50 years or more. The Stereo, 5.1, 7.1 formats are multi-channel horizontal representations. 3D is obtained by adding elevated speakers, like in the 11.1 format, where 4 ceiling speakers are added to a 7.1 horizontal speaker layout. One of the main drawback of the Multi-channel audio representation is that it is loudspeaker set up dependent and that one needs one mix tor type of each set-up, whereas Object-Based and Ambisonics contents are independent of the loudspeaker set-up [1] . Another disadvantage is that a Multi-channel audio system needs an array of speakers and relies on the number of speakers. When the number of speakers is limited the system becomes poor and without possibilities.

Object-Based Audio

In the Object-Based representation, the listener is located on the centre of the scene with headphones and some virtual sound sources surrounds them. The unit of information is the virtual sound source. The scene is made of several virtual sound sources and

1 'Developers - 3D Sound Labs' <http://www.3dsoundlabs.com/category/developers/> [accessed 28 December 2016].

information about their locations, their directivity patterns and the rendering environment (room size, reverberation parameters…). The 3D audio rendering is made by calculating the combination of all the sources, including the reverberation, at the listener position. This is a great paradigm to interactively create content, but it also uses a lot of CPU resources. The more complex (number of sound sources) and realistic (precision of the reverberation) the scene, the more CPU is needed [2] . Moreover, Object-Based audio has to render the environment according to the virtual model, what is not always the most exact approximation to the reality. This last drawback is pretended to be solved with our filter proposal, as we explain afterwards.

Ambisonics

Unlike the two other representations, the Ambisonics format does not rely on the description of individual sound sources (speºakers or objects) but instead represents the resulting sound field at the listener's position. The mathematical formalism used to describe the sound field is called spherical harmonics and the unit of information is the number of component (or the Order) of this spherical representation. The more components or the higher order you have, the more precision in the spatial representation of the scene you get. This paradigm is not new and has been used by a small sound professional community for several decades with a concept called the B-Format which is in fact a Higher Order Ambisonics representation at the 1st order. The representation of the resulting sound field at the listener's position is one of its

2 'Developers - 3D Sound Labs'.

main advantages when computing the information, but can be also one of its main drawbacks when considering the listener's position as a fixed point. If one wants to record a whole place, one must make as Ambisonics recordings as possible positions of the listener, and this can be a tedious task.

Ambisonics can be understood as a three-dimensional extension of M/S (mid/side) stereo, adding channels for height and depth. The resulting signal set is called B-format. Its component channels are labelled:

- W: for the sound pressure (the M in M/S).
- X: for the front-minus-back sound pressure gradient.
- Y: for the left-minus-right (the S in M/S).
- Z: for up-minus-down.

The W signal corresponds to an omnidirectional microphone, whereas XYZ are the components that would be picked up by figure-of-eight microphones oriented along the three spatial axes.

The simplest Ambisonic panner (or encoder) takes a source signal S and two parameters, the horizontal angle θ and the elevation angle ϕ. The different gains of the Ambisonic components are the following:

$$\mathrm{W}=\mathrm{S}\cdot 1/\sqrt{2} \qquad (1)$$

$$X=S\cdot\cos\theta\cos\phi \qquad (2)$$

$$Y=S\cdot\sin\theta\cos\phi \qquad (3)$$

$$Z=S\cdot\sin\theta \qquad (4)$$

In this part of the section we are going to expose the features of our new VR audio format. We must remain that the purpose of our work consists of the definition of a way of representing the soundscape of an architectural environment able to be implemented in a VR environment or to make an acoustic analysis of a place. For the definition of the Acoustic Filter, we need to make an experiment. The materials required for the experiment are an anechoic chamber for the sound recording in a pure state, a recording equipment consisting on a Zoom H6 recorder with two incorporated microphones and two KM 183 Newmann omnidirectional microphones, and a dodecaedrical ball for the reproduction of the sound into the anechoic chamber and into the analyzed places. Additionally, we need a software sound editor as Adobe Audition and the knowledge of correlation of acoustic wave principles. Our experiment consists of some steps derived from the audio correlation technique.

First of all, a known and basic sound is reproduced in the anechoic chamber with a dodecaedrical ball. This basic sound is recorded in the anechoic chamber with the KM 183 Newmann matched pair omnidirectional microphones connected to the Zoom H6. As the environment in the anechoic chamber is free of interferences from the ambience and additional noise, the basic sound recorded contains the acoustic information of the pure basic sound.

Secondly, the pure basic sound is analyzed and its frequency range is tested to be complete.

Thirdly, the pure basic sound is reproduced in the case study place. This sound is reproduced with the same dodecaedrical ball which was recorded in the anechoic chamber, in order to reproduce the basic sound under the same conditions as the first recording. This resulting sound is recorded in the case study place by the KM 183 Newmann matched pair omnidirectional microphones connected to the Zoom H6. The recording of the sound can be made from several points in the case study place, simulating the different positions of the listener.

Fourthly, the resulting sound is analyzed. The presence of an urban and architectural environment, city sound and position from the sound, modifies the basic sound in a way that the resulting sound registers. Usually, the resulting sound is attenuated, colorized, enriched or delayed by the presence of the environmental agents.

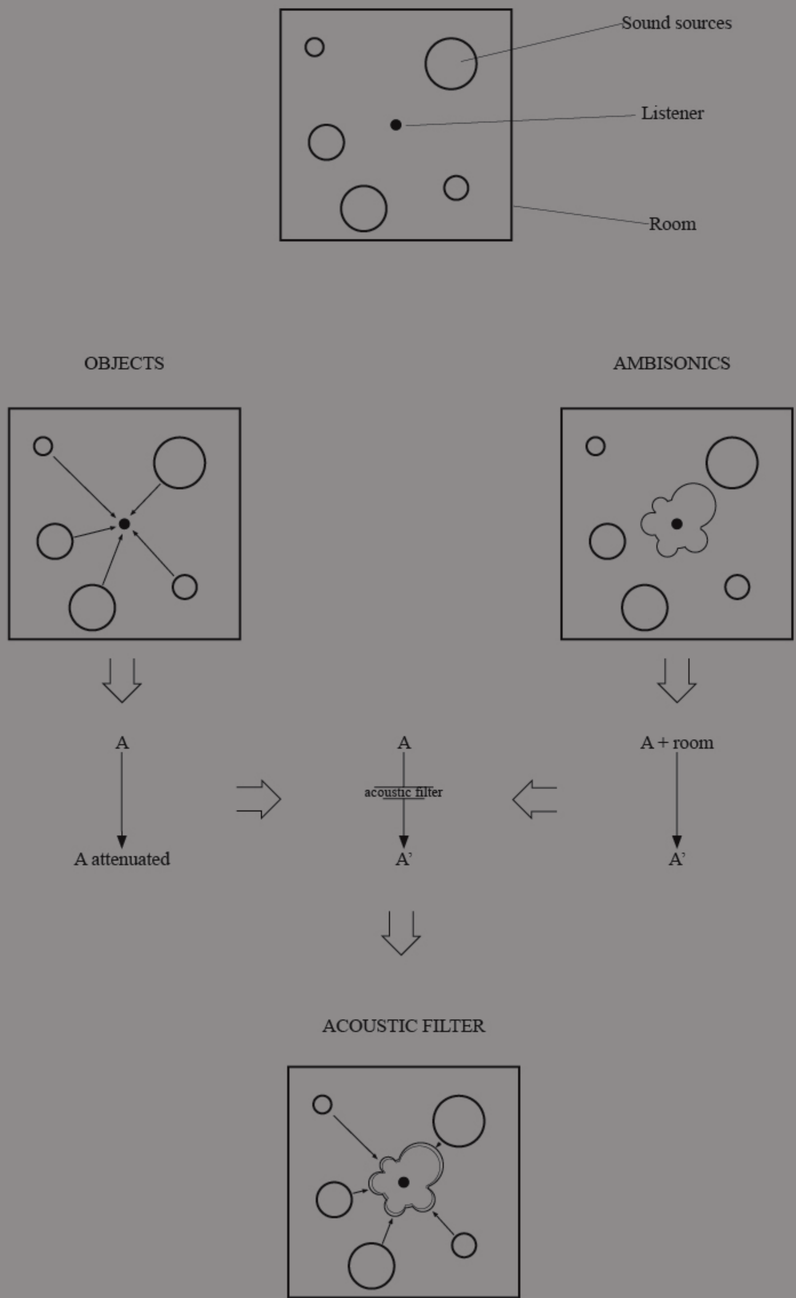
Finally, by a cross-correlation process [1] we can compare the basic sound with the resulting sound. In order to search the environment features, which are recorded in the resulting sound, it is easy to make the difference between the resulting sound and the basic sound. The sonic difference contains only the features of the place, which we denominate as the place sound.

Fig. 17. Graphic comparison between the two audio formats (Objects and Ambisonics) with the new Acoustic Filter: a) above all, the generic scenario is presented; b) then the working process of Objects and Ambisonics; c) the basic properties of Objects and Ambisonics and the main feature of the Acoustic Filter; d) the resulting scenario for the Acoustic Filter.

This place sound can be treated as a function [2] and constitutes the basis of our Acoustic Filter. The Acoustic Filter is able to reproduce the acoustic features of the place with any basic sound. This is the reason why the Acoustic Filter is very useful

1 Ronald N. (Ronald Newbold) Bracewell, *The Fourier Transform and Its Applications* (McGraw-Hill, 1978).

2 Walt. Kester and inc. *Analog Devices, Data Conversion Handbook* (Elsevier, 2005).


Sound sources
Listener
Room
OBJECTS
AMBISONICS
A
A attenuated
A
acoustic filter
A'
A + room
A'
ACOUSTIC FILTER

in architectural VR, because the different basic sounds that take place in an environment can be treated under the Acoustic Filter in order to get the impression of the sound in that place without a complete virtualization of the acoustics in the model, as Object-Based audio does, and without a prerecorded image of the environment acoustics, as Ambisonics does. The design of this Acoustic Filter is required and in the next part of the article we are going to introduce the basics of filter design.

Audio Filter Design and Analysis. Basic Parameters.

A filter, generally, is a system that avoids some parts of the processed object, following one or more attributes. For example, a gravel filter, or sieve, allows the sand passing but stops the stone passing. In a similar way, a processing signal filter is a very wide concept, because it can be any system treating signal. The filtering concept is very important for our experiment. For this reason, it is necessary a correct definition of the filter concept and types.

We can define the classical types of filters, in a similar way that Ruiz and Duxans [1] do:

A low-pass filter that allows low frequencies pass and attenuates high frequencies.

A high-pass filter that allows high frequencies pass and attenuates low frequencies.

1 Helenca Duxans Barrobés and Marta Ruiz Costa-Jussà, *Procesamiento de Audio*, ed. by UOC (Barcelona, 2012) <http://datos.bne.es/edicion/a5223887.html> [accessed 27 January 2017].

A band-stop filter, that is complementary to bandpass filter because it eliminates a band of frequencies, allowing the rest of the frequencies.

A bandpass filter, that allows a band of frequencies, eliminating the high and low frequencies.

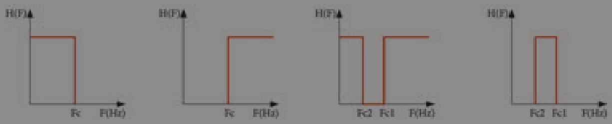


Fig. 18. Frequency representation of the following ideal filters, from left to right: a) low-pass; b) high-pass; c) band-stop; d) bandpass. The filters are symmetric from the horizontal axis.

A digital classic filter can be defined as a system that modifies a digital signal in a way that allows the pass of an interval of frequencies and attenuates the others. It has a main objective: an output with some features. [2] For our experiment, we need to study the feasible digital filters. These feasible digital filters must verify some properties: linearity, time invariance, causality, and stability:

- If it verifies the linearity, we know that the filter does not modify the signal form. It can postpone it, but it maintains the signal form. A lineal filter, in discrete time or non-discrete time, is that one which verifies the superposition property: if an input consists of the pondered sum of some signals, the output is simply the superposition (the pondered sum) of the answers of the filter to each one of those signals [3] .

- If it verifies the time invariance, we know that the behavior and features of the filter are fixed in time. A filter is time invariant if a time sliding in the input signal causes a time sliding in the

2 Helenca Duxans Barrobés and Marta Ruiz Costa-Jussà.

3 Alan V. Oppenheim, Alan S. Willsky and Syed Hamid. Nawab, *Signals and Systems* (Prentice Hall, 1997).

output signal. The property of time invariance tells us that the answers of a time invariant system to time slid unitary impulses, are simply scrolled versions one from each other [1] .

- If it verifies the causality, we know that the filter output, in any moment, depends only from the input value in the present moment and in the past. Sometimes, this filter is called a non-anticipative filter, because the filter output doesn't anticipate future values of the input [2] .
- If it verifies the stability, we know that the little inputs of the filter lead to non-divergent answers. If the stable filter input is limited (that is, if its magnitude doesn't increase in a non-limited way), the output is also limited and it cannot diverge [3] .

In the next part of this section, we describe the characterization of a filter regarding its impulse response and transfer function.

In the temporal domain, the impulse response relates the input and the output of a lineal and time invariant system (SLIT) [4] .

If we talk about digital systems, which is the domain that we are going to treat in our experiment (digital filters), we have to bear in mind that the output is the convolution sum between the input x[n] and the impulse response h[n]. This means that the output is the sum of the input, plus the answer, plus the echoes . From now and ahead we are going to

1 Oppenheim, Willsky and Nawab.
2 Oppenheim, Willsky and Nawab.
3 Oppenheim, Willsky and Nawab.
4 Helenca Duxans Barrobés and Marta Ruiz Costa-Jussà.

denominate the lineal a time invariant filter (linear time invariant system) as SLTI. In the filters' case, the impulse response and the transfer function determine the next concepts:

- The gain (G(f)) is defined as the amplification of the output signal regarding the input signal. If it is negative, it is called attenuation.
- The amplitude response of a filter is defined as the modulus of the filter frequency response.
- The phase response of a filter is defined as the phase of the impulse response.
- The order of a filter is the rate that a filter has got and it matches up with the maximum delay (in terms of samples) used or with the input signal or previous outputs in order to calculate y[n].
- The bandpass of a filter is the frequency range that a filter allows the pass from the input to the output with an attenuation.
- The group delay evaluates the output signal compared to the input signal in samples for each frequency. Hence, the global delay experimented by a signal is evaluated. If the group delay is constant, the phase is lineal.

The definition of a filter in finite differences equation allows us to make a clear distinction between two types of filters:

- Non-recurrent filters: the impulse response of the filter has got a finite number of samples different from zero and, for this reason, they are called under the name of FIR filters (finite impulse response)

- Recurrent filters: those in which the impulse response has got a non-finite number of samples different from zero, and they are named as IIR filters (infinite impulse response).

The basis of the filter design technique assumes that measurements can be made in the reproduced sound field in order to compare the reproduced signals with the signals that are wanted to be reproduced [1] .

Filter Design

Having seen the basic parameters of the filters, based on the system features, we are going to consider the design of our filter.

We have already seen that a feasible, lineal, invariant, causal and stable FIR filter has got an impulse response of a finite length L, and an output that depends only on input values, never on output values. If we want to have lineal phase (without distortion of the wave form of the original signal), the impulse response must be symmetric or asymmetric.

The filter design should be flexible enough for its implementation in a Virtual Reality environment. In particular, a Gamification of the study cases that were previously exposed is been developed. The final intention is to implement the Acoustic Filter to the VR environment in order to listen the current soundscape in its actual version, and afterwards to listen the different urban proposals of the same place only by changing the sound sources.

1 Philip A. Nelson, Felipe Orduña-Bustamante and Hareo Hamada, 'Multi-Channel Signal Processing Techniques in the Reproduction of Sound', 1992.

The filter design implies a complete comprehension and application of the cross-correlation tools applied to audio filter production. The definitive Acoustic Filter design will be explored in future research.

Conclusion

The present study confirms that a new audio format for virtual reality can be possible. Based on the initial hypothesis, it is now possible to state that the up-to-date audio formats for virtual reality are not suitable for the characterization of the acoustic features of the urban environment because they do not interact with the environment (Objects) or they do not split the environment from the sound sources (Ambisonics).

The current findings add substantial information to our understanding of the acoustic properties of a place. In particular, the proposed Acoustic Filter can be considered a sound filter containing spatial information of the place. This finding suggest that architect's conception of space can be approached not only by visual parameters, but also acoustic ones.

Finally, an important limitation needs to be considered. If the proposed Acoustic Filter is required for the complete acoustic comprehension of a public space, several measurements must be done in order to interpolate the results and predict a possible acoustic plan. This means that the more measurements are made, the better is the resolution of the acoustic plan.

Further research is required in order to establish a complete design and put into practice of the Acoustic Filter. In particular, next steps will be done in audio filtering design by means of cross-correlation methods and the field measurements in the places above mentioned will be carried out. With these future objectives, it is logical that the experiment will show the results that are searched.

Chapter 9

Evaluation of instruction

Learning room acoustics by listening

Chapter 9

Evaluation of instruction

Learning room acoustics by listening

The present chapter is derived from the work entitled *Learning Room Acoustics by Design: A Project-Based Experience*. This work was presented by Josep Llorca, Ernest Redondo and Michael Vorländer as an article in *International Journal of Engineering Education*.

9.1. Introduction

Carefully treating the acoustics in an interior space is absolutely necessary when designing auditoriums, concert halls and theatres where the enjoyment of the music and the sung voice must be of the highest quality. But acoustics is also necessary in more functional environments such as conference rooms, classrooms, train stations, airports, supermarkets, where the speech must be intelligible to understand the spoken message. The architecture and building engineering have the responsibility to design and build spaces that help to these purposes.

Against this necessity, it is commonly thought that the acoustic problems of building interiors are solved only by electroacoustics [1]. This conception is not only supported by the normal user of a building, but is also echoed in the conception of many architects and building engineers. They usually ignore that architecture modifies and conditions the perception of the sound that is propagating there. They usually suppose that an architectural interior sounds good by default and, as a consequence, they turn to electroacoustics when, once built, they encounter a very different reality. The spatial envelope of an architectural interior, therefore, must be treated to direct, attenuate, accentuate or modulate the sound that one wants to hear there. This task is largely the responsibility of the architect and building engineer.

Despite the importance of the topic, acoustics education in the areas of Architecture and Construction Engineering is rather scarce. Little

1 Emily Ann. Thompson, *The Soundscape of Modernity : Architectural Acoustics and the Culture of Listening in America*, 1900-1933 (MIT Press, 2002).

or nothing about acoustics is explained to future architects in the schools of architecture and building engineering.

This chapter presents a study carried out at the Faculty of Architecture of the RWTH Aachen University. The objectives are to present and evaluate an acoustic educational experience for architects and building engineers. This educational experience proposes a different way of learning architectural acoustics based on the paradigm of Active Learning [2]. In particular, it focuses on project-based learning, where the student designs the space with the desired acoustics and then analyses the acoustic properties of its design to understand the acoustic behaviour of the architecture. This study evaluates student performance during an architectural acoustics course, analysing student satisfaction, performance and design results. Students are assessed against two types of teaching in acoustics: teaching through a design-based workshop (A) compared to teaching through a theoretical masterclass (B).

This study uses a mixed methodology. On the one hand, quantitative data are used to assess student outcomes, while qualitative data are collected to determine the reasons behind these outcomes. These methodologies are based on the research and publications of Fonseca, et al, on the introduction of new technologies in the Architecture curriculum [3].

2 Charles C. Bonwell and James A. Eison, *Active Learning : Creating Excitement in the Classroom* (School of Education and Human Development, George Washington University, 1991) <https://eric.ed.gov/?id=ED336049> [accessed 21 May 2018].

3 Jose Ferrandiz, David Fonseca and Abdulaziz Banawi, 'Mixed Method Assessment for BIM Implementation in the AEC Curriculum' (Springer, Cham, 2016), pp. 213–22 <https://doi.org/10.1007/978-3-319-39483-1_20>; David Fonseca, Francesc Valls, and others, 'Informal Interactions in 3D Education: Citizenship Participation and Assessment of Virtual Urban Proposals', *Computers in Human Behavior*, 55 (2016), 504–18 <https://doi.

These studies provide the appropriate framework and confirmation of a tested and reliable methodology.

org/10.1016/j.chb.2015.05.032>; David Fonseca, Ernest Redondo and Sergi Villagrasa, 'Mixed-Methods Research: A New Approach to Evaluating the Motivation and Satisfaction of University Students Using Advanced Visual Technologies', *Universal Access in the Information Societ*y, 14.3 (2015), 311–32 <https://doi.org/10.1007/s10209-014-0361-4>; Albert Sánchez Riera, Ernest Redondo and David Fonseca, 'Geo-Located Teaching Using Handheld Augmented Reality: Good Practices to Improve the Motivation and Qualifications of Architecture Students', *Universal Access in the Information Society*, 14.3 (2015), 363–74 <https://doi.org/10.1007/s10209-014-0362-3>; David Fonseca, Sergi Villagrasa, Francesc Valls, and others, 'Motivation Assessment in Engineering Students Using Hybrid Technologies for 3D Visualization', in *2014 International Symposium on Computers in Education (SIIE)* (IEEE, 2014), pp. 111–16 <https://doi.org/10.1109/SIIE.2014.7017714>; David Fonseca, Sergi Villagrasa, Francesc Valls, and others, 'Engineering Teaching Methods Using Hybrid Technologies Based on the Motivation and Assessment of Student's Profiles', in *2014 IEEE Frontiers in Education Conference (FIE)* Proceedings (IEEE, 2014), pp. 1–8 <https://doi.org/10.1109/FIE.2014.7044209>; David Fonseca, Sergi Villagrasa, Nuria Martí, and others, 'Visualization Methods in Architecture Education Using 3D Virtual Models and Augmented Reality in Mobile and Social Networks', *Procedia - Social and Behavioral Sciences*, 93 (2013), 1337–43 <https://doi.org/10.1016/J.SBSPRO.2013.10.040>; Ernest Redondo and others, 'Augmented Reality in Architecture Degree New Approaches in Scene Illumination and User Evaluation', *Journal of Information Technology and Application in Education (JITAE)* JITAE, 1.1 (2012), 19–27 <https://upcommons.upc.edu/bitstream/handle/2117/16557/JITAE10017-20120331-101701-4172-2560.pdf> [accessed 21 May 2018].

9.2. Framework

In architectural acoustics, concepts have generally been taught before they are experienced. Murray Schafer argued that in acoustics, what we should use was, above all, our ears [1]. The experience of a student of architecture and building engineering in explaining acoustic concepts is often quite confusing. The student lacks a basic knowledge of sound, so he or she does not know that:

- Sound can be measured according to its frequency
- The sound can be low or high depending on its frequency
- Sound can be measured according to its amplitude
- The sound may sound loud or weak depending on its amplitude
- What the decibel means and on what scale it is measured
- What the timbre means and how it can be defined
- Etc.

All this basic knowledge is preliminary to any acoustic study. Therefore, it follows from this that to begin to explain concepts of architectural acoustics without understanding the above notions or having experience of them is a pedagogical error. This

1 R. Murray 1933- Schafer, *El Paisaje Sonoro y La Afinación Del Mundo* (Barcelona : Intermedio, 2013) <http://cbueg-mt.iii.com/iii/encore/record/C__Rb5555999__Sla afinación del mundo__Orightresult__U__X6?lang=cat&suite=def> [accessed 28 December 2016].

problem has already been described by Cabrera et al [1] . In these papers, the authors proposed to use the concept of "sonification" to teach acoustics and audio: "The term sonification refers to the process of converting data into non-speech audio, and is distinct from auralization in that the process does not aim to simulate an actual or imagined sound environment."

The professor of acoustics can often find himself in the following situation: he explains that the brighter a room is, the more the high frequencies are accentuated. And the student does not associate that what the professor has just explained means that when an orchestra plays in that room, the flutes and violins will sound louder and more strident than the double basses. Therefore, all music played there will be tinged with a sound more like that of a toy radio than that of a subwoofer. This is because the student of architecture and building engineering has never had contact with the rudiments of sound science. He doesn't know what a high-pitched and low-pitched sound is, and that this distinction is closely related to the frequency of the sound, and now those words sound strange to him in his vocabulary.

However, despite this limitation that the student of architecture presents to the world of sound, this student has a tool at his disposal: the ability to draw

1 Densil Cabrera, Sam Ferguson and Robert Maria, 'Using Sonification for Teaching Acoustics and Audio', in *Proceedings of ACOUSTICS 2006* (Christchurch, New Zeland, 2006) <https://www.acoustics.asn.au/conference_proceedings/AASNZ2006/papers/p105.pdf> [accessed 16 May 2018]; Densil Cabrera and Sam Ferguson, 'SONIFICATION OF SOUND: TOOLS FOR TEACHING ACOUSTICS AND AUDIO', in *Proceedings of the 13th International Conference on Auditory Displa*y (Montréal, 2007) <https://smartech.gatech.edu/bitstream/handle/1853/50029/CabreraFerguson2007b.pdf?sequence=1&isAllowed=y> [accessed 16 May 2018].

and design architectural spaces [2]. This tool plays into his hands as long as he knows how to analyse what he has drawn. This student, generally, will not have the ability to define and speak about the sound of a space, but he or she will be able to transfer the space he or she perceives by his or her ears into to paper. Every architect has or should have the ability to draw the spatial idea contained in his imagination. Otherwise, he may never transmit his design proposal to a third party. Therefore, the teaching methodology of acoustics for the student of architecture and building engineering is the inverse of what could be provided to a music student. If the latter can be directly explained the concepts of acoustics because he is familiar with the concepts of sound for years, the architect can only be taught acoustics if he is asked to reflect on the space he imagines and captures on paper.

This methodology is therefore based on the design of an architectural space based on a soundscape in order to later analyse the acoustic properties of the

2 Edward Robbins and Edward. Cullinan, *Why Architects Draw* (MIT Press, 1994) <https://books.google.de/books?hl=es&lr=&id=f3AgBLIG4I4C&oi=fnd&pg=PT95&dq=drawing+imagined+spaces+architecture&ots=CQ9p48YE8O&sig=G5DUPAK3Zw8m3AzDgIookvB7Z0g&redir_esc=y#v=onepage&q&f=false> [accessed 16 May 2018]; Iain. Fraser and Rod. Henmi, *Envisioning Architecture : An Analysis of Drawing* (Van Nostrand Reinhold, 1994) <https://books.google.de/books?hl=es&lr=&id=zcs4BCXwBm8C&oi=fnd&pg=PP7&dq=drawing+imagined+spaces+architecture&ots=cC_1wU5orz&sig=VfZUZFL8DTnlizuzZaEfokjry1I&redir_esc=y#v=onepage&q=drawing imagined spaces architecture&f=false> [accessed 16 May 2018]; Masaki Suwa and Barbara Tversky, 'What Do Architects and Students Perceive in Their Design Sketches? A Protocol Analysis', *Design Studies*, 18.4 (1997), 385–403 <https://doi.org/10.1016/S0142-694X(97)00008-2>; Masaki Suwa, Terry Purcell and John Gero, 'Macroscopic Analysis of Design Processes Based on a Scheme for Coding Designers' Cognitive Actions', *Design Studies*, 19.4 (1998), 455–83 <https://doi.org/10.1016/S0142-694X(98)00016-7>; Zafer Bilda, John S. Gero and Terry Purcell, 'To Sketch or Not to Sketch? That Is the Question', *Design Studies*, 27.5 (2006), 587–613 <https://doi.org/10.1016/J.DESTUD.2006.02.002>; Aarati Kanekar, 'Between Drawing and Building', *The Journal of Architecture*, 15.6 (2010), 771–94 <https://doi.org/10.1080/13602365.2011.533543>.

designed space. In this context, experiences have already been made in the history of architecture and construction where sound was the generator of ideas. Iannis Xenakis, architect and composer, designed the main façade of the La Tourette monastery using stochastic methods similar to those used in his orchestral compositions [1]. Renzo Piano designed the architectural stage for a piece of music by Luigi Nono and the spatial demands it required [2] . Stockhaussen and Fritz Bornemann designed a place where the spatiality of music was the central theme [3]. In addition, some research has been done on the close relationships between composers and architects [4] .

In recent years, the influence of acoustics on students of architecture has been studied. Sheridan and van Lengen [5] studied an educational approach in which students experienced the properties of different spaces to make a proposal for architectural design. Michael Fowler teaches architecture students about the importance of sound in cities and encourages them to make urban proposals to generate

1 Josep Llorca and Doménec Llorca, 'La Tourette y Metastaseis : De Cómo Ordena El Material Un Arquitecto y Un Músico.', *Circuito de Arquitectura*, 1.7 (2010), 5–16 <https://upcommons.upc.edu/handle/2117/85038> [accessed 8 March 2018]; Iannis Xenakis, Music and Architecture : Architectural Projects, Texts, and Realizations (Hillsdale: Pendragon Press, 2008).

2 Cristina; Palmese and José Luis Carles, 'Música y Arquitectura', *Scherzo*, 193.1 (2005) <http://www.scherzo.es/hemeroteca/2005-01-193.pdf> [accessed 19 January 2018]

3 Michael Fowler, 'The Ephemeral Architecture of Stockhausen's Pole Für 2', *Organised Sound*, 15.03 (2010), 185–97 <https://doi.org/10.1017/S1355771810000269>.

4 Susana Moreno Soriano, *Arquitectura y Música En El Siglo XX*, Fundación (Barcelona, 2008); Gastón Clerc González, 'La Arquitectura Es Música Congelada.', 2003; Thompson.

5 Ted Sheridan and Karen Van Lengen, 'Hearing Architecture. Exploring and Designing the Aural Environment', *Journal of Architectural Education*, 57.2 (2003), 37–44 <https://doi.org/https://doi.org/10.1162/104648803770558978>.

particular acoustic conditions [6] . Other studies have highlighted the ability to draw intangible cultural heritage such as sound, popular stories or hiking trails [7] . However, as far as can be known, none of the researches have tackled the teaching method on acoustics to architects and building engineers from design.

6 Michael D. Fowler, 'Soundscape as a Design Strategy for Landscape Architectural Praxis', *Design Studies*, 34.1 (2013), 111–28 <https://doi.org/10.1016/j.destud.2012.06.001>.

7 Adolfo Ruiz, 'Transformation through Repetition: Walking, Listening and Drawing on Tlicho Lands', *International Journal of Art & Design Education*, 36.3 (2017), 253–60 <https://doi.org/10.1111/jade.12156>; Kristine E. Sunday, 'Drawing and Storytelling as Political Action: Difference, Plurality and Coming into Presence in the Early Childhood Classroom', International Journal of Art & Design Education, 37.1 (2018), 6–17 <https://doi.org/10.1111/jade.12097>.

9.3. Materials and methods

9.3.1 Participants

13 subjects participated into the experiment. They are aged between 19 and 35 years old. All participants are architecture students, so they are considered trained participants [1] . 45,2% of the students work during their architectural studies. Regarding their background education, 26,2% of them have no musical education; 61,3% of them have elementary musical education and 9,5% have professional musical education.

9.3.2 The design-based workshop

The experience consisted in two stages which completely differ from a theoretical masterclass, to which they are used to. While a theoretical masterclass superimposes the theory to the praxis, the design-based workshop flips this learning process.

The first session of the test consisted of the so-called Listening-Design Test. This was done by the architectural students under the following conditions: a short duration soundtrack could be individually reproduced as many times as desired by the student. During the duration of the test (total: 45 minutes) they were allowed to sketch and draw the suggested architectural environment by the soundtrack on A4 and A3 sheets of paper. On the A4 sheet, a ground plan and a section of the listened environment was required. They could draw them

1 S Namba and S Kuwano, *Psychometric Testing Method for Sound Evaluation* (Tokyo: Corona Company, 1998).

with a pencil and a ruler on a grid of 1 x 1 meter. This task lasted 15 minutes. On the A3 sheet, an axonometric military perspective of the listened environment was required. They could draw it with a pencil, a straight ruler and a square ruler. They could include in the drawing geometry, materials, shadows, people, objects, vegetation, etc. They should include in the drawing a graphical scale, sound sources and listener positions. This task lasted 30 minutes. The soundtrack consisted of a sequence of sounds lasting 1 minute and 49 seconds. It contained the recording from a receiver point in a hall. The environment where the sound sources and the receiver point were situated was modelled in 3 dimensions in Sketchup and subsequently auralized [2] in RAVEN [3]. The soundtrack contained four sound sources plus one fixed receiver. Two of the four sound sources (the guitar and the people talking and drinking) were static and the other two were dynamic (the steps on the staircase and the squeezing woman).

The second session consisted of the understanding of some concepts derived from the previous experience. This was conducted in small student groups (max. 10). They were introduced to the fundamentals of acoustics and were asked to investigate on the acoustic properties of their own designs done in the first session. In particular, the concept of Room Impulse Response, and Lateral Energy Fraction was

2 Michael. Vorländer, *Auralization : Fundamentals of Acoustics, Modelling, Simulation, Algorithms and Acoustic Virtual Reality* (Berlin: Springer, 2008).

3 Dirk Schröder and Michael Vorländer, 'RAVEN: A Real-Time Framework for the Auralization of Interactive Virtual Environments', in *Forum Acusticum* (Aalborg - Denmark, 2011) <https://www2.ak.tu-berlin.de/~akgroup/ak_pub/seacen/2011/Schroeder_2011b_P2_RAVEN_A_Real_Time_Framework.pdf> [accessed 8 December 2017].

explained to them [1]. Consequently, they were asked to analyse and correlate the Lateral Energy Fraction with the geometric properties of their drawings to clearly understand that there is a strong relation between the architectural design and the acoustical properties of that design.

9.3.2 Bla method (Bipolar Laddering Assessment)

By using complementary qualitative research, it is possible to obtain variables to study in future iterations and more detail for quantitative data [2].

Quantitative and qualitative approaches have been the main methods in the history of scientific research. On the one hand, quantitative research focuses on analyzing the degree of association between quantified variables, as enacted by logical positivism; therefore, this method requires induction to understand the results of the research. Because this paradigm considers that phenomena can be reduced to empirical indicators that represent reality, quantitative methods are considered objective [3].

On the other hand, qualitative research focuses on the detection and processing of intentions. Unlike

1 A. Gade, 'Acoustics in Ha 9. Acoustics in Halls for Speech and Music', in *Handbook of Acoustics* (Berlin: Springer, 2007), pp. 301–50 <https://ccrma.stanford.edu/courses/318/mini-courses/papers/rooms/Gade - Handbook Ch9.pdf> [accessed 10 April 2018].

2 Marc Pifarré and Oscar Tomico, 'Bipolar Laddering (BLA): A Participatory Subjective Exploration Method on User Experience', in *Proceedings of the 2007 Conference on Designing for User EXperiences - DUX '07* (New York, New York, USA: ACM Press, 2007), p. 2 <https://doi.org/10.1145/1389908.1389911>.

3 Joanna E. M. Sale, Lynne H. Lohfeld and Kevin Brazil, 'Revisiting the Quantitative-Qualitative Debate: Implications for Mixed-Methods Research', *Quality and Quantity*, 36.1 (2002), 43–53 <https://doi.org/10.1023/A:1014301607592>.

quantitative methods, qualitative methods require deduction to interpret the results. The qualitative approach is subjective, because it assumes that reality is multifaceted and cannot be reduced to a universal indicator [4] .

Qualitative methods are commonly used in usability studies and, inspired by experimental psychology and the hypothetical-deductive paradigm, deal with user samples that are relatively limited. However, the Socratic paradigm of post-modern psychology is also applicable and useful in usability studies because it targets details related to UX with great reliability and reveals subtle information about the technological product studied [5] . Through qualitative methods, the aim is to explore users' wishes, needs and objectives.

The BLA method is based on positive and negative poles to define the strengths and weaknesses of the product. Once the element has been obtained, the laddering technique will be applied to define the details of the product. The purpose of a laddering interview is to reveal how the attributes of the product, the consequences of its use and the personal assessments of the product are related to the user's thinking. The characteristics obtained through the laddering application will define which specific factor will result in considering an element as a quality or a weakness. The BLA method consists

4 Ulrike Pfeil and Panayiotis Zaphiris, 'Applying Qualitative Content Analysis to Study Online Support Communities', *Universal Access in the Information Society*, 9.1 (2010), 1–16 <https://doi.org/10.1007/s10209-009-0154-3>.

5 Marc Hassenzahl and Noam Tractinsky, 'User Experience - a Research Agenda', *Behaviour & Information Technology*, 25.2 (2006), 91–97 <https://doi.org/10.1080/01449290500330331>.

of three steps, following the similar methodology of Fonseca, Redondo and Villagrasa [1] and Llorca et al.[2]:

1. Elicitation of elements. The implementation of the test starts from a blank template for the positive (most favorable) and negative (less favorable) ele-ments. The interviewer (in this case the professor) will ask the users (the stu-dent) to mention a positive and a negative aspect of the two types of music than can be heard (Otion A and Otpion B). Thus, we are going to obtain two positive aspects and two negative aspects.

2. Marking of elements. Once the list of positive and negative elements is com-pleted, the interviewer will ask the user to mark each one from 0 (lowest pos-sible level of satisfaction) to 10 (maximum level of satisfaction);

3. Elements definition. Once the elements have been assessed, the qualitative phase starts. The interviewer asks for a justification of each one of the ele-ments performing laddering technique. Why is it a positive element? Why this mark? The answer must be a specific explanation of the exact characteristics that make the mentioned element a strength or weakness of the product.

From the results obtained, the next step was to polarize the elements based on two criteria:

1 Fonseca, Redondo and Villagrasa.

2 Josep Llorca, Héctor Zapata, Ernesto Redondo, and others, ‘Bipolar Laddering Assessments Applied to Urban Acoustics Education’, in *WorldCIST’18 2018: Trends and Advances in Information Systems and Technologies* (Springer, Cham, 2018), pp. 287–97 <https://doi.org/10.1007/978-3-319-77700-9_29>; Josep Llorca, Héctor Zapata, Jesús Alba, and others, ‘Evaluation between Virtual Acoustic Model and Real Acoustic Scenarios for Sound Urban Representation’, in *From Natural to Artificial Intelligence - A Chaotic View*, ed. by Prof. Ricardo Lopez-Ruiz (Intech Open, 2018).

1. Positive (Px)/Negative (Nx): The student must differentiate the elemtns per-ceived as strong points of the experience that helped them to understand the music as satisfactory, in fornt of the negative aspects that were not satisfactory or simply need to be modified to be satisfactory;

2. Common Elements (xC)/Particular (xP): Finally, the positive and negative el-ements that were repeated in the students' answers (common points) and the responses that were only given by one of the students (particular points) were separated according to the coding scheme shown in Table 1, 2 and 3.

The common elements that were mentioned at a higher rate are the most important aspects to use, improve, or modify (according to their positive or negative sign). The particular elements, due to their citation by only a single user, may be ruled out or treated in later stages for development.

The individual values obtained for both indicators, positive and negative, are shown in the following Table 2. Once the features mentioned by the students were identified and given values, the third step defined by the BLA initiated the qualitative stage in which the students described and provided solutions or improvements to each of their contributions in the format of an open interview.

Table 3 shows the main improvements or changes that the students proposed for both positive and negative elements.

Additionally, some particular questions were done to the students regarding "efficiency", "effectivity" and "satisfaction"

E. Code	*Description*	*Av. Score (Av)*	*Mention Index (MI) (%)*
1PC (A)	It is easy to understand	8,33	(3) 23
2PC (A)	It is a good introduction	9,5	(2) 15,4
3PC (A)	It is a practical work with sound	7,33	(3) 23
4PC (A)	It consists on learning by listening – learning by doing	9,33	(3) 23
1PP (A)	It combines acoustics and space in graphic way	9	(1) 7,8
2PP (A)	It is more active than in a lecture hall	8	(1) 7,8
1NC (A)	There is not enough theoretical information	5,33	(3) 23
2NC (A)	More clarity in explanation of tasks needed	4,66	(3) 23
1 NP (A)	Too long meetings	5	7,8
2 NP (A)	You cannot understand clearly the concepts	4	7,8
1PC (B)	You know what to analyse beforehand	7,6	38,5
2PC (B)	Learning details about the acoustics	8,5	15,4
3PP (B)	A lot of knowledge in a short period of time	7,5	15,4
1PP (B)	It is an interesting method	9	7,8
1NC (B)	Difficult to follow	3,5	15,4
2NC (B)	More difficult method for introducing acoustics	4,66	23
3NC (B)	Lack of practical appliance	5,77	23
1NP (B)	There is no enough time	4	7,8

E. Code	Description	Mention Index (MI) (%)
1CI (A)	Improve the planning of the course	23,1
2CI (A)	Devote more time in introducing more concepts and explanations	9,2
3CI (A)	More exercises and practise would be welcome	15,38
1PI (A)	Reduce the complexity of the topics	3,8
1CI (B)	Combine theory and practice	19,2
2CI (B)	Include more practical exercises	11,5
1PI (B)	Include more acoustic courses in architecture curriculum	3,8

Fig. 1. Table 1. Positive common (PC), positive particular (PP), negative common (NC) and negative particular (NP) elements for A option (design-based workshop) and B option (theoretical masterclass).

Fig. 2. Table 3. Proposed common improvements (CI) and particular improvements (PI) for both positive and negative elements for common and particular items in A option (design-based workshop) and B recording (theoretical masterclass).

E. Code	Student												
USERS	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S10	S 11	S 12	S 13
1PC (A)	-	-	-	-	5	-	-	-	-	-	8	-	10
2PC (A)	-	-	-	-	-	-	-	-	-	10	-	9	-
3PC (A)	-	-	8	-	-	8	-	6	-	-	-	-	-
4PC (A)	-	-	-	10	-	-	8	-	10	-	-	-	-
1PP (A)	9	-	-	-	-	-	-	-	-	-	-	-	-
2PP (A)	8	-	-	-	-	-	-	-	-	-	-	-	-
1NC (A)	-	-	5	-	4	-	-	-	7	-	-	-	-
2NC (A)	-	-	-	6	-	-	3	5	-	-	-	-	-
1 NP (A)	-	-	-	-	-	-	-	-	-	5	-	-	-
2 NP (A)	1	-	-	-	-	-	-	-	-	-	-	-	-
1PC (B)	-	-	7	-	-	-	10	7	-	-	7	7	-
2PC (B)	-	8	-	-	-	-	-	-	9	-	-	-	-
3PP (B)	-	-	-	-	-	7	-	-	-	8	-	-	-
1PP (B)	-	-	-	-	9	-	-	-	-	-	-	-	-
1NC (B)	-	-	-	-	-	7	-	-	-	1	-	-	-
2NC (B)	-	4	4	-	-	-	-	-	-	-	-	-	6
3NC (B)	-	-	-	-	-	-	6	-	5	5	-	-	-
1NP (B)	-	-	-	-	-	4	-	-	-	-	-	-	-

Code	SD	Av. Score
E1.1	Do you think "DESIGN-BASED WORKSHOP" method is useful to learn architectural acoustics?	7
E1.2	Has the workshop material got a good presentation?	7,4
E1.3	Is the structure of the sessions appropriate?	7,2
E1.4	Is it easy to handle with the proposed exercises?	7,2
E2.1	Would you use this method to deep more into acoustic knowledge?	6,6
E2.2	Is the number of exercises related with the proposed time?	7,4
E2.3	Is it possible to solve the presented exercises?	8,2
E2.4	Is it easy to imagine spaces from a soundscape	6
S1.1	Do you like this method?	77,1
S1.2	Do you feel comfortable working with this method?	7,1
S1.3	Is this method enhancing your acoustical knowledge?	7,3
S1.4	Is this method enhancing your spatial imagination?	7,4

Fig. 3. Table 2. Individual scores for PC, PP, NC and PC elements for A option (design-based workshop) and B option (theoretical masterclass)

Fig. 4. Talbe 4. Questions regarding "efficiency", "effectivity" and "satisfaction".

At this point, it is possible to identify the most relevant items obtained from the BLA, which had high rates of citation, high scores or a combination of both. It is important to separate the types of results obtained. The first group belongs to option A (design-based workshop), and the second group to option B (theoretical masterclass). After the elicitation of the most relevant features of each of them, a comparison is going to be done.

Option A (desing-based workshop). It is possible to highlight that this kind of teaching method holds a good reputation as easy to understand (MI: 23%, Av: 8,33) and it seems to be a good introduction in the world of acoustics (MI: 15,4%, Av: 9,5). In terms of the main negative comments, students clearly identified a lack of theoretical background in this kind of experience (MI: 23%, Av: 5,33), that was clearly related in the need of conceptual clarity in explanations (MI: 23%, Av: 4,66).

Option B (theoretical masterclass). Two main positive aspects were highlighted by students in this second method: the clarity of concepts explained before the exercises are done (MI: 38,5%, Av: 7,6), and the high level of details learned by this method (MI: 15,4%, Av: 8,5). Conversely, some negative comments were pointed out: the difficulty to follow the masterclass (MI: 15,5%, Av: 3,5), a more difficult method for introducing acoustics (MI: 23%, Av: 4,66), and the lack of practicity (MI: 23%, Av: 5,77).

In summary, two clear opinions about the experiment were shown, which confirm the first question of the survey: Which method do you prefer, A or B? Most people (77%) agreed that option A was better than option B. The reasons for this answers were clearly explained in the rest of the survey. Although there was a high valuation of the facility to understand concepts in option A (MI: 23%, Av: 8,33), it was also certain that the level of theoretical background was worse in A than in B, as it is possible to see when comparing 1NC (A) with 2PC (B). This confirms that the design-based workshop implies a decrease of the amount of theoretical concepts. This loss could be a drawback for students who want to learn about acoustics. However, the survey reveals another feature that must be taken into account: almost a quarter of the students (MI: 23%) considered that learning by listening was a value of option A with an excellent score (Av: 9,33) (4PC [A]). This shows the hidden potential of this method for architects and building engineers.

An overlook of the improvements suggested by the students and the limitations of the method, some modifications on it should be taken into account. Firstly, a better organization of the workshop regarding timing, tasks deliveries, and meeting planning should be done. Secondly, it seems crucial that this practical method 1CI (A) should be reinforced with some theoretical explanations: the practical teaching should not blind the clear view of acoustic concepts.

9.5. Conclusion

The present chapter concludes that a good acceptation of the project-based experience in the field of room and building acoustics learning has been recorded by the students. Moreover, they value specially the change of paradigm from passive learning to learning by listening. These results encourage us that the inclusion of this method for acoustics teaching can be valuable in architecture and building engineering curricula. However, some remarks must be done in order to achieve better results. The clue of these improvements has been demonstrated in the survey. In particular, this method needs a high level of organization to avoid the distraction of the student and, additionally, it should always be combined with theoretical explanations on acoustic concepts.

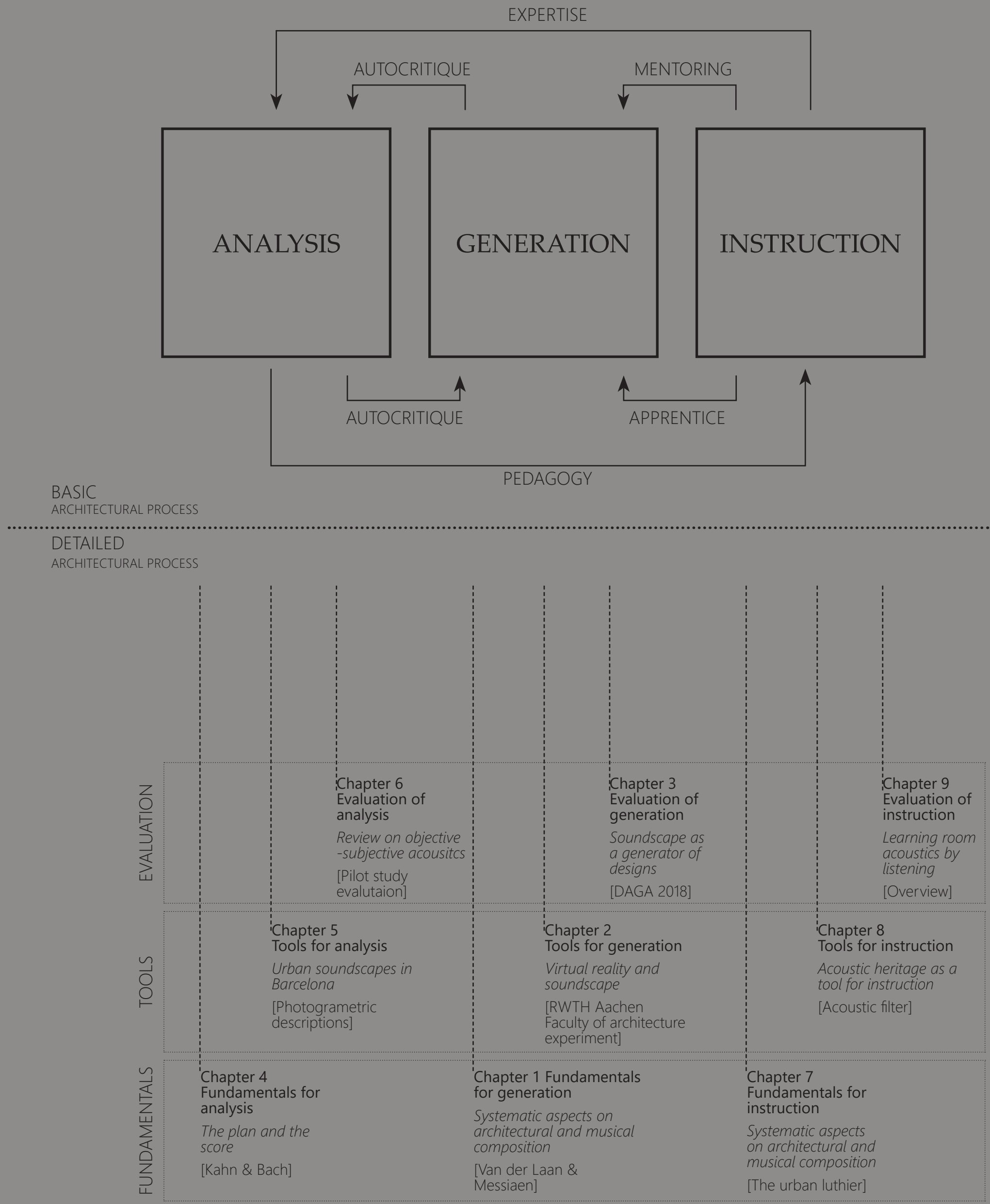
Looking back. The architectural capacities of sound.

Along this dissertation, the influence of sound in three architectural milestones have been tackled: generation of architectural design, analysis of architectural environments and instruction for new architects. The following graph shows the differnt relations among the different milestones.

The graph is divided in two parts. The upper part shows the basic architectural process. The three main aspects of this procedure interact each other in different actions. Meanwhile, the bottom part details the distribution of each milestone in the frame of our work. Each chapter is referenced and positioned into the general map.

The aim of this last chapter is to close the cycle opened with this thesis: *is the sound able to help the architect in his daily tasks?* Analysis and generation interact each other through autocritique in the daily architectural work. Additionally, instruction affects the educational process of the architect.

To sum up, sound may be able to help the architect not only in his daily routine, but also in pedagogic purposes. Generation, analysis and instruction are tackled by sound.


EXPERTISE
AUTOCRITIQUE
MENTORING
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GENERATION
INSTRUCTION
AUTOCRITIQUE
APPRENTICE
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BASIC
ARCHITECTURAL PROCESS
DETAILED
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Chapter 6
Evaluation of analysis
Review on objective -subjective acousitcs
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Chapter 3
Evaluation of generation
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[Acoustic filter]
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Systematic aspects on architectural and musical composition
[Van der Laan & Messiaen]
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Systematic aspects on architectural and musical composition
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Conclusions and future work

Conclusions

and future work

Conclusiones

La educación musical y sonora para los arquitectos no debe ser exhaustiva pero sí debe transmitir los temas fundamentales. En esta tesis se han tratado, por orden de aparición, los siguientes:

- *la naturaleza sistemática de la composición arquitectónica y musical, que forma el marco teórico para la generación de proyectos;*
- *la introducción de las herramientas actuales para la visualización y auralización de proyectos arquitectónicos, como es la realidad virtual;*
- *el diseño arquitectónico desde el paisaje sonoro, que se ha evaluado de acuerdo a cuestionarios de usabilidad;*
- *las herramientas analíticas clásicas de la arquitectura y de la música, que son el plano y la partitura en todas sus facetas y características;*
- *la relación entre el espacio público y la acústica de la ciudad, herramienta de análisis urbano;*
- *la evaluación subjetiva de los parámetros objetivos de acústica de salas, que se ha realizado de acuerdo a criterios de usabilidad;*
- *la progresiva separación entre la arquitectura y la música, como contexto histórico para la educación en arquitectura;*
- *el proceso de diseño sonoro desde la escucha, como herramienta pedagógica para los arquitectos;*
- *la evaluación de la pedagogía del sonido para arquitectos, que se ha realizado de acuerdo a criterios de usabilidad;*

Conclusions

Music and sound education for architects should not be exhaustive but should convey the fundamental themes. In this thesis, the following have been dealt with, in order of appearance:

- the systematic nature of the architectural and musical composition, which forms the theoretical framework for the generation of projects;
- the introduction of the current tools for the visualization and auralization of architectural projects, such as virtual reality;
- architectural design from the sound landscape, which has been evaluated according to usability questionnaires;
- the classical analytical tools of architecture and music, which are the plane and the score in all its facets and characteristics;
- the relationship between the public space and the acoustics of the city, a tool for urban analysis;
- the subjective evaluation of the objective parameters of room acoustics, which has been carried out according to usability criteria;
- the progressive separation between architecture and music as a historical context for architecture education;
- the process of sound design from listening, as an educational tool for architects;
- the evaluation of the sound pedagogy for architects, which has been carried out according to usability criteria;

1. *Del capítulo 1: La naturaleza sistemática de la composición arquitectónica y musical urgen al arquitecto y al compositor a buscar, definir y componer con un sistema lógico coherente.*

2. *Del capítulo 2: El uso de la realidad virtual para la visualización y auralización de proyectos arquitectónicos permite entender el impacto de la arquitectura en la propagación del sonido a tiempo real. Además, estas herramientas muestran al arquitecto que sus decisiones de proyecto tienen repercusiones en el comportamiento acústico de la arquitectura. Por ello, se propone introducir estas herramientas en el campo de la arquitectura.*

3. *Del capítulo 3: El paisaje sonoro puede ser usado como generador de proyecto arquitectónico. No existe correlación significativa con el conocimiento musical previo de los estudiantes. Además, este método de diseño puede ser muy útil para la enseñanza del proyecto arquitectónico.*

4. *Del capítulo 4: Los estudiantes de arquitectura deben comprender los conceptos de forma y estilo tanto en arquitectura como en música. Éstos quedan plasmados en el plano y en la partitura. Este conocimiento les introduce en una visión analítica de ambas disciplinas.*

5. *Del capítulo 5: La correlación entre el análisis acústico urbano y el análisis del espacio público, desvela tipologías de espacios urbanos de acuerdo a sus características acústicas. Este análisis constituye una nueva capa de la ciudad: la de la configuración urbana de la música callejera, la de las interacciones entre las personas y el entrono construido, la de la actividad comercial de la ciudad y, en definitiva, a su urbanidad.*

6. *Del capítulo 6: Existen métodos rigurosos de evaluación de los parámetros subjectivos-objectivos de la acústica arquitectónica. Estos métodos deben ser estudiados en detalle si se desea realizar una valoración de la percepción acústica del sujeto.*

7. *Del capítulo 7: La progresiva separación entre la música y la arquitectura ha ido creciendo, sobre todo, en el último siglo XX. La aparición de la electroacústica ha sustituido el papel fundamental que la arquitectura ejercía para la propagación del sonido.*

1. *From Chapter 1*: The systematic nature of architectural and musical composition urges the architect and composer to seek, define and compose with a coherent logical system.

2. *From Chapter 2*: The use of virtual reality for the visualization and auralization of architectural projects allows us to understand the impact of architecture on the propagation of sound in real time. In addition, these tools show the architect that his or her design decisions have an impact on the acoustic behaviour of the architecture. It is therefore proposed to introduce these tools into the field of architecture.

3. *From Chapter 3*: The sound landscape can be used as a generator of architectural design. There is no significant correlation with students' prior musical knowledge. In addition, this design method can be very useful for teaching the architectural project.

4. *From Chapter 4*: Architecture students should understand the concepts of form and style in both architecture and music. These are captured on the plane and on the score. This knowledge introduces them to an analytical view of both disciplines.

5. *From Chapter 5*: The correlation between urban acoustic analysis and the analysis of public space reveals typologies of urban spaces according to their acoustic characteristics. This analysis constitutes a new layer of the city: that of the urban configuration of street music, that of the interactions between people and the built environment, that of the commercial activity of the city and, in short, its urbanity.

6. *From Chapter 6*: There are rigorous methods for evaluating the subjective-objective parameters of architectural acoustics. These methods must be studied in detail if an assessment of the acoustic perception of the subject is to be made.

7. *From Chapter 7*: The progressive separation between music and architecture has been growing, especially in the last 20th century. The appearance of electroacoustics has replaced the fundamental role of architecture in the propagation of sound.

8. *Del capítulo 8: Las cuestiones del "qué" y el "cómo" se debe evaluar y enseñar el patrimonio acústico cultural, llevan a una respuesta en dos palabras: la objetividad desde la subjetividad. Los parámetros objetivos se deben evaluar desde el punto de vista subjetivo si se quiere enseñar el patrimonio cultural acústico.*

9. *Del capítulo 9: Los estudiantes de arquitectura acogen con mayor entusiasmo una experiencia educativa en el campo de la acústica basada en el proyecto. Además, valora especialmente el cambio de paradigma de un aprendizaje pasivo a un aprendizaje desde la escucha.*

8. *From Chapter 8*: The questions of 'what' and 'how' should be evaluated and taught in cultural acoustic heritage, lead to an answer in two words: objectivity from subjectivity. Objective parameters must be assessed subjectively if acoustic cultural heritage is to be taught.

9. *From Chapter 9*: Students of architecture are more enthusiastic about an educational experience in the field of project-based acoustics. In addition, it particularly values the paradigm shift from passive learning to learning by listening.

Futuras líneas de trabajo.

1. *Esta tesis doctoral se presenta como un posible programa docente de una asignatura sobre sonido para el estudiante de arquitectura. Los capítulos 1, 4 y 7 forman un marco teórico apto para su introducción. Los capítulos 2, 5 y 8 ofrecen herramientas muy potentes para el proyecto y el análisis y a docencia del sonido en el arquitectura. Los capítulos 3, 6 y 9 evalúan aspectos del proyecto, el análisis y la docencia para los estudiantes de arquitectura. No obstante, quedan algunos temas que sería provechoso introducir en el programa. Entre ellos están:*
    - *Una introducción a la física del sonido que trate los temas de descripción del fenómeno sonoro, caracterización de las fuentes sonoras y descripción de los fenómenos de reflexión, dispersión y difracción del sonido.*
    - *Una introducción a los fundamentos de la teoría de señales y sistemas que contenga las bases de las series de Fourier y transformadas de Fourier, la descripción del espectrograma, introducción a los filtros y los fundamentos del teorema de convolución.*
    - *Una introducción a la anatomía y fisiología del sistema auditivo, con las bases de la escucha binaural, la función de tranferencia en relación a la cabeza (HRTF), y los fundamentos de la reproducción binaural.*
    - *Una introducción a al psicoacústica, con las bases del fenómeno de enmascaramiento, el concepto de bandas críticas, los conceptos de loudness, pitch y strength, los parámetros de calidad sonora, y una base sobre el enmascaramiento binaural.*
    - *Una introducción a los métodos de grabación y reproducción que contemple las bases de la psicoacústica de la estereofonía.*
    - *Las bases de la acústica de salas, con la presentación de los parámetros objetivos y subjetivos que la caracterizan.*
    - *Una introducción a la simulación de la acústica de salas, detallando el concepto de respuesta al impulso, de fuentes de imagen, el modelo de rayos y el proceso de auralización.*

Future work

1. This doctoral thesis is presented as a possible teaching programme of a subject on sound for the student of architecture. Chapters 1, 4 and 7 form a theoretical framework suitable for introduction. Chapters 2, 5 and 8 offer very powerful tools for the design and analysis and teaching of sound in architecture. Chapters 3, 6 and 9 evaluate aspects of the project, analysis and teaching for architecture students. However, there are still a number of issues that would benefit from being included in the programme. Among them are:
   - An introduction to the physics of sound covering the topics of description of the sound phenomenon, characterisation of sound sources and description of the phenomena of sound reflection, dispersion and diffraction.
   - An introduction to the fundamentals of signal and system theory containing the basics of Fourier series and Fourier transforms, a description of the spectrogram, an introduction to filters and the fundamentals of convolution theorem.
   - An introduction to the anatomy and physiology of the auditory system, with the basics of binaural hearing, the head to head transfer function (HRTF), and the fundamentals of binaural reproduction.
   - An introduction to psychoacoustics, with the bases of the phenomenon of masking, the concept of critical bands, the concepts of loudness, pitch and strength, the parameters of sound quality, and a base on binaural masking.
   - An introduction to recording and playback methods that considers the basics of psychoacoustic stereophonics.
   - The basis of room acoustics, with the presentation of the objective and subjective parameters that characterise it.
   - An introduction to the simulation of room acoustics, detailing the concept of impulse response, image sources, the lightning model and the auralization process.

2. *Los capítulos 2 , 3 (y 8) son la promesa de una aplicación de realidad virtual que consiga llevar las decisiones de proyecto en un entorno arquitectónico a su experiencia immersiva en tiempo real. Algunas plataformas han conseguido incluir la auralización de entornos arquitectónicos a tiempo real en entornos tridimensionales. Son el caso de VA o RAVEN, desarrollados en el Instituto Técnico de Acústica de la RWTH Aachen University. No obstante, la calidad gráfica visual de dichas aplicaciones es todavía limitada. En particular, RAVEN funciona sobre la plataforma de SKETCHUP y su representación visual es cómoda pero no realista. Por su parte, VA funciona sobre UNITY, entorno de representación de realidad virtual mucho más realista que SKETCHUP pero con una interfaz un tanto compleja para el estudiante de arquitectura y el arquitecto. Se propone implementar VA en el entorno de la plataforma UREAL ENGINE. Esta plataforma de realidad virtual ofrece calidades fotorrealistas buenas en un tiempo de aprendizaje más corto que UNITY. Se deberá trabajar con C++ y su implementación debe pasar por el tratamiento de los Blueprints que UNREAL ENGINE ofrece.*

2. Chapters 2, 3 (and 8) are the promise of a virtual reality application that brings project decisions in an architectural environment to your immersive, real-time experience. Some platforms have managed to include the auralization of real-time architectural environments in three-dimensional environments. These are the case of VA or RAVEN, developed at the Technical Institute of Acoustics of RWTH Aachen University. However, the visual graphic quality of these applications is still limited. In particular, RAVEN works on the SKETCHUP platform and its visual representation is comfortable but unrealistic. For its part, VA runs on UNITY, a virtual reality representation environment much more realistic than SKETCHUP but with a somewhat complex interface for the architecture student and the architect. It is proposed to implement VA in the environment of the UREAL ENGINE platform. This virtual reality platform offers good photorealistic qualities in a shorter learning time than UNITY. You must work with C+++ and its implementation must go through the treatment of the Blueprints that UNREAL ENGINE offers.

Appendix

1. On the possibility to compare both arts.
2. On the use to compare both arts
3. On the harmonical division of the musical scale
4. On the rations between the intervals of this sca-le
5. On the problem witch arise form this.
6. On the three tonesystems.
7. On the power of express of the ancient tonesys-tem.
8. Comparing with architecture.
9. Conclusion for the church-architecture.

1 Lecture given by Dom Hans Van der Laan. This document is not publi-shed and it was translated into English by André Dam in 2009.

Musicen autem architectus sciat oportet, ut canonicam rationem et mathematicam notam habeat.

Vitruvius

You might suppose that we want to give a double discourse, one on music and one on architecture. Nevertheless this is not my intention. I am incompetent in the field of music; daily contact with church-music doesn't change this. A musician won't become an architect just by staying in buildings daily like the one we are staying in at the moment [1].

We would just like to try to make a comparison between the two domains; this seems hazardous, because a greater difference is not conceivable in art. Music occurs in time, whereas architecture occurs in space. But for every comparison it is prerequisite that there is a difference in one respect, while there must be a similarity in another respect. From a material point of view both arts differ greatly, but in both cases a certain order exists. This order is static in architecture, dynamic in music, but it is the same wisdom which underlies both orders. Hence, we have to look for the connection in the principles of both arts, where we can disengage from time and space, and attain the most universal form of art.

Moreover, both domains use the same vocabulary. This is only justifiable if one is mindful of the universal form of art. So we speak of the construction of a piece of music and about the rhythm of a row of columns. The original meaning of the word

Fig. 5. Folder cover in Van der Laan Archive contining the lecture.

1 The kruithuis in 's Hertogenbosch in Holland (red.) where the course is held, is an excellent example of 17th-century military architecture.

construction is adopted from the static order of architecture, while the word “rhythm” belongs to the order of movement. Both in music and in architecture we distinguish between the more static elements and the more dynamic elements. In a melody tones and intervals succeed each other in time. However all of these tones belong to a specific scale and maintain with each other a cert-ain, ever perpetual harmony. Now one is apt to call this scale a static element in musical dynamics, because this scale stays the same while the melody unfolds in time. In architecture as well we distinguish between the overall form of a building and the individual parts which repeat themselves such as rows of windows, columns or arcs. This sequence of congruent parts could be called a dynamic part in architectonic statics.

So in spite of the contrast between both arts, music and archi-tecture, there is reason enough to come to a comparison. One and the same principle underlies both orders and in both arts one can distinguish elements whose distinction looks like that between both arts themselves.

Comparing architecture to music offers great advantages to the architect. Obviously we possess monuments of architecture in the form of concrete buildings. Nothing or little has been handed down to us about the composition of these buildings. Naturally we don’t have vangible examples of music, but we do have valuable information on the composition by means of the notation. We do not know anything about the performance of old music but we do have the formula. We don’t know the formula of architecture but we do have the constructions.

We posses information, already formulated by Pythagoras, concer-ning the musical gamma which underlies our western music and we do know that buildings were composed according to a certain canon, but we grope in the dark as to the correct data. Therefo-re, a certain knowledge of musical structure is of great impor-tance to an architect, who wants to penetrate to the basis of his profession. By means of comparisons he can draw conclusions. It should be clear that we are not talking about a material simila-rity, but that one field can definately learn something from the other field by going back to their basis.

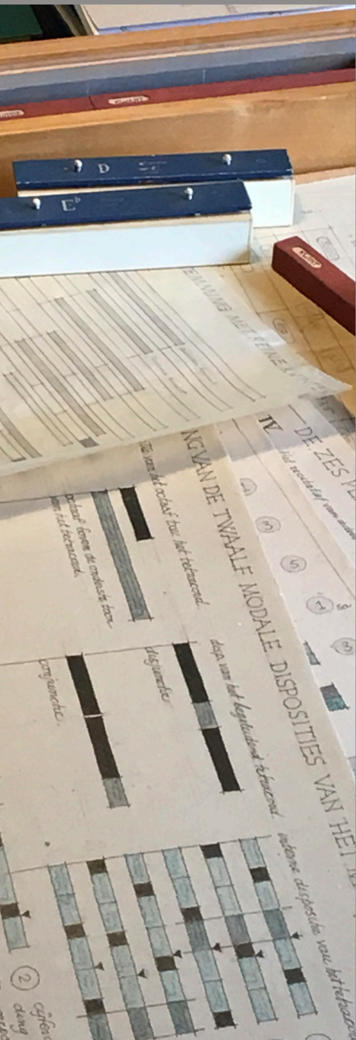
*

*

The musical scale, this system of intervals, from which the elements for every musical composition must be chosen, is based on purely physical laws. When hearing two tones of different pitch together, their mutual sympathy is dependent on the greater or lesser arithmetic ratio of their vibration numbers. The same eardrum which undergoes the frequencies of both tones, either sequential or simultaneously, will be more or less pleasantly affected, so far as the frequencies bear some resemblance.

If the frequencies of vibrations of one tone is twice as big as the other tone, then every other vibration of both tones will coincide:

The consonance is nearly as big as between two equal tones, because all vibrations of the lowest tone are accompanied by a vibration of the highest tone. For a real consonance, a harmony between two tones, needs not only a similarity but a difference in



pitch as well. The sympathy between two tones can be missing by having too little difference or too little similarity. At a frequence-ratio of 2/1 there is too little difference to talk of harmony; the tones are, as it were identical. If the frequencies are in the ratio 3/2, then every third vibra-tion will coincide with another vibration:

At a frequence-ratio 4/3, every fourth one:

The difference between the tones becomes bigger, their sympathy more striking. However, the rarer the moments become, at which the vibrations coincide, the weaker the sympathy, the less harmonious the consonance between the two tones.

That which is denoted in music by the word octave, is an inter-val, at which the vibration-frequence of the highest tone is twice as big as that of the lowest tone. The euphony of this interval, the proportion, the harmony suffers from a too great similarity of the terms. Therefore, both tones are denoted by the same word. One talks of the high “do” and the low “do”.

The next interval which is called a quint, is more harmonious than the octave, because in spite of a lesser similarity between the vibrations -- only every third vibration coincides with another one -- there is a clear harmony. However, if the diffe-rence is too great, the consonance will slowly disappear again. Frequencies which coincide only every tenth or fifteenth vibrati-on are experienced as seperate entities by the ear so that one doesn’t talk of consonance, just as little as one talks of consonance

Fig. 6. Graphs and drawigns by Van der Laan Explaining the Gregorian Modes.

between two random tones whose vibrations will never meet.

Thus, the tones of a scale, a system of harmonious intervals, are related to each other as regards their vibration-frequencies in a purely arithmetical connection. The octave with the frequence-ratio of 2/1, divides into a quint and a fourth, successively with the frequence-ratios 3/2 and 4/3. These are the two largest harmonious intervals.

If the lowest tone of an octave has, for example, six vibrations in a certain period of time, then the highest tone of the octave will have twelve in the same period of time. If the lowest tone of a quint has six vibrations in a certain period of time then the highest tone will have nine. If the lowest tone of a fourth has six vibrations, the highest will have eight. Consequently, the frequence-ratio between the two highest tones of the quint and fourth is like 9/8. Both intervals differ by an interval with a frequence-ratio of 9/8. This interval is called a second in musical terminology and counts as the smallest interval and as the criterion of the all other intervals. All other intervals take their names from their relation with this interval *). It is clear that with regard to the two largest intervals their diffe-rence has to be counted as the smallest interval.

The musical gamma has been built on this first division of the octave into a quint and a fourth. The distance from six to twelve has been divided by eight in such a way that the fourth is placed under and the quint is placed above. The same distance is divided by nine in such a manner that the fourth is placed above and the quint in placed under. According to Platoon (Timaios) eight and nine represent two particular middles between the farthest terms six and twelve. There is a middle, that with the same part of the extremities exceed the one extremity, while being exceeded by the other extremity. There is another middle, which with the same numerical value exceed the one extremity while being exceeded by the other. The first middle between six and twelve is represented by the number eight, the latter by the number nine. The quint can be divided in a similar way into two parts as a result of which the major third and the minor third arise. The major third with a frequence-ratio of 5/4, the minor with a ratio of 6/5. Such a division of the octave into a quint and a fourth or further into a major third, a minor third and a fourth, produces four tones which can be blown naturally by a trumpet without a slide. All soldier tunes, e.g. the reveille are always combinations of the above mentioned three intervals, the so-called triad.

*

At first sight these intervals are purely arithmetically connec-ted to each other, but looking more closely this arithmetical connection confines itself to the ratio between the tones them-selves and does not deal with the ratio between the intervals. *)The names haven't been taken from the number of smallest intervals, but from the number of tones, which have been included in the intervals.

The fourth, for example, is determined by the frequence-ratio 4/3 of both tones; the octave by the ratio of 2/1. The connection between the frequencies of the tones of each interval is purely arithmetical. But we compare both (the above mentioned) intervals with each other and ask ourselves how many times an octave is bigger than a fourth, we cannot say, that the octave, represented by 2/1, is half as big as the fourth represented by 4/3, taking into account the fact that 2/1 is one and a half times as large as 4/3. Only one and a half fourth would fit the octave, whereas we know that an octave is composed of one fourth and one quint, of which the quint is larger than the fourth. So in fact more than two fourths will fit the octave.

What we have calculated, is not the ratio between octave and fourth, but their difference. An octave namely is a quint with a frequence ratio 3/2, larger than a fourth. If, for example, the lowest tone of a fourth counts three vibrations in a certain period of time, then its highest tone will count four in the same period of time. If we consider this highest tone to be the lowest tone of a quint, then the highest tone of that quint will have six vibrations in this same mentioned period. So the highest tone of the quint makes an octave (frequence-ratio of 2/1) with the-lowest tone of the fourth which counts three vibrations.

In order to find out how many fourths will fit an octave, one should have to examine how many times the frequence-ratio of a fourth will have to be multiplied with itself to yield the frequence-ratio of the octave, i.e. examine to which power 4/3 has to be raised to render two. So the ratios between the inter-vals, which arrange the octave harmoniously, are expressed by involutions.

It is clear that this involution cannot occur in whole numbers. Continual multiplying of 4/3 or 9/8 with themselves can never render the number 2, and never a whole number. The presence of the number 2 in the denominator and 3 in numerator,

Fig. 7. Bar system explaining the dimensions of each music interval, done by Van der Laan.

or upside down rules this out. So the ratios between the frequencies of tones are arithmetical. The ratios between the intervals cannot be expressed in whole numbers.

*

This conclusion presents us with a remarkable problem. For music is not only a matter of harmonic intervals, which are purely natural. The harmonic division is only a basis on which the actual creation of a melody takes place. The musical figure, as we call a melody, moves around the tones, as they arise at a natural division of an octave. These tones constitute as it were the frame-work of the melody.

The harmonic division starts from the octave with its most simple frequence-ratio of 2/1. The melody however departs from the second, the interval with the smallest frequence-difference, at which one may speak of harmony. We have already mentioned that there is a certain culmination of euphony, going from the octave to the decreasing intervals of quint and fourth. This euphony however declines as soon as we approach the second via the major and minor terts. This secunde has to be considered the smallest interval at which we may speak of euphony. This interval is used to build the melody, by gradual risings and lowerings, starting from one of the tones of the harmonic division and going to the other. Round these keynotes of harmony, the melody is weaved, coming from one, going to another keynote, like the weft between the warp threads. The problem facing us now, catches the eye. The fact is that it is impossible that a sequence of equal intervals can lead us from one of the tones of the harmonic octave-division to another. It would be necessary that the intervals are related to each other in arithmetical ratios, which is out of the question. The sequen-ce of two or three seconds can never lead us from the lowest to the highest tone of a fourth or a quint. Technically expressed: 9/8 raising to the second, third or fourth power can never produce a ratio such as 4/3,3/2 or 2/1. Two seconds are a little more than a major terts, a little less than a fourth. Three seconds a little less than a quint, a little more than a fourth. Six secundes a little more than an octave.

We could look upon the world of music as a complex of tricks to be able to perform practically what seems to be impossible theoretically. The way this happens is characteristic of certain kinds of music. We can distinguish three kinds of music this way: the first forces slightly the harmony of intervals for the sake of a melodic tone-succession; the second, on the other hand, forces slightly the melodic succesion for the sake of pure harmony; finally the last accepts the differences which arise by the going together of melody and harmony and doesn't dissolve this in the order of the music itself. It tries to utilize those differences for the intellectual power of expression which music is capable of.

We only have to think of the fact that an orator raises his voice continually to give his words more expression. These small raisings cannot be valued objectively, like the intervals of the scale; They are just tolerances within the girth of a second. They are of the same order of magnitude as the differences which have to arise between the harmonic division and the melody.

*

The three above mentioned manners in music come to light by themselves, if we take a closer look at the tone-system which the music uses.

The modern tone-system of our western music dates from the 18th century. It was introduced for the first time by the mathematici-an Simon Stevin in 1608. This system really came into being use after Bach and Rameau composed their music with it. In spite of the fact that a succession of melodious intervals can never come to an octave, the octave is compounded of five whole seconds and exactly two half seconds in this tone-system. The octave consist of six seconds. This way the minor third consist of a whole and a half second together, and can repeat itself exactly four times in an octave, and the major third three times. The major third is equally smaller than a fourth, as bigger than a minor third.

In this tone-system no interval is pure; i.e. the frequence-ratio of the tones is not according to whole numbers. All intervals are somewhat disharmonious. The forming of the melody however doesn't meet with a single difficulty. The sequence of whole and half seconds always coincides with the so-called harmonic division of the octave. This complete coinciding of melody and harmony has given the music unknown possibilities of development. Every natural resistance and limitation is gone, and the ingenuity of mucisians can spread unrestrainedly. The purity of the harmonic division is, however, forever abandonned, and with that the natural foundation of the music, which cannot be restored by any other device.

Another tonesystem, which seems to have been known already in the classical times, starts from a pure harmonic division of the octave in a fourth, a major and a minor third. It doesn't want to deviate from these intervals and therefore abandons its equality of melodic sequence. Two successive seconds, each with a frequen-ce-ratio of 9/8, give a total interval with a ratio of 9/8 x 9/8 = 81/64. However, a pure major third has a frequence-ratio of 5/4 or, which is the same, of 80/64. This is 1/81th smaller than the combined interval of two seconds. Besides the second of 9/8 there only remains room for a reduced second, to form together a pure major third. This tonesystem accepts this imperfection in forming of the melody.

The division of a major third in a normal and a reduced second is a harmonic division according to the same principle of the division of an octave into a quint and a fourth. According to the both middle ones a major third with a ratio of 5/4 will be divided into both intervals: 10/9 and 9/8.

In this tonesystem the melody isn't undone of its harmonic division and does not appear to its full advantage. The music according this process is very pleasant for the ear and very natural, but she hides a higher beauty. The classical tonesystem, as one might conclude among others by the writings of Platoon (Timaios), knows only the harmonic division of the octave according to both middle ones by a quint and a fourth. Both these intervals will be divided again by the second, i.e. their mutual difference. In both divisions there remains "a margin" with the value of a little less than a half second.

*

Fig. 8. Graphs and drawigns by Van der Laan Explaining the Gregorian Modes.

This last system accepts all differences which arise between the harmonic division and the melodic succession, and searches the solution to the conflict in the expression of the music. Analyzed hierarchically the following differences will arise:

a) Because the harmonic division of the octave doesn't occur in two equal parts, a melodic sequence of two fourths differ one second from the octave. To come to the octave anyway, a second should be added somewhere. This can happen in two ways: between the both fourths, or above or under. Both these ways are of fundamental influence on the music, as far as its expression is concerned, and divide it as it were into two races.

b) Because the fourth is bigger than two seconds, something is left at a melodic sequence. To come to a fourth anyway, this tone difference of the less than half a second should be added. This can happen in three ways: above, under or between the two seconds. These three ways divide the music again, with regard to the expression, but in a more special way. The antiquity knew the original Dorian tetrachord with half the second below and later also the Lydian with half the second above and the Phrygian one with half the second in the middle. All of them have their own expression, by which the deviation between harmony and melody will be taken care of, and for which this deviation will be used.

c) The last difference, but of a lower order, arises because of two secundes never can coincide with a major third. This difference, of about 1/9 second has to be taken care of by the special expression of every melody itself. Certain melodic figures accept such a difference for the sake of their own character.

In this way the differences, which arise between harmony and melody, are in order of magnitu-de, successively determining the classifications of every piece of music on account of her expres-sion. There is a special expression characteristic of each piece of music, depending on minimal differences; There is a more general expression characteristic of each modality, depending on the differences from the order of magnitude of half a second.

Finally there is a whole general expression, which divides the music into two races (authentic and pla-gal) depending on the differences from the order of magnitude of the second. All these considera-tion apply mainly to the static aspect of music. The rhythm, the order of movement, lends itself to a analogue considerations although it can't start from equally fixed outlined physical data *).The analysis of the musical scale is sufficient for our comparison to architecture. For those, who have followed our discussion about measure and number in archi-tec-ture, it won't be difficult to discern the resemblan-ce between music and architecture, after we have come down to the princi-ples. Even in architecture, there cannot be a question of an arithmetic connec-tion between the dimensions of the parts. Here it is due to the three dimensions, by which the elements are simultaniously long, broad and high, that the connection with the unity is not singular as with the abstract number but threefold. While the arithmetic relations are based on the twofold, as the first di-fference to the unity, the spatial relations with the unity of magnitude are based on a basic-relation, which cannot be expres-sed in whole numbers, be-cause she is the result of a cubic equation consequent the threefold relation. Yet every building is necessarily a structure of parts, which builds up a whole by juxtaposition. Moreover, we know the symme-try in every composition (building), by which two reflections form a unity. This twofold or plural junction has to come into conflict with the harmonic coinciding of the measures, which don't happen arithmetically.

Even here there are three ways to solve this conflict:

a) To do violence to the basic-proportion, by making an arith-metic ratio of it (all measures are multiples of each other).

b) To avoid every symmetry and equivalent juxtaposition as much as possible.

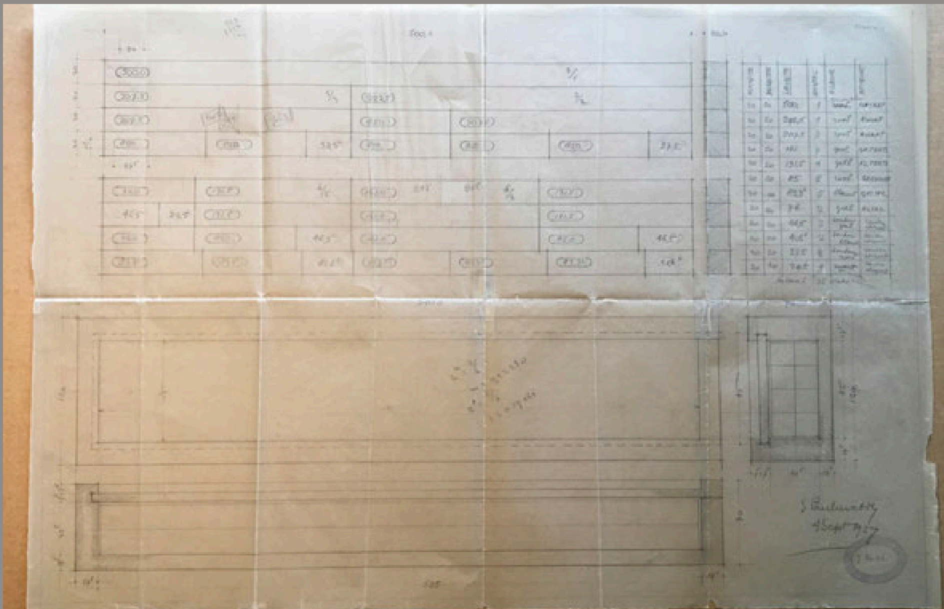
c) To accept the conflicts and use it for the expression of the building. [1]

Widening and narrowing end or middle bays, inserting friezes and frames, fitting heads and basements, these are all processes to smooth out differences by addition of elements, which reveal the function of the building and its parts. Even here we

1 Also the rhythmical division of a composition has to come necessarily into conflict with the arithmetic sequence of the unities of time. The solution to this conflict can be found in a pure arithmetic division of a piece (measure-music) or in avoiding every regular or arithmetic sequence of unities of time. The real solution however will be found in a regular sequen-ce of the unities of time, which sometimes has to give up its regularity for the sake of the rhythmical division. This nuance is used for the expression of a piece of music, as in Gregorian chant.

could again distinguish between the tendency of a building in general, of a building in particular, and of this special building, and that with reference to margins of three different orders of magnitude.

We can be brief about the merit of the three different ways to solve the unavoidable conflict; we can even omit every judgement, if we consider, that the liturgical function of a churchbuilding is based entirely on her architectonic ability of expression (the latter was discussed in detail at the last study-meeting). For church architecture there is no choice, no more than for church-hymn. The third point of view should taken and from there the composition should be defined.

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&
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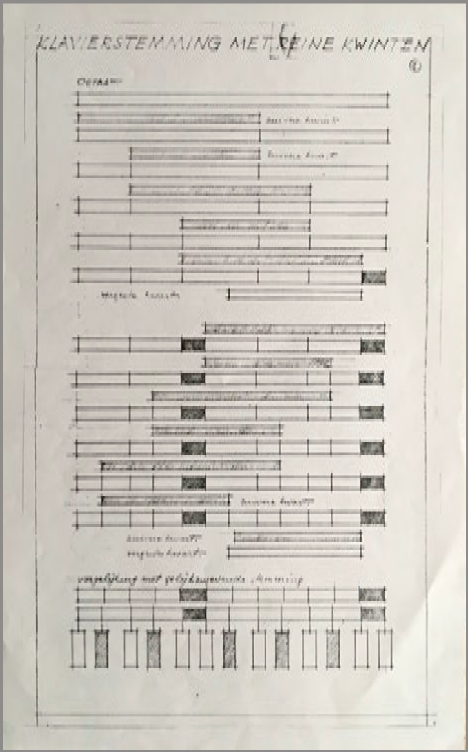
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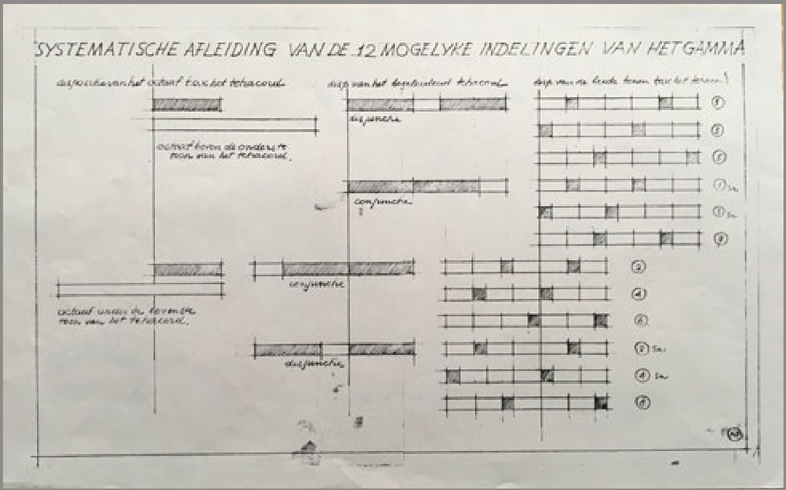
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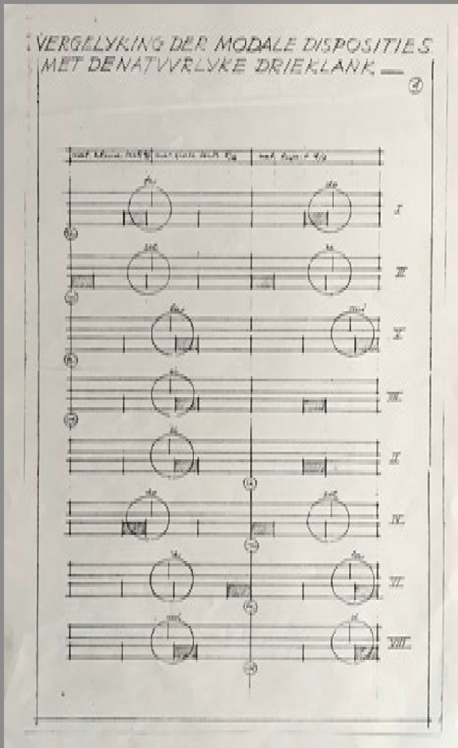
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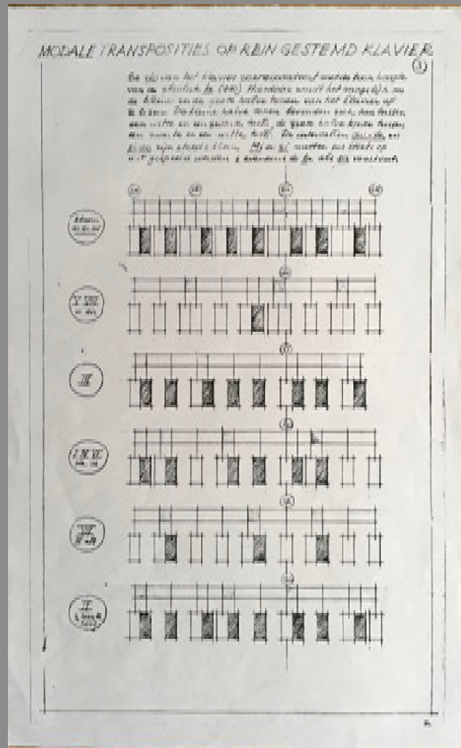
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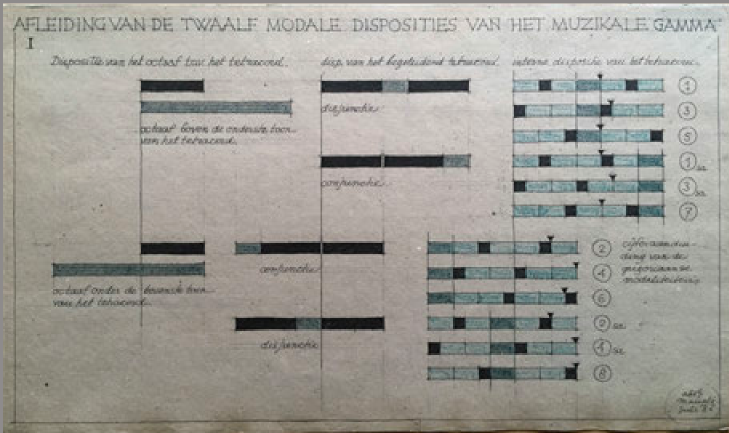
AFLEIDING VAN DE TWAALF MODALE DISPOSITIES VAN HET MUZIKALE GAMMA
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DE ZES PLAGALE MODALITEITEN OP HET REIN GESTEMDE KLAVIER
IV
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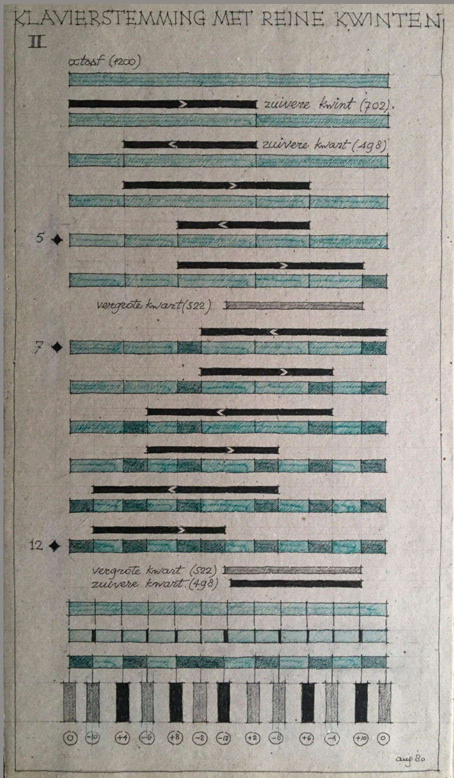
klavier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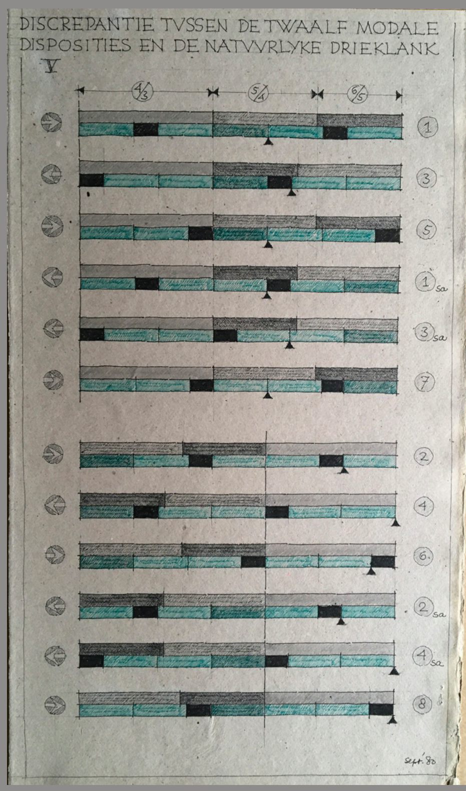
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CHAPTER 1

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CHAPTER 9

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APPENDIX

All photos in the Appendix were taken by Josep Llorca Bofí at the Van der Laan Archive in Saint Benedictusberg abbey, Vaals, Netherlands (4th March, 2018)

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