Universitat Politècnica de Catalunya

BIM implementation in architectural practices:

towards advanced collaborative approaches based on digital technologies

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DOCTORAL THESIS

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To my wonderful parents
for their love, endless support, and encouragement.

Summary

We are at a stage where Building Information Modelling (BIM) has reached a maturity level to be widely adopted by the professionals and organizations within the Architectural, Engineering and Construction (AEC) industry. An industry which is highly fragmented and not advanced in terms of digitalization, making an effective collaboration hard to achieve. The advances in Information and Communication Technologies (ICT) have brought about the promise of improving collaborative procedure in a wide range of industries. The widespread adoption of BIM has paved the way for the introduction of ICT within the AEC sector. The reported benefits of BIM imply on its potential for contributing to a successful inter-disciplinary collaboration. This calls for attention from architects who shall consider how BIM allows the architectural practices to operate in truly novel ways to achieve new building efficiencies and organizations.

This research was designed to investigate the crucial factors for an effective collaboration based on advanced ICT and enabled by BIM with respect to architectural practices. An effective inter-disciplinary collaboration allows architects as the authors of the projects to oversee the development and delivery of the projects more consistently with their design intends. The concerns about the move towards adopting BIM by architectural firms were reviewed and its influential factors and barriers were discussed. As we read about it, BIM is indicated by different terms to describe its essence: ‘’BIM methodology’’, ‘’BIM technology’’, ‘’BIM process’’, ‘’BIM systems’’ and etc. However, none of these terms can include all aspects of BIM. The term ‘’ecosystem’’ was adopted to describe the nature of BIM and the reason for which is described in this work. To further constitute the BIM ecosystem, its dimensions of People, Products and Processes were presented in detail with respect to collaborative procedures. It included the delineation of a number of BIM policies and protocols, tools and technologies, roles and skills which are all related to and suitable for architectural practices in their interdisciplinary collaboration.

Through three case studies, the research questions and hypothesis were put into investigation. Based on the idea of change management and the socio-technical nature of BIM collaboration, a qualitative research approach was adopted. Various techniques were used to gather information to be analyzed through a coding process of the qualitative data. The codes were interpreted as the factors influencing collaboration and were grouped to form the crucial concepts contributing to effective BIM-enabled collaborative procedures. It was revealed that the “joint decision making” factor is the most crucial one in this respect followed by “collaboration involvement” and “interoperability”. These findings were based on the frequency of the codes related to these factors in the data analysis. The crucial concepts in BIM-enabled collaboration were revealed to be “collaboration conditions” followed by “software capacity” and “human resources organization”. The findings confirm the research hypotheses that BIM implementation asks architects to assume a leadership role in collaborative procedures and that it allows for the integration of ICT into the technological pipeline of architectural practices. However, the validity of the two hypotheses is subject to certain conditions that are discussed in this work.

The research finds the area of BIM education a place of great interest for future research work as the factor of “training” has a great influence on the overall success of BIM-enabled collaboration. Furthermore, it was revealed that the crucial factor of “interoperability” needs more attention from both industry and academic sectors. The impacts of BIM implementation on existing and emerging roles within the industry is another area of great interest for future works and research.

Acknowledgments

I would like to thank my supervisors whose help and guidelines were essential to the development of this work:

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List of Figures and Tables

List of Abbreviations

3D	3-Dimensional
AEC	Architecture, Engineering, and Construction industry
AI	Artificial Intelligence
AIA	American institute of Architects
BCF	BIM Collaboration Format
BEM	Building Energy Model
BEP	BIM Execution Plans
BIM	Building Information Modelling / Model
BIM	Building Information Management
BMS	Building Management System
BSI	British Standards Institute
CAD	Computer Aided Design
CD	Construction Documentation
CM	Construction Manager
CMAR	Construction Manager at Risk
COBie	Construction-Operations Building Information Exchange Format
CPI	Construction Project Information
CRT	Cathode Ray Tube
CSC	Construction Specifications Canada
CSI	Construction Specifications Institute
DAC	Design Automated by Computer
DB	Design-Build
DBB	Design-Bid-Build
DP	Digital Prototype
EIR	Employer's Information Requirements
ERs	Exchange Requirements
gbXML	Green Building XML
GPU	Graphic Processing Unit
GSA	General Services Administration

HMD	Head-Mounted Display
IAI	International Alliance for Interoperability
ICI	British Construction Industry Council
ICT	Information and Communication Technology
IFC	Industry Foundation Class
IPD	Integrated project delivery
IT	Information Technology
LOD	Level of Detail
LOD	Level of Development
MEA	Model Element Author
MEP	Mechanical, Engineering, and Plumbing
MVD	Model View Definition
OCCS	OmniClass Construction Classification System
OGC	Open Geospatial Consortium
PAS	Publicly Available Specifications
PDA	Personal Digital Assistants
PDF	Portable Document Format
PIM	Project Information Model
SMEs	Small and Medium-Sized Enterprises
UI	User Interface
UX	User Experience
WBS	Work Breakdown Structure
XML	Extensible Markup Language

“BIM implementation in architectural practices: towards advanced collaborative approaches based on advanced digital technologies”

1. Introduction

1.1 Research motivation

A few years ago, I was working in an architectural practice in Milano where we were developing the interiors of a shopping mall in Tehran being developed by Satsa Co. I was in the design team and also coordinating the project with our collaborators in Tehran. The designs being developed in a country and executed in another, the collaboration between our team and the local teams was determining on the project success. However, often we encountered problems related to the information in our hand. For example, the 2D drawings that we received to work on were sometimes different than the as-built situation and we relied on secondary information to draw up our designs. Also coordinating the project based on the 2D drawings that had to be constantly updated manually leaded to confusions for both teams. Communicating the issues and information sharing using simply emails also was not quite efficient. The local team used to build-up their 3D models based on our 2D drawings which often resulted in mistakes and inaccuracies. Later on, I moved to Tehran working directly in the site to do instructions.

During my time in Tehran, I got involved in other projects of Satsa. They were developing two other shopping malls from scratch working with architectural consultants and engineers from Spain. In this projects the amount of information involved was considerably larger than the interior design project. A number of coordinators form different parties involved in the project were working on the projects coordination. I was witnessing that the inefficiencies in their collaborative approaches led to continuous disputes and delays, especially in the case of Vanak project. Being developed by a number of teams from different countries using multiple languages contributed to more issues as the project was being developed. They were using conventional communication channels such as emails to carry the heavy load of coordination needed between project stakeholders. As I had acquired some knowledge about Building Information Modelling (BIM), I thought using collaborative approaches based on digital technologies tailored for Architecture, Engineering and Construction (AEC) industry might be helpful to address such issues.

I first started learning about BIM while developing my Masters' thesis project. I was introduced to *Revit* software and could see the potentials of using a data enriched 3D model. I developed the model of my final Masters' thesis project building and performing energy analysis, creating renderings and other outputs directly from the model. This helped me save a great deal of time in the project development phase, and showed me some benefits that BIM could have for architectural practices. By reading some books and articles, I was curious that if BIM is the change our industry needs for improving its efficiency. Especially I gained insight about the potential benefits for architectural practices to deliver a better building by an effective collaborative approach. Nevertheless, the idea of digital transformation in our industry and the introduction of BIM have been relatively new phenomenon. Most of the literature written in this field were concerning with aspects such as project management and few focused on the promises of BIM collaborative approaches for architects. I believed BIM has great potentials for architects, from the design phase of a project to its eventual delivery and operation. Therefore, by conducting this research project I wanted study further the impacts of utilizing Information and Communication Technologies (ICT) through BIM in collaborative and have a contribution to the body of knowledge in this field.

1.2 Background and the problem statement

A successful project delivery in the AEC industry relies heavily on an adequate collaboration. With advances in digital technologies and their availability in the market, there is a move towards digitalization in the AEC industry and adopting digital technologies in collaborative process. As data becomes more accessible, the quality and quantity of information grows to be fundamental to support decision making and delivering business value. However, AEC sector is still lagging behind other sectors when it comes to leveraging information to its full potential, with information remaining a static asset. The industry has always been criticized for a lack of growth and effective delivery of construction projects [1]. A number of academic and governmental studies have been undertaken to identify the root cause of the problems and provide pragmatic solutions to improve the efficiency and growth opportunities. All the studies have highlighted the need for a better utilization of ICT to bring together the fragmented and dispersed project teams to improve efficiency and eliminate waste (in terms of time and cost). The lack of such an efficiency has affected the role of architects in project developments, diminishing their historic role of leadership. Among the ideas for creating and managing such data, Building Information Modelling (BIM) has shown great potentials. It was already presented by Van Nederveen and Tolman in 1992 [2], though the original BIM concept can date back to 1970s [3].

The complexity of today's projects and the contractual concerns have further prevented a truly collaborative approach to project delivery. Nevertheless, it is believed that BIM would be a key enabler to improve the quality of information produced (coordination) and reduce the quantity of information exchanges (collaboration) [4]. The digitalization of communication patterns and coordination of project based on a 3D model enriched with data, has the promise to overcome collaboration challenges present in traditional working methods. Model-based workflows are key enablers of integrated teams. Also, advancements in technology for collaboration and communication, and the prevalence of social, mobile, and cloud technologies is transforming how people can work together. Through shared information model, the design team can iterate, simulate and test all aspects of architecture prior to their operation on the project site. The unified information model brings construction and design inputs together, while still promoting the architect as a creative director of sorts - who authors design intent, or a project's general features. The architect then supervises a collaborative team of experts who each input data, or variable aspects, into the model.

The governmental mandates have been a pushing factor in some countries for BIM adoption, such as the UK Government that announced its "Government Construction Strategy" which included a mandate for the implementation of BIM Level 2 on all public projects by 2016 [5]. A number of city and regional authorities have also been publishing and promoting their BIM guides such as New York City [6] and the community of Catalonia [7]. Therefore, the shift is already here and what assumed to be a just a trend some years ago now has been embraced by many and it is important to investigate the early results of its adoption in respect to collaboration between the architects and other project stakeholders.

From the point of view of AEC researchers, a gap is evident when considering the studies conducted on BIM implementation with a focus on architectural practices. A remarkable study by Xinabo Zhao [8] conducts a scientometric review of global BIM research in 2005–2016, through co-author analysis, co-word analysis and co-citation analysis. A total of 614 bibliographic records from the Web of Science core collection database were analyzed. A network of the co-occurring subject categories in BIM research, including 38 nodes and 112 links, was produced to analyze the emerging trends, as shown in figure 1.

The node size denotes the number of articles within each category. Engineering (463 articles), civil engineering (368 articles), construction & building technology (257 articles), computer science (123 articles) and multidisciplinary engineering (70 articles) were found to have the most abundant publication records. It is evident that although architects are among the first adopters and users of BIM, there has been little research done on their profession-related subjects. Therefore, it has been of the interest of this research to conduct research on the aspects of BIM collaboration for architectural practices.

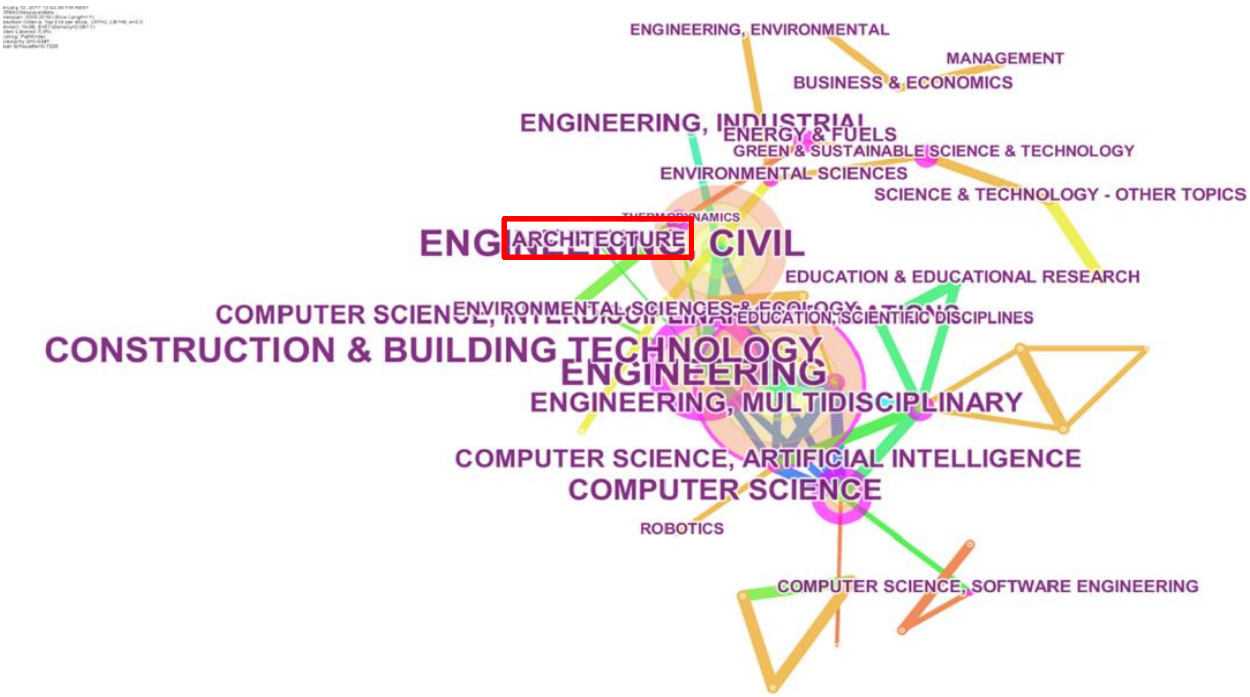


Figure 1 Network of co-occurring web of science subject categories. Courtesy of Zhao. (2015)

1.3 Research Scope and objectives

Although collaboration within traditional architectural design and construction has been studied, with the recent BIM adoption there is a lack and therefore an urgent need for a solid understanding of the concept and its importance to architectural practices. Therefore, the main aim of this research study is to investigate the impacts BIM would have on collaborative approaches and on communication methods. The study also raises the argument that utilizing digital tools for collaboration and communication through BIM implementation impacts the role of architects in collaborative processes during the development and delivery of the project.

It is worth mentioning that by Architectural Practices we mean any entity who practices the profession of architecture, be it a large organization, or a single architect. The impacts of BIM implementation refer to the changes and areas affected that come by adopting BIM in such practices. The research will study that by analyzing the factors that are impacted by BIM implementation in architectural practices. The literature review tries to provide an insight on the crucial factors in BIM collaboration and further investigates them in the research works.

The research investigates if the digital transformation through BIM can respond to collaboration issues found in traditional approaches. Digital transformation involves using digital technologies to remake a process to become more efficient or effective. The idea is to use technology not just to replicate an existing service in a digital form, but to use technology to transform that service into something significantly better [9a]. Finally, the argument of possibility of architects assuming a leadership role in projects collaborative processes during the projects development and delivery will be evaluated.

Bilal Succar [9b], a prominent researched in the domain of BIM, has worked on a framework that is adopted as a guideline for this research. He indicated that in many writings, seminars and workshops, BIM is argued to be a catalyst for change poised to reduce industry's fragmentation, improve its efficiency/effectiveness and lower the high costs of inadequate interoperability. These assertions — abridged as they may be — include several mental constructs derived from organizational studies, information systems and regulatory fields. Such divergence and coverage highlight the lack of and the necessity for a research framework to organize domain knowledge which, in turn, requires a systematic investigation of the BIM domain. The availability of a framework will assist in organizing domain knowledge, elicit tacit expertise and facilitate the creation of new knowledge [9b].

In his proposition the framework is multi-dimensional and can be represented by a tri-axial knowledge model (Figure. 3) comprising of:

- BIM Fields of activity identifying domain ‘players’ and their ‘deliverables’. These fields are represented on the *x*-axis.
- BIM Stages delineating implementation maturity levels (*y*-axis)
- BIM Lenses providing the depth and breadth of enquiry necessary to identify, assess and qualify BIM Fields and BIM Stages (*z*-axis)

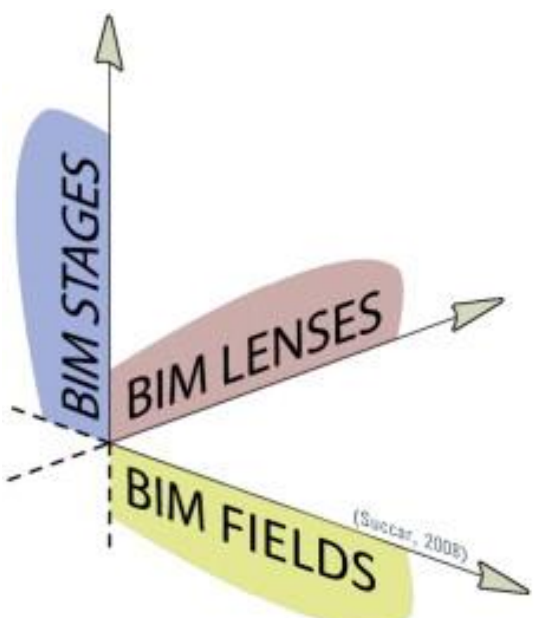


Figure 3 BIM Framework: Fields, Stages and Lenses tri-axial model. Courtesy of Succar (2008).

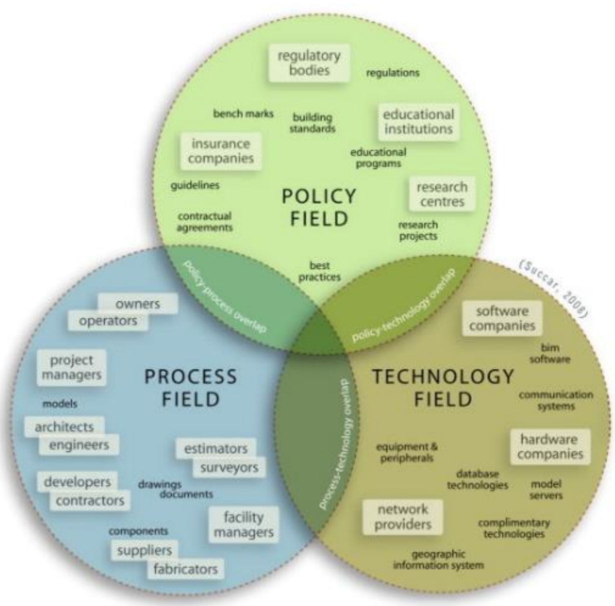


Figure 2 Three interlocking Fields of BIM activity. Courtesy of Succar (2008)

The focus of this research will be in the domain of BIM fields, which will be the basis for the BIM ecosystem described in this work. BIM Fields of activity include (Figure. 2): Technology, Process and Policy (TPP). In this work we adopt ‘Products’ instead of technology, as it entails a broader concept which includes the technology as well and ‘People’ instead of Process and ‘Process’ instead of Policy. The detailed and up-to-date description of these fields, which will be the dimensions of our BIM ecosystem, we will be able to depict the essential concepts for adopting BIM by architectural practices. The ecosystem will then be referred to in our case studies and their related analysis.

The dimensions of a BIM ecosystem for architectural practices are described. Once established, the crucial the crucial factors in collaboration are highlighted end evaluated through the research. Such aspects are key elements for an advanced collaboration, integration of digital technologies in daily practices and defining the role of architects in BIM-enabled collaboration in building projects. A building project is a social process in multi-organizational settings [10]. Specially collaboration relies heavily on human interactions. For this reason and other reasons that will explained the methodology chapter, this research adopts a qualitative approach.

The qualitative research assumes the following questions to be investigated:

Question 1: What are the most crucial factors in an effective BIM-enabled collaboration?

Question 2: What information and communication technologies are more effective in BIM-enabled collaborations?

Question 3: How the role of architects is impacted by implementing BIM-based collaboration?

Based on these questions, the research follows the following objective:

Objective 1: Studying the areas and factors impacted by BIM implementation in architectural practices and providing an insight to the necessary changes in collaborative approaches.

Objective 2: To explore deficiencies in traditional methods of collaboration in order to address such issues with the utilization of ICT within the BIM context.

Objective 3: Investigating the impacts of BIM adoption on the role of the architects in advanced collaborative approaches.

1.4 Thesis structure

Chapter 1 - Introduction: this chapter gives an overview of the thesis and introduces its context and background and its relevance based on the problems. The author motivation for undertaking the subject is also described. The main scope surrounding the thesis subject that will be investigated in the research is also indicated in the chapter and the research questions are formulated and the research objectives are outlined. It also includes this section that describes the structure of the thesis.

Chapter 2 - Collaboration and BIM in the AEC industry: this chapter highlights the importance of collaboration within the AEC industry and provides a brief definition for the concept of collaboration. The utilization of ICT within the collaborative processes and its significance for enabling collaboration is discussed. It continues with giving a critical review of the relations between BIM and collaboration and the idea of BIM enabling the effective use of ICT in the context of collaboration.

Chapter 3 - BIM for architectural practices: this chapter reviews the literature about BIM implementation in architectural practices. It starts with reflecting on the relevance of BIM with different phases of architectural project development. It then reviews the internal and external factors encouraging the adoption of BIM by architectural practices. It continues with reviewing the obstacles of BIM adoption and discussed the solution for overcoming the barriers discouraging the adoption.

Chapter 4 - Factors impacted by BIM implementation in collaboration: this chapter discusses why BIM is adopted as an ecosystem in this research and introduces the dimensions of such an ecosystem. Based on the three dimensions of Processes, Products and People it reviews the factors within each dimension that are impacted by implementing BIM. To be focused on the subject of collaboration, only the factors effective and important for collaboration are reviewed within the three dimensions. These factors provide a basis and are considered in the coding process of the qualitative data in the next chapters.

Chapter 5 - Proposal: this chapter presents the hypothesis and the methodology used in the thesis. It includes the research design and processes, the qualitative research plan and the data gathering techniques used in this work. It ends by a reflection on the ethics consideration.

Chapter 6 - Case Studies: this chapter starts with the considerations about data obtained from the case studies. It then continues with presenting the three case studies and the information obtained from the sources within the case studies. In includes the codes obtained from the qualitative data to be analysed in the next chapter.

Chapter 7 - Qualitative data analysis: This chapter presents the method and results of the analysis of the qualitative data obtained from the previous chapter. It then interprets and discusses the results.

Chapter 8 - Conclusion: this chapter concludes the thesis. It tries to answer the thesis question and addresses the hypotheses based on the analysis results of chapter seven. Key finding and are also presented in this section, and recommendations for future works are suggested.

Chapter 9 - References: the list of articles published in journals and conference papers.

Chapter 10 - List of Publications: the list of articles published in journals and conference papers.

Chapter 11 - Appendixes: it contains the additional information and documents of the thesis.

2. *Collaboration and BIM in the AEC industry*

2.1 Introduction

Fostering collaboration in the AEC industry is difficult, due to the differing educational and disciplinary backgrounds of the participants, the lack of understanding of the nature of multi-disciplinary design and the lack of tools that can support them [11]. The fragmented nature of building projects that involves participants with different expertise who are often geographically dispersed make effective collaboration hard to achieve which could contribute to changes, claims and eventually increasing times and costs. This increased complexity of building projects inevitably calls for collaboration among many professionals. The purpose of collaboration is to integrate the separate knowledge possessed by the participants in the design process into one meaningful whole. The integration helps the participants to comprehend, critique, debate, adopt, or incorporate the propositions made by other participants into their own part of the project.

Collaboration in the AEC industry is highly fragmented such that each discipline has evolved its own knowledge and representation methods. Architects are educated to deal with providing sufficient, efficient and aesthetic spatial environments for a given set of activities. Structural engineers are educated to provide stability by resisting or transmitting forces, moments, and inertia. Mechanical engineers are educated to provide functions such as thermal comfort and climate control through mechanical equipment. Construction managers are educated to assess the overall constructability of a building [11]. These specializations have fostered their own knowledge and representation methods, and even reinforced the symmetry of ignorance. This emphasized the importance of collaboration, as mentioned above, with the purpose of integrating separate knowledge.

The AEC sector is a typical paradigm of a project-based industry. The new non-routine design and construction processes also accompany complex working relationships and interrelations [12]. Because of the complexity of the AEC industry, the multiple phases of the construction project life-cycle, and the involvement of multidisciplinary teams (including owners, architects, consultants, engineers, contractors, sub-contractors, and suppliers) they make inter-dependent discipline decisions and naturally form a temporary multi-organization. The individual participants will finally affect the overall progress and their input is determining the project outputs [13]. The collaboration process involves sharing decision making as well as data and resources [14].

Many advocates call for changes and initiate collaborative project delivery in the construction industry. Although collaboration is important to change the fragmented nature of construction industry, it is difficult to implement. Project participants are selected through different tenders in traditional construction projects. Both professionals and researchers recognize that collaboration in complex construction process needs more attention, because poor communication, poor coordination, misinterpretation and lack of information management in current practice cannot generate maximum value for the clients [15]. Despite the increasing demand for more effective collaboration, there are few studies analyzing the challenges, feasibilities and opportunities of existing project practice of cross-disciplinary collaboration [16].

2.2 Definition of collaboration

The very basic meaning of collaboration defined by Oxford dictionary is: "The action of working with someone to produce something''[17]. Collaboration focuses on working together with others who share common goals and find solutions in order to satisfy all participants [18]. It is a collective work of individuals or teams undertaken with mutual objectives and aims within a shared environment that combines all kinds of resources. For Gray [19] collaboration occurs when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain.

In the context of building projects, Xue et al. [20] define collaborative as "the joint working or working together of project stakeholders or different organizations to effectively and efficiently accomplish a product". Here we realize the importance of the participation of all project stakeholders to deliver a product which is a building in this context. Bouchlaghem [21] defines collaboration as" an activity in which a shared task is achievable only when the collective resources of a team are assembled. Contributions to the work are coordinated through communications and the sharing of information and knowledge". He further explains that collaboration in construction "involves multidimensional and cross-disciplinary tasks that require interactions between stakeholders and the exchange of information across organizational boundaries using shared information and communication technology (ICT)-based collaborative environments"

Some characteristics of collaboration are identified by reading the mentioned definitions. Working towards a common goal, following certain rules, shared responsibility, a joint completion of a work and having a common collaborative environment are some essential aspects of collaboration. Using effective means of collaboration is also highlighted which involves the employment of information and communication technologies. These elements also remarkably contribute to a successful product delivery in construction projects. Xue et al. [22] argue collaborative working is one of the most important critical success factors in the construction process, and collaborative working becomes a new management paradigm in the construction community. To meet the demands of clients and requirements of other participants, all project participants need to collaborate with each other through their legal frameworks in order to achieve their organizational objectives with highest economic benefits. Such collaboration confronts barriers across geographical, cultural, organizational and other uncertain boundaries [21].

Coordination is another term commonly seen in the AEC literature which is directly related to our topic of collaboration here. Malone and Crowston [23] define coordination activity as "the act of managing interdependencies between activities". Construction project is a process of combining all materials and information in an orderly and timely manner by utilizing all relevant resources to aggregate building components as per design specification, quality standards and client requirements. In project coordination each party has compatible goal yet maintains its own authorities, but there is an established communication channel. On the other hand, in collaboration different stakeholders give up some degree of independence to achieve a common goal. Therefore, it can be concluded that collaboration is a long term ongoing process that involved coordination sessions focusing on a certain problem which requires a leading party to ensure all other stakeholders are properly coordinated. The communication channels and the tools used in such sessions have remarkable influence on their efficiency. To better understand such an influence, in the following the role of information and communication technologies in collaboration is reviewed.

2.3 ICT in collaboration

Although AEC industry has always been criticized for poor communication and lack of collaboration, there has been awareness of the need for a more effective communication by academic researchers, governmental reports and industry professionals [24]. Several decades of effort have been spent on improving design collaboration in the building process. In particular, Information and Communication Technology (ICT) has been widely applied to facilitate AEC collaboration. Egan [25] considers good information and communication technology to be a crucial part of improving the effectiveness of construction projects. A more effective project is the key to greater efficiency on site which will considerably improve quality. However, Egan [25] does not recognize technology to be the only solution to the need for greater efficiency and quality in construction. He believes new technology has been utilized in the industry to emphasise and support obsolete processes where it does not work. Inspired by the manufacturing industry, he recommends a change the culture within the industry, followed by defined and improved working processes, and finally the application of technology as a tool to support the cultural and process improvements.

ICT strengthens the communication and interaction between project participants in the whole supply chain. Through share of knowledge, exchange of information and support of integration, ICT facilitates inter and intra-organizational collaboration [26]. Comprehensive adoption of ICT requires the industry to alter its conventional working practices and procurement methods. This requires a change management in the parties involved in a building project. Change management is a systematic approach to dealing with the transition or transformation of an organization's goals, processes or technologies. The purpose of change management is to implement strategies for effecting change, controlling change and helping people to adapt to change. Such strategies include having a structured procedure for requesting a change, as well as mechanisms for responding to requests and following them up [27]. To be effective, the change management process must take into consideration how an adjustment or replacement will impact processes, systems and employees within the organization.

As mentioned in the introduction chapter, BIM fields of activities impact People, Processes and Products. These fields can relate to the aspects impacted by change management process which are processes, systems and employees. To improve collaboration by employing ICT, first an architectural practice needs to implement a change management process. A successful change management in AEC sector can be achieved through the implantation of BIM as will be described in the next chapter. Such a comprehensive implementation impacts the aspects similar to a change management (Figure 4).

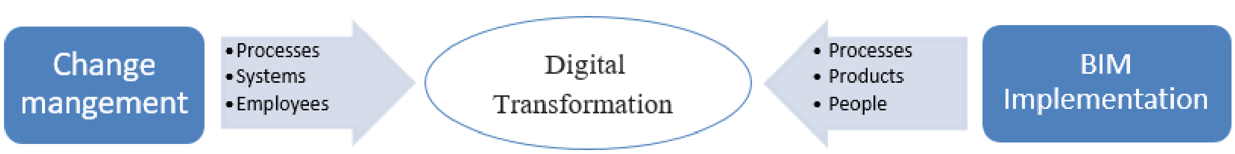


Figure 4 BIM and change management as digital transformation in AEC

In summary, we argue that a successful project collaboration and coordination relies on the utilization of ICT in an integrated way into architectural practices. This requires innovation in different aspects of a practice which requires a change management. As implementing BIM also impacts such aspects, we conclude that digitalization through BIM paves the way for advanced collaborative approaches in building projects. However, we must study how this will affect the role of architects in the project coordination and collaboration processes. This initially required an in-depth study of BIM implementation in architectural practices that will be done in the next chapters.

2.4 Collaboration with BIM

Building Information Modelling has been identified as a collaborative platform and an enabler for more efficient working in the industry [28]. It enables the use of a 3D, real-time, intelligent and dynamic modelling which can be very beneficial in facilitating collaboration. This will allow all participants to share, apply and update project information in real time and simultaneously. In traditional 2D CAD implementation, each profession completes their design separately. By adopting BIM, all designs are in 3D model embedded with rich information. To build up a model it requires all disciplines to collaborate in order to exchange related information for reference. The whole design process integrates all building information from different parties, so that the final model covers and integrates all the design and construction information. This necessary collaborative approach the build up a building information model, by itself enables collaboration among project stakeholders [29]. The structure and processes of such collaboration can be maintained throughout the project development and delivery.

A successful BIM-enabled project requires high level of collaboration and coordination. BIM connects professionals involved in a project, but real collaboration requires project participants to truly interact with each other to share knowledge. As a result, all project participants have full knowledge of the requirements, outcomes, and responsibilities of other participants. So BIM-enabled project causes the development of collaborative activities and relationships among project participants. Neff et al. [30] have clearly stated that the current practice within industry has mainly adopted BIM because of its technological advances and therefore organizations still remain divided which in theory is not the aim of BIM adoption. Therefore, the aim of BIM to bridge the gap between interdisciplinary teams has failed. This failure is not only technological but also organizational and social. It has been observed by Neff et al. [30] that terms collaboration and communication within construction industry is not fully understood and there is a need for further research to clarify these terms, especially within the new BIM environment.

BIM implementation is a combination of products (technology, hardware, infrastructures and etc.) processes and people. Collaboration is the core value of BIM implementation. Collaboration here is not about electronic communication, visualization or online file sharing. Collaboration is about systematic communication strategy, processing protocols and organizational management. Bouchlaghem [21] claims that recent research on information management highlights the demand for enhancement of collaboration and coordination between stakeholders. BIM success relies on collaboration between project team members. Current wide adoptions of BIM technology in the construction industry do not promote collaborative relationships across organizations thus far [29]. BIM provides a collaborative platform for project participants to better cooperate, coordinate and integrate. However, current BIM implementation cannot achieve such benefits without taking into consideration all the aspects of an architectural practice that must undergo a change for its adoption. The BIM implementation approach uses a socio-technical view, which does not only consider the implementation of technology but also considers the socio-cultural environment that provides the context for its implementation [29]. In addition, its implementation and usage requires following certain processes, protocols and standards.

So far we argued that conventional project development and delivery methods suffer from the lack of an effective collaboration. It was evident by literature review and the primary results of the case study 1. Then we argued that an integrated use of ICT can improve the collaboration. Such an integration requires digital transformation of architectural practices which requires a change management. It was then discussed that a comprehensive framework work for implementing BIM entitles a change management. This is summarized in figure 5:

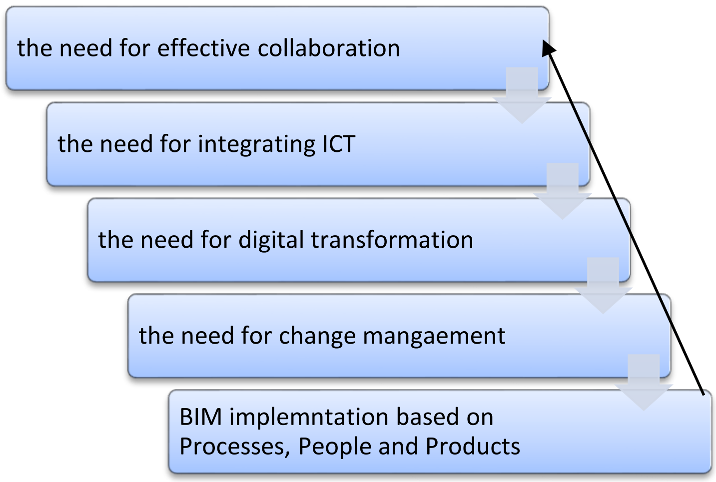


Figure 5 Towards effective collaboration

The above figure implies that by implementing BIM, we are enabling the change management required for digital transformation of architectural practices. The digital transformation allows for various information and communication technologies to be integrated in the technological pipeline of architectural practices. As literature review revealed, it is agreed that ICT based tools have potentials to improve collaborative approaches in building projects. By investigating the aspects of BIM and the factors impacted by its implementation in collaborative processes, we will have a perspective of crucial factors for a successful collaboration based on building information modelling. Therefore, the next chapter is dedicated to an in-depth review of various aspects of BIM implementation in architectural practices. It will help us with evaluating the outcomes of the data obtained through the qualitative research.

3. *BIM for Architectural practices*

3.1 The Context of BIM for Architectural practices

The industry perception and expectation of BIM-related products, processes, and people vary across disciplines [45]. The dimensions of BIM as mentioned above will be further discussed in the following sections. Before that and to help us understand the impacts of BIM implementation on architectural practices, the capacities that BIM promises will be discussed. Each of these potential capacities may need comparable readiness in the three mentioned dimensions of BIM. For example, considering documentation, we will review what processes and tools are involved, and what skills or behaviors of professionals is required for an appropriate documentation workflow in BIM ecosystems. Obviously, such discussion will be developed considering their contribution to and their impacts on architectural practices. It is worth mentioning that by Architectural Practices we mean any entity who practices the profession of architecture, be it a large organization, or a single architect.

At a fundamental level, the areas in which the capabilities of BIM in architecture are more relevant can be categorized into design, representation, documentation and information management, inbuilt intelligence, analysis, simulation tool and collaboration and integration. Each of these areas can be applied during different phases of a typical architectural project. According to the American Institute of Architects (AIA), the phases from design to construction can be broke down into seven steps of:

Step 1. Programming/ Deciding What to Build: The owner and architect discuss the requirements for the project (how many rooms, the function of the spaces, etc.), testing the fit between the owner's needs, wants and budget.

Step 2. Schematic Design/Rough Sketches: The architect prepares a series of rough sketches, known as schematic design, which show the general arrangement of rooms and of the site. Some architects also prepare models to help visualize the project. The owner approves these sketches before proceeding to the next phase.

Step 3. Design Development/Refining the Design: The architect prepares more detailed drawings to illustrate other aspects of the proposed design. Floor plans show all the rooms in correct size and shape. Outline specifications are prepared to list the major materials and room finishes.

Step 4. **Preparation of Construction Documents:** Once the owner has approved the design, the architect prepares detailed drawings and specifications, which the contractor will use to establish actual construction cost and build the project. The drawings and specifications become part of the building contract.

Step 5. Hiring the Contractor: The owner selects and hires the contractor. The architect may be willing to make some recommendations. In many cases, owners choose from among several contractors they have asked to submit bids on the job. The architect can help you prepare bidding documents as well as invitations to bid and instructions to bidders.

Step 6. Construction Administration: While the contractor will physically build the home or the addition, the architect can assist the owner in making sure that the project is built according to the plans and specifications. The architect can make site visits to observe construction, review and approve the contractor's application for payment, and generally, keep the owner informed of the project's progress. The contractor is solely responsible for construction methods, techniques, schedules and procedures.

Step 7. Project Close Out: The architect can help bring the project to a close by ensuring that it is complete and ready for use and that the contractor is entitled to final payment. The owner now has a working relationship with the architect, and no one knows owner's building better. The owner may wish to retain the same firm to assist with start-up, to review operations at a later date, for tenant-related services, or for later alterations and modifications.

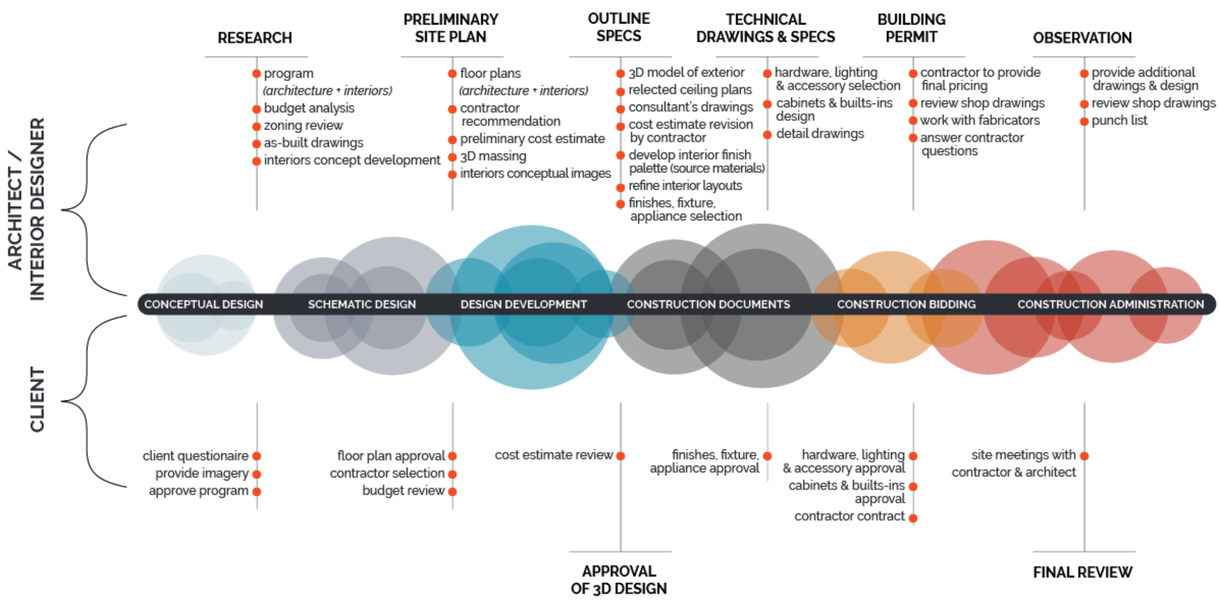


Figure 6 Architectural project phases – courtesy of HMH Architecture + Interiors. (2014)

In the diagram above (Figure 6), the architectural project and services phases are illustrated in the main phases of conceptual design, schematic design, design development, construction documents, construction bidding and construction administration.

Relevance of BIM with architectural project phases:

Design: Design and development of the concept is the most fundamental part of an architectural practice. The success of a project, from in its biding or competition stage to its perception by the public, relies heavily on a mature design intent. This is not only about the aesthetics and the appearance of the building, but also about its functions in different aspects. BIM ecosystem allows architects to enjoy sketching in the digital age. For instance, a sketch model can be 3D scanned and be converted into a digital model, on which we can perform very early energy analysis. The physical materials that architects use to develop a concept, can be digitalized to be used in the digital environment of BIM. This allows for the creation of more amounts of information at earlier stages of a project.

Representation: Clear representation of the design intent is an essential part of the design and construction process. Representation aids design thinking and development, allows the communication of design intent to the client, and helps with winning competitions and bids. Representation also provides common ground and a visual language for communication between the multidisciplinary team. Clear representation and high-quality visualization are an important aspect of BIM. Recent innovations in the field of computer graphics has paved the way for adoption of technologies such as virtual reality and real-time rendering in BIM ecosystem, to be used for representational purposes.

Documentation and information management: While representation and visualization are also part of documenting the project-related information, it is equally important to be able to record, manage, and use all other forms of data generated across the different stages of the project lifecycle. BIM allows for the application of the power of cloud technologies throughout the project lifecycle.

Inbuilt intelligence, analysis, and simulation tool: The inbuilt intelligence in BIM applications provides the users' assistance and proactive tools for managing the complexity and improving the design decisions through analyses and simulations. The ability to provide inbuilt relationships and constraints and to define the functions to use these relationships and constraints to improve the project outcomes is another important characteristic of BIM. Thus, BIM not only allows data management, but it also enables making sense of the data. Simulation accommodates new approaches to the design development of a project, such as data-driven design method.

Collaboration and integration: Construction projects typically require multiparty collaboration and integration of the project information developed across the different parties. The primary benefits of BIM can only be derived if the building data generated across the different parties are integrated and checked for compatibility and consistency. That is, by design, BIM is envisioned as a collaborative tool as well as a process. Project coordinating based on a 3D model, is a core concept in BIM collaboration methods, with a diverse range of advantages.

These characteristics of BIM are derived from its underlying object-oriented modeling approach. On one dimension, BIM evolved as an improvement to CAD, along the way progressing from 2D drafting to solid modeling to parametric modeling, and finally object-oriented modeling. On the other dimension, BIM evolved as an improvement to project information management systems, along the way evolving from paper-based filing systems to standalone databases and spreadsheets to linked databases and finally to integration with object-oriented building models that support embedded information.

Representation has evolved from symbolic representation (i.e., 2D drawings and images) to 3D virtualization. For example, rather than a line representing a wall, a virtual wall model represents a real wall, reducing ambiguity. Information management has evolved from an independent set of specifications, documents, and spreadsheets to the information that is typically embedded in (and appended to) the objects. Accordingly, there is a transition from documentation toward management. In order to support inbuilt intelligence and analysis, these tools have evolved from passive representation and modeling tools to active knowledge-based systems.

3.2 BIM adoption by architectural practice

AEC industry has stayed far behind many other industries in terms of digitalization, take automobile and ship making industries for instance. For architects, the introduction of CAD systems brought about a considerable change in the document production. It helped them reduce the time and produce more precise drawings compared to manual ways of working. Also advances in the field of computer graphics has helped architects in the production of photo-realistic images, which is a use-case limited to presentation purposes.

The real benefits of digitalization through BIM goes beyond a replacement of manual tasks; it opens doors to possibilities that did not exist before, as we will review in the following chapters.

Nevertheless, as discussed in the previous section, adopting BIM brings a paradigm shift in the ways we are working today. This can be a tough decision for architectural firms to undergo such a change, and the decision-making process can be influenced by internal and external factors. Based on Chwelos et al.'s work [32], the adoption of new technology is affected heavily by three factors: perceived benefits, external forces and internal readiness. Internal readiness mainly includes IT sophistication and top management support. External forces include government mandates, regulations and the role of the market that pushes for BIM adoption, whether by software companies or the need for the competitive presence in the industry.

BIM has been in the center of attention both in academic environments and the industry. There is extensive works in theorizing and evaluating the assumed benefits of BIM. Yet the true benefits of BIM can be only realized once put into practice, and this can be a very personalized experience for and architectural practices. The more architects learn about BIM; it helps them perceive the impact of implementing BIM on their practice. Direct benefits include reduced project costs and time, and improved teamwork; while indirect benefits mainly refer to intangible benefits, i.e. reputation, and benefits, which cannot be realized in short terms.

Despite the significant importance of BIM's successful adoption by design firms, understanding the factors that influencing this adoption has yet to be seriously explored. Consequently, it is important to examine the question of how those factors affect an architect's decision to adopt BIM. In this section, we will review the internal and external factors influencing on such a decision-making process.

3.2.1 Internal Factors:

The internal factors that influence the decision to adopt BIM for architectural practices, can be categorized based on the benefits and risks of BIM adoption. For implementing innovations in the AEC industry, a study [33] categorizes influential factors in three groups: Adoption Motivation, Organizational Competency, and Ease of Implementation. Although the impact rate of each factor differs from firm to firm, having a look at the studies in this field help us understand the areas that need more attention inside an organization to prepare for BIM adoption. During the innovation implementation process, the initial stage involves developing an awareness of the innovation and perceiving the needs to adopt the innovation. Adriaanse [34] indicate that substantial benefits of implementing BIM in projects and external adoption motivations are key drivers for a company to approach BIM.

In this study and in line with the existing literature on technology adoption in the field of information technology, perceived usefulness of BIM implementation, organizational innovativeness, subjective norms, and awareness are categorized as major motivations of BIM Adoption.

Motivations for BIM adoption

Perceived Usefulness: The term perceived usefulness or benefits of BIM, refers to the degree to which an individual believes that using a system would enhance his/ her job performance. BIM utilization benefits not only individuals but also organizations. Measures for PU include direct and indirect BIM implementation benefits in the organizational level. Direct benefits include reduced project costs and time, and improved teamwork; while indirect benefits mainly refer to intangible benefits, i.e. reputation, and benefits, which cannot be realized in short terms.

Innovativeness: In a BIM acceptance study reported by Lee et Al. [35], this term was measured in two aspects: organizational innovativeness and individual innovativeness. A general survey of McGraw Hills Constructions [36] found that the innovativeness of an organization's leaders is a critical initiator of BIM adoption. Two proposed measures for innovativeness include the desire to build up organizational competitiveness and the need to streamline an organization's workflow.

Subjective Norms: Fishbein and Ajzen [37] defined this term as the person's perception that most people who are important to him think he should or should not perform the behavior. Since in construction industry, activities are linked contractually, and contractual obligations are critical for an organization to accept new technologies. Sexton and Barrett [38] found that one of the motivations for small construction firms to implement innovations is survival in the market, which refers to the need for acceptance of technology as an operating necessity in the market.

Awareness: Technology awareness is an essential component at early stages of the implementation process. A comprehensive understanding of innovations before decision making improves the efficiency of innovation implementation. A study conducted by Parida et Al. [39] indicated that managers' knowledge of BIM has positive effects to BIM implementation. BIM awareness, as will be referred to in this research, can be measured by the understanding of BIM definition, and knowledge of BIM applications.

Technical issues have been highlighted by a number of studies as the main barrier affecting BIM adoption, especially in smaller size firms due to their limited resources. The three primary factors contributing to **Ease of Implementation** include Ease of Operation, Ease of Maintenance, and Down Time.

Ease of Operation: Also commonly termed as "ease of use", this term refers to the degree to which an innovation is perceived as being difficult to use. Some may argue that difficulties in operating BIM are key barriers to BIM adoption. Ease of operation can be measured in terms of difficulties in the learning process, model creation, and refining the project documentations, considering the latter two as very basic operations in a BIM ecosystem.

Ease of Maintenance: Maintenance for information systems generally refers to the maintenance of applications, ongoing technical supports and upgrades (i.e. software and hardware). Maintenance is mentioned as an important factor for determining the cost of change management using BIM.

Down Time: Down Time refers to a period of time that BIM fails to provide or perform its primary function either planned or unplanned. The transition from traditional CAD drafting to BIM modelling causes higher requirements of hardware's capability. However, the tight budget may not allow the practices to invest sufficiently in hardware upgrade. Rogers et Al. [40] found that technical downtime contributed high probabilities to unsatisfied BIM implementation results.

Organizational competency can be measured in the following areas: Organizational Support, Expertise, and Organization Intention.

Organizational Support: This term is defined as the degree to which an organization's policy supports BIM utilization. Previous experiences show that top management support, including providing training and encouraging staff to use BIM in daily work, is critical to BIM adoption.

Expertise: BIM implementation is a complicated process, which requires professional technical skills. The IT team plays a critical role in hardware selection, software installation, and ongoing support of the BIM implementation process. In the project context, the variety of applied BIM software raises up issues in data interoperability. Therefore, a technical support to shoot down relevant problems may improve the BIM implementation performance.

Organizational Intention: Fishbein and Ajzen [37], labelled this term as user acceptance, which is a prerequisite of actual use. Lee et Al. [35] estimated the organizational acceptance by the strength of willingness of an organization's intention to adopt, implement or recommend BIM to others.

The results of this particular study [33] show that three main factors of 'Awareness', 'Innovativeness', and 'Ease of Operation' have been identified as critical factors that have been influenced the respondents' decision when considering to adopt or reject BIM.

In summary, we can outline once again the internal factors and put them in a gradual setting. At first, an architect or the organizational entities should be informed, learn and embrace the benefits of BIM. This might happen by self-studies, hearing from colleagues, conference, magazines and eventually by actually trying BIM in practice. Then a quest for adopting BIM should occur. This can be caused by the desire for innovation, by the requirement of market or client, and by believing in the benefits of BIM adoption. The next step is the evaluation of the requirements considering the investment it takes, the staff training it requires, the downtime during adoption and other factors that affect the daily practice of an office because the changes translate in time and cost.

Talking about internal factors, it appears to be more of a choice than an obligation. One should understand and appreciate the technology and move towards its adoption, considering the factors mentioned earlier. But External factors are more of obliging nature. It can be that an architectural practice is not ready for the adoption, but the client asks them to deliver a project in BIM, or a bidding requires the delivery of the project in BIM. This may cause pressure and difficulties if a practice is not prepared for the change. However, it is also important to see what are some external factors that may oblige firms to transform.

3.2.2 External Factors

In this part, we will review the factors that compel or push architectural practices towards BIM adoption. This research categorizes the factors as the Government Mandates, the Contractual Requirements and the Market Push. Many governments and local authorities have initiated regulations for the project deliveries using BIM methodology, at least for public projects. Also, more clients are requiring the delivery of projects by architects using BIM. These two factors oblige architects to implement BIM in their practice at least for certain projects. Market influence can be categorized in the role of BIM software and service companies that encourage architects to use BIM, and the need to survive in a very competitive market.

3.2.2.1 Government Mandates:

Worldwide, many governments are mandating BIM because data shows that its adoption provides quantifiable business benefits by improving collaboration, cutting costs, and reducing the risk of budget and schedule overruns during the design and construction phase of building projects. Various countries including the USA, Finland, Norway, Denmark, Germany, Singapore and Korea are currently in the process of or have released BIM guidelines. The involvement of companies in the BIM initiatives by International Alliance for Interoperability (IAI) and buildingSMART in European countries is on the rise [41]. As the BIM-enabled case studies in this research regards the projects in Spain, we review the government take on BIM in this country.

Government influence on BIM adoption in Spain

In Spain, there were some pioneering experiences of implementation of BIM by institutions and public administrations. The Spanish Chapter of the international organization BuildingSMART sets itself the task of encouraging the use of BIM nationwide, engaging all actors in the sector, both public and private. The Spanish Association for Standardization and Certification, AENOR, responsible for the development of technical standards and certifications, set up the Standardization Committee AEN / CTN 41 / SC13 in 2012 for the organization of information models relating to construction and civil engineering. The Catalonia Institute of Construction Technology joined this committee in 2015, contributing its expertise in the structure and use of databases in these fields. The Spanish Ministry of Public Works announced on April 28 2015 at a conference in Madrid [64] the creation of a public-private task force to work on measures for implementing BIM methodology in Spain. On July 14th 2015, the working group EsBIM was formed and since then have been defining the Spanish roadmap for the transposition of Directive 2014/24/EU [65].

In Catalonia, since 2014 the public company Infrastructure of the Generalitat of Catalonia (Infraestructures de la Generalitat de Catalunya) initiated pilot projects in the use of BIM in construction projects as a first step to assess the adoption of BIM in public works. In February 2015 in Barcelona, under the auspices of the European BIM Summit several Catalan institutions signed and published a letter of intent and schedule goals for the adoption of BIM by all stakeholders working in Catalonia.

3.2.2.2 The influence of BIM market

Here, by market we refer to the BIM-related software and service providers, not the construction market. Apart from scholarly articles and industry reports, another source of BIM publicity comes from the companies making the BIM software packages and service providers. This is very crucial for the architectural practices to be able to recognize the real benefits of particular tools they purchase; as inaccurate understandings can lead to unfruitful investments in the software packages. The BIM market is expected to grow from USD 3.16 Billion in 2016 to USD 7.64 Billion by 2022, at a CAGR of 16.51% during the forecast period [66]. The BIM market ecosystem includes BIM software and services providers such as Autodesk Inc. (U.S.), Nemetschek SE (Germany), Trimble Navigation Limited (U.S.), Bentley System, Inc. (U.S.), Asite Ltd. (U.K.), AVEVA (U.S.), RIB Software AG (Germany), Dassault Systèmes (France), Archidata Inc. (Canada), Intergraph Corporation (U.S.), Beck Technology, Ltd. (U.S.), Computers and Structures, Inc. (U.S.), Robert McNeel & Associates (U.S.), and Cadsoft (U.S.) among others.

As mentioned above, the big names and enterprises are involved in pushing the AEC professionals to adopt BIM, resulting in purchasing their software and services. The sales organization of such enterprises are designed in ways to bring in the most clients possible. Therefore, a crucial part of BIM adoption process shall be focused on understanding their real needs, and the tools that will meet those needs. In recent years a shift has been evident in the business model of many software companies, the most notable by Autodesk, which is the subscription model base instead of perpetual software licenses.

3.2.2.3 The project need for BIM

It is a common case that architects win a design competition and enter a project that requires to implement BIM. In this case, even if the architectural practice is not BIM-enabled, they need to adopt BIM for this external requirement. It is usually the client that asks for BIM to be implemented in the project. However, for architects to stay competitive in the industry, the BIM adoption must be initiated by themselves. This will allow them to enter a wider range of competitions, especially in counties where BIM has been a mandate on public projects. What is important here to notice is that there is a global movement towards the change, even though the complexities of such a move is considerable. A challenge is adopting standards that can be understandable and applicable for all professional, another is governments regulating complication especially where autonomous and local governments have their own power.

What is important for architects operating in countries that governments have stepped in towards encouraging the BIM adoption, is that it may not just be a choice, but a must to adopt BIM in order to win certain bids and be part of certain projects. Although it is worthy to mention that not all firms who are not BIM-enabled should ignore such projects because still there are working methods such as outsourcing the BIM-related parts of of projects to other entities. Nevertheless, to stay competitive in the market to pioneers in BIM adoption may enjoy benefits for being outstanding in their market. Furthermore, as the BIM software market players encourage AEC professionals to invest in their software, it is crucial for architects to evaluate well their needs and find the right tools to address them, before investing in software packages. The propaganda in the market is huge and it takes efforts to really understand what is under the hood of all the mesmerizing tools and products out there.

3.3 Obstacles of BIM adoption for Architects

In the previous sections, we reviewed the factors that influence the adoption of BIM, whether perceived as a move to improve one’s practice, or an obligation imposed by law or contracts. The other side of the equation that will be discussed in the following, is the barriers and obstacles architects may face in the adoption. Recognizing these obstacles and addressing them properly paves the way for the changes necessary towards BIM implementation. In a survey done by National Building Specification of the UK [42], the following obstacles were mentioned by firms which have not yet adopted BIM:

- **No client demand:** This was cited by 73% of practices employing five staff or fewer. Whilst the Government is in the process of enforcing BIM for publicly-funded work, clients of smaller organizations don’t often make similar demands – and the smaller they are, the less likely this is.
- **Not always relevant to projects worked on:** 71% of small practices (five or fewer staff) felt that BIM simply is not applicable, or appropriate, to the nature of their typical workload. They may feel that there is not the level of complexity to warrant BIM, but the fact is that even domestic projects can be complex.
- **Cost:** A common observation was the ‘need to get through the downturn’ before looking at BIM. The recession has increased cautiousness, particularly when it comes to financial outlay. It cannot be denied that the move does involve expenditure on software, training, and time. But the costs need to be weighed against the potential benefits. Those who have adopted BIM tend to report that the experience has been better than they had anticipated.

- **Projects worked on perceived as too small:** Contrary to common perception, BIM can work on any size of project from a domestic refurbishment upwards. The biggest inhibitor to its effectiveness is the quality of the survey undertaken, but this is, in fact, the case regardless of whether a building is drawn in 2D or 3D. Although small contractors are likely to provide resistance to technological changes in working practices initially, the workplace is nevertheless evolving all the while, and the benefits can still be realized during the earlier stages of a project in the meantime.
- **Lack of in-house expertise:** 62% of practices with five or fewer staff expressed this concern, and 77% of practices with six or more staff. Although organizations, particularly smaller practices, may not currently have the skills in-house, the upturn in the industry is leading to an increase in recruitment, and this is the ideal time to recruit staff with the necessary skills. Savvy employees will have upskilled during the recession, and smaller practices can be more agile in their response to and adoption of BIM by being able to take advantage of lower aggregate training costs.

Looking at the results of the above-mentioned report, we realize that redundancy in BIM adoption can be seen more in small sized-firms. One reason for this is the limited resources the smaller firms have, and the size of the projects they can take, which are smaller. Indeed, many practices think BIM is only relevant to large scale projects and for larger firms. On the contrary, BIM is scalable, meaning it can be tailored to meet the specific needs of a project and a firm. Reviewing other academic studies about BIM adoption obstacles, we can organize them into some categories.

BIM implementation barriers can be categorized into five major groups: lack of a national standard; the high cost of application; the lack of skilled personnel; organizational issues; and legal issues [43]. Each barrier can then be divided into two or three sub-groups, as shown in the table below, its rightmost column enumerates several typical pieces of literature discussing these barriers. Each category will be explained in more details.

Category	Item	Literature
Lack of national standard	Incomplete national standard Lack of information sharing in BIM	Bernstein & Pittman, 2004; Thomson & Miner, 2006; Björk & Laakso, 2010; Azhar, 2011; Aibinu & Venkatesh, 2014; Alreshidi et al., 2014
High cost of application	High initial cost of software High cost of implementation process	Allen Consulting Group, 2010; Thomson & Miner, 2010; Azhar, 2011; Ganah & John, 2014
Lack of skilled personnel	Lack of professionals High cost of training and education	Smith & Tardif, 2009; Allen Consulting Group, 2010; Sharag-Eldin & Nawari, 2010; Becerik-Gerber et al., 2011; NATSPEC, 2013 ; Wu & Issa, 2014
Organizational issues	Process problems Learning curve Lack of senior support	Arayici et al., 2011; Won et al., 2013; Aibinu & Venkatesh, 2014; Demian & Walters, 2014
Legal issues	Ownership Responsibility for inaccuracies Licensing problems	Thomson & Miner, 2006; Chynoweth et al., 2007; Azhar, 2011; Udom, 2012

Figure 7 Summary of barriers in BIM implementation. Liu. et. Al. (2015)

Lack of national standards

The development of a national strategy for BIM implementation would set out national priorities and provide guidance across the whole industry. It is necessary to standardize the BIM process and publish guidelines for its implementation [44]. However, there is no clear general agreement regarding BIM implementation and use. Some building guidelines have been developed, but no formal standard exists to organize industry practice. Standards are common throughout the AEC industry, but BIM implementation requires the development of new standards. The lack of a national standard for sharing data between all stakeholders in the implementation process is seen as a barrier [45].

Data inconsistency is the most prominent data-related issue, and data compatibility for sharing or exchange is the second most common [46]. Willingness to share information among project stakeholders is considered critical. This means BIM should include the capability to transmit and reuse the information embedded in the graphical mode, and therefore a lack of information sharing could constitute a barrier to BIM implementation [47].

High cost of application

While BIM is expected to provide significant benefits to the AEC industry, its implementation requires costs, as with any new technology. The perceived costs of implementing BIM technology include education and training costs, administration and start-up costs, and transition and behavioral costs. The cost of implementation is frequently recognized as a barrier to BIM implementation. BIM implementation requires specific software and data storage, which mean a significant cost to a company. The cost of purchasing new software depends on the firm's existing IT facility, while that cost could present a barrier to small firms. This issue of cost must be studied well and as mentioned in the previous section, a firm should be cautious about the marketing efforts of large software enterprises.

Lack of skilled personnel

Education and training costs have two broad elements: ensuring a company has the required personnel, either by hiring new staff or retraining existing staff, to establish and integrate BIM technology into its operations; and retraining the majority of existing staff to support the behavioral and organizational changes required to fully adopt BIM technology within a business model [45]. Studies have shown that BIM education can significantly enhance students' competitiveness in today's job market [48].

Organizational Issues

The organizational issues with BIM implementation include professional liability, process problems, and trust [47]. An important factor in BIM adoption as discussed in the previous section is the willingness of top managers to shift to BIM. Some managers are concerned that the learning curve required with BIM could affect their business, and the lack of knowledge about what needs to be done to progress from traditional work is clearly identified as a barrier to BIM implementation [47].

Legal Issues

Addressing the legal aspects of BIM development is also necessary. The first legal risk is related to the ownership of BIM data. If owners pay for the architectural design of construction projects, they may claim ownership of the design documentation. Licensing problems may arise when other stakeholders than the owners and architects contribute data that is integrated into BIM [44]. Another issue is how to determine who will control the access to data, and be responsible for inaccuracies; Stakeholders require security of confidential data in the BIM model, but a range of legal and security issues have been identified in connection with the administration of construction projects within an electronic environment.

According to the above-mentioned research, the critical barriers are the high cost of application, the lack of national standards, and lack of skilled personnel. The high cost of BIM implementation comes from the need to invest in software and hardware. We must add the downtime, learning curve and education of staff, the hiring of staff for new positions created by BIM and the higher salaries of skilled staff. Lack of national standards brings with it confusions in the protocols and standards to be followed. Already a number of different standards and classification exist in the industry and the absence of a local one to follow may cause incompatibilities and clashes, especially while working with other project stakeholders. Finding skilled personnel can also be a challenge, notably when looking for experienced professionals who have worked for years using BIM and in higher organizational levels.

In another research [49] conducted in Australia on small and medium sized firms we read that the main barriers are all stemmed from lack of interest from parties in the construction supply chain exacerbated by lack of evidence showing the advantages of BIM for small-sized projects. This makes BIM adoption too risky and unrealistic in view of the limited resources available for small businesses. So considering the influential factors in BIM adoption we mentioned before, it is evident that those motivational factors in BIM adoption can eliminate the lack of interest mentioned in this study. In other words, not being well informed about the benefits of BIM or having unrealistic perceptions about it, bring this lack of interest. Here again, we see the importance of innovativeness and awareness in the high management levels of company in BIM adoption, the factors mentioned in the previous section.

3.3.1 Overcoming the Obstacles

Lack of national standards: While a company alone cannot do much about it, they can be influential to encourage their professional associations and similar organizations in moving towards the creation of national standards. The lack of such standards can lead to confusions and issues working with others. To prevent that, it is important to specify a protocol and set standards for each particular project, together with other parties involved in the project. This can assure the interoperability between different software and file formats used in a project. This should be tailored to the needs of each project and according to the capacities of the stakeholders.

The cost: Implementing BIM is probably going to cost some time and money at the front end on things like training or software. Those things are short term and we need to offset our investment in them with a longer-term view of the value it can bring. Furthermore, as mentioned in the previous section, the subscription-based models available today offered by many software companies allows for acquiring software even for short periods to conduct trials and only continue if they are relevant. The investment can also be gradual and starting with very basic tools of model authoring such as Revit and eventually, add to the software collection more tools as we advance with the implementation process. Another way to overcome the cost issue could be by generating more value for the client in order to be better paid.

Lack of skilled personnel: When imparting skills and investing in BIM becomes necessary but impossible, the best way is to partner with a BIM service provider who can understand your requirements. It could be architecture, structure, MEP, design coordination, interference solutions, or construction schedule. A BIM service provider is the correct entity to invest in, to be compliant with internationally accepted BIM platforms, standards and protocols. In case there is not an urge for delivering a project using BIM, a company may invest on their current employees to learn the new set of skills, meanwhile searching to hire skilled staff for specific roles, such as the BIM manager.

Legal issues: A well-defined contract where the ownerships and responsibilities are clearly indicated, can address this issue. Nevertheless, the role of previous experiences here is crucial. A practice can refine its contractual processes as the learn in practice about the legal aspects of BIM implementation. Working together with local authorities and law makers in order to adopt BIM-related regulations is another step to be taken in this regard.

BIM adoption factors will be investigated in the case studies to understand the inter-dependencies between them and their overall impact on the collaboration in BIM projects.

4. *Factors impacted by BIM implementation in collaboration*

4.1 The BIM Ecosystem for Architectural practices

Design professionals have clearly been the beneficiaries of technological advances in the tools of their trade. The evolution from the slide rule to the calculator to computer modeling to CAD have all helped design professionals provide their services faster, better, and less expensively. As new tools and processes for design delivery are presented, design professionals face an inherent tradeoff between opportunity and risk that were summarized in the previous sections. BIM as a systemic innovation entails interdependencies between technological, process, and organizational/cultural aspects, requiring innovation across all three dimensions. These mutual dependencies across the different aspects has created a BIM ecosystem in which BIM-related products, processes, and people form a complex network of interactions, influencing one another, determined by factors that are internal as well as external to the AEC sector [50]. The research adopts these three dimensions of People, Products, and Processes as the pillar of the true BIM ecosystem (Figure 8) that will be described in detail in this chapter.

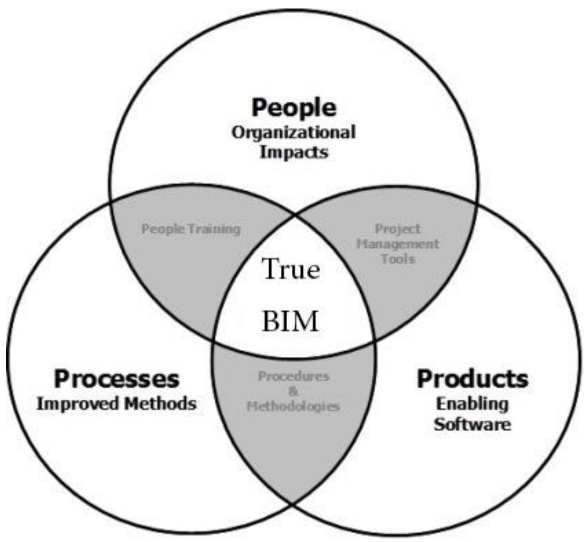


Figure 8 True BIM Diagram. Courtesy of Deutsch. (2011)

In general use, ‘’Ecosystem has been defined as a complex network or interconnected system’’ [51]. Given the complex dependencies between products, processes, and people in the BIM ecosystem, it is important that the evolution and growth across each dimension remain compatible. That is, the pace of innovation and development across these aspects should be comparable, and they should facilitate one another. When the products, processes, and people have mutually coevolved into an established system, it sets into a routine or tradition. For example, a pre-CAD paper-based practice had set into a routine such that stakeholders had a general agreement and understanding of how the construction projects worked. However, in established systems ongoing innovation and innovation adoption across products, processes, or people would require other aspects to realign. For example, when CAD-based drafting was introduced and adopted as a technical innovation, it required people to learn new skills and some procedural changes. However, the misalignment and gap could still be managed even if early inefficiencies were observed as the routine was disrupted. Once again as the industry practices and skills around 2D CAD matured, another tradition was established that set into a routine. Thus, partial adoption requires catch-up and realignment that does not necessarily lead to a system breakdown. On the other hand, if the introduced technical innovation or innovation along any one aspect is radical and entails a paradigm shift, it may lead to system breakdown unless the other aspects are developed within reasonable limits to avoid skewed situation [52]. Skewed adoption refers to unplanned adoption of a radical innovation in one aspect, without due consideration or assessment of the compatibility of the complementary aspects. For example, BIM applications by design require a paradigm shift, as mentioned in previous chapter, in how projects are managed. Therefore, unless the BIM supporting processes or skills are developed or adopted, at least to an acceptable level, BIM projects may not produce desired outcomes and can be a setback in innovation diffusion.

BIM implementation will impact people, processes and products, as discussed previously. The potentials of BIM that will improve the architectural practice during different phases of a project, can be fully enjoyed only when the ecosystem works correctly. We read another definition of ‘’ecosystem’’ in the Merriam-Webster dictionary, which is defined as “the complex of a community of organisms and its environment functioning as an ecological unit”. BIM ecosystem is based on concepts of coevolution and emergence in a complex network of constituent elements of products, processes, and people [53].

This research investigates the idea that establishing the BIM ecosystems lets architectural practices benefit from digital technologies in an integrated way in their collaborative processes. Such an ecosystem will be like an infrastructure based on which we can enable the digital transformation of the practice. Therefore, it is important to discuss further the forming elements of the ecosystem in order to understand the crucial factors in its implementation. The lack of a systemic understanding of the BIM ecosystem is a critical knowledge gap that needs attention. More recently, a systemic view of BIM is starting to emerge in the discussions such as BIM research frameworks e.g., BIM execution plans, and maturity matrices. Along with these, a comprehensive understanding of the BIM ecosystem is required, especially from the viewpoint of evolutionary mechanisms and dependencies across different levels of granularity [50].

The next sections will be devoted to three main dimensions of BIM, People, Products and processes. A review of the literature about these aspects will be introduced that will help us gain a deep insight into the main pillars of a BIM ecosystem. We have limited the study in the main manuscript to the elements in each dimensions that are related to collaboration. Meaning, only the factors related to collaboration that are affected by BIM implementation will be reviewed. Although all factors in BIM implementation can have influence on each other, we will try to focus only on factors crucial for an effective collaboration. Studying these factors will help us with the coding process of qualitative data and their eventual analysis. These and more points will be discussed in the next three sections.

4.2 Collaborative BIM Processes

In this section, we will review the impact of BIM implementation on the processes and methods of working that are common in an architectural practice. For this purpose, we will investigate the processes by categorizing them into categories of internal and external processes. By internal we mean how BIM impacts the methods of working in an architectural practice and by external, we mean how architects work with others in BIM-enabled construction processes. Internally we will focus on two of the main functions of an architectural project, design and documentation and collaboration. Externally we will review BIM contracts and BIM execution plans to see the situation of architectural practices in such documents.

4.2.1 The impacts of BIM on internal processes

The creation of the 3D model with enriched data is at the core of building information modelling. A coordination model based on the main model is used in BIM collaboration processes. Therefore, it is worth reviewing the design process of the creation of the model in architectural practices. If the move towards BIM has been made and assuming that the creation of a 3D BIM model will be the center of data production, a typical design process may be as the following:

Predesign

In predesign, it is determined if BIM is going to be used on the project. Assuming that BIM is the approved method, the architect gets started on the schematic model, either by using masses or real elements in a BIM environment. Once the schematic architectural model is prepared, a presentation will be given to the owner. A walkthrough or renderings is a necessity for this presentation. The owner will then offer thoughts on the design, tweaks will be made, and the model is ready to enter into the design phase. Other use cases of BIM tools in this stage include the ability to use 3D-scanned spaces and perform basic analysis such as solar analysis, building volumetry, topography and excavation works. The data gathered by such invocative technologies help with planning and better decision makings in this very early stage of the project.

Design Phase

At this early stage, energy performance and site orientation towards the sun can be analyzed using generic models. During schematic design, scheduling(4D) and estimating(5D) start to get involved (Figure 9). Scheduling must make sure that this building can be built in the time allotted and estimating needs to

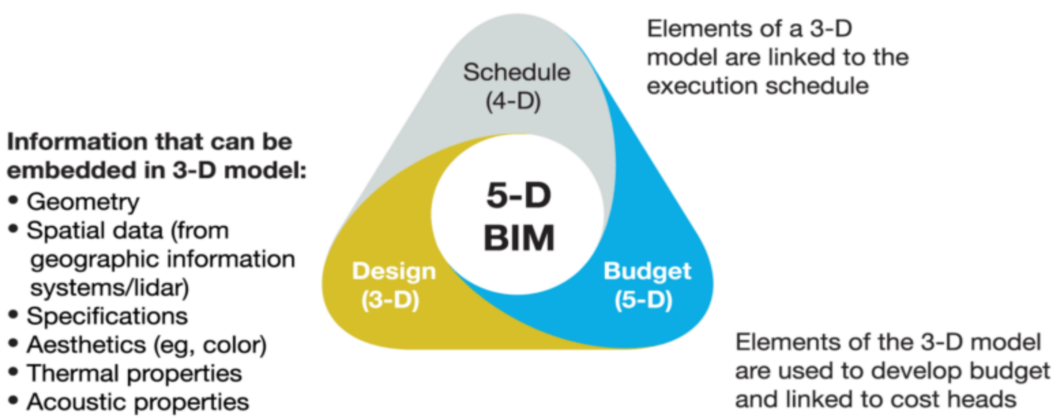


Figure 9 4D and 5D BIM - Courtesy of McKinsey & Company. (2016)

make sure that they constantly track the cost of the project. The BIM models need to be set up correctly from the start. For scheduling, the model has to be built with building in mind. For estimating, Project Parameters need to be added to the models. This is important for two reasons. The schedules need to be filtered correctly so estimating can utilize the model to help in their estimates. Also, the elements in the project need to have enough information so that estimating knows what type, size, etc… of elements they are estimating. This is especially important in projects that are heavy on the process side. It is very laborious for estimating to try and count all of the elements of a process project from a 2D plan.

Design development / Construction documents

During detailed design, collaboration is key. It is imperative that weekly coordination meetings take place in order to ensure that everyone is on the same page. In these meetings, the architects and engineers, project manager, estimator, scheduler and construction manager are in attendance. In this phase of the design process, Interference Checks and Coordination Reviews are done weekly. This is an obvious step to take, but many firms do not utilize the collaborative tools that BIM provides. Interference Checks or Clash Detections can prevent mistakes in the field that could be caught early in the design phase. Scheduling, sections, elevations, and walkthroughs are just some of the coordinated processes that can make BIM more efficient and if done correctly, save time and money.

Another important factor is the ownership of elements. When we talk about ownership, we are referring to which discipline originally modeled an element. The owner is also referred to as the Model Element Author (MEA). When it comes to copy/monitor, the disciplines that copy/monitor an element from a linked model may have input into that element, but are not the owners of that element. Therefore, the owner of an element needs to pay extra attention to the coordination of that element. One of the best uses of BIM's efficiency is one in which every element type is modeled only once. If there are multiple instances of the same element stretched across disciplines, this can be a headache for coordination and collaboration between models.

Construction Phase

A successful collaboration with other project stakeholders is crucial for the overall success of a project. After the design is completed, construction is ready to begin. As discussed, throughout the design, estimating and scheduling were updating their respective processes. This means that long-lead items have been purchased and the schedule has been modified to ensure project completion by the due date. Also, site work has already been started and foundations are ready to be poured. During the construction phase, Navisworks which is a BIM coordination tool, will be available in the field and the design models may have been replaced by models from the subcontractors.

The Construction Manager and field superintendent will work with the design team to make sure that the design intent is followed, and they will run their own Clash Detections on all models. With Navisworks monitoring and workflow tools, identified problems can be reported and tracked through resolution which contributes to an effective collaboration. Construction can be simulated to make sure everything is being built on time. This process was made easier by the fact that BIM was used early in the design phase. Along with that, the owner has actually seen what he/she is getting with the aid of walkthroughs and accurate renderings. This better understanding of the project compared to reviewing the project with 2D technical gives the owner the ability to participate in collaboration with others.

4.2.1.1 Architectural documentation process

One of the most significant areas that is impacted by implementing BIM, is the process of creation and storage of architectural documentation. These documents are the means of communication, especially in the projects that are still using papers and are not fully digitalized. Once the BIM model is developed to a certain level of maturity as required in a certain project phase, endless numbers of visualization can be obtained from it (Figure 10). This may include 3D visualizations or 2d plans, elevations, sections, and detail drawing. This tremendously helps architects in a process that otherwise done in programs such as Autocad is a manual workflow, requiring much more amount of time. Scripting tools such as Dynamo have the capabilities to automate the process of extracting information from models in customized manners. This allows for obtaining certain visual or numeric data which can be used for scheduling, cost estimation, and other applications.

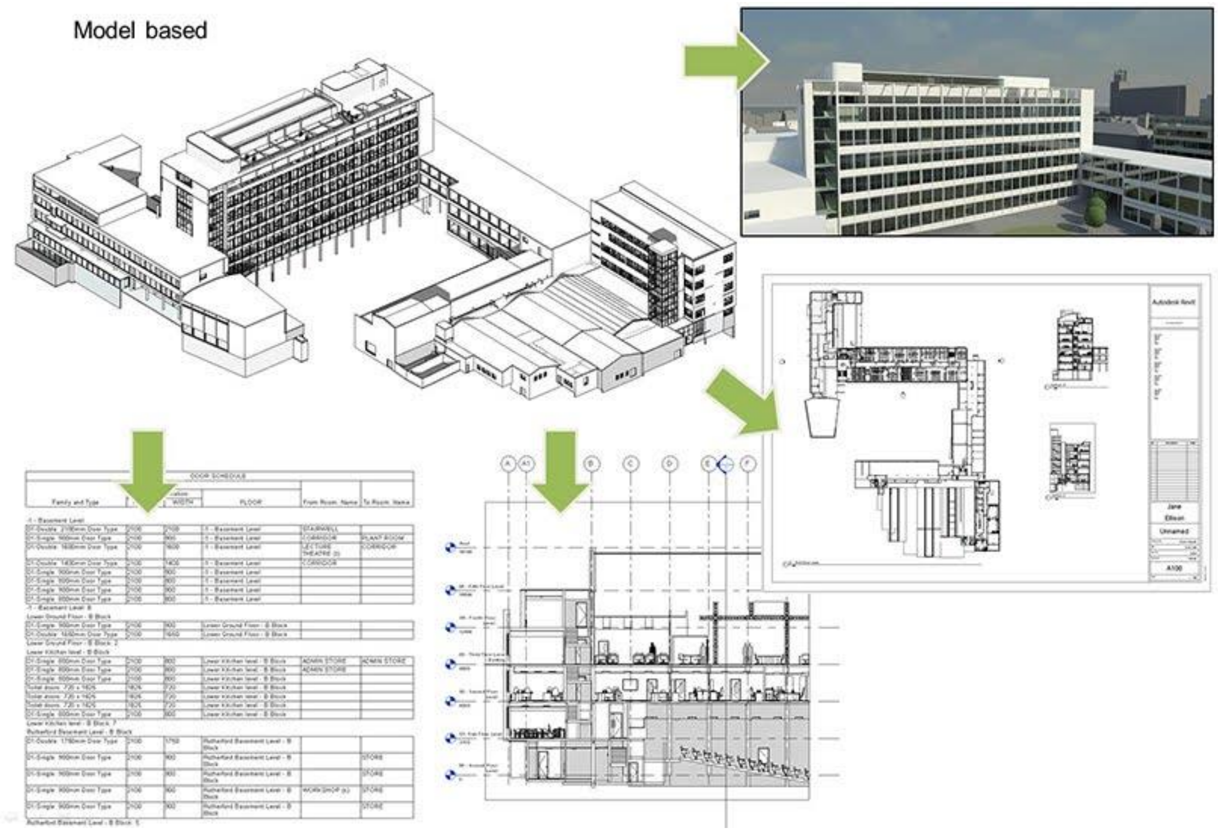


Figure 10 Architectural documentation with BIM. Courtsey of Autodesk.

This automated process of document production from a BIM model becomes even more important in the event of changes. While working with others claims and changes are inevitable event in the building projects. Events which costs architects with extra work and is usually a place of disputes and claims for extra charges. In conventional methods, with a change in the plan design for instance, all other drawings such as section and elevation, need to be updated manually. In contrast, working in with BIM model, as the drawings are created as a representation of the model, with applying a change on the model, all other drawings are automatically updated. This alone is one of the main benefits of BIM for architects, even if other project stakeholders are not BIM-enabled.

The architectural Construction Documentation (CD) and the detailing phase focuses on adding information to the building model to fully describe the proposed design through drawings and details that can be used to guide the construction process. Every feature of the building assemblies, the connection details, and the components that will be installed must be documented in the architectural CD set and presented on sheets for distribution to the project delivery team. The Building Information Model provides an overall framework for generating the details of the architectural CD set which must be created.

Rather than drawing each detail from scratch as a series of lines, views of the model can be created that form the basis for details drawings. Annotations and notes are added to the CD set to complete and fully explain these details, but the building model as such serves as a valuable starting point as well as for consistency checks. Since model views are live, any changes to the building model are automatically reflected in the derived details of the documentation set. While the output of the architectural CD phase is typically a set of printed plan sheets, the building model can be shared with the project delivery team to facilitate automated quantity takeoffs as well as conflict and interference checking.

In addition to the advantages of the document creation process, data repositories also can help architects with the management of their documents. Technologies such as cloud storage and their integration with BIM software, allow for a seamless flow of information through an architectural practice. In a centralized repository, either a cloud-based server or a server deployed in an organization's ICT infrastructure is established to provide features such as management, governance and versioning of BIM data, often bringing significant advantages to users [54].

4.2.2 The impacts of BIM on external processes

In the following section, the external processes affected by BIM will be reviewed. By external processes, we mean those processes and activities that deal with architects working with others. Therefore, we will review some examples of BIM contracts, BIM standards and BIM execution plans to determine where the architects are placed in BIM-enabled projects. This is particularly important to this study as contracts and standards are crucial factors in determining an effective collaboration. Also, we will review the project delivery methods using BIM, to evaluate how the outcome of an architectural project will be impacted by BIM. Project delivery methods as will be discussed are supposed to be other crucial factors in BIM-enabled collaborations.

4.2.2.1 Contracts in BIM-implemented projects

In construction contracts, words alone do not define the agreement. Many documents, including graphical representations, come together to form the contract. These documents are naturally referred to as contract documents and are used to define the scope of work. Traditionally, contract documents include the contract, general conditions, plans, specifications, and any other written conditions upon which the parties agree. The plans included in this traditional definition of contract documents are typically two-dimensional drawings [55]. BIM potentially could upset the traditional definition of contract documents and replace some or all of the two-dimensional drawings, specifications and other written conditions with BIM-based information and data.

Defining the contract documents is much more than a trivial part of the construction process. It is the basis from which the parties will work, coordinate, and collaborate throughout the construction process. According to the Spearin Doctrine [56], if a contractor follows the plans and specifications provided by or on behalf of the owner, and if those plans or specifications turn out to be defective, the contractor cannot be held liable for any losses related to those defects. Despite the age of the Spearin case, this doctrine remains the law in the United States and, as such, "contract documents" are of critical importance to the entire construction process. To stand in place of traditional two-dimensional contract documents, BIM must contain a tremendous amount of information and be relied upon by the parties as the primary source of information. Depending upon how BIM is utilized on a project, each model may not include enough design information to be referred to as a "contract document."

Theoretically, each construction project utilizing BIM would have a fully integrated model from which all design and construction information could be obtained. If this were the case, BIM could be used to replace many contract documents and stand by itself as the single source of information for the design, construction and operation of a facility [57]. While conceptually possible, several key points have prevented BIM from being fully adopted in this manner. First and foremost, the concept of a single model for a building project is not currently a reality. Often on projects that utilize BIM, several federated models are created for individual components of the facility. Secondly, the federated models are often themselves not the product of shared efforts and information. Instead, each is created independently from the two-dimensional drawings received from the designers [58].

The very nature of BIM introduces additional risks that must be allocated among the Project Participants. The BIM Addendum attempts to allocate these risks in the fairest and efficient manner possible. At the same time, the BIM Addendum attempts to deal with these additional BIM-related risks in such a manner as to not upset the typical allocation of risk on a project utilizing two-dimensional drawings and specifications. One of the risks unique to a BIM project is the risk that project participants may rely on the contribution of another project participant as accurate when in fact that contribution is not accurate. CD301 handles this risk by making each party responsible for any contribution that it makes to a model or that arises from that party's access to that model. E202 addresses this potential problem with indemnification language whereby each party agrees to indemnify the other against claims resulting from modifications or unauthorized use of a mode [59].

If we look at the updated version of AIA addendum, we read in description: ''AIA Document E203–2013 is not a stand-alone document, but must be attached as an exhibit to an existing agreement, such as the AIA Document B101–2007, Standard Form of Agreement Between Owner and Architect, or A101–2007, Agreement Between Owner and Contractor. Its purpose is to establish the parties' expectations for the use of digital data and BIM on the project and provide a process for developing the detailed protocols and procedures that will govern the development, use, transmission and exchange of digital data and BIM on the project [59].

In a research conducted on architects and contractors in form of a questionnaire [59], the participants were asked about in their experience whether they had ever used the model as a contract document. This question allowed the respondent to select only one response and generally the architects and the contractors agreed that the model is typically not defined as contract documents. The next question was asked to both the architects and contractors as a follow up to the previous question to clarify some of the inevitable confusion related to 2-D documents which were derived from the BIM. This question allowed the respondents to distinguish between 2-D documents derived from BIM and those created independent of BIM. Respondents were allowed to select all that apply and generally the architects and the contractors agreed that two-dimensional drawings created independently of BIM are most often defined as the contract documents.

The review of the literature and common practices in BIM implemented projects, make it clear that BIM is not usually used as a contract document and often traditional 2D drawings are used for such a purpose. Other factors which contribute to this reluctance to take advantage of BIM include the shifting roles and increased risks and liability for some of the project participants. These inherent, underlying factors may not be as easy to overcome. The next step towards incremental change would seem to be that models derived from the BIM process and two-dimensional drawings created independently of BIM would both be defined as contract documents, and share an equal footing. On the other hand, it is evident that additional documents are often included to cover the matters related to BIM. In the next part, we will review the two main documents of this kind.

4.2.2.2 BIM protocols and standards and BIM Execution Plans (BEP)

BIM Execution Plans (BEP) and the BIM protocols are usually included in the main contract to determine the BIM planning and related matters. These documents at their minimum are expected to cover the following broad categories for BIM implementation:

- **Process and Data**: A main aspect of BIM at its heart, is a management tool that establishes processes. In order to utilize BIM to its fullest, any protocol should include clear and accepted processes which establish each party’s responsibilities. For example, the protocol may establish a mechanism for dealing with changes in design and variations, stating how to notify all design team members. This may include the appointment of a BIM Manager to oversee design changes. A protocol may also specify the design information to be included within that model, which party will host or store that model and data, and what security should be provided to ensure there are back-ups of the data.

- **Interoperability:** There remains a risk of a loss of data integrity where different systems and software are used. To reduce this risk, a protocol is expected to specify compatible software programs that may be used as well as providing a procedure to minimize the risk of errors in the data infecting the design.

- **Standardization and Consistency:** Given the collaborative nature of BIM it is important to have a standardized dictionary. A protocol may include defined terms, confirm deliverables and specify how compliance is demonstrated. As a practical note, contract conditions should include that the protocol terms and outcomes are to be included in all subcontracts that have a design responsibility.

- **Copyright and Ownership:** Traditionally, the position has been that each party will own the copyright for each element of the model for which they are responsible for the design. Where parties are to be working on the model for which another party is responsible for the design, the protocol may grant a non-exclusive license. This may also extend to where the owner is to use the model for maintenance purposes before handing over the project. The protocol is also likely to define when ownership of the model will vest in the employer or end user.

- **Risk Allocation:** A protocol may also include a provision for the inclusion of a form of warranty for the data provided in the model by the various designers.

- **Collaboration:** To assist with collaboration, a protocol may include requirements on all project stakeholder to attend coordination meetings and to work with the BIM Manager. The clear roles and responsibilities definition in BEPs and protocols is crucial for an effective collaboration. Also, the collaborative processes and they related matters must be seen in the BEPs to ensure its success.

BIM Protocol

One of the most prominent BIM protocols has been published by the British Construction Industry Council (ICI). It is a standardized supplementary legal agreement that can be incorporated into professional service appointments and construction contracts by a simple amendment. There are two parts at the end that can be edited to make it specific to your project. The Protocol's key objective is to enable the production of information models at defined stages of a project. It also supports collaborative working, requires the appointment of an Information Manager and enables common standards or working practices to be made an explicit contractual requirement. The protocol includes the following subjects:

- **Responsibilities, liabilities and limitations:** These are defined for project team members in the Protocol.

- **Copyright**: The Protocol gives the client the right to use information contained in the project model(s) for the permitted purpose intended given the level of detail set out. A client can also issue a sub-license to allow other project team members to use models prepared by other project team members. Using third-party models may require a new license.

- **Expected deliverables:** These are defined, as is the required Level Of Detail (LOD) and when these should be provided via a series of data drops at various project stages. Appendix 1 of the protocol features a Model Production and Delivery Table.

- **Collaborative practices and the use of Publicly Available Specifications (PAS) 1192-2 for information management:** These are advocated but not prescribed by the Protocol. Information Management standards to be adopted on the project will be set out in Appendix 2.

The Protocol expects the client to appoint an information manager. Who actually undertakes this role may vary as a project develops (for example, a lead designer may take the role during the early stages and a contractor when construction starts). The information manager is expected to ensure the model follows the Protocol and also has the responsibility for ensuring that the data is secure. The information manager has no responsibilities for coordination or clash detection - their focus is on the application of the Protocol. This protocol can be supplemented by British standards that the ones related to BIM are:

- BS 1192:2007 + A2:2016: Collaborative production of architectural, engineering and construction information. Code of practice.

- PAS 1192-2:2013: Specification for information management for the capital/delivery phase of construction projects using building information modeling.

- PAS 1192-3:2014: Specification for information management for the operational phase of assets using building information modelling.

- BS 1192-4:2014: Collaborative production of information. Fulfilling employer's information exchange requirements using COBie. Code of practice.

- PAS 1192-6:2018: Specification for collaborative sharing and use of structured Health and Safety information using BIM.

Apart from the ICI protocols, each region, project, or firm may create and use their own protocol. However, the ICI one has been regarded as one of the most used ones and has been referred to for the creation of other individual protocols. The importance of collaboration has caused the dedication of 3 chapters of the above mentioned standard to the subject of collaborating.

BIM Execution Plan (BEP)

To successfully implement BIM, a project team must perform detailed and comprehensive planning. A well-documented BIM Project Execution Plan will ensure that all parties are clearly aware of the opportunities and responsibilities associated with the incorporation of BIM into the project workflow. A completed BIM Project Execution Plan should define the appropriate uses for BIM on a project (e.g., design authoring, cost estimating, and design coordination), along with a detailed design and documentation of the process for executing BIM throughout a project's lifecycle. Once the plan is created, the team can follow and monitor their progress against this plan to gain the maximum benefits from BIM implementation.

There is a lot of information that should be included in the plan, including how the data in the actual BIM files should be generated, managed, documented and shared. It should include elements such as agreed roles and responsibilities within the BIM process, a strategy for key deliverables, and a guide to vital project milestones. Project Implementation Plans and Task Information Delivery Plans can be components of the overall implementation plan, which demonstrates when information will be prepared, who is responsible for doing what, and which protocols and procedures they will use. The BEP should also include practical working procedure details such as file name conventions and the software that will be used, as well as a common set of annotations, abbreviations, and symbols to be used in the BIM process

A BEP can provide a number of key benefits. As a comprehensive document that helps different members of the team identify and execute the function BIM provides in the various phases of the project, it can help everyone stay on the same page and present a clear plan of goals and targets every step of the way. The main benefits of having a BEP include:

- **Communication:** Having a plan in place encourages early communication. It also sets out who is responsible for communicating information along different stages of production, while prescribing responsibilities in certain areas.

- **Collaboration and standards:** This is particularly important for large or international projects, where different regions might have different protocols, standards or regulations. International teams can collaborate via a single plan, preventing the creation of silos and multiple plans or ideas on how to do things that might not all fit together.

- **Time savings:** It might take time to put the plan together, but once it is up and running, it will set out key deliverables, procedures and other information that will streamline the BIM process and keep everyone moving forward. This can save a lot of time in the long run.

The most important parts of a BEP are the ones regarding the collaboration mapping and modelling responsibilities. For this reason, it is remarkable to review the parts in a BEP regarding these activities.

Core Collaboration Team: List all stakeholders that form the project management team below. These individuals share in the responsibility of providing oversight pursuant to validation of the project program, cost and value.

Collaborative Process Mapping (Coordination Plan): All stakeholders on the project are to briefly describe and identify their roles and responsibilities below (table 1). The purpose of the process map is to plan events, coordination, and the deliverables for each milestone. Role owners, described as a column will reflect their responsibilities per project phase.

The BEP is an extremely necessary part of any construction project going forward and if done correctly, will be able to answer almost any question put to the project. Every construction is different and requires a different BIM Execution Plan; but by properly implementing a BEP, the project has a far greater chance of being successful.

Communication is a key component of all construction projects. To be successful, it requires many different people working in tandem to achieve a unified goal. This is only possible with strong communication. This is another element a BEP can bring to a project. A well-built BEP requires the project team to work together and communicate from the very beginning to the completion of the project. The collaborative factor of a BEP creates a stronger team goal, rather than individual teams working on their own sections

On any construction project, transparency is also extremely important. A well-done BIM execution plan is ideally available to all stakeholders involved, from the client/developer and contractors to the construction teams; everyone should have a clear idea of what they are doing and what their role within the project requires. This will create a more open and stress-free working environment. There is often an unknown element to construction projects. Something as simple as weather can often derail the best laid plans. A well thought out and implemented BEP will ensure all parties involved within the project have a clear understanding of the process. If setbacks do happen, they can be more easily resolved.

A good way of looking at a BIM Execution Plan is to view it as a construction project's rule book. The BEP will detail the roles of those involved, meaning who is working on the project and what their individual responsibilities are. On top of this, the document will show everything from the project milestones to the regulations that need to be adhered to, as well as all details involved with the supply chain, procedures, technology to be used, and a whole lot more.

	Owner	Architect	Consulting Engineers	Construction Manager	Commissioning Agent
Conceptualization/ Program of Requirements	**Provide requirements related to form, function, cost and schedule**	**Begin design intent model with massing concepts and site considerations**	**Provide feedback on initial building performance goals and requirements**	**Provide feedback on initial building cost, schedule, and constructability**	**Provide feedback on advanced commissioning requirements**
Criteria Design/Schematic Design	**Provide design review and to further refine design requirements**	**Refine Design Model with new input from Owner, Consulting Engineers, and Construction Manager. Conduct Reverse Phase Scheduling Activity**	**Provide schematic energy modeling and system iterations as Design Model continues to develop**	**Provide design review and continued feedback on cost, schedule, and constructability**	**Refine advanced commissioning requirements**
Detailed Design/Design Development	**Department design reviews. Final approval of project design and metrics**	**Continue to refine Design Model. Introduce consultants' models and perform model coordination**	**Create Discipline specific Design Models. Create detailed energy model.**	**Create Construction Model for simulation, coordination, estimates, and schedule**	**Review design model for all disciplines**
Implementation Documents / Construction Documents		**Finalize Design Model, Construction Documents, and Specifications**	**Finalize Discipline specific Design Models and Final Energy Model**	**Enhance Construction Model and perform final estimate and final construction schedule**	**Review design model for all disciplines**
Agency Coordination / Final Buyout	**Assist with code compliance negotiations and permitting**	**Work with agencies on code compliances, plan acceptance and respond to construction RFI's**	**Work with agencies on code compliances, plan acceptance and respond to construction RFI's**	**Manage bid process, project buyout, and preconstruction RFI's**	
Construction	**Monitor construction and give input to construction changes and issues**	**Perform contract administration, update Design Model with changes**	**Assist with RFI's and update Discipline specific Design Models, field conditions, and commissioning**	**Manage construction with subcontractors and suppliers, inform changes to Design Model**	**Observe construction and perform advanced commissioning.**
Facility Management	**Engage Architect and Facilities Group for model turnover to staff.**	**Coordinate information exchange through model to Facilities Group**			

Table 1 Collaboration Process Mapping. Computer Integrated Construction Research Program. (2010).

4.2.2.3 BIM Standards

Projects need standards, not just common use but explicit and written standards. Without some standards, a little bit of chaos starts to derail a project as information starts to become difficult to interpret and responsibilities begin to blur. There are a growing number of standards from various organizations in every country where BIM is becoming popular. Standards will also differ slightly depending on the BIM software being used. Even the titles of the documents are not standard as one organization's execution plan is another's protocol and someone else's standard.

The activities conducted throughout the life cycle of any facility generate an enormous quantity of data that needs to be stored, retrieved, communicated, and used by all parties involved. The advances in technology have improved the process of gathering, providing access to, exchanging, and archiving the data for future reference. Continuing advances in smart building technologies, BIM technologies, and construction practices have not only increased the amount and detail of data generated and exchanged, but have also further raised expectations about its use and value as an asset. This increase in the amount and types of information generated, and the AEC industry's subsequent reliance on it, demands an organizational standard that can address the full scope of this information throughout a facility's life cycle. This organizational standard will enable and add certainty to information communicated between parties separated by miles, countries or continents.

Classifications

Classifying building products models in a standard way is a major step in organizing building product libraries. By giving the proper classification code to the product models, they can be arranged for different purposes such as cost estimation. However, several classification systems have been developed across the globe such as Uniclass in the UK and OmniClass in North America. Each system has been developed for a different purpose since the same collection of objects can be classified with different criteria [60].

Classification organizes the most general classes at the higher levels which are also known as root levels. Then, accordingly, the most special classes are arranged at lower levels. In any node of this hierarchy, the subclasses are in fact specializations of their superclass and any superclass is a generalization of its subclasses [61]. In other words, properties of a super-class are general and properties of subclasses are specific to the members in that collection. In this section, four classification systems that are developed in North America and in the UK and are being used for classifying building product models are summarized and reviewed. The study is structured based on four major criteria presented earlier as the main features of the classification systems [60].

OmniClass: The OmniClass Construction Classification System (OCCS) is established for organizing all construction information. OmniClass is supported by CSI (Construction Specifications Institute) and CSC (Construction Specifications Canada). Various editions of OmniClass, and its predecessor tables such as MasterFormat and UniFormat, have been widely used across North America for many years [62]. The OmniClass is designed to assist in the organization, sorting and retrieving information for use in preparing project information, cost and specification information and other information generated throughout the full facility life cycle. It is useful for many applications such as organizing library materials. Its purpose is to provide a classification for all products and procedures through the project life cycle.

MasterFormat: MasterFormat is produced by CSI and CSC. It is used for most building design and construction projects in North America (CSI and CSC, 2004) and has been a standard for organizing construction information since the 1960s. The 2004 edition was modified with OmniClass in mind so that it can be used as one of the OmniClass tables and be coordinated with other related. MasterFormat is a master list of numbers and titles classified by work results for organizing information about construction work results, requirements, products, and activities Its primary uses have been in organizing bidding and contract requirements, specifications, and product information [60]. Its original purpose was for organizing the project manual. Then, it started to be used for the classification of product models and other technical information. MasterFormat is a hierarchical classification system. It is organized in an enumerative manner.

UniFormat: In 1973, Hanscomb Associates, a cost consultant, developed a system called Mastercost for the American Institute of Architects (AIA) while U.S. General Services Administration (GSA) was also developing a system [63]. The AIA and GSA agreed on a system and named it UniFormat. Then in 1989, ASTM International began developing a standard for classifying building elements, based on UniFormat. It was renamed to UniFormat II. In 1995, CSI and CSC revised UniFormat and latest version was published in 2010. UniFormat organizes construction information around the physical parts of a facility called systems and assemblies known as functional elements. These systems and assemblies are characterized by their function without identifying the work result. Since UniFormat organizes items by their component elements, a modified version of it was used in developing table 21 of OmniClass. Its main use is as a format for estimators to present cost estimates in the schematic design phase.

Uniclass: Uniclass is intended to substitute for the CI/SfB standard that was being used as a representative work breakdown structure (WBS) in Europe. Uniclass first published in 1997 in the UK is supported by Construction Project Information (CPI). In 2011, the CPI Committee (CPIc) endorsed NBS (National Building Specification) proposal to unify Uniclass. It is developed with the purpose to be a classification system for all aspects of the design and construction process. It is intended for organizing

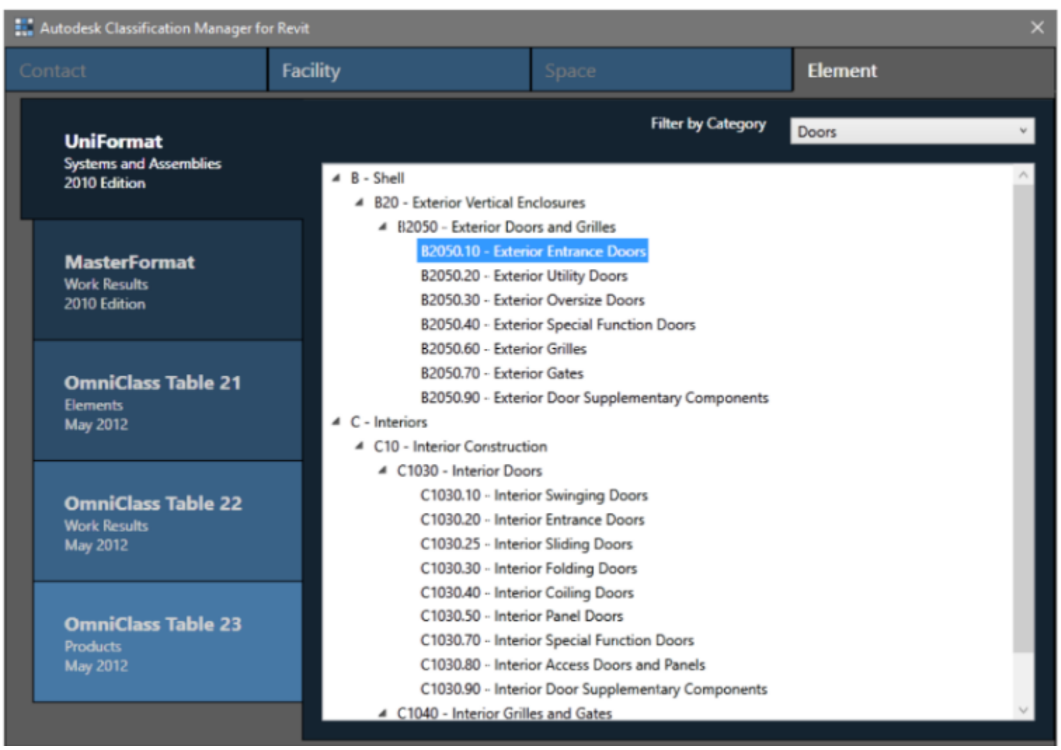


Figure 11 Autodesk Revit Classification manager, courtesy of Autodesk.

library materials and for structuring product models and project information. Uniclass 2015 has been adopted for the deliveries in BIM level 2 in the UK [63].

It is up to the architectural practices to choose the classification system, based on their location, previous firm experience, and project requirements. A well-structured information system is crucial in a BIM ecosystem to allow exploiting its full potentials. Autodesk Revit, as one the mostly used BIM authoring tools, has a classification manager that allows users to easily apply their desired classification. The user can simply navigate through the tree in the right-hand window (Figure 11) and select the wanted classification. One can easily toggle between classification systems on the left if the database supports multiple systems.

4.2.2.4 Interoperability

Many believe that the problems of silo working and badly coordinated documentation will be greatly reduced through the adoption of Building Information Modelling [98]. BIM is all about structured information that is coordinated. This is information that flows through the construction process from brief through to facility management. For this to work successfully, interoperability is critical. It is one the most important factors in collaboration as it enables it computer-to-computer interaction. This helps with condiserabley reducing time and facilitates automaton in processes. Let us look at the definition from the Association Francophone des Utilisateurs de Logiciels Libres (AFUL) interoperability working group: ''*Interoperability is a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions''*. Wikipedia has a separate sub-chapter on software interoperability that is a bit more specific. It reads: '*'With respect to software, the term interoperability is used to describe the capability of different programs to exchange data via a common set of exchange formats, to read and write the same file formats, and to use the same protocols*'' [64].

One common use case for software interoperability is for the customers' freedom to switch from one product to another while keeping the data intact after the transfer. This is especially important for use cases where the data will stay in one system for a long time (e.g. in Computer Aided Facility Management - CAFM systems) to prevent vendor lock-in. For BIM interoperability, there is another just as important driver. In the construction industry where one-off projects teams are assembled across different organizations, disciplines and phases you want the different discipline tools to share information with each other and you want data generated in one phase to be usable without re-entry for the next phase.

To communicate with each other's systems, need to use common data formats and communication protocols. Examples of formats are XML, JSON, SQL, ASCII and Unicode. Examples of protocols are HTTP, TCP, FTP and IMAP. When systems are able to communicate with each other using these standards they exhibit syntactic interoperability. For BIM tools to work together, we need more than just the ability to transfer information. We need the ability to transfer meaning. What is sent must be the same as what is understood. To achieve this both sides must refer to a common information exchange reference model. We need semantic interoperability.

In the mid-1990s the Industrial Alliance for Interoperability (IAI) was created, with the purpose of enabling software interoperability, providing a universal basis for process improvement and information sharing in the construction and facilities management industries. Consequently, IAI developed the International Foundation Classes (IFC) as an open standard model to allow software vendors to create interoperable applications via the IFC file format. The ISO EXPRESS language (STEP-11) was adopted by IFC to describe its models. Objects defined in the IFC data model allow the sharing of intelligent information contained in a BIM. These objects support the entire facility life cycle from planning, design and construction, through facilities operations, management, and demolition. They represent the facilities' objects, such as doors and windows, and the abstract objects, such as construction costs. All objects can have a number of properties such as geometry, materials, finishes, product name, costs, etc., as well as relationships to and data inheritances from other objects.

The first version of the IFC data model was released in 1997, and currently, the latest release is IFC2x3. Extensible Markup Language (XML) based implementations of the IFC data model are available as ifcXML. Implementation of IFC is thus based on a particular view or a combination of views of IFC that define data set requirements in support of specific industry processes, a given organization's work practice, or typical business cases. IAI has been working with the ISO in order to develop IFC as a de jure international standard, and it is currently denominated as ISO TC184/SC4 PAS 16739 [65].

When we talk about "open standards" and BIM, we are talking about non-proprietary file format and exchange protocol technologies that have been developed by public, private, and public/ private entities. These include the following groups and base technology standards:

BuildingSMART International, BIMforum, and buildingSMART alliance are responsible for industry technologies and processes standards for data interoperability.

- IFC - Industry Foundation Classes, the data model specification for building information modeling and data exchange. A list of application certified by buildingSMART International for the import and export of IFC data can be found on buildingSMART website.
- MVD - Model View Definition, the specification for subsets of all available BIM data to serve a stated purpose or process.
- IDM - Information Delivery Manual, the business case specification for exchange BIM data, including end user Exchange Requirements (ERs).
- bsDD (IFD) - buildingSMART Data Dictionary (International Framework for Dictionaries), a catalog of common industry concepts rationalizing varied terminology, due to language, market, or professional idioms, for the same concept.
- COBie - Construction Operations Building Information Exchange, an information exchange specification for capturing BIM data related to building lifecycle management.
- BCF - BIM Collaboration Format, an XML schema that encodes messages to enable workflow communication between different BIM (Building Information Modeling) software tools.
- OGC - Open Geospatial Consortium, an international industry consortium for developing standards for geospatial data-enabled technologies.

- gbXML - Green Building XML, a file format schema for exchanging BIM data for building energy performance simulation and analysis.

- BIMXML - An XML schema developed to represent a simplified subset of BIM data for web services.
- PDF - Portable Document Format, originally developed by Adobe for the electronic exchange of any printable document.

- DWF/DWFx - Design Web Format, originally developed by Autodesk, as a PDF alternative for CAD data/documentation.

The exchange of BIM data is dominated by proprietary solutions, meaning most integrated construction projects are based on a solution in which all collaborators have software from the same or compatible vendors. despite the fact that the industry began working on specifications for an open data format relatively early with regard to the technological maturity of BIM software [66]. Therefore, it is of interest of future research work to further investigate the issues of interoperability within the BIM context.

4.2.3 Project Delivery with BIM

The delivery method is the way in which the owner contractually works together with the designer and the builder. It's one of the first decisions an owner makes when deciding to build a structure. This decision has crucial impact in enabling or preventing a truly collaborative approach to project delivery. According to Barbara J. Jackson [67], before the fifteenth century, this was a relatively simple process: An owner would hire a master builder, who oversaw all aspects of design and construction for an entire project. Over the years, the singular role of the master builder separated into designer (architect) and builder (contractor), assuming that this separation started with Leon Battista Alberti in the mid-fifteenth century. Alberti directed the construction of a new façade on Florence's Gothic church, Santa Maria Novella, from plans and models, which, says Jackson, was the "*first time in history that plans and diagrams enabled the 'designer' to instruct the builder*." This deviation from the master builder approach is why Alberti is commonly referred to as the first modern-day architect [68].

Jackson goes on to say that throughout the Industrial Revolution "*specialized design and construction expertise was needed to address unique production and facility needs*." This specialization created focused efforts within the entities that made up the design and construction teams, which led to the development of professional societies in the mid-nineteenth and early twentieth centuries. Some familiar ones were the American Institute of Architects in 1857 and the Associated General Contractors of America in 1918. These societies, by their very name, further segregated the industry.

Now the industry is quite fragmented, which makes contracting vehicles more complex [68]. In order for owners to decide on the appropriate method of delivery, they must answer a number of questions about their project: What type of building is it? Which designers have experience on this type of structure? How risky is this job? When does this project need to be completed? What is the budget? Do we want a contractor on board during design? Can we legally contract the designer and builder under one agreement? Can we legally share the risk among the designer, the builder, and ourselves? The answers to these questions will guide owners in deciding the appropriate delivery method. There is not a universal solution, so every project will be a little different. Architectural practices must understand the advantages and disadvantages of each delivery method to properly implement BIM. In this section, we will review four delivery methods:

- Design-Bid-Build
- Construction Manager at Risk
- Design-Build
- Integrated Project Delivery

4.2.3.1 Design-Bid-Build

Design-Bid-Build (DBB) is the most traditional type of delivery method practiced today [68]. In this method, the owner has two contracts: one with the architect and one with the contractor. DBB is considered a linear process because there is no overlap of the architectural services and the contractor services (Figure 12).

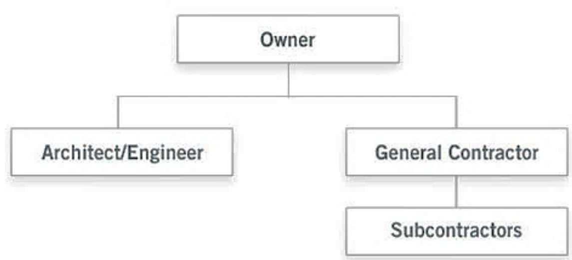


Figure 13 Owner, Architect, Contractor relation in DBB. Courtesy of Hardin.D (2015).

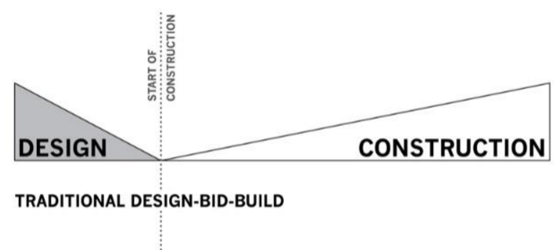


Figure 12 The linear process of DBB. Courtesy of Hardin.D (2015).

At the beginning of the design phase, the owner selects an architect to develop a program and conceptual design for the building. The program includes the function criteria o requirements, number of floors, and building footprint) and is typically in narrative form. The conceptual design could range from hand sketches to a 3D model. Once the owner agrees with the program and conceptual design, engineers (structural, mechanical electrical, and plumbing) are engaged to further develop the design. The result is a complete set of construction drawings and specifications used for permitting and bidding. In the bidding phase, general contractors handle the following steps:

- Review the final drawings and specification.
- Collect subcontractor estimates on their relevant scopes of work.
- Compile the estimates into a complete bid.
- Deliver the bid as a proposal to the owner

The owner then awards the project to the general contractor with the lowest bid and releases the contractor to start building the project.

In a perfect world, the process is that simple, but in reality, a number of challenges may arise. First, it is possible that the low bid is not as low as the owner expected it to be. As mentioned, the architect and engineers create the drawings and specifications with little to no contractor input. This may lead to miscalculations on what is required to construct their design. Another challenge that may arise in DBB is that gaps or errors are found in the design once the contractor has already begun to build the project. Regardless of how big or small the gap, the contractor will submit a Request for Information (RFI) to get clarification on the issue. If the RFI is complex, the architect may have to involve the engineers in the response. After a resolution is found, the RFI is submitted back to the contractor, who then compiles all costs associated with the added time, material, and labor necessary to make the change. This additional cost is submitted to the owner in the form of a change order, since it is a change to the original design. The owner "owns" the risk associated with these gaps and is responsible for negotiating and paying the contractor any additional costs associated with the change.

Advantages:

- The architecture, engineering, and construction (AEC) industry is familiar with this method.
- It is a straightforward competition. If you're the low bid, you get the job.
- The owner keeps a traditional relationship with the architect and has complete control over the design.

Challenges:

- There is limited or no communication between the designers and the contractors during the design phase.
- The lack of communication typically leads to cost overruns due to estimates (cost tracking) not being done throughout the design.
- The RFI and change order process can create friction between the architect/ engineers and the contractor, because the gaps or errors have to be justified to the owner who pays for the issues
- There may be increased litigation due to the lack of collaboration. It is a slower delivery method, since the full construction drawings must be completed prior to bid and construction.

The architect's role in traditional design–bid–build

This sequential process separates design and construction into independent tasks. Furthermore, the owner's two contracts, the first with the architect and the second with the general contractor, sets up discrete teams of specialists. Each may take too narrow a view of the whole, and if, with respective responsibilities unclear, tasks overlap or are overlooked, the parties' relationship can become more adversarial than collaborative. If less involved on site, the architect may lose opportunities to inform construction, as an advocate for the client's vision and as a steward of the original design intent. Not only does this handover of responsibility diminish the architect's standing, the lack of continuity may also compromise the quality of the project outcomes.

BIM in Design-Bid-Build

The DBB delivery method limits the ability for BIM to be used to its full potential mainly because the builders are not involved during the design phase [98]. This has to do with the way in which BIM is being used. Architects and engineers in DBB use BIM during the design process either due to owner requirements or for their own benefit. They are finding that it is faster to use 3D modeling software than 2D software to produce the necessary documents for bidding.

The value BIM brings compared to traditional drafting is its parametric ability, this means that no matter what view you are looking in (plan, elevation, or 3D) the model elements change universally, So, if you moved a door in plan view, it would persist through all the related views (such as elevations, sections, and 3D). This cuts down the time associated with editing the views, because BIM creates them automatically. That saves the architects and engineers a lot of time and money.

Although BIM may not be able to alter the rigid lines of the DBB approach, it can still add value to this delivery method in the following ways:

- Allow contractor and subcontractor a foundation for coordination of MEP systems.
- Saves subcontractors' money by allowing them to prefabricate their systems using the model provided.
- Makes the initial estimating prices easier for the contractor.
- Being 3D gives another level of clarity to all members on the design and construction of the project, previously only afforded in 2D.

The general contractor and subcontractor can find value in utilizing the 3D architectural and engineering models, if available, for general coordination of systems. These models are typically just showing the design intent; therefore, the contractually required documents are still delivered as 2D documentation.

4.2.3.2 Construction Manager at Risk:

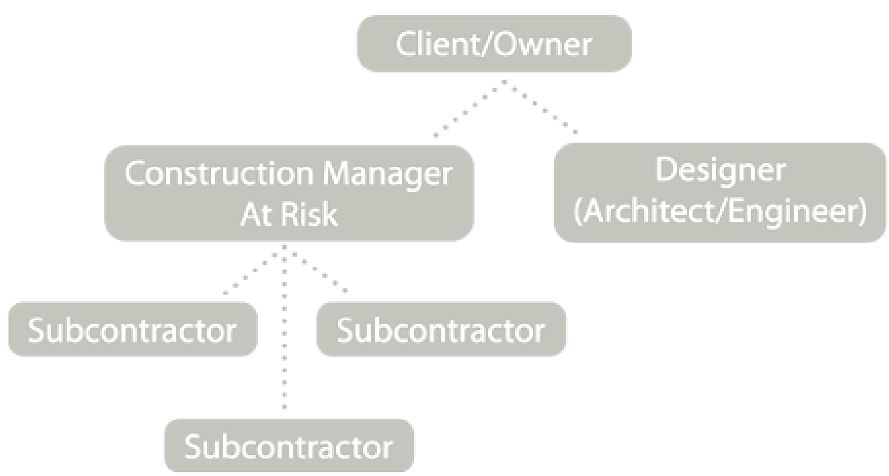


Figure 14 Owner, Architect, Contractor relation in CMAR. Courtesy of Hardin.D (2015).

The Construction Manager at Risk (CMAR) is a delivery method which entails a commitment by the Construction Manager (CM) to deliver the project within a Guaranteed Maximum Price (GMP) which is based on the construction documents and specifications at the time of the GMP plus any reasonably inferred items or tasks (Figure 29). The CMAR provides professional services and acts as a consultant to the owner in the design development and construction phases. Often times, the CMAR also provides some of the actual construction of the project depending on the availability of bidders and the expertise the company has. Generally, the CMAR will give the Owner a GMP prior to bidding the project. By giving the Owner the GMP prior to bids, the CMAR assumes the risk of bids coming in higher as he is contractually bound to deliver the project per the plans and specifications and any additional allowances as defined in his GMP.

The owner still owns the risk of the design and again has to manage two separate contracts: one with the architect and one with the contractor. However, unlike DBB, the contractor is brought in during the design phase, which breaks the linear process of service and is often referred to as ‘’Design-Assists’’ [68]. In CMAR, unlike DBB, construction can start prior to all documents being finalized.

Advantages

- Contractors are involved in early stage
- It allows the contractor to run estimates during design and aids in value analysis.
- It allows construction to start before the design of the entire building is complete.
- The owner still keeps a traditional relationship with the architects by having a separate contract.

Challenges

- The contractor may not be brought early enough to make a significant impact.
- The contractor spends more time in the competition to win the contract, which costs them money.
- The owner still has to manage two separate contracts and owns the risk of the design, which means that friction still exists between the design team and the construction team.

BIM in Construction Manager at Risk

The expectations of BIM and the team must be aligned clearly on by the owner. The owner must create or require a plan to illustrate how BIM will be used or CMAR faces the same pitfalls as DBB. Owners might ask the contractor to utilize BIM during the design phase in order to find clashes and errors that would eventually speed up the construction project and reduce costs. Although this can be a valid assumption, implementing BIM requires well-defined purposes and its scopes of use needs to be well defined in accordance with the two contracts with the design team and the contractor. The lack of such consideration may lead to frustrations and more complications due to the parallel efforts. The threshold for contractors providing BIM services in a CMAR delivery method should be at 50 percent of Design Development [69].

4.2.3.3 Design-Build

In a Design-Build (DB) project delivery method, the owner manages only one contract with a single point of responsibility. The designer and contractor work together from the beginning, as a team, providing unified project recommendations to fit the owner's schedule and budget. Any changes are addressed by the entire team, leading to collaborative problem-solving and innovation, not excuses or blame-shifting. While single-source contracting is the fundamental difference between DB and the old ways, equally important is the culture of collaboration inherent in DB. With one DB entity, the roles of designer and constructor are integrated. One entity drives one unified flow of work from initial concept through completion [69].

Advantages

- Integrated process: overlapped design and construction, typically fast-tracked.
- Two prime players: owner and DB entity.
- One contract – owner to design-builder with a single point of responsibility.
- An Entity can take on many forms including:
    - Integrated design-build firm;
    - Contractor led;
    - Architect-led;
    - Joint venture; or
    - Developer-led.

- Cost efficiencies can be achieved since the contractor and designer are working together throughout the entire process.
- DB can deliver a project more quickly than conventional DBB or CMR.
- Fewer changes, fewer claims and less litigation.
- Ability to enhance project coordination.

Challenges

- This method is not traditional and requires a trust-based and collaborative team for success.
- The contractors and architects typically spend more time competing to win the contract in this delivery, which costs more money.

Architect-led design–build projects

Architect-led design–build projects are those in which interdisciplinary teams of architects and building trades professionals collaborate in an agile management process, where design strategy and construction

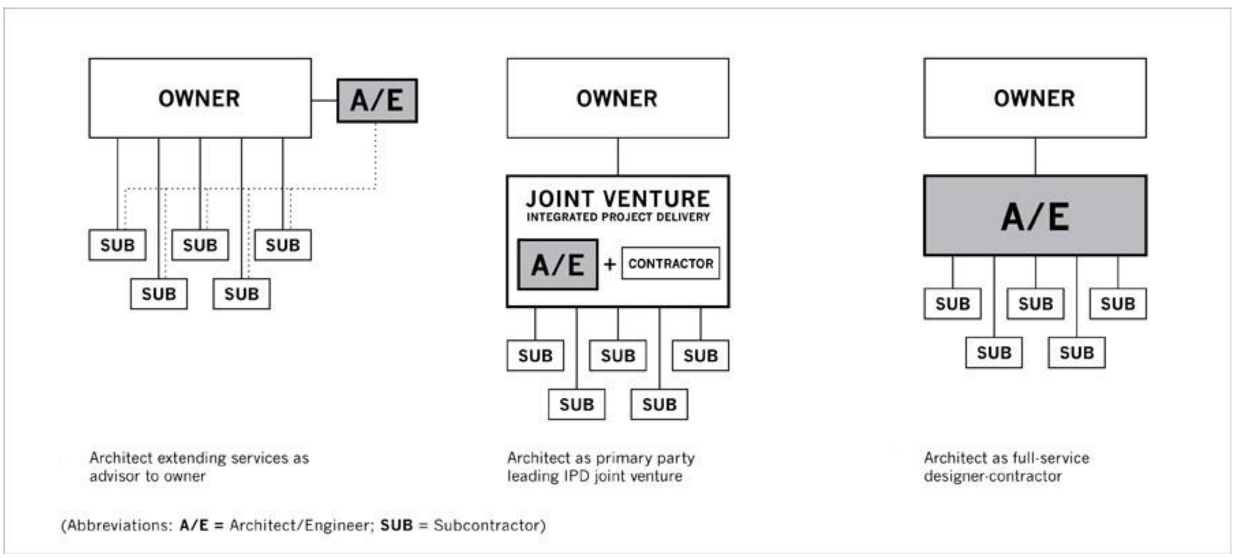


Figure 15 Different Architect-led DB arrangements - Courtesy of Hardin, D.(2015)

expertise are seamlessly integrated, and the architect, as owner-advocate, project-steward and team-leader, ensures high fidelity between project aims and outcomes. In architect-led design–build projects, the architect works directly with the owner, acts as the designer and builder, coordinating a team of consultants, subcontractors and materials suppliers throughout the project lifecycle. Architects lead design–build projects in several ways, with varying degrees of responsibility (where "A/E" in each diagram represents the architect/engineer) (figure 15):

In DB projects led by architects, the architect has the opportunity to lead the team through progressive iterations during the design–build process instead of producing sequential, schematic, design, construction drawings and construction administration documents. These continuous feedback loops extend the phase in which the team is dedicated to producing the most informed design. Each iteration is progressively informed by budgets, continuously improving information and the best efficient construction techniques.

BIM in Design-Build

BIM models during the Design-Build delivery method opens up the opportunity to fully leverage tools and practices, but the most valuable benefit is having a constructible design. In other delivery methods, BIM is limited because models have to show only design intent for all or the majority of the design process [68]. This solves constructability issues early in the cost curve. With Design-Build constructible models can evolve throughout the entire design, which serves two purposes:

- It is a leaner process because efforts aren't doubled between engineers and subcontractors.

- The model is constructible, which allows the team to be proactive with issues as opposed to reactive.

The most popular 3D software platforms used for design does not integrate seamlessly and/or meet the needs of the subcontractors who are fabricating from the model yet. This means that architects and engineers might use one platform to create design models. The purpose of the model is essentially the same except that the subcontractor's version is typically more detailed, is coordinated with the other trades and can be used for fabrication.

4.2.3.4 Integrated project delivery (IPD)

The American Institute of Architects defines IPD as: "a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste and maximize efficiency through all phases of design, fabrication and construction" [70]. The primary team members include the architect, key technical consultants as well as a general contractor and key subcontractors. The IPD system is a process where all disciplines in a construction project work as one firm, creating faster delivery times, lower costs, no litigation and a more enjoyable process for the entire team – including the owner.

IPD combines ideas from integrated practice and lean construction to solve several problems in contemporary construction such as low productivity and waste, time overruns, quality issues, and conflicts during construction among the key stakeholders of owner, architect and contractor. The growing use of BIM in the construction industry is allowing far greater information collaboration between project participants using IPD and considered an important tool to increase productivity throughout the construction process.

This method is similar to design-build method, however, unlike the design–build project delivery method which typically places the contractor in the leading role on a building project, IPD represents a return to the "master builder" concept where the entire building team including the owner, architect, general contractor, building engineers, fabricators, and subcontractors work collaboratively throughout the construction process [68].

IPD contracts have a shared risk/reward component based on the financial outcome of the project. The signatories and other risk/reward partners agree to put their profit at risk in exchange for a guarantee of their costs and shared savings if the project performs well. These firms agree to be reimbursed on a transparent cost plus overhead and profit basis [71]. In DBB and CMAR, the owner ‘’owns’’ the risk. In DB, the designer-builder owned the risk. In IPD, the risk is shared between the owner, architect and contractor, but so is the reward. The contract becomes a multiparty agreement.

In general, IPD team members must perform at higher levels than in their traditional roles. The IPD team is expected to develop a design that is coordinated, that can be built without significant change orders arising from field coordination issues, and that can be maintained and operated as desired by the owner. Today many of these problems are discovered as the project progresses, often leading to costly and time-consuming rework or functional failures after project completion.

BIM and IPD

Incorporating a building information modeling toolset into any aspect of the IPD process enables project teams to use information in an integrated environment, increasing efficiency and enabling new ways of working that inspire more creative and sustainable designs. The interrelationship between BIM and IPD is reflected in the AIA Guide [70]:

‘‘It is understood that integrated project delivery and building information modeling (BIM) are different concepts – the first is a process and the second a tool. Certainly, integrated projects are done without BIM and BIM is used in non-integrated processes. However, the full potential benefits of IPD and BIM are achieved only when they are used together’’.

BIM models enable the integrated project team to collaboratively review and coordinate the composite project, the aggregate of the designs created by each discipline and trade, and jointly resolve conflicts that would traditionally result in finger-pointing and costly change orders. The BIM model serves as a neutral platform for visualizing and assessing the composite design in a way that leaves little question around who or what needs to be changed.

4.2.4 Conclusion

In the previous section, we reviewed the impact of implementing BIM processes on collaboration architectural practices. We mentioned that BIM implementation brings about certain processes and workflows that affect the internal processes of a practice and how they work externally with other project stakeholders. The effect of BIM related processes in different phases of project development by architectural practices was reviewed and its opportunities and threats were presented. It was mentioned that implementing BIM requires following certain protocols, standards and contractual considerations that impact the working processes of architectural practices.

A successful implementation requires a well-studied plan, tailored to the needs of a practice and their projects. Once the proper protocols, standards and contracts are adopted, it is heavily dependent on the delivery method to prosper the full potentials of BIM. That is where the role of the project owners become crucial. It was discussed that the most compatible project delivery methods with BIM are Architect-led Design-Build and the Integrated Project Delivery. Therefore, the owner by choosing one these two methods facilitates a successful BIM implementation which will be beneficial to all stakeholders, by sharing risks and rewards. This will be further questioned in the case study 3 and through the interviews with a BIM-enabled architectural practice.

4.3 BIM Products

Technology is what we use to get things done, and new technologies that purport to improve our productivity have been relevant to the profession of architecture for some time. In this section, BIM technologies, software, and tools under the umbrella of BIM products and as a dimension of BIM ecosystem will be reviewed. ICT advances have been considering promising in the collaboration and communication of the project team members. BIM products include a constellation of technologies and software often specialized to different disciplines or specific purposes. In the following, the most important products related to architectural discipline will be introduced in categories based on their use. Before progressing to the software and tools themselves, it is important to consider the role of software and tools in building up the ecosystem, which helps architects with defining a correct strategy for technology adoption. As this research is interested in the subject ICT utilization in collaboration, some prominent tools are also introduced that help with proposing a BIM implementation strategy in CS1.

4.3.1 Strategies to adopt new technologies and tools

The successful implementation of BIM involves using BIM tools and software that work best for each practice, project, and purpose. The strategy of analysis and selection of new technologies for architectural practices is important because it determines how nimble and operative a team will be. The method for selecting tools in the construction industry typically falls into three approaches, each with different results [68].

The first strategy for selection and integration is the ‘’pile on’’ method. In this approach, an architectural practice looks at tools consistently as an addition to their current systems. The main hypothesis in this method is that the firm will begin by piloting the new tools and then look at how it interfaces with the company’s other systems to see whether the product can meet its demands. If the tool looks like it is valuable and can be used, then the company begins a broader series of pilots that explore it further. The intention is that the new tool will ‘’weave’’ its way into the fabric of tools used within the company and ultimately the best tools will be used while the others fade away.

The second strategy is a "swap out," or a direct replacement strategy. In this method, a company examines a new tool and its features and then looks internally to see which current tool or tools could be replaced. This one-to-one analysis allows for systems to be upgraded and consolidated. This method also creates the ability to continually optimize the "toolbox" of a firm to stay relevant and competitive. One of the shortcomings of the swap-out method is that the related processes and in-depth discovery of how a team works together take a backseat to the feature comparison of each piece of software. Additionally, this method of selection is weaker against disruptive technologies that change the fundamentals in the way a company works, because behind the tools there is usually an established way of working. The improvement cycle in this methodology often follows industry trends, though this method does allow tool selection to be consolidated and the toolbox of an organization to be focused.

The third strategy is less well known but is now growing in popularity due to the rise of lean concepts and outcome-focused thinking. Using this method, known as the "process first" strategy, a team begins by looking at their current processes and then asks "How do we want to work?" This question requires "blue sky" thinking and assumes that the technologies needed to enable this new way of working will be there when they determine their optimal working conditions. This method of selection is more tedious and time-consuming than the two previous strategies and requires a significant investment of time and research to work. The outcomes from this effort vary, but many firms come away with a plan that includes input from a broad cross-section of their stakeholders. The difference is that the team understands the desired outcomes, and the selection of one tool versus another requires considerably less effort.

Unless a firm truly has not changed tools in some time, it will typically use one of these three methods or some combination [68]. Whether the methodology of selection was purposeful or less rigid, a firm that wants to continue to adapt and improve should look at the way it analyzes and selects tools. Doing so determines the speed and efficacy of that company to stay at the forefront of technology and market trends. Overall, BIM in construction is seeing a trend of consolidation in quantity and a focus on cross-platform integration. Some vendors are rising to the call of interoperability, Application Programming Interfaces (APIs), and open source information sharing that limits redundancy and starts to create interesting new ways of using BIM information.

This continued improvement in BIM software can largely be attributed to user communities and feedback. Whether that feedback comes from online forums, consumer councils, or involvement in industry organizations and committees, the lifeblood of improvement in BIM relies on users in the industry to take an engaged stance in the future iterations of existing tools in these venues.

4.3.2 BIM collaboration tools

As mentioned repeatedly in this thesis, collaboration is a key point in a successful BIM implementation. Therefore, collaboration tools and their related workflows are of great importance in determining the project success. Project coordination with the guidelines of a 3D model has been attributed to one of the main advantages of using BIM [72]. That is why most of BIM collaboration tools are based on a model visualized so that the participants in a collaboration session can work within a 3D environment where the model is visualized. Hence, it is inevitable for architects to study well and choose the tools that help them achieve better collaboration internally and externally.

The AEC sector is a typical paradigm of a project-based industry. The new non-routine design and construction processes also accompany complex working relationships and interrelations [73]. A set of teams from various disciplines including the owner, designer, general contractor, project manager, civil engineer, MEP (Mechanical, Engineering, Plumbing) engineer, subcontractor, material and equipment supplier and BIM coordinator are employed to deliver a project. They made inter-dependent discipline decisions and naturally form a temporary multi-organization. The individual participants will finally affect the overall progress.

The notion that communication can have different degrees of richness is based on how much understanding different types of communicated information provide. Daft and Lengel [74] explain that rich information provides substantial new understanding; information with low richness, on the other hand, provides little new understanding. Furthermore, the different types of channel/media used for communication will have a direct effect on its richness. Daft and Lengel [74] acknowledge that communication media differ in their capacity to convey information; they consider that the more information that can be pumped through a media, the richer the media is. Furthermore, they define three important characteristics for a rich communication medium, notably the ability to handle multiple information cues simultaneously, the ability to facilitate rapid feedback and the ability to establish a personal focus.

Architectural practices need to take into account some considerations before choosing the right tools for collaborative purposes. In the following, we review some of these considerations.

4.3.2.1 Choosing the best collaboration tools

Choosing the proper collaborative tools for the architectural projects can be a difficult task. Especially if one has no experience using any one of them. Each app has its advantages and drawbacks. Some are specialized for a specific phase of the project, whereas others are more generalist. Nevertheless, in choosing the best tools some main considerations are:

- Size and complexity of the project

Depending on the size and complexity of your project, be it a small house or a new airport terminal, a collaborative tool would be a benefit in your project workflow. Of course, the level of complexity and requirement differs for each venture. For example, team management with its different permissions levels as well as the communication log is an important feature for a bigger project. While for a smaller undertaking, the ease of use and amount of time saved will probably be the most important aspect.

- Control of access for different team members

Not everyone is given access to all aspects of the building project. Engineers, architects, and construction companies may need to have access to some aspects of the project. Having a more open communication line does not mean everything is visible to everyone. It is important to preserve a certain degree of privacy to give you the opportunity to work quietly without the need to look over your shoulder to check on what others think about it. Architects should consider also the fact that not everyone will have the same learning curve. So, it is necessary to keep non-expert users on a clean, easy to navigate interface with only the most important features.

- BIM model integration and 3D navigation in the tool

Many collaborative tools feature BIM model or 3D integration. The idea to have the 3D model directly in the tool seems great. Many tools have an attractive viewer; however, you may end up not using it in real life as simple tasks or viewing options are not available, or because of inconsistency of the importation of your BIM files. Indeed, many BIM collaborative tools that allow 3D viewing depend on proprietary software like Revit and Archicad to export in IFC files, and the compatibility of all those formats are far from perfect.

- File management

Along with the upload of 3D models and other assets including images, PDFs, and Autocad 2D files, there is a need for a powerful file manager so you can explore and filter the files more efficiently. A file manager is an important feature that works in a similar way to that of the Windows file explorer and Mac finder. Additionally, the files should also be readily accessed online in the cloud.

- Phase of the project: Design or Construction

Although a BIM collaborative tool can follow a building project from start to finish, some tools are effectively purposed for the work of a specific project phase such as the design phase or even the use of the building after completion and turned over to its new occupants. It is not a problem to switch tools between phases as needs in the design, construction and exploitation phases are very different. Of course, a collaborative tool can cover all this stage, but being too general, it will probably fail at covering all phases effectively with the same quality. In order to make it easy to switch from one tool to another, one must consider the import and export options of the collaborative tool.

- Connectivity with other apps, BIM software or services

Depending on when you began and decided to make use of a BIM model and/or a BIM collaborative app, your team may already have existing project data as well as files from previous projects. Inter-operability is very important in BIM collaboration, as the tool claims to be the center of the software ecosystem that we use to design a project.

- Workflow

Setting up an efficient workflow in a design team with diverse profiles can be a hard task. Some collaborative tools leave the users free to set up any workflow that they think is appropriate for an organization. While others already have built-in workflows to help you organize your team and your project. Other tools try to innovate by bringing the best of new innovative methodologies, like lean or agile adapted to construction.

- Help information, support and hotline

Some collaborative tools are sold at a very affordable price or even are free. You may choose to use them first if you are on a tight budget. Most AEC professionals are not IT specialists and some are not very fast at learning new technologies. The tool information, help desk, and an efficient online support - available in different languages could also be an important factor in choosing a collaborative tool.

As mentioned above, choosing the right tools is a crucial task for architects. Especially when they are new to BIM and the budgets are limited. A profound study on the software available, utilizing the trial periods of the software, and receiving advices from BIM consulting companies or other colleagues who are already utilizing certain tools can help architects in choosing what meets their needs best. In the following, we review some of the most prominent tools for architectural practices enabling them to perform an efficient collaboration.

4.3.3 BIM collaboration tools

As argued in previous sections, in traditional project delivery settings, a true collaboration between the design and construct project teams is hardly achieved. Through Design-Build and IPD project delivery types, optimization in design phase coordination can occur through early team engagements, which means working to create a more streamlined construction phase coordination effort. Like many facets of the building construction industry, we must challenge ourselves to "begin with the end in mind".

One of the main benefits of BIM implementation for architectural practices, is its ability to detect and prevent eventual errors and clashes that may occur during construction. This assures that the design intends will have a minimum change caused by conflicts with other disciplines' works. Here is why the coordination with other project stakeholders becomes a crucial part of BIM collaboration. A process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems. The goal of clash detection is to eliminate the major system conflicts prior to installation. Leading the project coordination with a 3D model had these potential values:

- Coordinate building project through a model.
- Reduce and eliminate field conflicts; which reduces RFI's significantly compared to other methods.
- Visualize constructive details.
- Increase productivity.
- Reduced construction cost; potentially less cost growth (i.e. fewer change orders).
- Decrease construction time.
- Increase productivity on site.
- More accurate as-built drawings.

As architects are the authors of initial BIM models containing the design intends, they have a heavier responsibility in project coordination. They are required to receive the models of other disciplines and double check them with their models to give the final approvals. This responsibility is usually carried by the BIM manager or BIM coordinator of each team and goes beyond only modeling. In general, BIM Coordination tasks can be broken into three distinct functions:

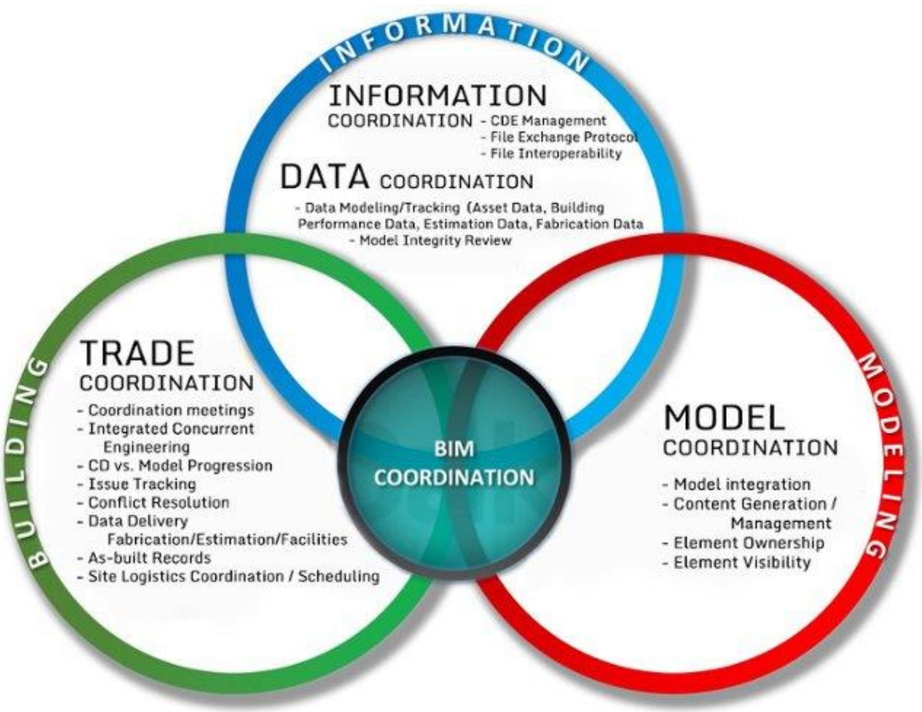


Figure 16 The three dimensions of BIM coordination. Courtesy of Dakota group . (2016)

- Physical construction (Building).
- Data coordination (Information).
- 3D model coordination (Modeling).

This shows that BIM coordination goes beyond modeling, and also includes information and construction management responsibilities. As the diagram illustrates (Figure 16), model coordination is only one part of the process. BIM Managers also have a role to play in guiding their project teams to ensure that all parts of a project are being coordinated. In order to keep a fluid workflow and proper documentation trail, it is imperative that the BIM team meet together before any modeling takes place. This meeting is commonly called the BIM Kickoff meeting. This meeting should address, at a minimum, the schedule, file naming convention, standard modeling locations, file transfer methods, and software versions. In the following, we review some of the prominent BIM collaboration and coordinating tools.

Autdodesk Navisworks:

Autodesk's Navisworks is a widely used project review software that allows AEC professionals to complete various tasks such as construction simulations, animations and whole-project analysis. Ultimately, the solution helps AEC users exert more control over project outcomes and improve stakeholders' collaboration. Navisworks facilitates easy and effective sharing of data and workflows, with users depending on it to promote better project coordination. AEC professionals can also use Navisworks in conjunction with AutoCAD and BIM 360, as Navisworks can open files from both programs to enable an integrated model review.

A primary usecase for Navisworks' includes a feature-rich solution for reviewing and analyzing 3D models. For instance, AEC professionals can detect clashes in design and inspect model functionality. The Autodesk Navisworks family comprises three 3D design project review products and a free viewer application:

Autodesk Navisworks Freedom software

The free viewer for native Navisworks format which is NWD and 3D DWF files. One can use Navisworks Freedom to extend the whole-project view to all project stakeholders, helping to improve communication and collaboration. Multi-disciplinary BIM models, digital prototype (DP), and process plant design applications can be combined into a single integrated project model and published into the NWD format using Autodesk Navisworks Manage or Autodesk Navisworks Simulate software. The published file provides access to model hierarchy, object properties, and embedded review data, including viewpoints, animations, redlines, and comments.

Autodesk Navisworks Review software

Extends access to existing design data to drive insight and predictability to improve productivity and project quality. It combines 3D design data created in BIM applications, such as the Revit family of products, with geometry and information created with other design tools for real-time visualization and collaborative review, regardless of file size or format. Dynamic navigation and an intuitive review toolkit improve understanding of even the most complex 3D models. Entire project models can be published and freely viewed in NWD and 3D DWF™ file formats to provide valuable digital assets during and after construction.

Autodesk Navisworks Manage software

Autodesk Navisworks Manage software is a comprehensive project review solution that supports coordination, analysis, and communication of design intent and constructability. Multidisciplinary design data created in a broad range of BIM platforms, digital prototype, and process plant design applications can be combined into a single integrated project model. Interference management tools help design and construction professionals anticipate and minimize potential problems before construction begins, helping to reduce expensive delays and rework. Navisworks Manage is integrated with Autodesk BIM 360 Glue software to help connect the entire project team and streamline BIM project review and coordination workflows. The software combines model coordination with project quantities and schedule to deliver simulation and quantification features, including analysis of time and cost. Entire project models can be published and freely viewed using Autodesk Navisworks Freedom software.

Autodesk Navisworks Simulate software

Autodesk Navisworks Simulate software provides advanced tools for 5D simulation and powerful features to help with better communication of project information. Comprehensive schedule, quantification, animation, and visualization capabilities assist users in demonstrating design intent and simulating construction, helping to improve insight and predictability. Real-time navigation combines with review toolsets to support collaboration among the project team.

Revizto:

Revizto is a real-time issue tracking software for architecture, engineering and construction with a focus on collaboration and BIM project coordination. Revizto unifies BIM intelligence and makes it immediately accessible and actionable for the entire project team. With Revizto's advanced Issue Tracker project team members can identify and manage model-based issues in the 3D space and on 2D sheets, including addressing clash groups from Navisworks. Additionally, Revizto allows users to follow the progress or resolve challenges in real time all while on any device and in VR.

Using gaming technology and cloud solutions, Revizto brings together various BIM and CAD data to track all project issues in one centralized 3D environment. The Revizto platform is intuitive, easy-to-learn and adaptable to BIM workflows. With Revizto, BIM implementation is streamlined, allowing AEC teams to speak a common language and share a single window into all project information. Revizto converts Autodesk Revit BIMs and Trimble SketchUp models into interactive 3D environments with tools for collaboration and issue tracking platform.

Tekla BIMsight

Tekla BIMsight is an enterprise-class, Windows-based construction collaboration tool for construction industry professionals. It is a free professional tool that provides a convenient BIM environment where construction experts can combine 3D models, share information, and check for clashes. The platform allows project participants to pinpoint and remedy problems in the design stage before construction.

Tekla BIMsight streamlines the whole construction cycle by allowing project managers to resolve conflicts using the automated clash detection tool. The program also provides the entire construction industry a no-cost solution for the modern, model-based coordination. The entire construction workflow can combine their models, check for conflicts and share information using the same easy to use BIM environment. Tekla BIMsight enables project participants to identify and solve issues already in the design phase before construction begins.

BIMx

BIMx is a set of desktop and mobile software tools to interactively present the 3D model and 2D documentation of Building Information Models created with ArchiCAD through a much simpler and intuitive interface than ArchiCAD's complex BIM authoring environment's UI. 3D models with 2D drawing sheets exported to BIMx document format can be viewed with native viewer applications developed for

Apple iOS, Android, Mac OS X, and Microsoft Windows operating systems. BIMx presents three-dimensional building models in an interactive way similar to First-person shooter video games. Clients, consultants and builders can virtually walk through and make measurements in the 3D model without the need for installing ArchiCAD. The real-time cutaway function can help to discover the construction details of the displayed building model. 2D construction documentation can be accessed directly from the BIMx Hyper-model's 3D model views providing more detailed information about the building.

BIM 360

Autodesk BIM 360 is a comprehensive project management platform designed for the construction industry. The software is designed to help Project, Field and BIM Managers to speed up the delivery of their projects while staying within their project budget and adhering to industry standards, safety rules, and project specifications. With BIM 360, teams are equipped with the tools and features they need to better coordinate their actions, effectively design and implement workable schedules, enhance communications, and resolve issues faster than ever. All these allow managers to have near absolute control over their projects, resulting in faster and more efficient delivery of their projects. BIM 360 is a versatile project management tool that works for just about everyone in the construction sector. Aside from project managers, the software is a perfect partner for superintendents, virtual construction managers, subcontractors, project engineers, and design teams among others.

Modelo

Modelo supports the complete design-build-manage process by with a robust, collaborative online BIM tool. Modelo automatically imports BIM properties and elements from compatible Revit files. By predictably, productively and profitably connecting workflows, utilizing BIM in Modelo permits team members to more completely navigate models, conduct fast 3D quantity takeoff calculations and analyze sectional material volumes, mark-up the design with their comments, and digitize their construction sites and processes, all in an online tool accessible from any device. The web-based 3D BIM tool allows users to quickly calculate the volume of materials required, construction costs, or any other number of construction-related calculations. These estimates can then be recorded and shared through Modelo and any construction issues that are foreseen in the design can be marked up directly on the design in the browser and addressed prior to construction beginning.

BIMReview

BIMReview is a BIM collaborative project review tool for use across the whole construction project. It is the affordable, feature-rich tool to import BIM models and associated data from multiple CAD authoring tools to consolidate effective review and visual communication. Its main advantages are its ease of use, intuitive clash detection, IFC import/export and ability to enrich BIM model data.

4.3.3.1 Co-location and long-distance collaboration

Most of the times, it is assumed that project teams understand and respect the input of others, their roles and responsibilities. Therefore, it follows that collegial relationships amongst project-teams may benefit from regular meetings, open dialogue and apportionment of risk, which in turn produce an atmosphere of mutual trust. Based on such an understanding, it can even be argued that where there is timely sharing of information, emerging problems may be resolved easily, particularly when all team members participate towards a common goal.

The modes of collaboration in a project have been grouped into four main categories depending on the nature of separation and pattern of communication [75]. For construction projects, collaboration could be face-to-face, i.e., occur at the same time in the same place (synchronous) or at the same time in different places (synchronously distributed). It could still occur different times in the same place (asynchronous) or at different times in different places (asynchronously distributed). Out of the four models, synchronous distributed collaboration appears to be the most advanced. A classification of existing collaboration communication processes (Figure 17) suggests that BIM and related cloud services have the potential of achieving face-to-face or distributed collaboration synchronously and asynchronously [76].

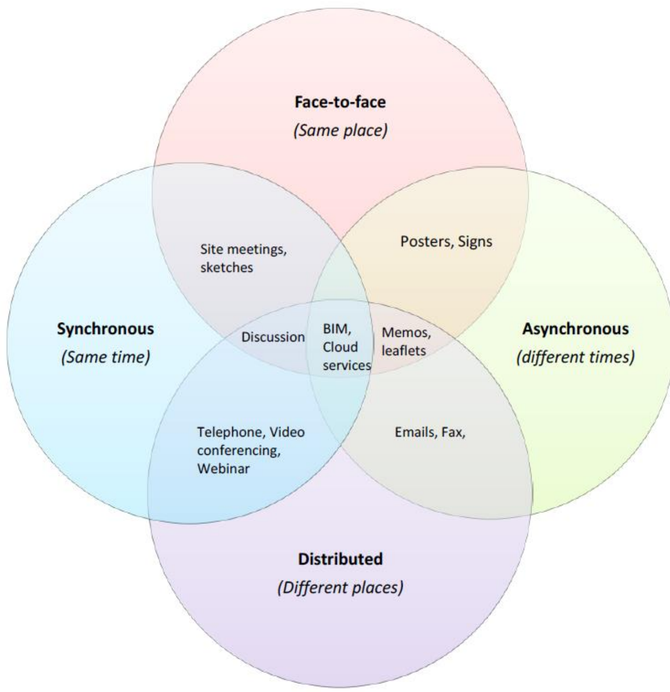


Figure 17 Forms of collaboration in AEC. Courtesy of Abanda et. Al. (2018).

The BIM Big Room

Regarding the same location or face to face kind of collaboration, the idea of the ''BIM Big Room'' has been proposed as an effective way of collaboration. The Big Room (Figure 18) is an on-site co-location space that physically brings together designers, builders, and often facility operators to work together. Collocating in a Big Room environment fosters collaborative behavior that encourages brainstorming and innovation. Teams within the Big Room can be broken into position groups, much like linebackers and quarterbacks. Groups focused on various aspects of the project such as site, mechanical, structural, interiors, enclosure, etc., are formed, very early on, to tackle different issues and challenges. Each group is tasked with identifying solutions to reduce time, waste, and cost to the benefit of the project.

Figure 18 An example of a BIM Big Room. Courtesy of Yoders. (2011)

Although forming a Big Room requires a significant investment of time and money, when conducted well the Big Room adds value to the project and drives down the overall project cost. Teams rapidly advance work in a relatively short amount of time with less paperwork because they have the collective brain power in the room working together. Having a well-established, effectively facilitated agenda is crucial to a Big Room's productivity and efficiency. The team should collaboratively create the agenda well in advance of the Big Room session. This ensures that all team members are prepared to advance the work. A good agenda has an expected outcome for the agenda items, timeframes, and required key participants.

Considerations for the physical space of the Big Room include:

- Large room supported by break-out areas.
- Lots of wall space and/or portable walls.
- Dedicated space (ideally).
- Access to coffee, water, snack, restrooms, etc.
- Technology to support team's activities (Smart board, videoconferencing, whiteboards, printers/plotters).
- File and information sharing structure.
- Connectivity (company servers, internet, email, etc.).
- Whiteboard, sticky notes, markers, flip charts.

Despite the numerous benefits of this collaboration method including the transparent flow of information, the requirements for creating the space and the scheduling for bringing everyone together can be challenging. The latter problem might be addressed recently by virtual reality technologies, where in a virtual space participant can be present, eliminating the need of the physical presence in a certain location. The research will investigate this idea in CS2. In continue we will review another breakthrough technology that helps architects with BIM collaboration, which is cloud technologies.

Cloud/Mobile BIM for Collaboration

Recently, the construction industry has seen a rapid increase in the use of mobile/cloud BIM computing technology in construction projects. It has been used for collaborative communication purposes through mobile devices like PCs, smartphones, tablets PCs and iPads. BIM is being integrated with cloud computing technologies, creating an innovative working pattern streamlining communication with the on-site processes. Indeed, cloud computing technology promises to offer enhanced accessibility of project data and site images simply by remotely linking mobile devices with a dedicated remote server. The mobile/cloud BIM technology promises to offer higher levels of cooperation and collaboration. One of its major strengths is in the ability to offer a real-time communication platform for project team members and other external stakeholders. Mainly, mobile/cloud-BIM technology offers:

- Actual-time monitoring of progress.
- Coordination.
- Clash detection.
- Data sharing amongst project teams regardless of location, inter alia.

The real-time cloud-based collaborative BIM platform used through mobile devices is enabling users to virtually communicate. Site teams are now able to view and make responses to site issues directly from their mobile/cloud devices. That has been seen as enhancing communication between project teams onsite. Therefore, it prevents unnecessary delays, which sometimes result in conflicts onsite. Cloud/mobile BIM technology facilitates the remote exchange of data wirelessly through the Internet. Matthews [77] reiterated in their findings that construction sites need to adapt their onsite processes to accommodate mobile/cloud-based and structured data entry. In the following dedicated section about BIM in cloud, such technologies will be reviewed more extensively.

4.3.4 BIM visualization tools for collaboration

As discussed in the previous sections, collaboration is a key factor in a successful BIM implementation. Visualization of a BIM model lays at the heart of most BIM collaboration tools and methods. Furthermore, the visualization of a BIM model serves for architectural presentation purposes. Therefore, BIM visualization tools are one of the most important aspects of BIM that can address the architects’ needs during different project phases. The advances in computer graphics have paved the way for the introduction of some of cutting-edge technologies of this field to the AEC industry. These new technologies such as real-time rendering and virtual reality have many potential use cases to improve the architectural practice.

With the introduction of BIM, the use of real-time 3D visualization as a communication tool has become more accessible. As 3D data can be extracted directly from the design authoring environment, there is no longer a need to create a separate 3D model for the sole purpose of visualization. However, most BIM authoring tools such as Revit and Archicad, are not suitable for sole visualization purposes. They need potent hardware to smoothly operate, and other colleagues or clients who want to visualize the model, need to have expensive licenses of these tools and the knowledge to operate them. For these reasons, many specialized visualization stand-alone platforms have been introduced to the market which receive the models form different formats and visualize them in easy-to-use environments.

Cloud technologies as mentioned above are being introduced into the AEC sector with great potentials. Recent technological advances in the field of computer graphics and cloud systems have enabled the web-based visualization of BIM models that allow for effective collaboration workflows. Another important aspect of technological advances that make BIM visualization ever more practical for architects, is the improvement of graphical quality. Often BIM models were visualized with low-quality material images and imprecise geometries. Although such a level of graphical quality could be acceptable for coordination purposes, they had no place in architectural presentations. Today with advances in this field, architects are able to create photo-realistic presentations directly and quickly from their BIM models.

Renderings have been one the costliest and most time taking parts of an architectural project, yet it has a significant role in winning competitions and communicating the design intents to the clients. This situation has been disturbed and improved by constant enhancements in the materials graphics quality. One-click render production directly from a BIM authoring tool are taking the place of the complicated processes of rendering with software such as 3DMAX and V-Ray. Furthermore, technologies like virtual and augmented reality, are accommodating unprecedented ways of presentation. In a virtual reality environment, architects can truly see and present their projects in a 1:1 scale, realizing the spatial relations and space qualities like never before. Augmented reality adds a 3D layer of information over the 2D drawings or in our real surrounding spaces. Therefore, visualization in BIM is one the most exciting topics and, in the following, we will further discuss it and present some more advanced tools in the field.

4.3.4.1 Real-time Rendering

Real-time rendering is an animation that is rendered instantaneously and can be generated in less than a second. This technology has been recently adopted in a range of BIM collaboration tools. It allows for exploring a BIM model in real-time where collaboration takes place on the visualized 3D model. Unlike the static image rendering tools, real-time renderings are measured by frame per second which normally range from 24 fps to 60 fps depending on the user requirements. With this amount of speed, it allows users to not only render the image instantly but to view it as an animated scene in real-time. Most of the real-time rendering platforms are based on a game engine. For years, game-engines have been used to visualize environments in which games take place. Perhaps surprisingly, it is only recently that the trend towards the application of gaming technology to visualization in the AEC segment has been broadly and publicly recognized by the industry experts and leaders.

Using a computer game engine as part of a design review system may not seem the obvious choice. However, due to the nature of the game engine providing networking features that enable real-time collaboration and real-time 3D graphics for real-time visualization of a building, a game engine could perform this task well.

Apart from collaboration, real-time engines with recent advances, are being utilized for presentational purposes. This is due to the improved quality of real-time rendering graphics which day by day is getting closer to the photorealistic expectation of architects and clients. In a recent 2018 architectural visualization survey [78], the majority of those experimenting with real-time rendering stated that they intend to use it for every part of their workflow that requires presentation. This is due to the fact that real-time rendering environments allow projects to be presented, explored and examined in novel immersive ways.

From the client's point of view, static images are not the best way to illustrate the full depth of the architect or designer vision. They cannot offer the flexibility to see the design from a different angle, but only from a fixed view, chosen by the architect. The client is unable to see the entire design before it gets built, thus the actual buildings may be different from the client's expectation. Real-time rendering allows the client to enter the model scene and walk through the design in any view or angle of their choosing. The light intensity and color, materials, the difference of shadow in different times of the day can all be shown in real-time. For the architect, the design process is a continuous loop of feedback between the architect and the client. Due to the limitations of the static rendering image, this process can be slow, requiring a lot of back and forth.

A number of real-time visualization tools have been developed for the use in BIM ecosystem. The main characteristics of such tools include receiving main BIM file formats, containing and displaying the BIM data and recognizing the views defined in BIM authoring tools. Usually, the 3D scenes created by such tools can be easily shared with clients and colleagues. As a tool for presentation, the graphic quality of this generation of renders is within high range once the materials are defined well in the authoring tool. The user is able to interact with the building elements in the scene, for example by clicking a wall and view its BIM data. The benefits of utilizing such tools is remarkable, although these tools usually required strong PCs, and usually require expensive Graphic Processing Units (GPUs) and other hardware to run. Nevertheless, advances in the field of computer graphics are constantly making them more affordable.

Real-time rendering tools

ENSCAPE™

Enscape

Enscape has proven to be one of the best real-time rendering tools for architects. It's easy to use plug-in integrates with Revit, Sketchup and other tools. In Revit, with a click of a button in a matter of seconds, the model opens up in Enscape platform, where users can explore the scene like a game environment. The high quality of materials and the ability to handle large Revit scenes has been making it a favorite choice. It also easily allows for the creation of virtual reality scenes with a click of a button. It has the ability to replace Revit proxy objects such as people and trees with its high-quality objects. Once in the scene and enjoying the real-time rendering, users can export even higher quality still images. It also features an intuitive to use daylight feature, where users can easily visualize the effect of the sun and shadows or artificial lightens at night.

CL3VER

CL3VER

I had the opportunity to collaborate with CL3VER to help them develop a new range of visualization tools that included a plug-in for Revit, letting them enter the BIM ecosystem. In CL3VER I had the privilege to work with some of the biggest architectural practices to understand their visualization needs and transfer them to the development team. CL3VER exports the Revit or Sketch-up geometry to its platform and visualizes them with high quality using real-time rendering engine. The advantage of CL3VER is that it is a web-based tool, meaning that users can create scenes and send them to their clients and colleagues using a web link. Having a cloud-based workspace, the users can upload their scenes to CL3VER cloud and access them anytime from anywhere with an internet connection.

4.3.4.2 Virtual Reality and Augmented Reality

Other visualization technologies that have shown great potentials to be used in collaborative processes are Virtual Reality (VR) and Augmented reality (AR). Researches and innovators have long been involved with the development of VR technologies, dating back to decades ago. But only recently, the hardware and software in the market have become available and affordable for its widespread use. As an immersive visualization method, virtual reality brings great potentials to the AEC industry. Architects can evaluate their design in 1:1 scale, and walk in their project as if it was built and let their clients perceive the design in such a way.

As a medium, VR has three defining characteristics (79). It is interactive (users can interact with models), spatial (models are represented in three spatial dimensions), and real-time (feedback from actions is given without noticeable pause). With the ability to exploit and reuse information directly from the models, the current interdisciplinary collaboration can evolve towards integrated multi-disciplinary collaboration on models [80]. VR provides a spatio-visual representation of the design object and can become a highly effective instrument for exploration of digitally modeled architecture. The use of stereoscopic head-mounted displays (HMDs) allows stereovision and thus a depth perception in digital environments. The degree of immersion is directly related to image quality and the reaction rate of the HMD.

A common case in construction projects is that some stakeholders are not from the AEC sector, and have no familiarity with conventional construction documents. A prevalent problem is that the information and design concepts are not presented in such a way that all stakeholders can perceive them well. In this context, real-time visualizations and VR have been shown to offer an efficient communication platform [81] [82]. VR lets us experience and discuss something that does not yet exist with a common perspective. Instead of speaking in abstractions, virtual reality gives us a more tangible frame of reference. As a result, it tightens the understanding gap between clients and architects, and between visual and non-visual thinkers.

Another advantage of using VR during different stages of the project design development and construction is its attraction for the involved stakeholders. Many collaboration or project presentation sessions can be burdensome and boring for the participants. The act of wearing the HMDs and being detached from the real world can have something interesting about it for people, similar to the attraction of playing with arcades or other gaming devices. The disadvantages assumed to be associated with it can be the physiological problems that it might cause, like motion or simulation sickness [83].

Feeling tired after a while wearing the HMDs or the struggle to get used to the environment and controls in the hand can also be negatively affecting the experience. Considering the impact of BIM on the construction industry, the importance of collaboration in BIM processes and the idea of social BIM and the opportunities of emerging technologies such as virtual reality for BIM collaboration, we found some space to be investigated. Therefore, this research includes a case study to examine and evaluate a BIM-enabled collaboration and presentation session in VR to observe the behavior of participants and analyze their feedback taken by semi-structured interviews.

Apart from virtual reality, augmented reality is another promising technology for architectural practices. As the name implies, augmented reality adds something to the real environment around us. It can be visualized by a tablet or a phone, or by innovative devices such as Microsoft HoloLens. The use cases can be adding a 3D model over 2D drawings, or on construction sites, adding instruction of work by scanning the AR codes (Figure 19).

Figure 19 An example of adding 3D on 2D drawings, Courtesy of augment.com (2017).

4.3.5 BIM in cloud tools

Cloud technologies have been a shining star in the IT galaxy, and the AEC industry has been paying attention to its possible applications. Information management as an important aspect of a successful BIM implementation can enjoy the benefits of information flow on the cloud. The accessibility to data stored in a central server with designated access level based on responsibilities allows for implementing an advanced level of data management. In the AEC sector, Cloud-BIM integration is considered to be the second generation of building information management (BIM) development and is expected to produce another wave of change across the construction industry [84].

Cloud-based computing provides ubiquitous, on-demand access to a shared pool of configurable computing resources (e.g. networks, servers, applications, devices and data) that can be quickly accessed and discharged with minimal management or service provider interaction [85]. Thus, cloud-based computing has enabled real-time collaboration and provided project teams with the ability to extend BIM from design to construction [86].

Cloud technologies are also the enabler of other tools and innovations in the construction industry. A number of studies have suggested that the introduction of mobile technology such as tablet personal computers, smartphones and personal digital assistants (PDAs) can improve the ability to capture real-time information on-site [87]. These technologies must run on cloud infrastructures to be effectively practical and accommodate advanced and innovative methods of collaboration in AEC. Today, most of BIM collaboration tools are moving towards adopting cloud technologies. The basis of such tools is that the user uploads the BIM models to the cloud space of a platform, and anyone with access to the cloud space can view and work on the models. It then facilitates the exchange of information between project stakeholeders throughout the life cycle of the building (Figure 20).

The architecture of cloud computing consists of four layers [84]: application, platforms, infrastructure and hardware (from top to bottom). The hardware layer consists of the cloud's physical resources (i.e. computer equipment such as servers). The infrastructure layer is also known as the ''virtualization layer'' because it uses virtualization technologies to manage computing resources by partitioning physical resources. The platform layer consists of operating systems and application frameworks that reduce the burden on the virtual machine, and thus acts as a kind of virtualized server. The top layer is the application layer, or the actual cloud application. These layers are loosely coupled so that each layer can evolve separately. The functionality and practacality of cloud technology, like many others, is heavily dependant on technological advances in these layers.

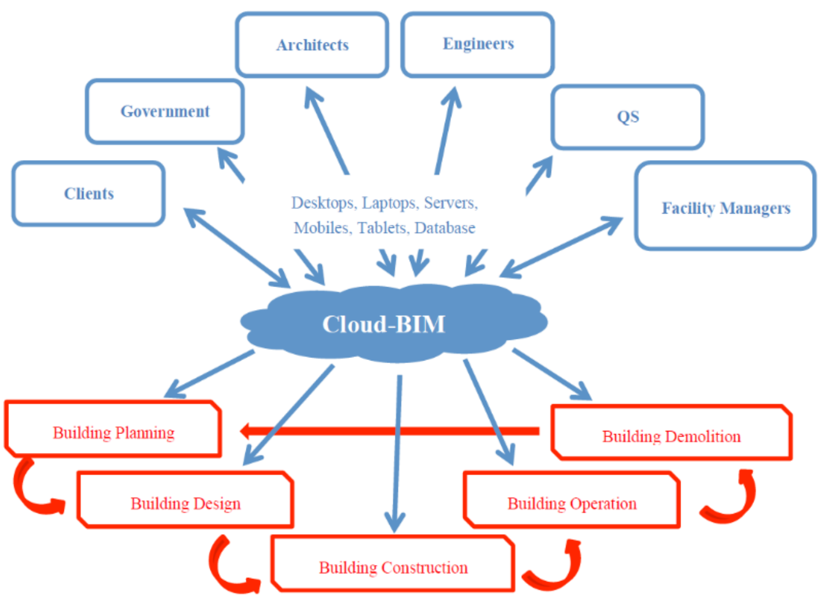


Figure 20 BIM Cloud collaboration. Courtesy of Wong. Et. Al. (2014)

Real-time collaboration works like the virtual presence of the architect on site to guide the team members directly. Leading the collaboration from a model in cloud on which comments can be added, decreases the chance of errors as in a 3D environment the clarity is higher. However, the willingness to collaborate and cultural differences are still considered as strongholds to the implementation cloud BIM technology. Moreover, the training time and costs are a major hindrance to the cloud technology adoption. Also, the integrity or trustworthiness of third parties is an issue as cloud services are often provided by a number of third parties through other cloud providers [74].

4.3.6 Conclusion

In the previous sections, we reviewed the Products aspect of a BIM ecosystem. the strategies for adopting such products were discussed and they were categorized by they use-cases. A brief literature review related to these categories were presented and some of the most common tools of each category were introduced. In conclusion, the thesis finds out the following points as the most important ones regarding the BIM Products:

- The selection of BIM products is heavily dependent on the needs of an architectural practice and even it can be narrowed down to the needs of each project. In this sense, the products with subscription-based licenses are more preferable compared to the perpetual ones. The lower initial investment and the flexibility of using them as long as necessary are some of the benefits associated with subscription-based product licenses.

- Architectural practices must determine well their actual needs before purchasing products, as there is enormous publicity in the BIM products market. The software vendors are constantly pushing for their sales and it is up to the architectural practices to make informed decisions in this respect. Some of the main considerations are: fitting of the products in the current technological pipeline of a practice, the use-cases of the products and the skills required to utilize them.

- BIM products can enable new possibilities and workflows in daily practices of an architectural firm. Awareness of such possibilities, especially in higher organizational levels, is crucial for the adoption and utilizing of the innovative tools. Therefore, staying informed about the latest trends in this field is an advantage for a practice to remain competitive in the AEC market.

- BIM products are the enabling factors for the integration of digital technologies in a BIM ecosystem. In this respect, special attention must be paid to the interoperability of these products with having the big picture of the ecosystem in mind.

- As a successful BIM implementation depends heavily on collaboration, the related tools in this field are of great importance. Visualization technologies are often at the core of such tools which allow for the project guidance through a 3D model. Therefore, the case studies of this research investigate and pay special attention to such tools and technologies.

4.4 BIM: People

In this section, we will review the third dimension of a BIM ecosystem, the People. By People, we mean the matters related to the actual participants in a BIM-enabled collaboration. Implementing a successful BIM ecosystem requires people to have certain skills, mindsets and roles. With the absence of these requirements, the use of Products and the application of Processes will be also affected negatively. Although acquiring new skills can be achieved by education and practice, social behaviors and human interactions must be addressed as well. In terms of roles, an examination of the existing workflows and resourcing capabilities would begin to highlight whether this would be an internally or externally resourced role. Singh and colleagues [88] suggest that the scale and business models of the different players in the industry mean that organizations need to develop strategies that suit their requirements and practices, contingent upon the capabilities of the firms they work with. In general, dedicated roles such as BIM manager will be inevitable for complex projects. Team members need appropriate training and information in order to be able to contribute to and participate in the changing work environment. In the following the idea of Social BIM will be described, following the concerns about collaborative mindset and a description of the main roles in the BIM ecosystem.

4.4.1 Social BIM

As mentioned earlier in this work, collaboration is a key factor for successful project delivery, particularly in BIM-enabled projects. With today's complicated projects in which numerous stakeholders from different disciplines take roles in a project, the lack of a comprehensive and efficient collaborative workflow may cause delays, extra costs and diminished project quality. Different methods have been suggested to improve collaboration and project delivery and it is well documented that these new mechanisms rely heavily on lean design and delivery processes and BIM tools [89]. Furthermore, the innovative tools and technologies are making decision making processes and their communication to other stakeholders more efficient and coherent.

Nevertheless, collaboration relies on broader aspects rather than just tools and technologies. In today's conventional methods used in the AEC industry, different teams of various disciplines have been tending to work separately and pass their part to the next team only when they finalize their tasks. This causes little collaboration to take place while they are developing their designs and works. Although the BIM Products aid with collaboration amongst professionals in the AEC industry, merely utilizing them by participants in a building project may not guarantee that collaboration is taking place or that such collaboration has been optimized [90].

The social aspect of collaborative working is one which enables the sense of community, democratic interaction, teamwork and leadership with ease of communication [91]. Only by a truly collaborative process, it is possible that architects could be able to realize their design as intended with little unwanted changes caused by other disciplines often due to the lack of an efficient communication during design stages. We cannot underestimate the importance of motivated and persistent people and their social needs as they are the essential building blocks of good quality processes [92]. People should be trained to have a collaborative mindset and break through the traditional barriers between different teams involved in a project.

BIM can be described as a socio-technical system, because it is made up of both technical aspects, such as 3d Modeling, and aspects with social impact, such as process reengineering [93]. The BIM trend has led to changes in the way designers and contractors work and collaborate, such as the way information is shared.) It is people (not systems) that collaborate, hence, optimization of human efforts and resources would be critical for BIM success, where it is postulated that designers should aggregate or produce a single BIM model in a central, integrated or federated location [94]. Therefore, the application of social and behavioral sciences in order to encourage collaboration can be a valid approach in highlighting the role of the People aspect of a successful BIM implementation.

Social context always has a strong impact on the actual implementation of technology [95]. Construction projects can be seen as collective socio-technical interactions, which is contextually embedded and socially constructed. Socio-technical theory is an appropriate theory that can capture the social and technical complexities as a whole. It provides a distinct framework for understanding exactly such systems of adoption and interaction within systems. Eason [96] claims that socio-technical approach is appropriate to any research “which people use ICT as a communication medium”. In this study, we aim to explore the factors in BIM collaboration as components of such socio-technical system and understand the interdependencies between them.

4.4.2 Collaborative mindset

The ability to collaborate and work productively in teams will be the most critical skill set design professionals will need to master if they are to survive the current professional, economic, social, and technological challenges [97]. Especially, with a growing use of BIM and integrated design-led projects, the need for collaborative skills will be felt by the AEC professional. A firm culture has to be taken into account as one of the main factors of encouraging or discouraging collaboration. A culture of collaboration is more likely to happen in a workplace that is more informal and where there are shared social activities, communities of practice, or social enterprise structures. Managing cultural changes in the construction industry poses a greater challenge than any technological transformation as BIM gains traction. Building industry partners will no longer be able to be adversarial, but will have to work as true collaborators [98].

Working collaboratively creates a social context for the BIM model. Since it is generally understood that information acquires meaning only through social context, the wider the social context the BIM model works within, the more meaning the model [97]. BIM puts special demands on teams when it comes to communication. The art of information exchange is changing with the technology. Person-to-person information exchange in the new BIM workplace requires BIM cooperative communication starting at the earliest project meetings. The new tools of working in BIM has facilitated collaboration dramatically, especially when working with people outside the office.

Trust is one key to working collaboratively. Project team members need to build on trust in order to pace the way for a fluent flow of information. Another aspect of trust is that project members must believe the other teams are trying to deliver the best outputs, thus eliminating blames and claims. The trust could be achieved by initially well-defined responsibilities and scopes of work. Obtaining an optimal collaborative process, includes the need for a transparent process, open information sharing, shared risk and reward, value-based decision making, and utilization of full technological capabilities and support. Each member’s success will rely on the team, which like the approach of partnering is tied up on the success of the project.

Global companies create multinational teams. This means that workers must learn how to work in teams with individuals they may never meet in person. They have to build trust, share information, juggle time differences, and develop a cultural understanding of themselves and those they are working with. In order to survive an employee of these multinational corporations will first have to learn about their own culture in order to learn how to communicate across cultures. They will also have to be able to utilize the technology available in order to facilitate the sharing of information and communication within these cross-cultural, decentralized teams [98]. A collaborative mindset requires the team members to focus on “we” rather than “me” and must be looking for what is best for the group, team, or project. Creating and working in silos has been an issue contributing to defective collaboration in AEC and the ability of BIM collaborative approaches to break down these silos must be considered and investigated.

4.4.3 BIM roles

Working with BIM requires employees to develop different competencies. While current employees of a practice are often required to learn new skillsets once BIM is implemented, new roles and responsibilities might emerge as well. Formal and informal BIM-specialist roles are becoming established in all aspects of the AEC sector, from initial design, project management and construction, through to operations and maintenance. The role of BIM specialists has been identified in the literature as an important factor in successful BIM implementation [99]. The use of BIM guides, handbooks, manuals and standards to define the project and organizational roles is a common approach in order to strengthen BIM practice and reduce ambiguity and uncertainty.

Like the other dimensions of a BIM ecosystem, the aspects related to People that are influenced by BIM implementation are heavily dependent on a practice approach to BIM and extents of its implementation. While utilizing certain technologies and processes create new roles and responsibilities, others may only require a brief training of current staff who may keep their role or assume new ones. Gu and London [100] claim that with BIM implementation in a practice some old roles will become obsolete, and specific new roles will be introduced. With this respect, defining key BIM roles becomes a vital activity in successfully advancing BIM implementation.

There is a wide variety of job titles which apply to BIM specialists. They can be seen in human resources advertisings and in BIM guidelines, among other sources. Based on a review of those sources, Davies et. Al. [99] have made a categorization. These job types fall into the categories of project roles, with the primary function fitting within a project team; and organizational roles, where the role is primarily performed at the company level. Based on their study on a wide range of BIM guidelines and other sources, this research adopts the four main BIM specialist roles that were concluded based on their functions and responsibilities in an organization or a project. In the following, the descriptions of these roles and their functions are presented.

BIM Manager (project role)

The most commonly described role is that of project level BIM Manager. The person or persons taking this role can represent the lead designer, the main contractor, and/or a third-party entity acting on behalf of the client. At this level, the BIM Manager is responsible for the development and delivery of the BIM execution plan and establishing BIM protocols for the project. According to the most common descriptions, quality assurance is also part of the role, as is maintaining oversight over BIM responsibilities and deliverables [99]. Guiding the collaborative process is an important aspect of this role, including organizing BIM project meetings and managing project records. The BIM manager contributes to the training and process change throughout the entire construction chain. Another function of the role is operating on a strategic, tactical and operational level to bring different parties together and encourage them to collaborate during the entire project.

In terms of competences, BIM Manager possesses leadership and organizational qualities. The figure must have the capabilities to form cooperative relationships between different parties on a strategical and tactical level. Furthermore, he/she should have an analytical and visionary mindset and possess the communication skills to ensure efficient collaboration between all parties. The BIM manager must be informed of all recent/current developments within the field and are capable of translating these developments to the operational context of BIM projects. The figure should have professional and intellectual capacities at Bachelor or Master level and keep his/her knowledge of Building-process management, BIM, IT, open standards and change-management up to date. Due to the crucial position of this role in a BIM ecosystem, case study 3 includes an extensive interview with the BIM manager of an architectural practice to study their BIM implementation.

BIM coordinator (project role)

The BIM Coordinator is responsible for the exchange of BIM models from their organization or discipline, including ensuring that models created within their team adhere to the agreed BIM standards and follow exchange protocols. Model coordination and clash detection is often described as falling within the remit of the BIM Coordinator; within a project team the BIM Manager leads the coordination activity but each BIM Coordinator takes responsibility for the coordination and management of their own model, and any required propagation of changes. [99]. This role is one of the most sought-after BIM specialist jobs as it holds a key responsibility in BIM-enabled projects. When it comes to connecting the BIM models from different disciplines for the purposes of model checking, clash detection, and generating specific information, BIM coordinator plays an important role. Therefore, the role holds a crucial position in ensuring the BIM ecosystem of a project is functioning well throughout the project life cycle.

BIM Manager (organizational role)

Although almost all of the guides and handbooks reviewed are concerned with the project-level processes involved in BIM implementation, many of them also define a BIM Manager role in terms of organizational as well as project responsibilities. Most commonly, this includes responsibility for training, as well as hardware and software issues [99]. In practice, the BIM Manager for an organization is often the BIM Coordinator (i.e the discipline-specific BIM representative) at the project level, so it is not uncommon for the same individual to undertake the project and organizational tasks [100]. The common approach for architectural practices taking the step towards BIM adoption is hiring a BIM manager who will oversee the general strategy of BIM implementation. Therefore, this position holds a key responsibility within a practice in their initial move towards BIM and ensuring its success in current and future projects.

BIM Modeler (organizational role)

The BIM Modeler role is described as a production role in developing the BIM model, a role that has a variety of job titles including model author, BIM operator, BIM user or BIM technician. Although BIM modelers work on project documentation, this has been classified as an organizational role because it is the documentation itself (whether the full model or other product) that is the project contribution and not the process by which it is produced [99]. Within an architectural practice, the BIM modeler is usually an architect who creates the actual model and 3D visualizations, adds building elements to the object library and links object data, with an operational emphasis during the design phase. The BIM Modeler reports to the BIM Coordinator and/or BIM Project Manager and must continually and carefully coordinate the work with external parties such as engineers, advisors, contractor and suppliers.

Expectations of BIM roles related to the dimensions of a BIM ecosystem

Another approach taken in some of the guides and handbooks is to define roles in terms of the skill sets and capabilities required. Succar et Al. [101] divide BIM competencies into abilities, activities and outcomes. All three of these types of competencies are used by the various guidelines to define BIM specialist roles, with some focusing on actions and responsibilities, and others also including abilities or skills requirements [99]. Table 2 presents a selection of the specified abilities, activities and outcomes, grouped in their relation to the three dimensions of a BIM ecosystem described in this thesis (People, Processes, Products).

Role	Products	Processes	People
BIM Manager (project role)	Ensure software is installed and operating properly	Lead development of BIM Management Plan/BIM Execution Plan	Provide BIM point of contact with client
	Determine reference points used for the project	Ensure compliance with BIM Management Plan/BIM Execution Plan	Train project staff
	Analyze model content to ensure it is fit for purpose	Management & quality control of the model dissemination; revision management	Facilitate technical meetings with BIM technicians
	Carry out the clash detection & provide the clash reports	Coordinate file management processes	
	Assist in the preparation of project outputs, such as data drops		
	Assemble composite models		
BIM coordinator (project role)	Carry out clash detection & provide clash reports	Provide guidelines for discipline team on agreed project rules	Team contact person in matters connected with BIM
	Ensure functionality of team contribution to merged models/ integration of design models	Contribute to keeping BIM Management Plan/BIM Execution Plan up-to-date	Allocate and coordinate BIM tasks within own discipline
		Ensure discipline model complies with BIM Management Plan/BIM Execution Plan	Communicate with other disciplines
		Manage discipline-based quality assurance, formulation of BIM reports & data management	Represent team at interdisciplinary model co-ordination meetings
BIM modeler (organizational role)	Production & modification of information in discipline-specific model		
	Must have appropriate technology skills to produce the model		
BIM Manager (organizational role)	Implement BIM technology	Create company-level BIM processes and workflows	Engage external stakeholders
		Develop company-level BIM standards and protocols	Collaborate with partners and internal teams

			Company-based change management and training

Table 2 BIM roles in relation to the dimensions of a BIM ecosystem. Adopted from Davies, K. et. Al. (2017)

The BIM specialists are also expected to move beyond a purely technical role and must also possess skills in leadership, communication, documentation writing, review and quality assurance procedures, in addition to discipline knowledge and proficiency in model authoring and coordination software. However, these skill sets need particular training and a problem might be the difficulty of finding such trained staff. Another issue in this respect is hiring experienced staff, which is due to the novelty of BIM itself. Many architectural practices have no or little experience with BIM and as a result, the staff that leave the practice will not have BIM competencies. In the case study 3 we will look over how the architectural practice of our research has responded to this matter. Nevertheless, education and training of architects plays an important role in preparing them to fit in BIM-enabled practice. In the following, we will have a brief review of this topic.

4.4.4 BIM education

BIM Education is an effort that ranges from spreading basic awareness about BIM risks and benefits to solidifying specialist BIM knowledge and skills. BIM Education facilitates collaboration between project participants of all disciplines and across all project lifecycle phases. It is the main communication method to spread technology-enabled, process-driven and policy-encouraged advances in design, construction and operation of facilities [102]. BIM education can happen within academia and as part of the curriculum of architectural studies, within the industry and encouraged by professional associations, or within organizations as part of their BIM implementation road map. There are also numerous courses available in forms of specialized Masters or online courses that target professionals and students.

BIM Education focuses on individual attainment of BIM skill and knowledge. Every BIM subject matter, if used within the context of educating individuals, here will be referred to as a BIM competency. According to the US Department of Education, a competency is a "*combination of skills, abilities, and knowledge needed to perform a specific task*" [103]. Using this definition as a base, a BIM competency is the combination of conceptual knowledge, BIM skills (practical knowledge) and experience necessary to perform a BIM-related task. A BIM Learning spectrum can be composed of all BIM topics (technical, operational and managerial), across project lifecycle phases, and specialties. Depending on the perspective adopted, these topics can be identified as learning topics, teaching subjects or individual competencies.

There are hundreds or even thousands of BIM Competencies which can be learned by individuals involved in the design, construction and operation of the built environment [101]. These individuals range in their position of responsibility and role within the construction supply chain. For example, an architect implementing a spatial program within a hospital model will require a different set of competencies from an engineer performing thermal analysis on those spaces. Even though architecture schools were among pioneers showing interest in BIM adoption when it first appeared, today, they are the ones with the least agreement on how to do it [104]. The underlying reason for this status could be in the fact that architecture education and practice still have divided opinion about BIM's value for architectural practices. Additional reasons contributing to this may include difficulty in learning and using BIM software, overloaded and unsuitable structure of the architectural curriculum for the adoption of BIM, incompatibility of practice-driven approach of BIM with the explorative character of design thinking and lack of BIM expertise among teachers [105].

Isanovic and Çolakoğlu [106] suggest that a hybrid model of leaning can be assumed as an efficient methodology of learning about BIM for architectural students and professionals. The hybrid model combines three complementary components (Figure 20):

- University class: provides supporting structure for the learning process.

- Architecture-Engineering (AE) practice: involving practice brings new teaching methods, contents, expertise and real-life cases from professional practice into the university class.

- Online learning repository: available to students as a supplement to in-class teaching to encourage students' self-learning processes.

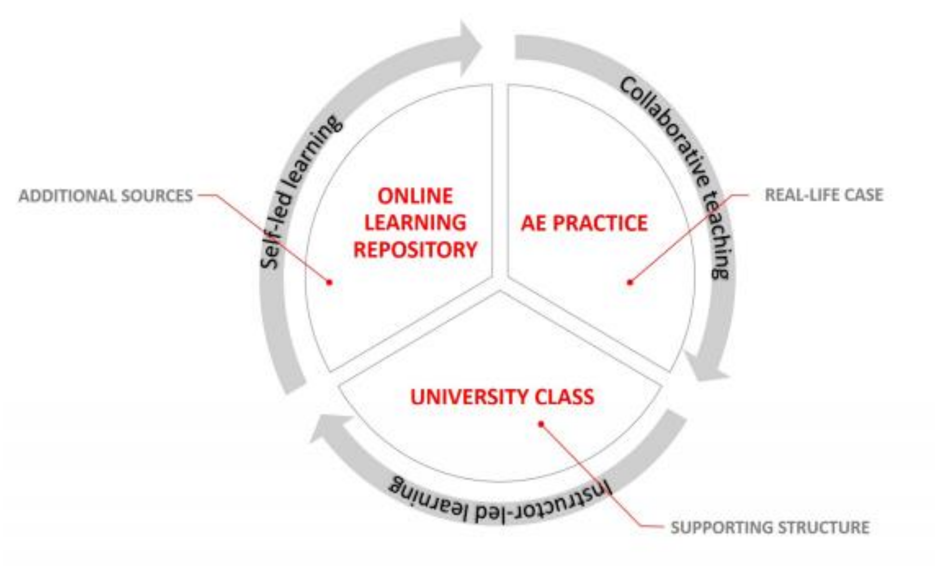


Figure 21 Hybrid Model of learning. Isanovic and Çolakoğlu. (2018)

Learning new technology and associated concepts, like BIM are greatly dependent on online sources. Examples like Lynda and Autodesk University, continuously develop high-quality online bases engaging professionals and instructors from all around the world. Learning using these sources allows the flexibility for learners to choose according to personal interests what to learn and when to learn. If provided with good sources and structure, acquiring technical skills can be achieved successfully through self-learning process. However, due to complications occurring in a real-life project, a practical experience is inevitable for architectural students and professionals to fit in a BIM-enabled project.

Resistance to change is often caused by lack of training and education. People are the key to success, however people raise concerns about the lack of training and awareness of BIM adoption. Resistance also combines other human factors and management support factors, but lack of adequate support for training in using the new technologies and tools is the main cause of resistance. y training and education, people can be more confident in adopting new technology and change their attitudes of resistance. Well-trained individuals have more confidence with adoption and more motivation to practice in their work. BIM education remains one the most important yet under developed aspects of BIM implementation and can be of interest for future research works.

4.4.5 Conclusion

In this section, the People dimension of the BIM ecosystem was reviewed. As described in the idea of Social BIM, the application of social and behavioral sciences in a group of people working together will be beneficial to the successful implementation of BIM. Encouraging teams from various disciplines and organization involved in a BIM-enabled project is crucial in achieving an efficient project delivery. Social BIM ought to be considered as an interactive and ''situation aware'' mode of BIM where technical interaction with a BIM model and social interaction with team members, is near-absolute [90]. Application of the Social BIM idea, therefore, is an important consideration in implementing the People dimension of the BIM ecosystem.

In a personal level, we argued that a collaborative mindset is an essential characteristic of the participants in a BIM-enabled project. Encouraging people to share their works early on in the design phase of a project contributes to error and clash prevention in the next phases. Collaborative mindset is also a solution-finding one, rather than tending to fine issues in the works of other team members. Foreseeing collaborative processes and workflows in BIM contracts and execution plans will allow the project team members to actually put in practice having a collaborative mindset.

Implementing BIM makes it inevitable that architectural practices adopt new roles. The hiring of BIM specialists and training the current staff are necessary measures to take when a practice makes to move towards BIM. Although the responsibility and titles of BIM specialist vary a lot, in this section we reviewed the main roles assuming the main responsibilities in the BIM ecosystem. However, BIM specialist roles can vary depending on each region or type of projects. It is especially important for AEC sector professionals to study well the job requirement when applying for BIM specialist jobs.

The last subject reviewed in this section was about BIM education. It argument extends from including BIM-related subject in architectural education curriculum, to practices' internal training of staff. This remains an area where further research can help with determining how to train a future generation of architects prepared for the digital era. For the time being, a handful of online courses, specialized Masters, and professional training can fill the skill gap necessary for participating in BIM-enabled projects.

BIM implementation requires changes in the organization and its social context. Linderoth [107] identify that it is important to consider the interactions between technology and organizational process. BIM adoption creates changes in organizational process. Like the other two dimensions of the BIM ecosystem described in this work, the dimension of People will be evaluated through the case studies. In this study, we aim to explore the factors in BIM collaboration as components of such socio-technical system and understand the interdependencies between them. The next chapter provides an insight on the hypothesis and the methodology used in this research in order to obtain and analyze data used in addressing the research questions and evaluating the hypothesis.

5. *Proposal*

5.1 Hypothesis

The focus of the discussion on leadership of collaboration in the age of BIM will therefore be centered on the possibility for the architect to regain the role, if not the title, of master builder. Without reiterating the long and storied history of the master builder, suffice it to say here that while design professionals are divided on whether once again to invoke the title or leave it for posterity, one thing is in agreement: the term master builder implies an understanding of all facets of the design and construction of architecture. “Through antiquity, architecture and construction were united by the cultural intentions of a “Master Builder who balanced art, science, materials, form, style and craft to achieve his vision.”[97] This balance now might be achieved through an efficient interdisciplinary collaboration enabled by BIM implementation.

The following are the hypothesis of the thesis research:

Hypothesis principal: BIM implementation essentially changes the architect’s role and responsibility in projects’ collaboration and coordination processes.

Hypothesis secondary: Implementing BIM allows for various digital technologies to be integrated into the technological pipeline of architectural firms.

5.2 Methodology

5.2.1 Introduction

In his foreword to *'Advanced Research Methods in the Built Environment'* Prof. Peter Barrett acknowledges the complexity of the built environment research domain. However, Andrew Knight (co-editor) notes that, many 'built environment researchers' have been academically trained in professional areas, and not in traditional postgraduate research, suggesting that it is still a relatively new and diverse field of study [108]. These two points of view make for an interesting discourse, on the one hand there is much happening, but on the other there is no well-established body on work bedded in the built environment from which to draw the very foundations on which to build. Equally, a subject such as BIM is very new within the built environment; meaning new approaches might need to be divined in order to support it and understand it.

Traditionally, a characteristic purpose of a methodology is to show not such and such appeared to be the best method for the given purposes of the study, but how and why this way of doing it was unavoidable - was required by - the context and purpose of this particular enquiry. Likewise, *‘’Pragmatic researchers are more likely to be cognizant of all available research techniques and to elect methods with respect to their value for addressing the underlying research question, rather than with regard to some preconceived bias about which paradigm*

is a hegemony in social science research’’ [109]. Thus, the quantitative approach which tends to lead to positivism, needs further insights and an understanding of various perceptions to unravel the situation leading to a qualified understanding. The qualitative approach enlists beliefs, opinions and views to gather data, which while being rich in content and scope is open to interpretation. '*'This means that not much has written about the topic being studied, and that the research seeks to listen to the participants and build an understanding based on their ideas''* [110].

The association of qualitative research with an inductive logic of enquiry and quantitative research with hypothetic-induction can often be reversed in practice; both types of research may employ both forms of logic [111]. However, this research mainly utilized qualitative studies to address its hypothesis. This is due to socio-technical characteristic of BIM that makes qualitative research which is considered suitable for the domain of social investigation. Qualitative research is a scientific method of observation to gather non-numerical data. This type of research "refers to the meanings, concepts definitions, characteristics, metaphors, symbols, and description of things" and not to their "counts or measures. This research answers how and when a certain phenomenon occurs [112].

5.2.2 Research methodology

Case study methodology has been adopted as the primary research method in the qualitative approach this thesis. Case study research excels at bringing us to an understanding of a complex issue or object and can extend experience or add strength to what is already known through previous research. Case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships. Researchers have used the case study research method for many years across a variety of disciplines. Researcher Robert K. Yin defines the case study research method as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used [113].

The advantage of the case study research design is that one can focus on specific and interesting cases. This may be an attempt to test a theory with a typical case or it can be a specific topic that is of interest. Research should be thorough and note taking should be meticulous and systematic. The first foundation of the case study is the subject and relevance. In a case study, you are deliberately trying to isolate a small study group, one individual case or one particular population [113]. The detailed qualitative accounts often produced in case studies not only help to explore or describe the data in real-life environment, but also help to explain the complexities of real-life situations which may not be captured through experimental or survey research [114].

Despite these advantages, case studies have received criticisms. A common criticism of case study method is its dependency on a single case exploration making it difficult to reach a generalizing conclusion [114]. Yin [113] considered case methodology 'microscopic' because of the limited sampling cases. Nevertheless, this research tried to minimize these sorts of disadvantages by conducting more than one case study and employing a mixed-method of data gathering, which will be described in the following. Numerous sources of data also helped us in confrontations with the limitations we had that are mentioned in the last chapters of the thesis.

5.2.3 Qualitative Research Plan

Creswell [116] argues that a good research design should cover a series of research procedures such as data collection procedures and data analysis methods. The objective of this study is to explore how implementimg BIM alters the Role of the Architect in collaborative building projects. A comprehensive framework for BIM implementation was provided in previous sections and the factors impacted by that were identified. A qualitative study is then conducted to evaluate those factors and also explore additional factors influencing collaboration in BIM-enabled projects. Prior to this, an exploratory study is conducted to understand collaboration issues in a non-BIM project. Therefore, Semi-structured interviews with industrial practitioners are conducted. Feedbacks from all the respondents are categorized with specific coding strategy and analyzed accordingly.

Case studies represent a type of qualitative research. Through case studies, researchers hope to gain in-depth understanding of situations and meaning for those involved. Insights gleaned from case studies can directly influence policy, procedures, and future research [117]. Case study research is richly descriptive, because it is grounded in deep and varied sources of information. It employs quotes of key participants, anecdotes, prose composed from interviews, and other literary techniques to create mental images that bring to life the complexity of the many variables inherent in the phenomenon being studied.

In this work we utilize case studies with various techniques to extract information. Conducting semi-structured interviews is the method used in all the 3 case studies, with similar questions being asked from all the participants. However, in cases 1 and 2 additional specific questions have been asked to better understand the situation. Questions reflective of how data are collected and procedures that are commonly used when conducting a case study are presented in Tables 8 Creswell [116] presents additional information on similarities and differences in data collection activities and other procedures related to doing research across approaches.

Characteristic	*Data Collection Question*
A bound "case," such as a process, activity, event, program, or multiple individuals, is investigated.	What is studied? (Define the case.)
A gatekeeper provides access to information and assistance in gaining confidence of participants.	What are any concerns related to access and rapport? (Establish access and rapport.)
A "case" or "cases," an "atypical" case, or a "maximum variation" or "extreme" case is defined.	What sites or individuals are going to be studied? (Sample with purpose.)
A collection of forms, such as documents and records, interviews, observations, or physical artifacts, is compiled.	What type(s) of information will be collected? (Delimit data.)
A variety of approaches (e.g., field notes, interviews, and observations) are used to gather data.	How is information compiled? (Record information.)
Concerns may emerge related to intensive data gathering.	Is data collection difficult? (Address field issues.)
A large amount of data (e.g., field notes, transcriptions, computer databases) is typically collected.	How is information stored? (Store data for analysis.)

Table 3 Case study questions adapted from J. W. Creswell. (2009)

5.2.4 Research design and process:

A research design is the logic that links the data to be collected and the conclusions to be drawn to the initial questions of a study; it ensures coherence. Another way of viewing a research design is to see it as an action plan for getting from the questions to conclusions. It should ensure that there is a clear view of what is to be achieved by the study. This involves defining the basic components of the investigation, such as research questions and propositions, appreciating how validity and reliability can be established, and and selecting a case study design [37].

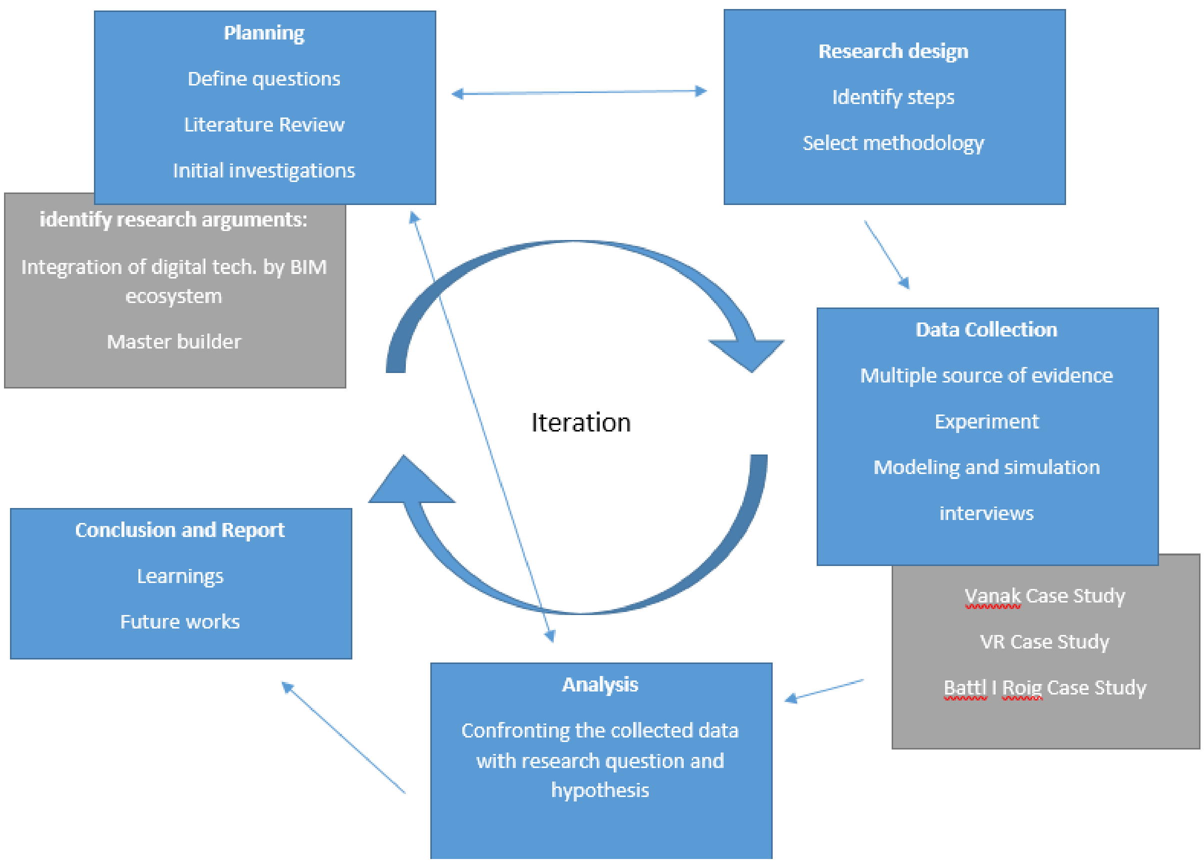


Figure 22 The research processes

5.2.5 Information gathering techniques

The following are the descriptions of sources and techniques for gathering information, to help us derive conclusions based on data from various sources.

5.2.5.1 Literature Review

The literature review is aimed at establishing a theoretical background of the thesis subject. It also serves to understand which areas in the BIM research relate to the interests of this thesis, and what areas need to be further studied. The literature review has been conducted in a way to establish the proposed dimensions of BIM ecosystem, which are people, product and processes, with respect to the architectural practices. Furthermore, the thesis tries to review the available literature on the adoption of BIM which then will help us evaluate its impacts by conducting the case studies.

BIM documents

The other important source of information for studying the situation around BIM in the world are the guidelines, standards, BIM execution plans and protocols that are provided by governmental bodies, standard organizations and other institutes such as universities. This sort of documents is usually intended to help with the adoption of BIM for professionals, and studying them gives us an insight of how BIM is utilized in the real contexts.

Books

A primary source of information to understand the BIM context were the books written in recent years on this subject. The process of the reference book selection includes several methods. One has been looking up for k eywords in search engine of the websites such as UPC library, Amazon and Google. Another method is getting informed by BIM related books through the advice of professionals. Also, I came up to know a book through the publisher advertisements on social media. And finally, by physically exploring the book shops and libraries, I have been able to source the needed books.

Social Media

As social medias have greatly influenced of how we encounter information and news, they also have been a useful source of information to keep me up to date with latest trends and news in the world of BIM. In order to do so, I have been following pages of many organizations, professionals and academic figures on Twitter, LinkedIn and Facebook. By following these sources on a daily basis, I have been constantly in touch with the latest tendencies of this Field.

Academic articles

Ultimately, in order to study the BIM in academic world, an extensive review of the literature written in academic papers is necessary. This helps us understand the works that have been done in the field and therefor give us the directions where more studies need to be conducted. In the reference chapter of this work, the full list of articles that were studied and referred to is available. The articles were chosen based on their relevance to the subjects under discussion and their scientific quality.

5.2.5.2 Semi-structured interviews

The use of interviews in case studies allows the researcher to get to the heart of the issue, allowing pertinent issues to come forth naturally in a free-flowing environment. It also provides a rich source of data, which can be utilized in the design of the subsequent stages of data collection. The familiarity with the environment, in which the interviews are to take place, is essential [118]. Usually, the researcher has a purpose for undertaking the interview, as s/he wants to gain information from targeted group of people. This means that the discussion does not occur by chance, but has been plan in some way by the researcher [119].

There are three types of interviews: (a) structured interviews, contains pre-determined, standardized, identical questions for every interview; (b) semi-structured interviews, a researcher have a list of themes to be covered and questions to be asked; (c) unstructured interviews, the research has less control over the conversation, as it starts with introducing the topic and let the interviews develop their ideas. Interviews are much used in case studies and ethnographies as well as with questionnaire as it used to obtain more detail about some questionnaire responses from BIM experts [119].

5.2.5.3 Observations and documents:

A frequent source of information in case study research is observations of the research setting by the researcher. Unlike interviews, which rely on people's sometimes biased perceptions and recollections of events, observations of the setting by a case study researcher may provide more objective information related to the research topic [120]. Observations are frequently used in the course of case study research. Typically, observations provide answers to questions being investigated. While observations are widely used, other methods are also used to gather data in case study research.

In addition to using interviews and observations, case study researchers often review existing documents or create and administer new documents from which to gather information related to the research questions. Documents take many forms and often vary in usefulness. The results of document analyses are often summarized in narrative form or integrated into tables that illustrate trends and other significant outcomes. Documents examined by a case study researcher include private and public records, physical evidence, and instruments created by the researcher. These three categories of documents are not mutually exclusive. When used separately or in conjunction, they provide a rich source of information with which to augment data collected through interviews and observations. Instruments created by the researcher often provide a powerful means by which to collect information pertaining to the researcher's questions.

The analysis of documents is a commonly used method in case study research. When combined with information from interviews and observations, information gleaned from documents provides the case study researcher with important information from multiple data sources that must be summarized and interpreted in order to address the research questions under investigation. To extract more data by observation and producing new documents to be analyzed, the following two techniques have been additionally used in case study 1 and 2:

Modelling

Scientific modelling is a scientific activity, the aim of which is to make a particular part or feature of the world easier to understand, define, quantify, visualize, or simulate. It requires selecting and identifying relevant aspects of a situation in the real world and then using different types of models for different aims, such as conceptual models to better understand, operational models to operationalize, mathematical models to quantify, and graphical models to visualize the subject. Modelling is an essential and inseparable part of many scientific disciplines, each of which have their own ideas about specific types of modelling [121]. The modelling method has been employed in case study 1, where the system was defined as the parking levels in Vanak projects. This specific part of the project was modeled in a computer software, where vehicle movement simulations were conducted. It was in order to address an existing issue in those levels, where the project stakeholders could not agree on its solution. This system which consisted of a collaboration method based on a 3D model and simulations, was compared with the real-life situation in the actual project.

Experiment

Experiments are used across all scientific disciplines to investigate a multitude of questions. It is a scientific research method, perhaps the most recognizable, in a spectrum of methods that also includes description, comparison, and modeling. While all of these methods share in common a scientific approach, experimentation is unique in that it involves the conscious manipulation of certain aspects of a real system and the observation of the effects of that manipulation [122]. An experiment was conducted in case study 2 in order the learn from the observations and to interview the participants about their experience. One criticism of experiments is that they do not necessarily represent real-world situations [122]. To avoid such an issue, a group of professionals were chosen to take part in the experiment, who were involved in a real construction project. It is further explained in the next section.

5.3 Sampling for Qualitative research and Case studies

The three main types of data collected and analyzed in qualitative research include in-depth interviews, direct observation, and studying artifacts. In order to collect these types of data for a study, a target population, community, or study area must be identified first. It is not possible for researchers to collect data from everyone in a sample area or community. Therefore, the researcher must gather data from a sample, or subset, of the population in the study. The goal of qualitative research is to provide in-depth understanding and therefore, targets a specific group, type of individual, event or process. To accomplish this goal, qualitative research focus on criterion-based sampling techniques to reach their target group. There are three main types of qualitative sampling: purposeful sampling, quota sampling, and snowballing sampling. For understanding collaboration issues in conventional methods and then the impacts of ICT integration in collaboration through BIM, and Purposeful sampling methods shall be chosen.

Purposeful Sampling

In this type of sampling, participants are selected or sought after based on pre-selected criteria based on the research question. For example, the study may be attempting to collect data from lymphoma patients in a particular city or county. The sample size may be predetermined or based on theoretical saturation, which is the point at which the newly collected no longer provides additional insights. There are a wide range of purposive sampling techniques that can be used such as Maximum variation sampling, Homogeneous sampling, Typical case sampling, Extreme (or deviant) case sampling, Critical case sampling, Total population sampling and Expert sampling. Considering the expertise required to address the research objectives, the ‘’Expert sampling’’ technique is adopted [123].

Expert sampling

It is a type of purposive sampling technique that is used when your research needs to glean knowledge from individuals that have particular expertise. This expertise may be required during the exploratory phase of qualitative research, highlighting potential new areas of interest or opening doors to other participants. Alternately, the particular expertise that is being investigated may form the basis of a research, requiring a focus only on individuals with such specific expertise. Expert sampling is particularly useful where there is a lack of empirical evidence in an area and high levels of uncertainty, as well as situations where it may take a long period of time before the findings from research can be uncovered.

5.4 Ethnics consideration

Ethical issues should be considered as priori. The Human Research Ethics Committee for Non-Clinical Faculties (HRECNCF) requests all research projects that involves human participants in research investigations should satisfy ethical approval criteria such as informed consent, confidentiality and consequences for the interviewee. All the interviewees should be informed about the purpose of the research project and the main process of the investigation. Interviewees need to agree with the usage of interview information without harming anyone. Researcher also needs to assure the confidentiality to interviewees. In addition to this consideration, all permissions were acquired by project stakeholders participating in the case study to use their materials and information. BIM models of the projects were shared only upon the approval of all the stakeholders. The author guaranteed the confidentially of the information obtained and not to share the BIM models and other documents used in the study in accordance with copyright considerations.

6. *Case Studies*

6.1 Introduction

This chapter presents the case studies conducted for this research. Each case was studied in chronological order during the course of the thesis development. To address the research questions and hypothesis, multiple-case design with real-life events was adopted to include numerous sources of evidence. Each case employs certain methods of information collection that will be mentioned in the following. Furthermore, each case had a focus on one or more of the thesis objectives and was chosen carefully to fit in the research design logic. By analyzing the results and crossing them with the hypothesis, the next chapter will present the findings and conclusions of this research work.

In the following a brief overview of the cases chosen to extract and gather data is provided:

Case Study 1: Vanak Project 2014-15

Vanak project case study studies the collaboration issues of a real project developed by traditional methods (non-BIM-enabled). The particular issue of collaboration deficiencies led to numerous disputes among project teams, causing delays and resulting in a more expensive solution than the original plan. Interviews are conducted with people involved in the collaborative processes to gather data about collaboration issues in the project. Documents and processes are also observed for additional data. Then a study is conducted to find how BIM can address the issues by modeling the situation in a BIM ecosystem. The collaboration process is then studied in the BIM-enabled state.

Case study 2: Campus de la Generalitat Project 2016-17

Campus de la Genralitat project is a BIM-enabled project which utilizes collaborative approach between different disciplines based on a coordination BIM model. By conducting interviews and evaluating their workflows the impact of BIM utilization in their collaboration was studies. I addition and to study the impacts of advanced ICT based tools in collaboration we conducted and experiment. In this case, we tried to integrate Virtual Reality (VR) technologies in the workflows of this under construction project. The results of the experiments were collected by observation and interviews. The case studies the impact of utilizing an advanced digital technology through BIM in interdisciplinary collaboration.

Case Study 3: Battle I Roig Architects 2017-18

This case study was conducted on an architectural firm in Barcelona which has been implementing BIM since four years before the study. Through semi-structured interviews and by observing the company's artefacts, the impacts of BIM implementation on their collaboration with other disciplines is investigated. The gathering of the mostly qualitative data contributes to the research about a post-BIM implementation case. The analysis of the data provides a base for addressing thesis questions and hypothesis. The focus of the is on the impacts of BIM implementation in interdisciplinary collaboration of this architectural practice.

6.2 Case studies data

To better understand how data are collected in the case studies and the relation between them, the following table provides answers to the questions adopted from table 8 presented in the previous chapter.

Data Collection Question	Case Study 1	Case Study 2	Case Study 3
What is studied?	Collaboration	Collaboration	collaboration
What are any concerns related to access and rapport?	Limited access due to project schedule	Limited access due to permissions	Limited access due to permissions
What sites or individuals are going to be studied?	Experts in the field	Experts in the field	Experts in the field
What type(s) of information will be collected?	Documents, artifacts, interviews,	interviews, artifacts, observations	Interviews, artifacts
How is information compiled?	Scientific modeling, interviews,	Lived experiment, observation, field notes, interviews	Interviews, observation
Is data collection difficult?	Yes due to limited access	Yes due to limited access	Yes due to limited access
How is information stored?	Computer database, transcripts	Computer database, transcripts, field notes	Transcripts, field notes

Table 4 Data collection outline

Although all the case studies investigate the topic of collaboration in building projects, each case study has a particular focus. Case study 1 investigates issues of collaboration in a conventional project and then studies the impacts of BIM implementation in it. Case study 2 investigates the issues of collaboration in a BIM enabled project and then studies the impacts of integrating advanced ICT tools in it. Case study 3 investigates collaboration in an architectural firm to evaluate the impact of BIM implementation in working with others to understand the role of architects in BIM collaboration environments. Different data gathering techniques are used among the cases. However, the same semi-structured interviews are conducted with the participants of the three cases. Additional case specific questions might have been utilized to investigate a particular case.

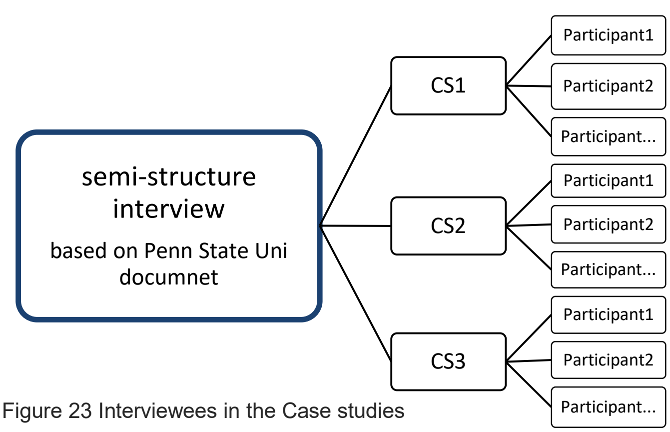


Figure 23 Interviewees in the Case studies

To conduct a successful interview, the following steps shall be taken:

- Key participant should be identified whose knowledge and opinion help the researcher gain an insight into the research questions. For this reason, all the participants in our interviews have dealt with the collaborative processes of the projects and practices under study for this research. In the following, the strategy for selecting the participants is discussed in the sampling section.
- An interview guide or protocol should be employed. This guide will identify appropriate open-ended questions that the researcher will ask each interviewee. These questions are designed to allow the researcher to gain insights into the study's fundamental research questions. The quantity of questions may vary depending on the person being interviewed. For this matter, the Penn State BIM-related case study guide was chosen for its versatile semi-structure interview guidelines.
- The setting and place in which the interview takes place should be considered as well. Although interviews in the natural setting may enhance realism, the researcher may seek a private, neutral, and distraction-free interview location to increase the comfort of the interviewee and the likelihood of attaining high-quality information. The participants of CS1 and CS3 were interviewed in their proper offices, while in CS2 they were interviewed in the location of the experiment.
- The researcher should select the means of recoding the interview. Handwritten notes sometimes suffice, but the lack of detail associated with this approach inevitably results in a loss of valuable information. The best way to record interview data is to audiotape the interaction. For this research, handwritten notes, audio recordings and filling in prepared digital forms were utilized to capture the information.

The sampling for this study is limited to professionals who have been involved in collaboration processes of building projects. In the first case study the focus is on the collaboration issues in a traditional project development method and personnel from the coordination units along with the architects' representative and the client were selected. In the next case studies, the people involved from in BIM-enabled projects were targeted that included the client, the architects, the MEP engineers, BIM modelers and BIM coordinators were selected.

The state of utilizing ICT in building projects are different in various projects and among the stakeholders which adopt different approaches. This is also influenced by the state of BIM implementation, as some projects may use only conventional digital communication tools for collaboration without implementing BIM, while other BIM-enabled projects integrate advanced digital tools in their collaborative processes. To further understand the influence of BIM implementation on collaboration in projects and observe empirical evidence, the three case studies are selected. They were chosen based on an interesting situation to be studied related to collaboration and the possibility to access the projects. Permission of access to project involves access of construction sites, project documents, project professionals, and relevant project data. In order to further interpret the case study, interviews with professionals involved in the project were conducted.

6.2.1 Case studies data coding

The data obtained from interviews, observation and documents of each case study is coded for further analysis. Coding is a key part of qualitative data analysis, some researchers even considering coding to be synonymous with analysis [124]. Codes identify a feature of the data that appears interesting to the analyst, and refer to "the most basic segment, or element, of the raw data or information that can be assessed in a meaningful way regarding the phenomenon" [125]. Codes are the building blocks of analysis and identify and provide a label for a feature of the data that is potentially relevant to the research question. Coding is a method that enables the researcher to organize and group similarly coded data into categories or because they share some characteristic. When the major categories are compared with each other and consolidated in various ways, you begin to progress toward the thematic, conceptual, and theoretical [126]. As a very basic process, codifying usually follows the ideal and streamlined scheme illustrated in the figure below.

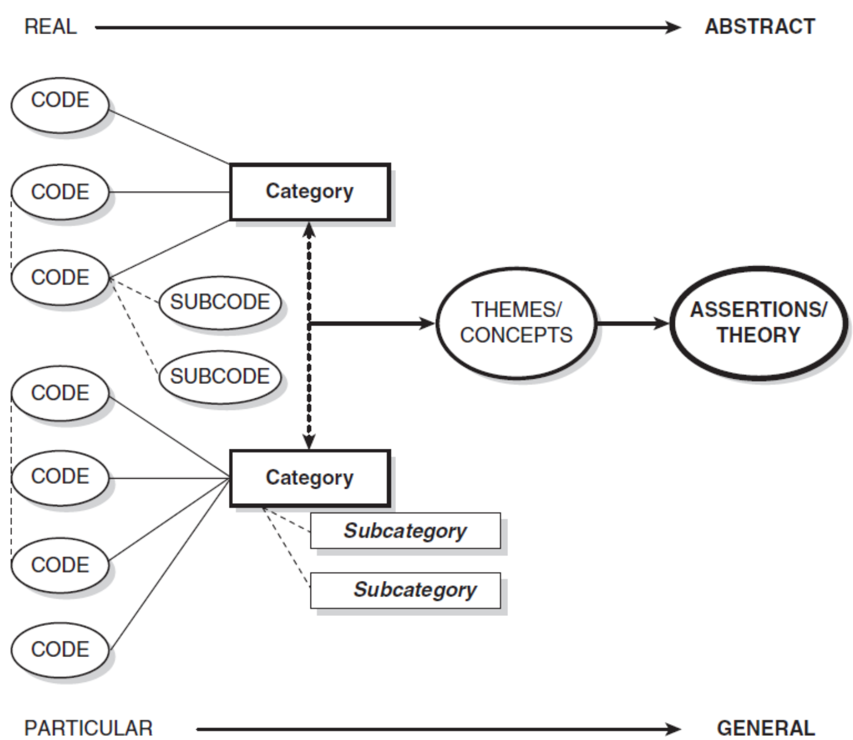


Figure 24 A streamlined codes-to-theory model for qualitative inquiry. Saldana 2009

Coding strategy facilitates researcher to analyze the content of transcripts of the interviews. Coding can summarize contents into different themes or categories. Coding content is based on the objectives of the research, therefore coding results can be used to validate the research questions and confirm the research hypotheses. There are two types of coding approaches that are inductive and deductive. An inductive approach allows researchers to generate more general statement based on the observations from a specific context. Deductive approach is adopted when coding has been developed based on previous knowledge and the purpose of the research (i.e. theory testing) [127]. Both inductive and deductive approaches are adopted in this research.

step 1: Researcher transcribes all the audio records of interviews into readable texts and saved as a soft copy. All the following coding activities are conducted directly with the transcribed texts;

Step 2: Researcher reads all the transcripts and generalizes inductively all the contents into themes. Themes can guide the researcher to focus on the specified relevant contents. According to the research frame and previous study, relevant contents are generalized into different themes. Identified themes can be further analyzed.

Step 3: Researcher presents an analysis matrix to show the coding results. The categories are shown in the row and the references of interviewees are shown in the column. The original texts are shown in the matrix rather than number of coding units.

Step 4: The final coding results are summarized in an analysis matrix. The researcher should also check the acceptable level of frequency to finalize the list of categories with satisfied frequency. There are two kinds of frequency measurement to test the construct validity. First, some researchers measure the number of appearances for each category in all transcripts. They usually set the average frequency as the cut-off line, which is calculated based on the highest frequency and lowest frequency of categories in the full sample.

The data obtained from each case study is coded and analyzed in the analysis section.

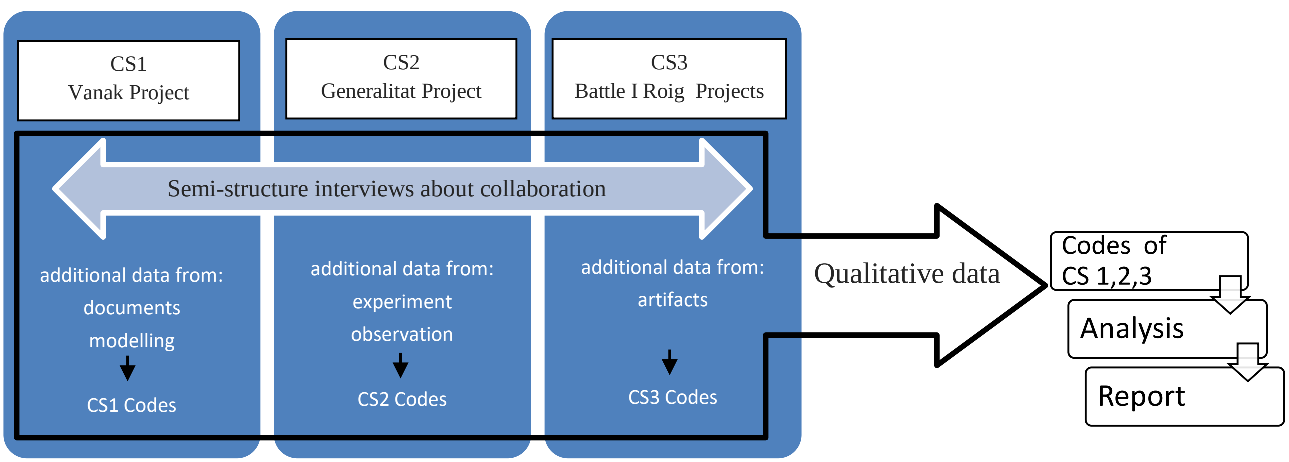


Figure 25 Case study research steps

For the deductive coding approach, a primarily list of codes based on the review of the BIM ecosystem in collaboration that was discussed in previous section is drawn in the table below. As the implementation of BIM in collaboration impacts the factors of People, Process and Products the research investigates the following categories belonging to each factor in the case studies and the interviews. The codes created from the data of the qualitative research shall be crossed with these primary codes to create new codes or eliminate some or to aggregate to form more appropriate codes.

Factor	Category
Processes	Standards
	Protocols
	Contracts
	Project delivery method
	Client involvement
	Collaboration environment
	Co-Location
	Leadership
	Government push
People	attitude
	skills
	Training
	Experience
	Trust
	Motivation
Products	New technology adoption
	Cloud based collaboration
	Real-time collaboration
	Visualization technologies
	Database technologies
	Interoperability

Table 5 Collaboration factors as a basis for deductive coding process

6.3 Case Study 1: Vanak Project

Vanak Project in Tehran, is the first candidate as a case study and serves as a pilot project for this. The project was being developed internationally by teams located in Spain and Iran. The architectural and engineering consultants were located in Madrid working with local architectural consultant, developer and contractors based in Tehran. Therefore, the importance of an effective collaboration was even more crucial in the project. In this case study, the focus is on a particular issue related to its parking floors which was a place of disagreement between the architectural consultant firm, local architects who were in charge of developing the construction documents and Satsa Co. as the general developer of the project. The project was being developed in conventional methods (non-BIM-enabled) and in this case study, we try to propose implementing a BIM ecosystem to address the recognized issues in our study of the project's current situation.

6.3.1 Reasons for undertaking this case

Personal Experience: In the period between September to 2013 to March 2014, I was the lead architect of one small commercial unit of Satsa Co. and in the design team of one of their other projects called 40Ketab. The latter one was about the interior design of a books multi-store project being designed by studio di Ezio Riva based in Milan, in whose office I was working for 2 years before this period. During these experiences, I was witnessing a number of communication and collaboration issues between our office in Milan and the project contractor and developer in Tehran. Later, I moved to Tehran to follow the projects locally.

During my stay in Tehran I was also following the execution of Ezio Riva's designs by Satsa Co. and I was observing the processes of development of other projects such as Vanak. I also had the chance to be present in one of the trips of Satsa CEO and consultants involved in Vanak project to Madrid to visit the office of the project's architectural consultant, Chapman Taylor Architects. This was during the schematic design stage of the Vanak project. There I got to get to know the firm directors and designers, and I could have an acquaintance to their working method.

My close relation with the project developer gave me the opportunity to have access to a large number of emails, communications and project documents. This made me able to study well some of their communication documents, particularly when things became problematic. I could also have some interviews with the coordination team of Satsa Co. about the particular issue of parking that later in this chapter will be explained. All the mentioned situations gave me the opportunity to be a first-hand witness of the project development and its related issues.

As I was at the time working as an architect and project coordinator for another project of Satsa Co., I knew in person some of the persons involved in the project. The persons with key position in project were:

-The CEO of Satsa Co., the developer company of the project.
-Developer Consultant and general coordinator of the project.
-The owner of the Holding to which Satsa Co. belongs.

-The vice manager of Satsa.
-The coordination and architecture office members.

The specific collaboration issue: At the stage where the schematic design of the project was almost done and shop drawings were being prepared, there was an issue about the height of the parking levels. The local architects, Atec, the shop drawing developer, Omran Mahoon, and the project architectural consultant, Chapman Taylor, were not agreeing on the possible height of parking levels. The disagreement was caused as there would be conflicts between the mechanical systems and the architectural heights of the parking levels and finding a solution was causing delays in the project delivery. The following is the report from the MEP engineers about the situation where project stakeholders were arguing.

Following this chapter, there will be the documents of emails and notes regarding this issue. What makes it interesting as a case study for this research, is the assumption that BIM could address such issues and facilitate the solution finding process. It is supposed that a BIM model, could provide the architects with the ability to guide other teams with a 3D model. They could run vehicle movement simulation, and run clash detections with structure and MEP BIM models, to quality-check their design. Furthermore, specific BIM collaboration tools could help resolve the issue in a quicker, more efficient way. These assumptions will be evaluated in the next parts of this section.

6.3.2 Project Description

Location: The project is located in one of the main commercial areas of Tehran characterized by a number of small shopping centers and numerous shops along the street. The area is a financial center of the city with high urban density and therefore the land price is quite high.

Figure 26 - Views of Vanak Square and the site location.

Function: The project consists of 3 main functions of a shopping center in its 3 first levels, levels of underground parking and 6 to 7 levels of office floors. Table 19 gives an overview of the functions and areas of the levels. There have been different options and proposals from which one has been selected and developed. The process was that the Architectural consultant proposed different options, and the architecture department within Satsa Co. would have revised them together with the local Architectural consultant and their comments would have been turned back to the main Architectural consultant for modifications. By the end of the concept design stage, the following numbers have been confirmed in accordance with the Tehran municipality regulations:

SHOPPING CENTRE

GLA	Typical Basement	Basement 1	Ground Floor	First Floor	Second Floor	Third Floor	Typical Floor	Total
MSU		696 m^2	179 m^2					**875 m^2**
SSU			684 m^2	912 m^2	913 m^2			**2.509 m^2**
Restaurants				63 m^2	62 m^2	59 m^2		**184 m^2**
Total GLA		**696 m^2**	**862 m^2**	**975 m^2**	**975 m^2**	**59 m^2**		**3.568 m^2**

Common Areas	Ground Floor	First Floor	Second Floor	Third Floor	Typical Floor	Total
Mall	241 m^2	233 m^2	243 m^2			**717 m^2**
Voids		*75 m^2*	*65 m^2*	*222 m^2*		*362 m^2*
Terraces		33 m^2	33 m^2	616 m^2		**682 m^2**
Common Areas (Technical, Corridors & WC)	125 m^2	111 m^2	111 m^2	120 m^2		**467 m^2**
Ramp	142 m^2					**142 m^2**
Total Common Areas	**508 m^2**	**377 m^2**	**387 m^2**	**736 m^2**		**2.007 m^2**
Total Built Area Shopping Centre (without Voids)	**1.371 m^2**	**1.352 m^2**	**1.362 m^2**	**795 m^2**		**4.879 m^2**
Landscaped areas				388 m^2		

OFFICES

	Ground Floor	First Floor	Second Floor	Third Floor	Typical Floor	Total
GLA Offices					691 m^2	**691 m^2**
Core	70 m^2	67 m^2	67 m^2	84 m^2	62 m^2	**349 m^2**
Lobby	65 m^2	17 m^2	17 m^2	17 m^2	17 m^2	**132 m^2**
Technical Areas					15 m^2	**15 m^2**
Subtotal Built Area Offices					784 m^2 8 Floors	
Total Built Area Offices	**135 m^2**	**83 m^2**	**83 m^2**	**100 m^2**	**5.488 m^2**	**5.890 m^2**
Total Built Area Shopping Centre + Offices	**1.506 m^2**	**1.435 m^2**	**1.445 m^2**	**895 m^2**	**5.488 m^2**	**10.769 m^2**

PARKING

	Typical Basement	Basement 1	spaces	Total (m^2)
Core (i/ lobby)	57 m^2	57 m^2		**114 m^2**
Common areas (Technical, corridors)	68 m^2	414 m^2		**482 m^2**
Parking	1.660 m^2	618 m^2		**2.278 m^2**
Subtotal Built Area Parking	1.785 m^2 7 Floors			
Total Built Area Parking	**12.496 m^2**	**1.089 m^2**		**13.584 m^2**
Parking Spaces				
Underground Parking - 1 floor			39 spaces 7 Floors	
Total Parking spaces - 7 Basements *(No spaces at B1)*			273 spaces	

Figure 27 Vanak project area

Final project drawings: To get familiar with the structure and the design of the project, a pair of drawings are presented below. They represent a typical commercial plan, a typical office plan and a typical parking plan and the section of the building.

Figure 28 Typical commercial plan.

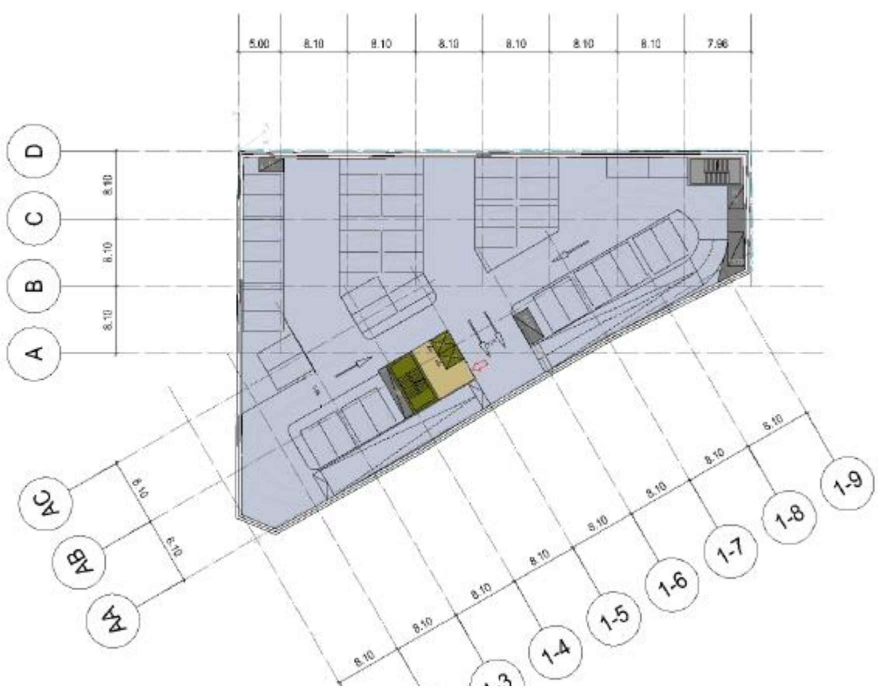


Figure 29 Typical parking plan.

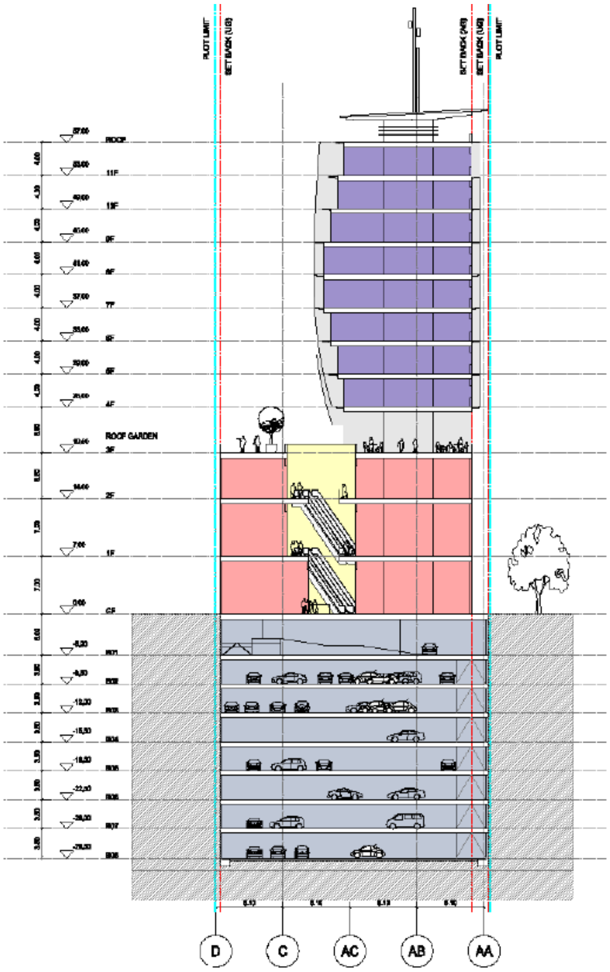


Figure 31 Typical section.

Figure 30 A 3D render of the exteriors.

Actual construction state: at the time of interviews which were done on March of 2014, the excavation of the project was completed. Unfortunately, due to financial issue of the mother investment company, the project has since been halted and not much construction has gone ahead. At this stage the excavation works had been finalized. Due to the safety concerns, the excavated land had to be refilled to a certain level to ensure the walls stability.

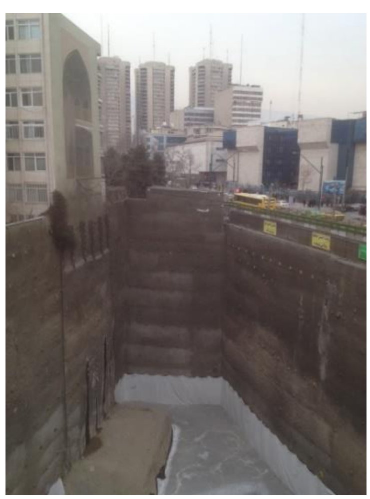


Figure 32 Project state on March 2014

6.3.3 Case Study Specific Design

Methodology: To further investigate how implementing BIM could affect the collaboration in this project, a modelling research method was adopted. It includes the definition of a system which in here is a simulation of the real-life situation. Simulation is an experiment conducted over a real-life stochastic system. In the case of Vanak project, we tried to simulate the situation surrounding the issue of parking height in a BIM ecosystem.

Data Collection: In order to obtain qualitative data, we conducted interviews with some of the participants in this project. Semi-structure interviews in the initial stage were done and the transcripts of them were made. The questions were adapted from a BIM Case study methodology document provided by Pennsylvania state university [128]. It was adopted as it contains questions to investigate factors regarding BIM implementation. Additional questions were asked based on the research objective oriented to collaboration. They were then analyzed and interpreted and eventually coded to provide us with a clear idea of the existing collaboration issues. All the emails and communications, meeting minutes and RFIs regarding this particular issue were also gathered and analyzed. Finally, the proposed BIM ecosystem was evaluated using qualitative data and empirical comparison to the existing project structure.

6.3.4 Data collection of existing collaboration method

In this part, the study of communication and collaboration tools and workflows of Vanak project will be presented. Similar to the dimension of a BIM ecosystem, the existing situation will be categorized into three dimensions of People, Processes and Products. These dimensions will be the themes for guiding the coding process. In addition, this categorization of the existing situation will facilitate its comparison to our proposed BIM ecosystem. This study is necessary in order to understand the collaboration issues in the existing method.

By People, it is intended the social and behavioral impact of the people in the project development. By studying the meeting minutes and notes, emails and letterings between the people with different roles belonging to different sections of the project, we can evaluate their mindset. The goal is to understand whether it has been a collaborative mindset, a solution-finding mindset, a responsible mindset when the issues happened, or the opposite ways. Also, we can realize the tendency of the people to collaborate with each other, or if it has been as if it has been to work in an isolated manner.

By Process, it is intended the workflows they have been following for communicating and delivering different parts of the project. The methods of communication that had been established for this project between parties involved will be taken into account. It will be studied how the deliverables were arriving in the hands of the recipients, what have been the issues of such a process, and the protocols they followed. Tasks such as following up issues and assigning them to the related responsible also fall into this category.

By Products, it is intended the software, technologies and tools which were utilized for the purpose of communication. It will be studied how the nature of those products, for example Microsoft outlook, could affect the overall workflow of the established communication system for Vanak project. All technological tools for such purpose even like phone calls or Skype meeting will be studied to find their deficiencies to make us able to offer a suitable system of tools under BIM technologies.

6.3.4.1 Documents and observations

6.3.4.1.1 People

In order to study the People's impact on the communication and collaboration system of Vanak project, two aspects were considered. First, the organization structure of this system and people's roles and titles, and second, the people's behavioral attitude and collaborative mindset. To have a better understanding of people involved in the communication and collaboration system, a number of questions were asked from co-ordination office of Satsa company. To get an insight of probable people behavior, the literature used in emails, meeting and other mediums of communication will be studied and presented in this section.

Vanak Project stakeholders:

The organization chart of the project is presented below with the main parties involved.

Project Owner: Sorinet Holding. Iran.

Project Developer: Satsa Co. Iran.

Architectural Consultant: Chapman Taylor. Spain.

MEP consultant: Aguilera Ingenieros.. Spain.

Structure Consultant: DAIE. Spain.

Local Architect: ATEC. Iran.

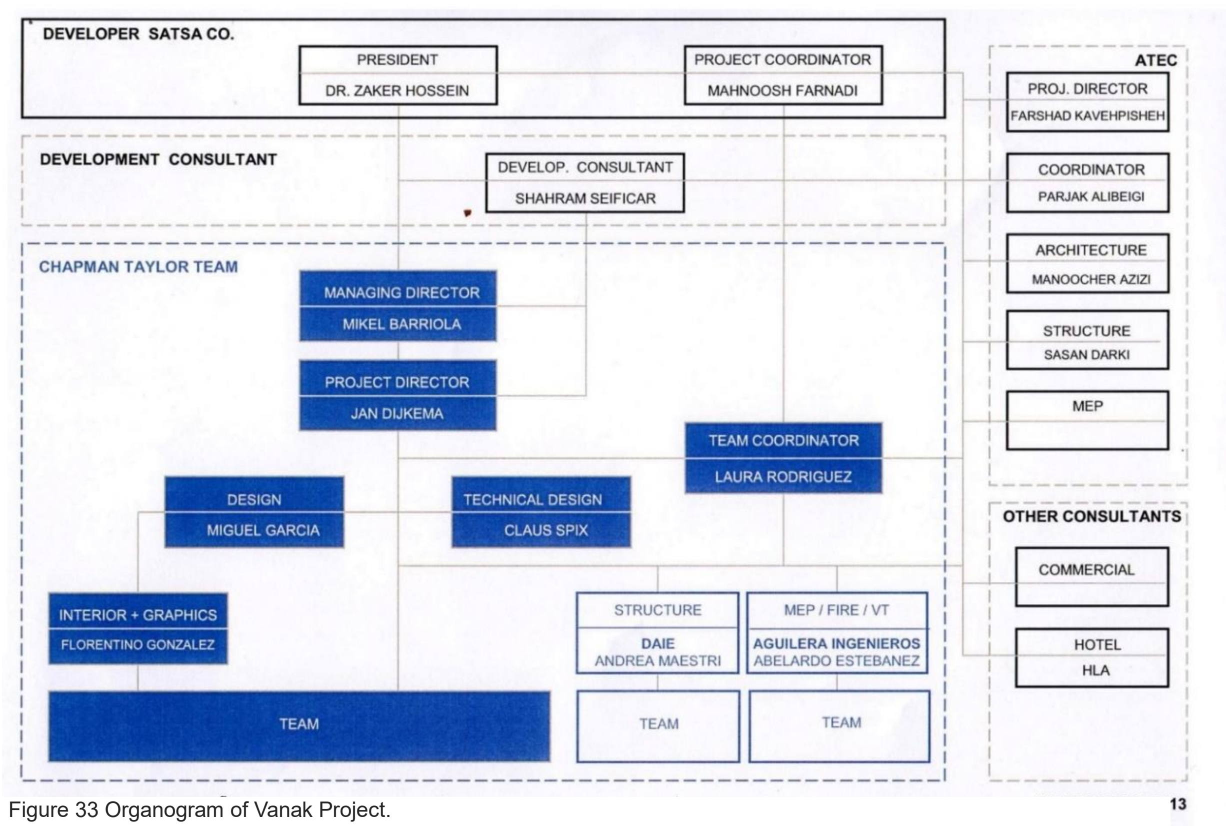
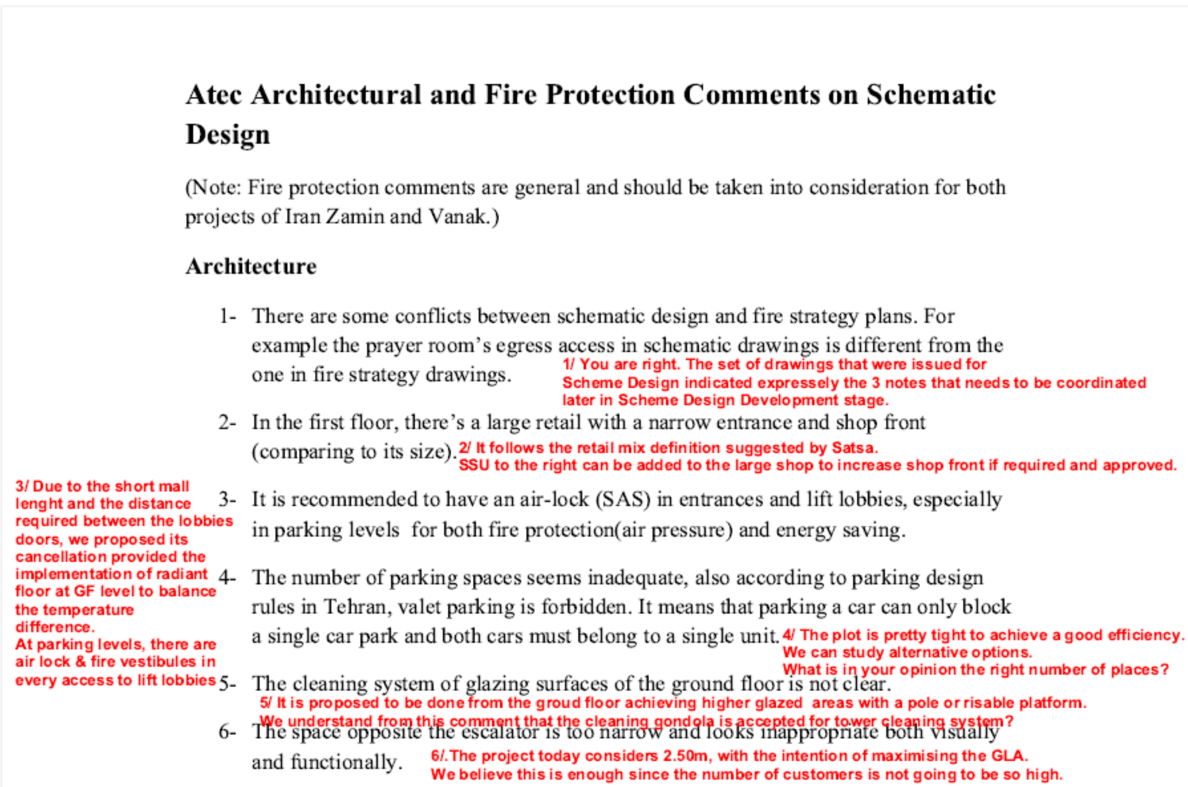


Figure 33 Organogram of Vanak Project.

Considering the roles that are important in collaborative processes, we see that the ‘’Project coordinator’’ was from Satsa Co. the developer company. Another coordinator role was the ‘’Team coordinator’’ that belonged to the architectural consultant. These two coordinating units could have interfering tasks leading to confusions or missing information. As we discussed in literature review sections, a leadership role in interdisciplinary collaboration is necessary to assure its efficiency. Although it is inevitable for project stakeholders to have their own coordinators, two project level coordinators might be conflicting. This will be questioned in the interviews with the ‘’Project Coordinator’’.

When it comes to collaboration, people involved in the collaborative process assume certain responsibilities and tasks. Although it can be tracked if each person has accomplished a task, a latent factor in a successful collaboration lays in people’s behavior. Reading the communications between the stakeholders such as the one in the following figure which is between Atec the local architects and Chapman Taylor the Architectural consultant a certain tone is apparent. This tone from Atec seems to be looking for issues in the works of the other part, rather than looking for solutions. It is like they consider themselves an external party rather than being in the same team. As if they consider their reward in finding the mistakes of other project team members, rather than finding the reward in solutions that helps all.



Atec Architectural and Fire Protection Comments on Schematic Design

(Note: Fire protection comments are general and should be taken into consideration for both projects of Iran Zamin and Vanak.)

Architecture

1- There are some conflicts between schematic design and fire strategy plans. For example the prayer room’s egress access in schematic drawings is different from the one in fire strategy drawings.

1/ You are right. The set of drawings that were issued for Scheme Design indicated expressely the 3 notes that needs to be coordinated later in Scheme Design Development stage.

2- In the first floor, there’s a large retail with a narrow entrance and shop front (comparing to its size).

2/ It follows the retail mix definition suggested by Satsa. SSU to the right can be added to the large shop to increase shop front if required and approved.

3- It is recommended to have an air-lock (SAS) in entrances and lift lobbies, especially in parking levels for both fire protection(air pressure) and energy saving.

3/ Due to the short mall lenght and the distance required between the lobbies doors, we proposed its cancellation provided the implementation of radiant floor at GF level to balance the temperature difference. At parking levels, there are air lock & fire vestibules in every access to lift lobbies

4- The number of parking spaces seems inadequate, also according to parking design rules in Tehran, valet parking is forbidden. It means that parking a car can only block a single car park and both cars must belong to a single unit.

4/ The plot is pretty tight to achieve a good efficiency. We can study alternative options. What is in your opinion the right number of places?

5- The cleaning system of glazing surfaces of the ground floor is not clear.

5/ It is proposed to be done from the groud floor achieving higher glazed areas with a pole or risable platform. We understand from this comment that the cleaning gondola is accepted for tower cleaning system?

6- The space opposite the escalator is too narrow and looks inappropriate both visually and functionally.

6/.The project today considers 2.50m, with the intention of maximising the GLA. We believe this is enough since the number of customers is not going to be so high.

Figure 34 A sample of comments between Atec and CT

Another example regarding the attitude in collaboration is seen in the following image. We found a number of emails where the architectural consultant needed to ask for confirmations or answers as they did not receive them naturally. It seems it was caused by a lack of assuming responsibility and the feeling to work collaboratively.

From: Vanak [mailto:vanak@chapmantaylor.es]
Sent: Monday, September 09, 2013 4:17 PM
To: Vanak@atec-ir.com
Cc: visionary.architect@gmail.com; vanak@satsa.co
Subject: VANAK: Modified floor plans: B7 - 3rd Floor

Dear Parjak,

We understand that the natural ventilation openings for parking levels shown in these layouts are accepted, since we didn't receive any comment from your side to this respect.
Can you please confirm?

Thanks,

Laura Rodríguez

Vanak
vanak@chapmantaylor.es

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Spain

Vanak <vanak@chapmantaylor.es> | Vanak@atec-ir.com; vanak@satsa.co; visionary.architect@gmail.com

VANAK - Toilets, lobbies, podium

Dear Parjak,

Are there any news regarding the mall toilets new proposal, parking lobbies alternative design and podium façade alternatives?

We were expecting to have received by today SATSA's comments, as suggested via Skype, but nothing has arrived.

Best regards,

Laura Rodríguez
Vanak
vanak@chapmantaylor.es

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Figure 35 Numerous follow up emails

Going further through the emails, it is evident that the numerous people sending and receiving email about an issue, in this case the parking height, had contributed to collaboration inefficiencies. One reason seems to be the missing of information when a large number of people were involved. In some emails we read team members had not received or seen certain emails or information. For example, a change in a meeting time that some members were not notified. We can argue that a lack of central coordination unit with people assuming certain leading roles in communication and coordination had contributed to such issues. It is seen in the emails files that for an email to get to the right person, multiple forwards were necessary between the stakeholders which implies on organization defects in the communications.

In summary, by reviewing the documents we can mention the following factors contributing to the collaboration issues:

- An issue finding attitude rather than a solution finding one between project teams.

It seemed that there existed a certain tone in communication. It was more evident where there were arguments about project issues. The tone of the communications seemed not to promote collaboration. Instead, it appeared to be an ‘’issue finding’’ one rather than ‘’solution finding’’. For instance, in the arguments presented in Figure 56, it seemed that the local architects rather tended to merely find issues in the work of architectural consultants.

- The lack of single leading party in collaboration

It seemed that various of coordinators from different project stakeholders did not have a unified leadership in their collaborative processes. Such processes could be less confusing if a single person or unit could lead other coordinators. This issues contributed to emails not arriving to the person, answers not received and the need for following up repeatedly the requests.

- The lack of work sharing during early stages of project development.

As each of these parties was contracted separately by the owner, they tended to work in isolation rather than working collaboratively. In a collaborative approach, people are encouraged to share their work while there are in the progress of development. This allows the project team members to have access to information in earlier stages and therefore preventing errors and saving time.

6.3.4.1.2 Processes and Products:

The diagram below shows a general project information distribution which was conceived based on studying the documents and my personal observations during the time of working in Satsa CO.

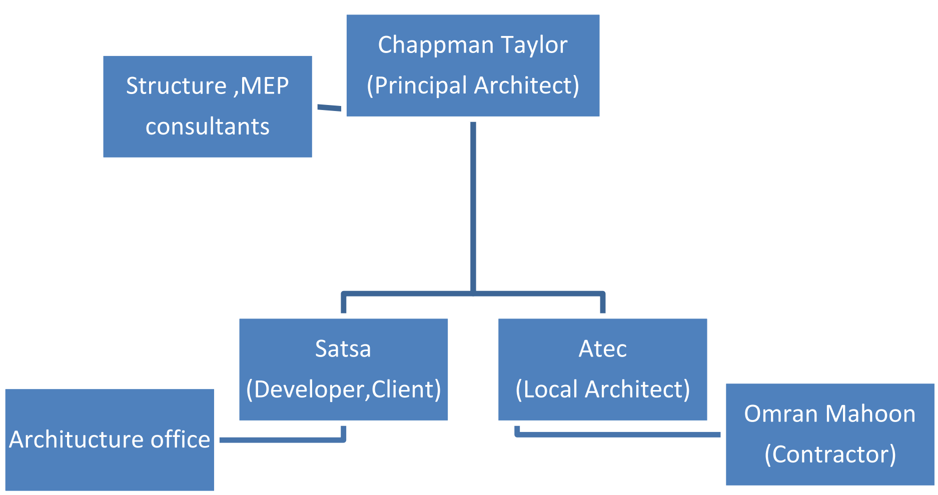

Figure 36 Project Information distribution diagram

As a general workflow, the project documents were sent to the parties through a defined File Transfer Protocol (FTP), which was uploading folders on a cloud service by Chapman Taylor. Other parties could have access to the files and could download the coming documents, which is generally coming with a PDF document (Figure 37), explaining the content of the coming folder. Then these files were saved on hard disk drive of Coordination office of Satsa Co. and making a duplicate on the server. The architecture office of Satsa Co. would have done a general revision, to make sure the requirements of the owner according to their strategic financial map are met. Also, they did a general revision to evaluate design issues or to check if they meet the city council and other regulatory codes. Then comments were sent to Chapman Taylor, or Atec or any other related party through emails between coordinators, or through letter between CEOs for more critical cases.

FTP		121119_excavation_line	VANAK 08-16		
		121127_excavation_sections	2VANAK 08-16		
	02_CONCEPT	A_ARCH	00_Booklet	*121123-FinalConceptUpdate*	
			01_Drawings	*01_Gral_Arrangement*	drawings & PDF prints
				02_Landscape	drawings & PDF prints
			02_3D MAX		
		B_STR	PLAXIS FILES		Plaxis Files
			S-CD-VNK 20121105 Completo		CONCEPT DESIGN: STRUCTURAL CRITERIA REVISION
		C_MEP	VANAK PROJECT BOOK REV-1		
	03_SCHEME_DESIGN	A_ARCH	121211_Stairs_Mezz_Lifts	*121211_StairsMezzanines+ ShopLifts*	
			130117_SD_progress	*130117_SDprogress*	PDF booklet: ARCH-STR-MEP
			130208_SDprogress_II	*Facades*	
				Sections	
				Skylight	
			130301_SDesign_Arch	*01_Interior Concept*	Themes for each part : sea,wind,movement, history,...
				02_Gral Arrangement Drawings	dwgs & pdf prints of plans, sections,...
				03_Areas	Schedule of areas
			130301_Skylight_Prop	*130301_Skylight_PROPOSAL*	4 Concept options
		B_STR	130110_FoundationDesign	*01_Report*	
				02_Drawings	dwgs & pdf prints
				03_BoQ	Bill of quantities
				04_DrainageBG	Floor Buried Swage detail (dwg & pdf print)
			130221_SD_Structure	*S-SD-03 VNK20130221_0*	report
				SCHEMATIC DESING STRUCTURE.xls	SCHEMATIC DESIGN ISSUE

Figure 37 Sample of FTP index of files

Atec as the project local architect and the construction documents developer, would check the Chapman Taylor drawings in a more precise way. They would try to match them with regulatory codes and try to understand the client and developer needs and comments. Furthermore, they would make modifications on the drawings or to send the comments to chapman Taylor, urging them to apply the modifications or to come up with new solutions.

Chapman Taylor on the other hand was in direct contact with the Spanish structure and MEP consultants and was making sure that their architectural designs match with the structure and MEP systems. In more crucial cases, the structure and MEP consultant, DAIE engineers, was getting in direct touch with the local architects and developer in order to solve issues. Here is an example of a revision done by Atec and sent to Chapman, and their comments back to it:

A common way of meetings between parties in distant locations was Skype meetings. Although both parties from Iran and Spain have been having scheduled travels to each other's offices for in-person meetings. The notes and minutes of meetings, were recorded by meetings secretaries, usually the same people from coordination offices. The documented notes were then sent to their representative responsible for further actions or just for information (Figure 38). The figure below is a sample of meeting notes:

Nº 25

MEETING NOTES

Chapman Taylor

Chapman Taylor España
Arquitectura Urbanismo

Project:	**IRAN ZAMIN & VANAK SHOPPING ENTERTAINMENT CENTRE**	**Project Ref:**	**B405 ZTI / B405 KTI**
Subject:	**Coordination Meeting**	**Date:**	**01 October 2013**
Place:	**Skype Conversation**	**Recorded by:**	**LR**

List of attendants:

PA	Parjak Alibeigi	ATEC	EM	Ehsan Mojtahedi	SATSA
JS	Jahangir Safavardi	ATEC	SG	Sahid Garcidueñas	CTE
FD	Fameteh Daneshvand	ATEC	LR	Laura Rodríguez	CTE
**	*And others pending of confirmation*				

Circulation: Those listed above and the following people

FK	Farshad Kavehpisheh	ATEC	AE	Abelardo Estebanez	AGUILERA
AN	Ahmad Norouzi	SATSA	AM	Andrea Maestri	DAIE

Note. Changes to previous version have been highlighted in red.

Item	Description	Action
1.00	**VANAK**	
1.01	*ARCHITECTURE* *SD General Lay-outs and Interior Concept & Landscape design approval.* GENERAL LAY-OUTS • *Upper Floors (not discussed)* • *Parking* - loading area for retailers *(not discussed)* Small loading area for retailers shall be include at B2 level. **Pending from mtg 18**.	**CTE** *In progress*
	- Access ramps width SATSA has requested on 30/9 the access ramps to have 6m clear width. CTE explain that it will require relocation of the parking exhaust riser. CTE is studying alternatives.	**CTE** *In progress*
	- Turning radius CTE is reviewing the layouts to adapt to the turning radius new requisites. CTE comment that they will need to separate the ramps since the paths for the cars IN/OUT at the central ramp overlap.	**CTE** *In progress*
	• Street & sidewalk levels ATEC asks for clarification of the ramps landing level at khodami street (+0.53) since there is a discrepancy in relation to ATEC's 17/9 drawing, level (+1.11). CTE explain they have based on the topographic levels received on 10/9/12 with the infrastructure utilities definition, and that the levels received aftewards were similar, but none of them defined the level at this certain point.	

Figure 38 Meeting notes sample

To keep track of drawings and specially revisions and editions of them after comments received and modification implemented, was a spreadsheet (Figure 39). The architectural consultant sent it along with its drawings to show the number of revisions of the same drawing, and secondly to mention the file

DRAWING ISSUE SHEET

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PROJECT NAME: **VANAK COMMERCIAL CENTRE**

STAGE / SERIES / PACKAGE: **SKETCHES** **SK 00** **GENERAL ARRANGEMENT PLANS**

PROJECT NO.: **B405 KTI** | SHEET NO. **2** OF **3**

PLANS PATH: I:\B405kti\2012\Planos_enviados\Sketches\SK00

The following plans are issued:

DIN	SCALE	NAME OF DRAWING	NO.																	
			DAY	07	19	22	22	23	04	05	14	19	17	04	11	13	27	21	27	**08**
			MONTH	11	11	11	11	11	12	12	12	12	01	02	02	02	02	02	02	**03**
			YEAR	12	12	12	12	12	12	12	12	12	13	13	13	13	13	13	13	**13**
				REVISIONS					* = 1st issue					A,B,C…= Revisions						✓
A1	1/200	NINTH FL LAYOUT - OFFICES	SK00-021		*	A			*	B	B		C				D			*
A1	1/200	TENTH FL LAYOUT - OFFICES	SK00-022		*		A		*	B	B		C	D			E		F	*
A1	1/200	ELEVENTH FL LAYOUT - OFFICES	SK00-023		*				*	A	A		B				C			*
A1	1/200	TWELFTH FL LAYOUT - ROOF	SK00-024	*	A			B	A	C	C	C	D				E			**A**
A1	1/200	THIRTEENTH FL LAYOUT - ROOF	SK00-025		*				*	A	A		B				C			*
A1	1/200	FOORTEENTH FLOOR - ROOF	SK00-026										*							
			SK00-027																	
			SK00-028																	
			SK00-029																	
A1	1/250	BUILDING SECTIONS / TRANSVERSAL SECTIONS	SK00-030	*	A				A			A								**A**
A1	1/250	BUILDING SECTIONS / LONGITUDINAL SECTIONS	SK00-031																	
A1	1/250	BUILDING SECTIONS / SEC 28	SK00-032									*								
A1	1/50	MALL CROSS SECTION / SEC 27	SK00-033											*	A	B				
A1	1/50	BUILDING SECTIONS/SEC 06/OFFICES DETAIL	SK00-034															*		
			SK00-035																	
			SK00-036																	
			SK00-037																	
			SK00-038																	
			SK00-039																	

ISSUE STATUS

PRELIMINARY INFORMATION / FOR COMMENTS			*	*	*		*	*	*	*	*	*	*		*	*	
OUTLINE DESIGN						*											*
SCHEME DESIGN	*	*															
DETAILED DESIGN																	
TENDER DOCUMENTS																	
WORKING DRAWINGS																	
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Development Manager	VA - Shahram Seificar						F										E	**F**
Commercial agent																		
Cost Consultant / Measurements																		
Architecture Cosultant																		
M&E Engineer	AGUILERA - A.Estebanez		F					F			F	E	E	E	F	E		
Structural Engineer	DAIE - A.Maestri		F	E	E	E		F	F		F			E	F	E		
Fire Consultant																		
Traffic Consultant																		
Lighting Consultant																		
Drainage Engineer																		
Local Consultant	ATEC - Farshad Kavehpisheh																	**F**
Others (For Manufacturers see Document Transmittal)		*								*								

RECEPTION

	Issued	MJC	MJC	SG	SG	SG	SG	SLC	SLC	SG	SLC	SG	SG	SG	SLC	SLC	LR	**LR**
By: Please sign and return to fax 0034 91 417 09 26	Author.	SG	SG	SG	SG	SG	SG	SG	LR	SG	SG	SG	SG	SG	SG	SG	SG	**JD**
Date	Ref:	5kti\Documentos\2admin\2a-Lista_planos\Entrega_planos\SchemeDesign\[ISS_SchemeDesign.xls																

Figure 39 Issue Sheet

path on FTP or on CDs or DVD s containing the files. This document also indicates a distribution list, in which the recipient of the documents and the files format is indicated such as paper, email through FTP or on disk.

To summarize the studies of Products and Processes in the project collaboration method we can mention the following:

Product: As for the means of communication, the project depended on conventional communication tools. Email for verbal communication, Skype for virtual meetings and cloud storage for file sharing. Although these are very common tools of communication, they are not specially developed for the AEC industry. This becomes more crucial in the case of collaboration and coordination between the project stakeholders. Confusions about the location of issues in the design, manually assigning to tasks to responsible, following up the issues are some problems we noticed in their use of these tools.

Another important issue in the use of products was the incompatibility between systems. For example, the architectural consultant and the developer of the project had their own internal communication system. Therefore, their communications received by the coordination offices of each company had to be redistributed using their own system. This opened the door to human errors and confusions, especially as the number of communications increased. The lack of automation was another factor contributing to the problem. As we heard in the interviews, coordination offices had to create an issue log file in MS Office Excel. Then, they had to manually assign responsible to follow up the job. This was due to not using the advanced tools available for such tasks.

In summary, to point out the main defects in the Product aspect of the case we can mention:

- Use of ordinary tools in communication, collaboration and coordination, lack of specialized tools made for the AEC industry.
- Incompatibility in internal communication systems of different project stakeholders.
- Numerous document formats used in communication.
- Use of cloud technologies limited to file sharing.

Process: One evident trouble with the processes involving communication and collaboration was the lack of automation. For example, the drawing files had to come with a separate spreadsheet, indicating their location, revision and other data. Therefore, the project teams' members were dependent on extra data separate from the original files. Another issue was the defined protocol for data access. The file transfer protocol (FTP), was merely about using a cloud storage to access project files provided by the architects. It did not provide who and to what level could access the data. Thus, when some data was needed by a team member, they had to ask it through the coordination office. This process increased the time and decreased the accuracy of information distribution.

Furthermore, as seen in some of the documents shown above, the workflow of discussing about an issue usually included manually responding under a paragraph in an email. This could become confusing and unclear after a number of email exchanges. The use of numerous different types of documents for different communications was also contributing to this issue. Meetings minutes, issue logs, file exchange documents and etc. had different formats, provided by different parties. The coordination office job to maintain and distribute these documents would become complicated as the numbers increased.

Another aspect that falls in the process category is the contractual concerns related to the delivery of the project. In this case, Satsa Co. as the developer of the project had separately contracted different project stakeholders. One with architectural consultant which included MEP and structure design as well, another with the local architects and one with the general contractor. This manner of contracting leads to works being developed in silos by each of these teams. Therefore, collaboration and work sharing would only happen at certain stages of project development, closing the door for a truly collaborative project delivery.

In summary, to point out the main defects in the Process aspect of the case we can mention:

- The lack of a well-defined protocol to access the project data.
- Manual distribution of data, issues, communications.
- Implementation of a conventional FTP, not designed for the AEC industry.
- The lack of a collaborative project delivery process.
- Errors in handling data.

In the previous pages, an overall image of the existing situation in Vanak project was presented. In the study, the focus was on handling information between the project stakeholders. Communication, collaboration and coordination are the main activities involved in handling information. In this respect, the project saw a number of issues that contributed to delay in finding a solution for the conflicts between the architectural, structural and MEP systems. The final solution was achieved after almost a 40-days delay and with the proposal of a more expensive ventilation system.

As mentioned earlier, in this case study we applied a modeling research method, where we simulate a real-life situation in our proposed model. The BIM model that will be described later in this section, has the three dimensions of People, Product and Process. Therefore, the study of the current situation was categorized in these three themes.

Codes:

The following codes were generated based on the study of the documents and observations:

People: attitude (collaborative mindset) – willingness to share – taking responsibility – leadership role

Product: compatibility – lack of specialized tools

Process: Standards – Protocols – Automation – data distribution

6.3.4.2 Semi-structured interview with Satsa Coordination office:

With a focus on the Communication issues of the Vanak project and because of the centric role of Satsa Co. as the developer of the project, the coordinators of Satsa Co. were asked a semi-structured series of questions adapted from the BIM Case Study Methodology document [128].

Employees: Mr.Mojtahedi – Mrs.Farnodi – Mrs.Salimi

-Mission and tasks:

- What is the mission of the operating unit? And what are the goals of this unit?

Mr.Mojtahedi answers:

The main goal of the unit is to assure the flow of information between parties and to follow up the issues and claims between different parties, in order to satisfy the project developer goals.

- What are the tasks, duties and responsibilities of this operating unit?

Mr.Mojtahedi and Mrs.Farnodi answer: *The main tasks could be identified as :*

- *Assign duties within the own organization and request other parties about on hold and not accomplished tasks.*
- *Communication with different parties involved in the project.*
- *Following the results of the assigned tasks.*
- *Request reports related to different matters from the parties involved in the project.*
- *Archiving the project documents and reports.*
- *Being the secretary of meetings. (writing the minutes of meetings).*
- *Visiting project sites and checking the project status and works done.*
- *Giving special reports to Satsa Ceo about projects.*
- *Attend client meetings and give assistance.*
- *Assisting the project manager and client's consultant. (Dr. Seificar).*
- *Preparing some project documents such as the organization charts.*
- *Chair site meeting and distribute the minute of meetings to all project stake holders.*
- *Track and monitor the progress of work by design disciplines.*
- *Monitor the project schedule and progress.*
- *Keep the project manager and other related persons informed about the project status.*

- How does this operating unit function?

Mrs. Farnodi answers: *According to the project organization and communication chart, the subject of letters and roles of people, the task and information were distributed to the related person or office.*

Mr. Mojtahedi adds: *Satsa has its own automation system for its communication and letters and information were sent to Satsa personnel through this channel.*

- What is the process for each of the major tasks?

Mr. Mojtahedi answers: *there is an issue log in which the task were assigned into it manually to the related parties and the tasks status were monitored according to this issue log (Figure 54).*
Such an '' Issue Log'' was generated every week manually by a ''Microsoft Excel'' file.
In addition, parties were asked to submitted reports explaining the status of the issues.

- Who are people to works with in order to gain further information on a day-to-day basis?

Mrs.Farnodi answers:

- *Satsa's architectural unit in order to obtain review on the Architectural consultant works*
- *Contractors in order to get the project status.*
- *Project manager for different issues and personnel on site.*
- *Satsa's CEO Mr. Zaker and general consultant Dr. Seificar for special orders.*
- *Local architect , Atec company ,as the primary reviewer of foreign consultants.*

- Information needs:

- What information does this operating unit manage (How, Where, Why)?

Mr. Mojtahedi: *the main information that this unit was coordinating, was related to issues between parties, and to follow up the tasks status. This information contained technical drawings, presentation and other project documents, email, letters and content of meeting are among the information this unit had to deal with. This different sort of information was received, categorized and saved, and distributed to related between for action with different mediums. After creating and updating the issue log, accordingly letters for action were sent to related personnel.*
This was happening with the Satsa's office and in its coordination unit.
The goal of this was to keep the related personnel up do date and to monitor the project process as its developer.

- What do you use to manage this information? Hardware, Software?

Mr. Mojtahedi: *there were a number of software used for the communication purpose such as:*

-*Microsoft Excel*
-*Automation software of Satsa Co.*
-*Microsoft Outlook*
-*Microsoft Sharepoint*

The main hardware involved in communication were PCs of personnel and hard copies of letters and documents.

- Number of users?

In Satsa's coordination team there were 3 personnel. (mentioned above).

- Do they share receive info from other departments?

They received/shared information with other parties such as Design disciplines and Contractors.

- Is the work/information duplicated anywhere?

All the information and received documents were saved/duplicated on Satsa's internal server.

- What are the issues regarding sharing/Duplication information?

The main issues regarding sharing were data loss or data not being seen, and the main issue regarding duplication was keeping the Latest version distinct and easy to access.

- General Questions:

- What issues do they experience with their facility?

Mrs. Farnodi: *the main issues are the maintenance and accessibility of data, they sometimes experience difficulties accessing required data, or lack of information for decision making is also another issues.*

- What would assist them in doing their job more accurately?

Mrs. Farnodi: *Additional information and more up-to-date information, for example, in the case of Vanak parking the lack of information was the main issue about deciding the feasible and adequate parking level heights.*

Coding results of the interviews:

People: information sharing – responsibility

Process: information distribution – automation – manual issue log – design review – organization – lack of information – decision making

Product: information accessibility – issue tracking tools

6.3.5 The proposed BIM ecosystem

In this section, our proposed BIM ecosystem to replace the existing situation is presented. The objective of our proposition is to address the issues found earlier in this case study. The ecosystem will be implemented based on the three main dimension of People, Product and Processes. Before we establish the extents of theses dimensions, we must start with the core concept of a BIM ecosystem which is the creation of the BIM model of the project. The interest of this case study is focused on the issue in the parking levels, therefore only this part of the building will be modeled and studied. The initial plan was to put the ecosystem in real practice with the participants of Vanak project, and compare the BIM collaboration results with their conventional method and obtain some quantitative data. However, due to the limitations it was not possible and we must settle for the qualitative data only.

We face some limitations to actually evaluate the proposed BIM ecosystem to its full extents in practice. Firstly, it would have required a considerable investment to buy the licensed for the software we used, to completely model the building elements of all the disciplines, to train people to use them and to implement the necessary processes. Secondly, the project was being developed by many different firms located in different countries, and to gather all of them to conduct the study was impractical as they were already dealing with delays and issues. Thirdly, during the time of developing this case study, the project was completely stopped due to the financial crisis of the investors.

The model

The building information model was developed based on the 2D drawings (Figure 40) we received from the architectural consultant. It included eight floors, seven of which are underground. It was evident that the spaces are tightly organized and maneuver for MEP systems locations was limited.

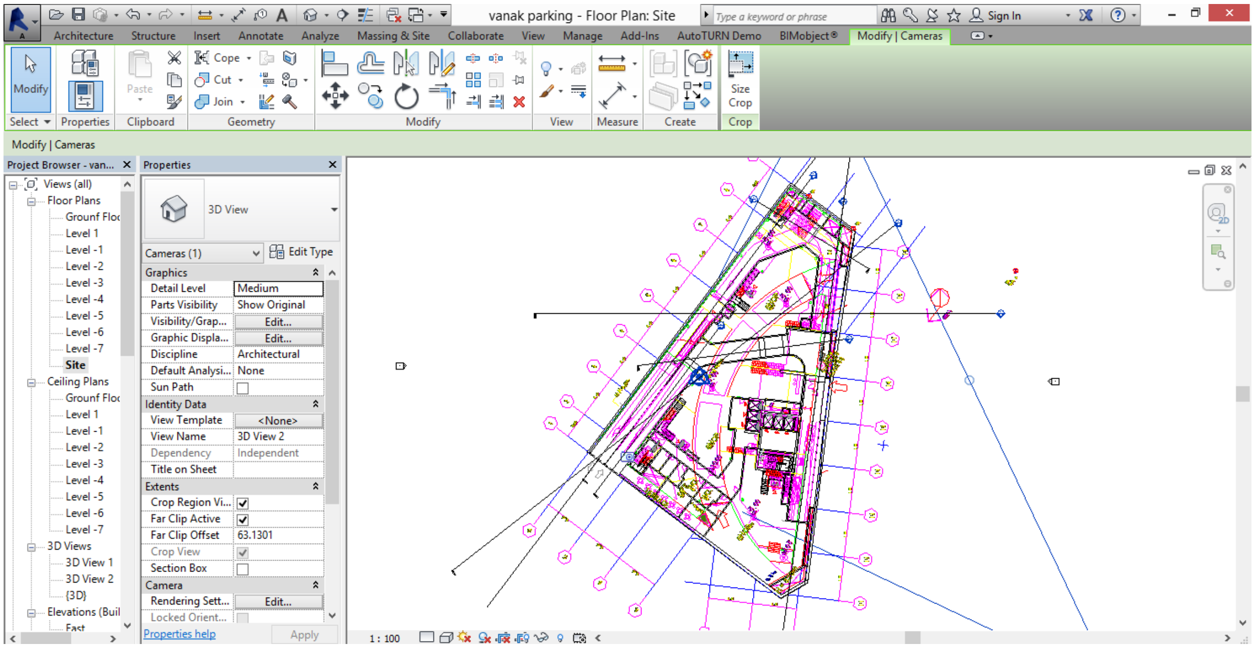

Figure 40 2D drawing of the Ground floor

The Level Of Definition (LOD) transcribes the evolution of the design. They are based on the model needs an uses to meet at the project stages or data deliveries. At this ‘’Design development” stage of the project that inter-disciplinary collaboration in required, a ‘’Coordination model’’ shall be used. At LOD 100, elements are generic representations, signifying the existence of a building component, but not its shape, size, or location. LOD 200 includes elements’ rough quantity, size, shape, location, or orientation, but information is still approximate. LOD 300 shows elements with a specific size, shape, location, orientation, and quantity. Considering the particular issue in this project, a LOD 300 should be satisfying to enable a coordination between architectural, structural and MEP elements, as the size and location of them are defined at this LOD. However, a detailed coordination between building elements may require at least a LOD 350 which provides precise information about a specific element and how it will connect to nearby or attached components.

In the following, two sections of the parking levels and an interior 3D view are presented (figures 41,42,43). At this very early stage, one of the evident benefits of creating the BIM model, is the ability to create numerous sections, elevations, 3D views and other forms of visualizations in a matter of seconds. This provides the architects and other team member the ability to quickly investigate various parts of the model, i.e the project.

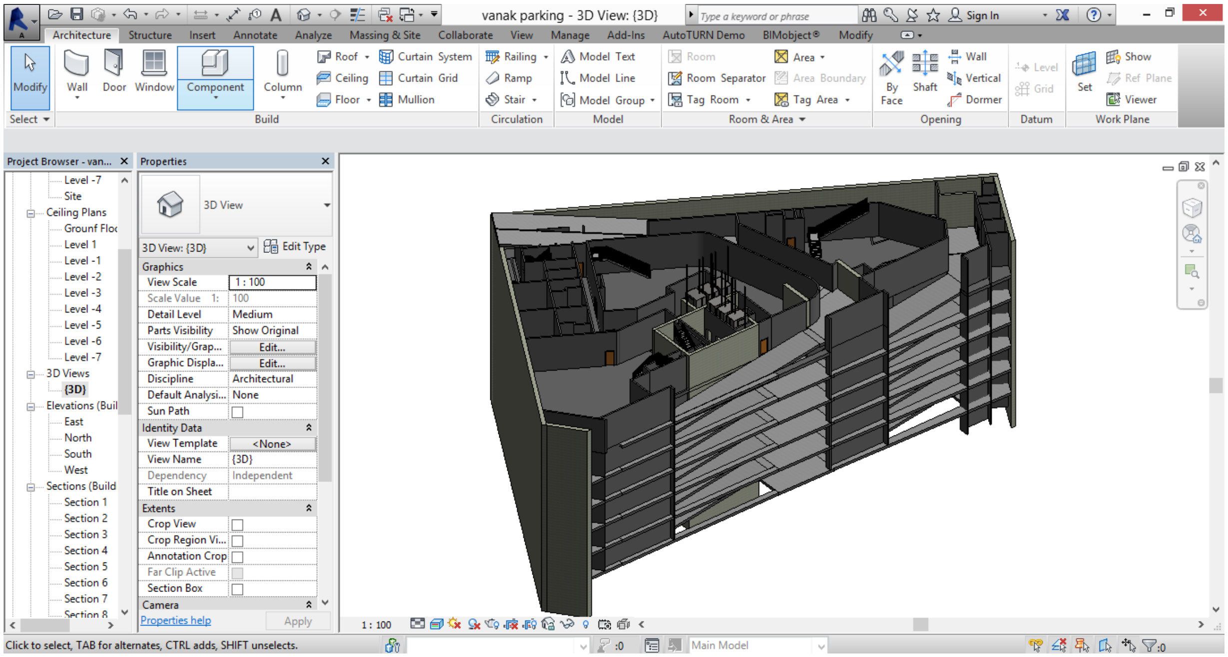

Figure 41 3D view of the a longitudinal section.

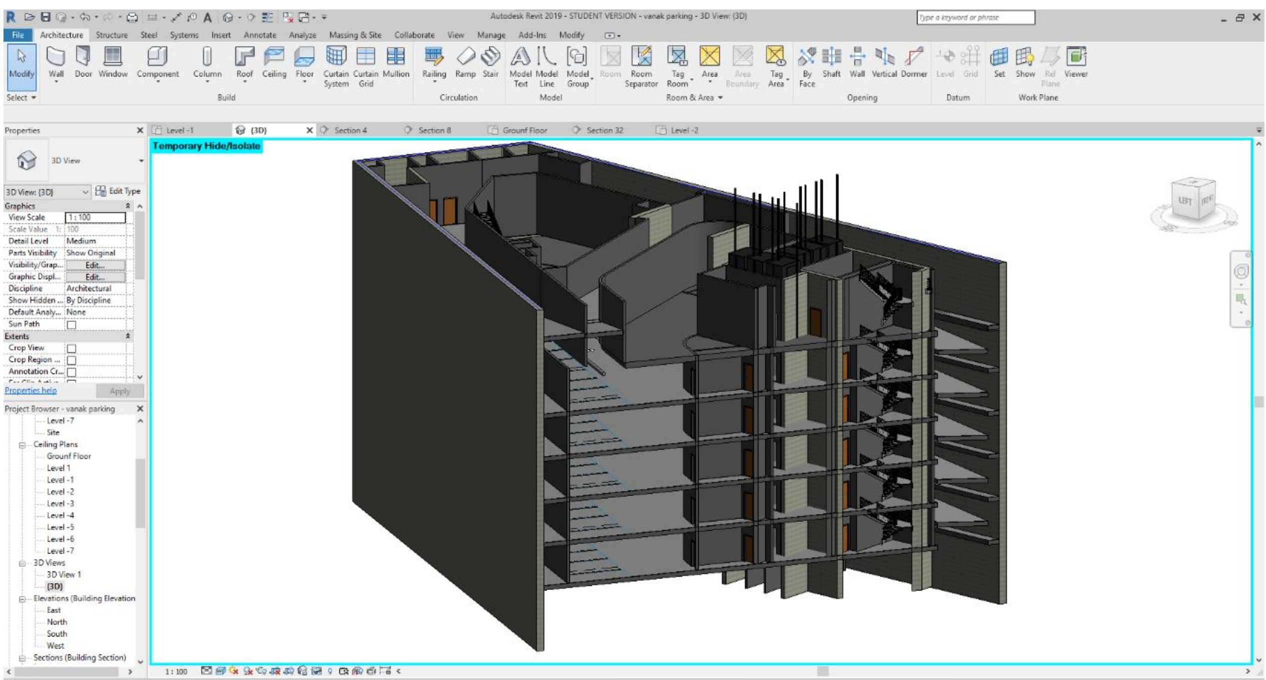

Figure 42 3D view of a transverse section.

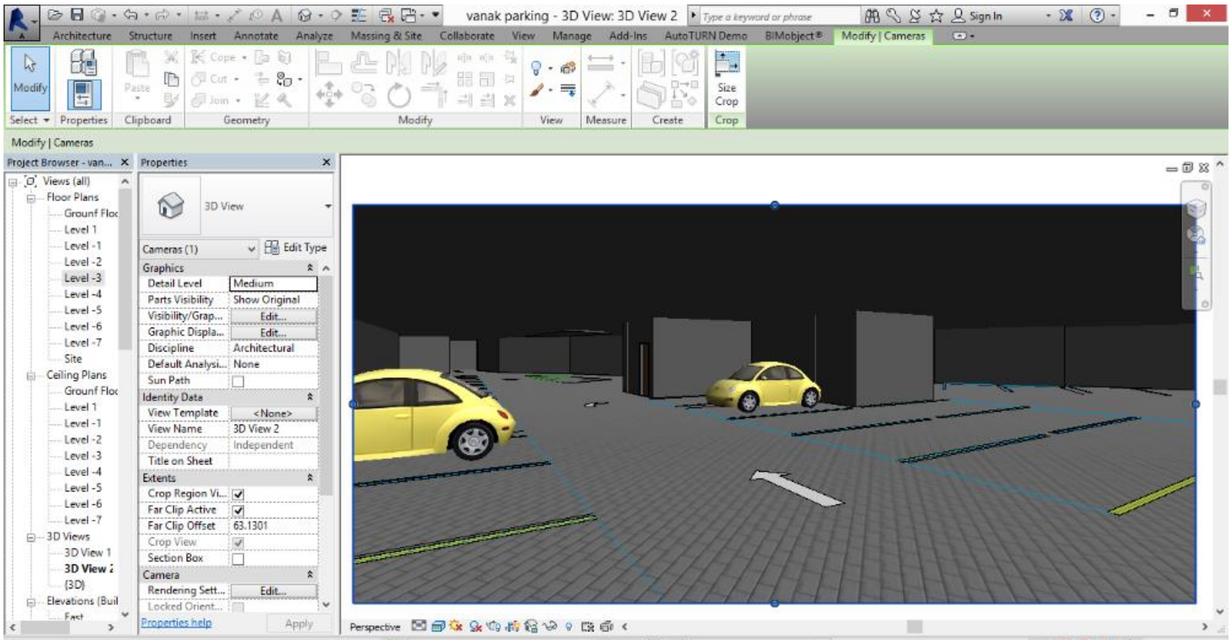

Figure 43 a 3D view of the parking interiors.

At this stage, we have an architectural BIM model of the parking levels. In a fully BIM-enabled project, it is expected that the structural and MEP consultants also develop their own model based on the architectural model. Therefore, in a BIM enabled project, architects are the authors of the main reference model, on which other models will be based. This main model is created and curated by the architects, who used it to coordinate the other disciplines. This can put them in a leadership position to guide and coordinate the project. Next, we must establish the BIM ecosystem based on the project needs as discussed earlier.

6.3.5.1 Product

BIM coordination tools: the complicated case of MEP systems interfering with architectural and structural design in the parking levels that led to delays and extra costs, could be addressed with an advanced coordination between the project stakeholders. BIM coordination tools coordinate the models developed by different disciplines, run automatic clash-detections and provide clarity by visualizing the BIM models. The quality check of the models, that are the digital representatives of the real building, can lead to quality assurance of the project. For this reason, we propose **Autodesk Navisworks** as one of the leading products for this matter. Navisworks allows users to open and combine 3D models, navigate around them in real-time and review the model using a set of tools including comments, redlining, viewpoint, and measurements (Figure 44). A wide range of file formats are supported in the tool, allowing for interoperability of different software used by the project stakeholders.

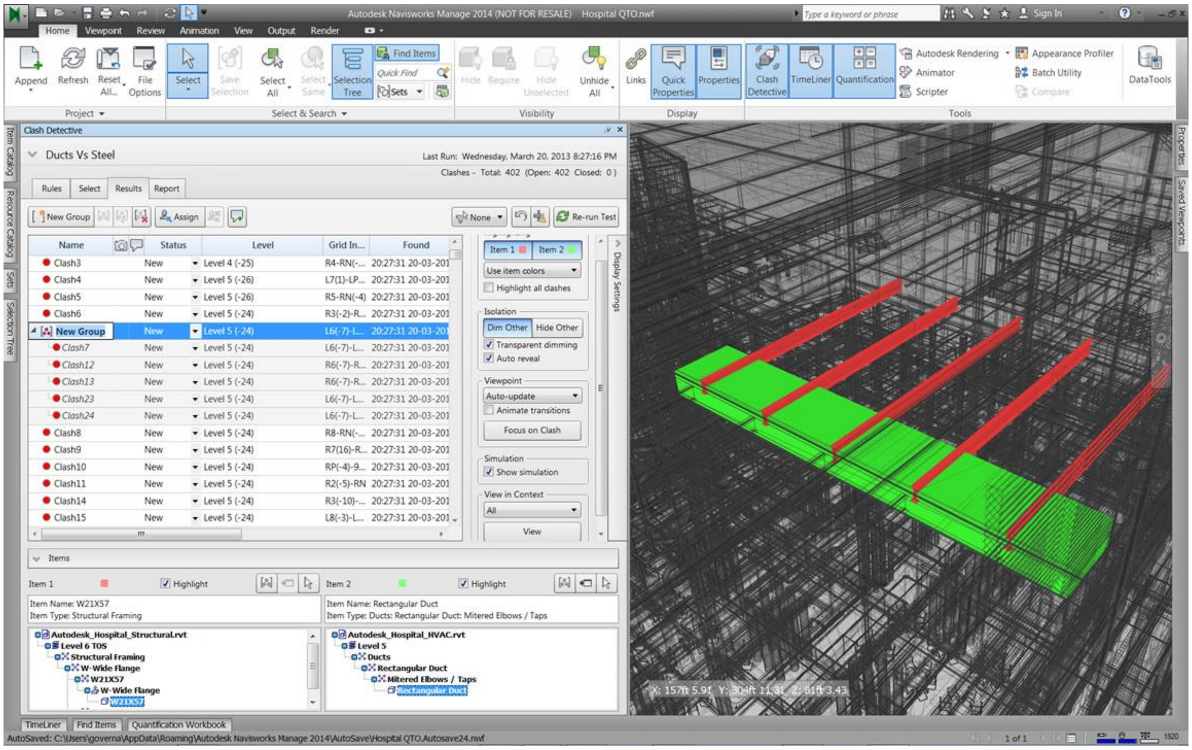

Figure 44 Clashes between MEP and structural systems detected by Navisworks. Courtesy of Autodesk.

BIM collaboration tools: in this case, the proposed tool is Autodesk's **BIM 360 team**. It visualized the BIM model in a web-based platform, where real-time collaboration between project stakeholders can happen (figure 43). One online workspace for all project team members, helping distributed teams stay connected and organized at all times. Its built-in chat system allows for communication, that can be later referred too. Its markup tools can address the issues visually on the model, eliminating confusions. different

Figure 45 Real-time collaboration and communication in BIM360

models and file formats can be opened in the platform, facilitating a smooth flow of information during collaboration sessions. We suggest that such collaborations be performed on a weekly basis.

Being cloud base, the tool allows for access to information anywhere on any device . Therefor project stakeholders can be always updated in real-time on latest changed. This was an evident issue in Vanak project, where issues had to be passed through coordination offices to get to the right hands. This caused delayed and confusions. BIM 360 has a dedicated issue tracking system, more efficient than the Vanak project manual issue tracking. It also visualized the different versions of the model, letting the project stakeholders be aware of the latest modifications.

BIM simulation tools: ‘’Simulation tools’’ is the other category of tools that helps with resolving issues in our case. Once the parking levels are modeled in Revit, using a plug-in called Autoturn from Transoft (Figure 46), we are able to simulate vehicles movements. This ensures that the circulation of vehicles is performed without interfering with the building elements. Utilizing this tool enables design by simulation for the architectural consultant. They can test different design options in this simulated environment and prevent potential errors during the construction phase of the project. This tool completes the process of quality checks of the model which once performed correctly, is a digital mock-up of what will be built later.

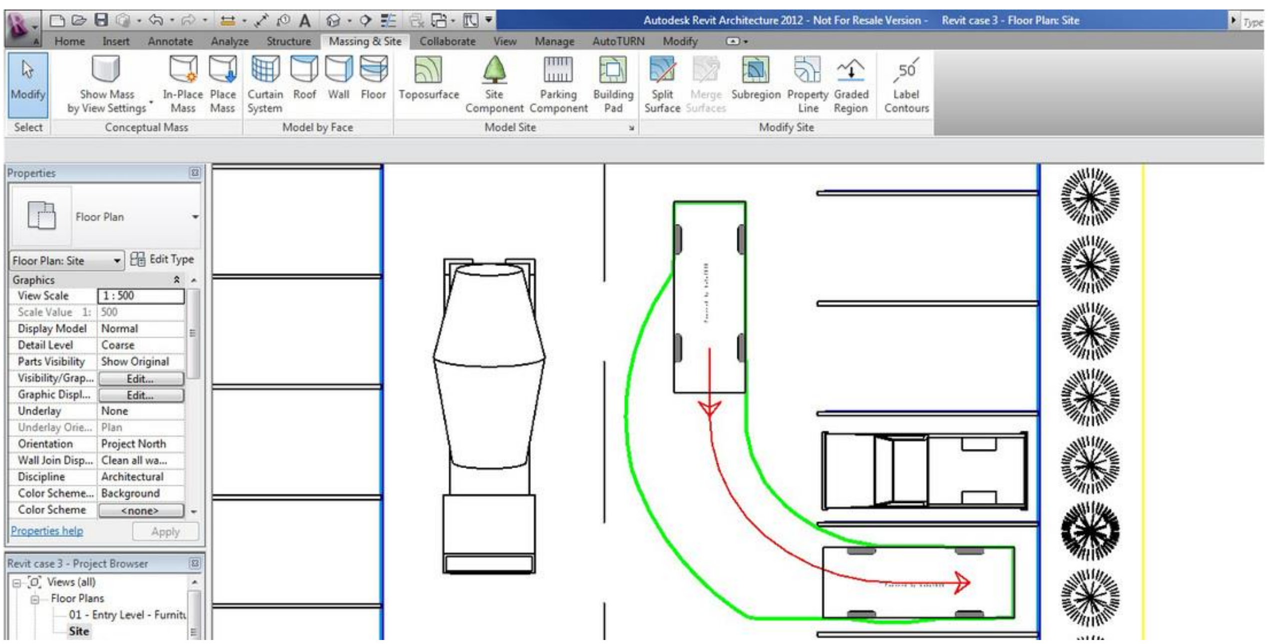

Figure 46 Vehicle movement simulation.

In the case of Vanak project, the architectural consultant could possibly find a solution spending less time and effort by utilizing the mentioned tools in collaboration and coordination. Starting with creating a BIM model, the CDE provides a single source of information, BIM 360 allowed for advanced communication and collaboration, and Navisworks led to advance coordination between the parties. Finally, simulation of vehicle movements ensures the quality of the parking designs. These tools could address the issues we recognized in our study of the existing situation in Vanak project. Although these are the basic ones, many other tools and software could be employed for specific use cases. The architectural consultant could stay on top of the project coordination by having access to the works of others at any time. They could lead the project development as the author of the project and the BIM model, by using these advance tools.

6.3.5.2 Process

As mentioned earlier, the lack of automation in processes was a contributor to the issues of parking levels. The suggested collaboration tools provide automation in issue tracking and assigning, allowing for more automation in collaboration processes. To ensure a collaborative data sharing in the proposed CDE, a certain protocol has to be adopted. The following is a typical structure adopted from the international standard ISO 19650 [129]:

- Work in progress (WIP): This area is used to hold unapproved information for each organization.
- Shared (or client shared) area: This information has been checked, reviewed and approved for sharing with other organizations, perhaps including the client.
- Published: This information has been authorized or accepted by the client or their representative (often the lead supplier (designer/constructor)).
- Archive: This area is used to create a constant record of progress throughout the lifecycles well as all transaction and change orders.

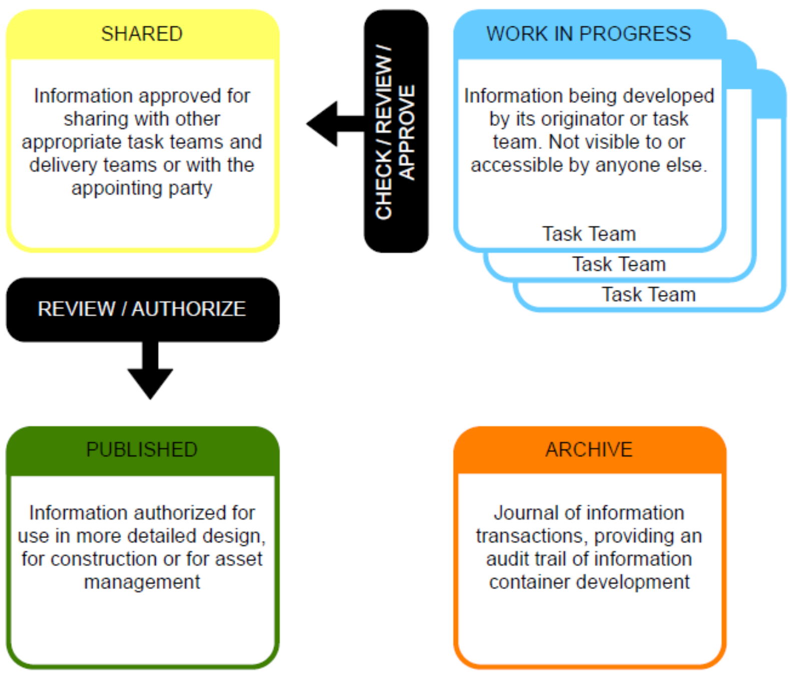

Figure 47 Information status level based on ISO 19650

For a successful collaboration in BIM, it is important that project stakeholders can have access to other teams works in Share area, or even in WIP. The earlier engages with other teams works allows for an integrated project development and eventual preventions of errors.

To ensure that a delivery method is in line with the BIM ecosystem, an architect-led Design-Build delivery method or Integrated Projected Delivery method are suggested. In these methods, the flow of design should provide the right information, at the right time, throughout all phases to allow the design intent to be efficiently implemented. Furthermore, the risk/reward sharing spirit of IPD methods, encourage true collaboration between project stakeholders.

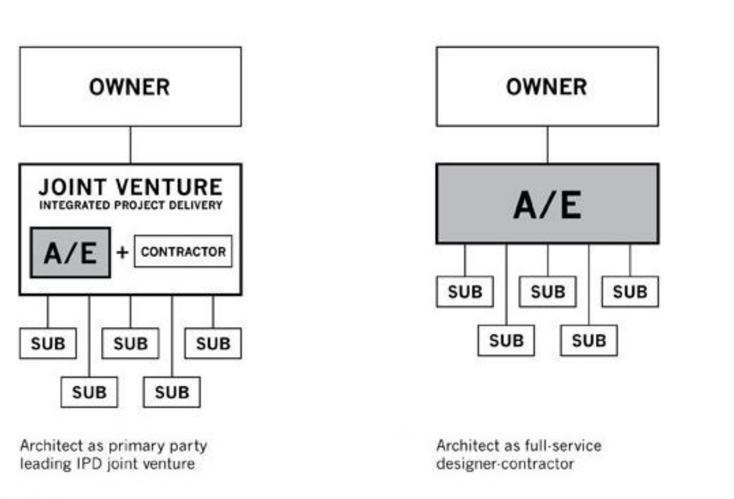

Figure 48 Architect-led DB arrangements and IPD- Courtesy of Hardin, D. (2015)

6.3.5.3 People

The proposed products and processes require specific training to be implemented and to be used efficiently. Therefore, in our proposed BIM ecosystem, training of project team member and ensuring that they have acquired necessary skills is crucial. In a contrary case, introducing products and processes without sufficient training of people, leads to confusions and extra costs. Eventually, disappointment with BIM implementation and moving back to traditional ways of working is predictable.

Encouraging people to collaborate and equipping them with a collaborative mindset is another important aspect of our proposed BIM ecosystem. As mentioned earlier, it was evident that project team members' attitude did not seem to be always collaborative. Sharing works at early stages of the project development and as mentioned in the proposed process, also depends on people's mindset. The more sharing of works happens before final delivery, the more chance for correction from other project stakeholders. Therefore, it is essential to educate people about the culture of working in a BIM ecosystem.

Another concern that falls in the People category, is the need of new roles and responsibilities. In the case of Vanak project, we witnessed the two project level coordinators contributed to confusions. We suggest that a single unit takes the responsibility of BIM collaboration processes. Also new roles need to be defined once BIM is implemented. The project stakeholders would need a BIM manager and the project would need a BIM coordinator and an information manager. These are new people to be hired by the project stakeholders once moving towards implementing of the BIM ecosystem. Apart from these key roles, a number of staffs have to be undertaking to role of BIM modelers.

6.3.6 Case Study Results

Previously, the study of the existing situation regarding collaboration issues in Vanak project was presented. The study included interviews with the project team members and a review of the project artifacts, i.e. documents, drawings, emails, meeting notes and etc. This helped with gathering qualitative data based on which the codes were extracted. Once the issues contributing to the parking levels problems were recognized, a BIM ecosystem was proposed to address them. A modeling research method was adopted to reconstruct the real-life situation in a BIM ecosystem. Although due to the limitations it could be put into test with project participants, it served as a pilot project to help us understand the factors influenced by implementing BIM and utilizing ICT in collaboration. In the following, the issues and the BIM solution are presented alongside in order to lead us to the conclusion.

6.3.6.1 Existing situation Vs. BIM solutions

The following are the statements resulted from the comparison of the BIM-enabled collaboration versus the existing collaboration method. They will be used for achieving further codes.

Statement: Manual communication system is inefficient: BIM Facilitates the flow of information.

Talking with the staff of the coordination unit, it was evident that there are deficiencies in their methods of working. These issues included the need to update the issues log manually, the distribution of letter and tasks manually, data loss during such operations and the eventual confusions they caused. BIM is about information. The tools that are proposed for collaboration, communication and coordination of projects based on BIM try to facilitate the flow of information. In designated BIM collaboration tools, issues are created and can be addressed directly to the model, the responsible can be assigned and the issue logs can be updated automatically. As this kind of information is stored in a central database where everyone upon the definition can access them, it will be easier to follow up the works later. The way of exchanging information is therefore affected in a BIM-enabled collaboration.

We also evaluated the workflow and tools used in the communication system of the project. It was evident that the use of conventional software such as office suit, and emails with file attachments as the main method of data transfer resulted in deficiencies. The specially designed communication tools for construction industry can solve the issues we encountered in this study. Although not all these tools are BIM based, but the ones that are made to be integrated in a BIM ecosystem, promise benefits that are the results of their information and visualization features of BIM. However, these new tools require some training before being used, which may imply initial resistance by the stakeholders.

Statement: The need for accessible, centralized database: BIM is cloud ready.

We realized in our interviews and studies of the coordination unit that not all the communications were easily accessible and stored in one place. This specially made the task of following up issues difficult. This is a common problem in many industries and businesses and cloud technologies have been offered as a solution to this. A handful number of BIM collaboration tools are also cloud base, facilitating an easy access to one place where all the communications happen. Through establishing a CDE which is managed by the BIM manager of the project, the architectural consultants can make sure that the information gets to the right people at the right time. A consideration about using CDE is about ownership of the models which must be addressed.

Statement: Lack of information for Decision Making: BIM is data enriched.

Another evident issue that the coordination unit encountered was the lack of information for decision making. In a complex system like a building, many decisions are to be made considering a wide range of factors. For instance, when an issue has been pointed out on 2D drawing of a certain level, to address the issue you may need to have additional drawings such as the sections of that point. In the case of such drawings have not been created yet, an informed decision cannot be made. The creation of a BIM model by its nature, brings about a higher amount of information. So in this example, if the BIM model was delivered, numerous sections could be generated quickly upon the needs of different teams. It is to stay by default the architects as the authors of the project, initially need to create a 3D model that includes more information than simply 2D drawings.

Statement: Lack of collaborative attitude: BIM encourages collaboration.

Numerous project team members located in different countries, tended to work in silos until a part of the project was delivered. This was due to the lack of training people to share works early on, and the contractual situation which did not encourage collaboration. BIM implementation works best with certain methods of project delivery that encourage collaboration. Furthermore, while training people for utilizing BIM, educating them to have a collaborative mindset is inevitable. Therefore, utilizing BIM collaboration tools, following BIM collaboration protocols and havening a collaborative mindset, the architectural firm together with others can find solutions to issues better and quicker.

6.3.6.2 Proposed BIM system analysis

Previously, we presented our analysis of the interviews and the studies of the coordination unit artifacts. We found out the issues that the unit was dealing with and discussed how BIM could address those issues. In this part, we present the analysis of our proposed BIM ecosystem for one particular problem in the project, the case of parking heights. We modeled the parking levels in Revit and modeled the real-life situation in a BIM ecosystem. The following are the results.

Statement: BIM enables design through simulation

The early stages of building design include a number of decisions which will have a considerable influence throughout the rest of the project development process. Eventually such decision determines the building performance and function, aesthetics and other aspect of the building. Energy simulation to understand how building behaves in terms of energy, has been around in the industry for quite some time. As BIM models ideally contain the information of its consisting parts, such simulation is considered an integrated part of programs such as Revit. Nevertheless, here in our case study we are referring to another type of simulation. It is about simulating the real-life activities that happen in a building.

By modeling the parking levels and placing the MEP systems, now we could simulate the movement of cars with a Revit plugin called Transoft. This would precisely regenerate a real-life situation, like having modeled the real world in a digital environment. It is evident that by employing such technologies more informed decision about the parking levels heights could be made. The mentioned software can exactly locate the points of interference between vehicle movement and the building elements. This leaves no place of doubt for the design of the parking levels. As new tools come to market and evolve, we will be having capabilities in our disposal that improve the early stage designs and decision makings.

Statement: BIM tools capacities such visual coordination increases accuracy and ease of problem solving.

As mentioned in our talks with the coordination unit staff, in some letters it could be a bit confusing what the subject of issue is. BIM issue tracking systems such as Revizto allow for direct indications on the model, hence allowing for teams to see what exactly they are talking about. Tools such as BIM360 allow for multi-user live sessions that project team members can participate on collaboration sessions while visualizing the BIM model, increasing the accuracy and efficiency of such sessions.

Statement: BIM enables better multidisciplinary coordination

As a common practice in BIM-enabled projects, each discipline develops its own model. These models belonging to structure, architecture and MEP disciplines, get aggregated in a single model. Here, the coordination tools such as Navisworks, can conduct automated sessions called clash-detection. By giving the system our desired parameters, it can detect clashes and interferences between these models of various disciplines. This is especially important because there are clashes that are not easily detectable by conventional methods, or can be neglected by human errors. This helps to improve the project quality greatly by reducing the design errors and eventually preventing extra costs and construction times. However, this coordination has to be conducted by somebody, and its seems clear that the Architect as the main appointed party should be the most appropriate stakeholder for doing that.

Statement: BIM provides one single source of truth for information to be shared

In conventional methods different disciplines work separately and rely on the 2D information they receive from other parties. In a BIM enabled project, there is one central BIM model, which disciplines make a copy of it internally, work on it and update their work on the central model. This model together with the CDE can be referred to as the single source of truth. Project stakeholders will have access to their required information from the early stages of the project development. This facilitates the collaboration between teams and ensures the ongoing flow of information.

6.3.7 Conclusions

The Vanak project saw complication during design development of the parking levels. The proposed design of the architectural consultant was interfering with the MEP systems and causing disputes about the feasible parking levels floor to ceiling heights. In addition, there were limitation posed by the local building codes which restricted modifications to the design. This caused about a month delay and the final solution to use a different ventilation system would increase the costs from the original proposed system. As collaboration and coordination between project stakeholders played an important role in this situation, this area was the focus of our study. By evaluating the communications and documents regarding this issue, and conducting interviews with coordination staff, some major problems contributing to this issue were recognized.

Next, the BIM potentials to address such issues were studied. The extends of a BIM ecosystem suitable for the case were determined, and articular aspects of it were introduced. The three dimensions of People, Product, and Process in both the existing situation and the proposed BIM ecosystem were extensively discussed. Eventually, a BIM model of the parking levels was developed to be at the core of the ecosystem. Finally, the suitable BIM products were chosen, the processes were described and considerations about people were determined.

This case has served to illustrate how the use of BIM can improve many of the issues found in the Vanak project. As we have seen, traditional communication methods have become obsolete because others have appeared that allow them to be centralized in a common collaborative environment in which the messages of each stakeholder can be traced and referred to specific locations of the model. Since this model accurately represents what each party is designing, communication refers to something tangible that all parties can recognize in the same way, eliminating misunderstandings and avoiding lots of bureaucracy, On the other hand, centralization in the cloud allows us to overcome distances between firms that are located in different countries.

However, we can also conclude that implementing collaboration environments based on BIM requires an investment that must be taken into account. Not only is it about the software, but especially the training in its use and in the culture necessary to collaborate through these tools. People tend to cling to their habits and the use of their tools and processes as always. Thus, although we make an ECD available to stakeholders, this is not a guarantee that it will be used. For it, an actor is needed to take care of the collaboration process. For example, reminding agents to use ECD communication systems every time they send an e-mail and preaching by his/her example. This figure can fit perfectly with the architect, especially when it is the main supplier of the appointment. As our studies on the exiting collaboration method of Vanak project revealed, the coordinator from the architectural consultant played an obviously more effective role in the project coordination. In the case of a BIM-enabled project, such a condition can be applied. Although BIM coordinators can come from a third party and not from the design teams, it is better that all project participant takes this responsibility and the architects can fit this role better due to their global vision about the product they are designing and the that they usually assume about the general design.

Then, architects acquire a broader coordination role, not only dealing with their own discipline and how the rest of the disciplines fit into it. They act as a global moderator, since, for example, a problem between structures and MEP systems must also be addressed. The lack of such communications between these parties can be fatal for the final architectural result.

6.3.7.1 Codes

Coding results from the documents and observations:

People: attitude (collaborative mindset) – willingness to share – taking responsibility – leadership role

Product: compatibility – lack of specialized tools – related hardware/software

Process: Standards – Protocols – Automation – data distribution

Coding results of the interviews:

People: information sharing – responsibility

Process: information distribution – automation – manual issue log – design review – organization – lack of information – decision making

Product: information accessibility – issue tracking tools – technology maturity

Coding results from statements:

People: willingness to share information – clear roles and responsibility - ownership

Products: software functionality

Processes: information exchange method

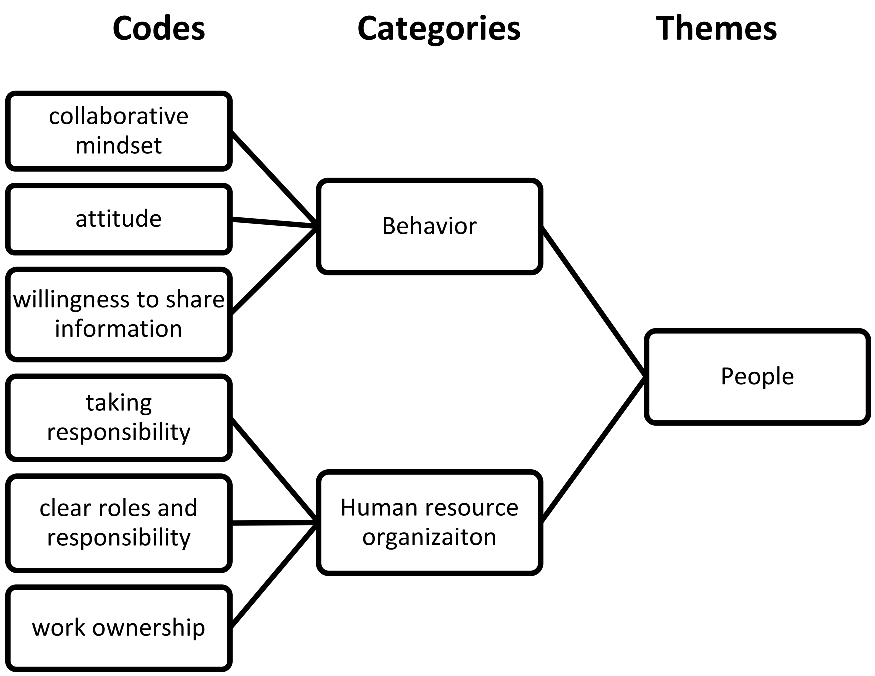

Figure 50 Codes and categories of the People theme

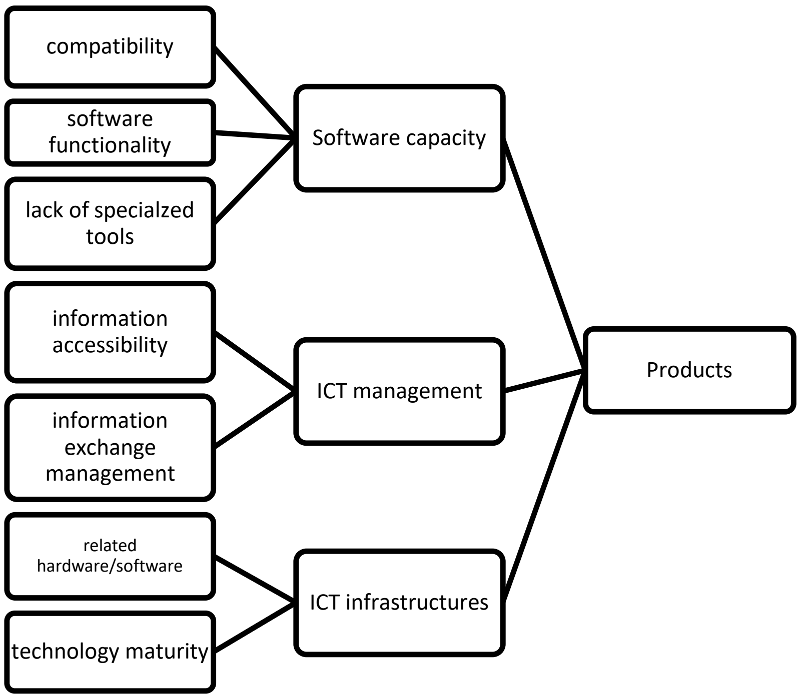

Figure 49 Codes and categoreis to the Products theme

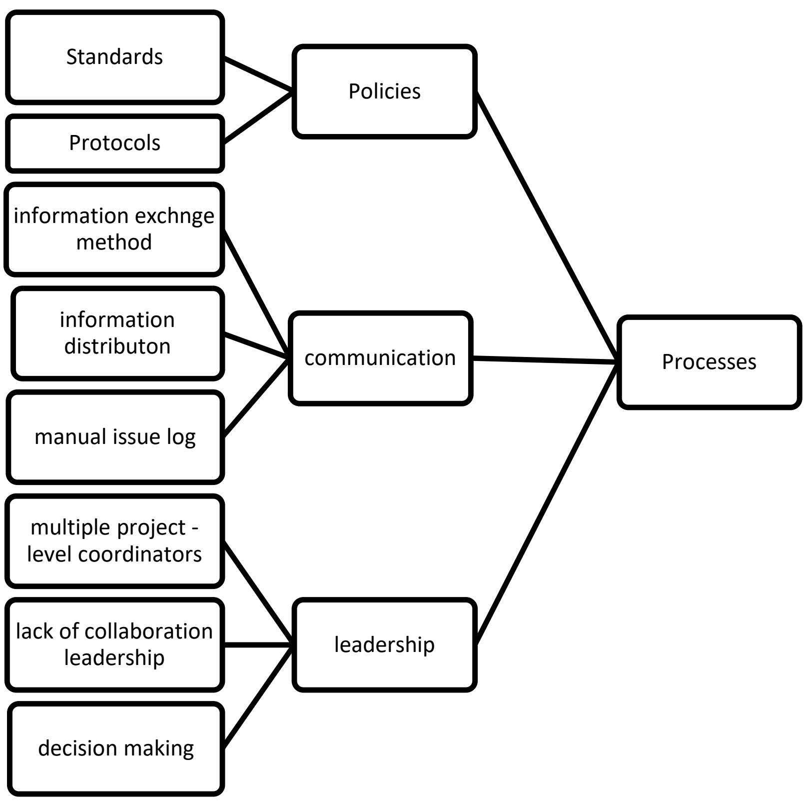

Figure 51 Codes and categories of the Processes theme

6.4 Case Study 2: Campus de la Generalitat project

This case study is about the integration of one of the innovative technologies that has recently been attracting attention from various sectors. Based on advanced visualization technologies, Virtual Reality (VR) has been considered to be promising for the AEC industry as well. With this case study, we try to integrate VR into the daily practices of an architectural firm and their collaborator through BIM. This case study is important to this research for several reasons. First, it points out two hypotheses of the research. Secondly, the experiment designed for this case has been conducted on a real project and its stakeholders. Thirdly, it was done in collaboration with a software development company to examine some of their most advanced product features. Finally, we published an article about this experience in a prominent journal called ‘’Visualization in engineering’’, a Springer’s publication.

6.4.1 Reasons for undertaking this case study

Collaboration issues: Talking with the participants of the project, we encountered to areas of interest for investigation. First, the architectural team wanted to examine innovative ways of involving the clients into collaborative processes. They wanted to use their BIM models to create renders and walkthroughs to better present their work to the client and hence, receive their feedback. We suggested that virtual reality can be a solution for such presentations. However, they were reluctant about it because they assumed difficulties that come with creating a VR scene. We asked them to participate in this case study to evaluate the workflow of integrating VR in their technological pipeline. Second, the MEP wanted to ensure that the design of the mechanical rooms are appropriate for the future maintenance operations. The already used Naviswork for clash detections, but wanted to have a better understand of spaces between MEP equipment to ensure the maintenance operation will perform smoothly. As we were aware of the features of a VR software that allows for simulation of such an activity, we asked as well to join the experiment and evaluate the VR environment for their collaborative purposes. Another important point for choosing this project was that it was fully BIM-enabled. Therefore, we could study their BIM collaboration workflows and evaluate the impacts of integrating VR as an advance ICT into their workflows.

Personal reasons: The reasons for undertaking this case study was based on two natters. Firstly, I was working with CL3VER, a high-tech company specialized in web-based visualization technologies. The company had just made a move to enter the AEC sector, with a focus on visualization for BIM and architectural presentations. Therefore, I had a firsthand know-how knowledge and experience about this subject. Secondly, the project and architectural practice under study in this case, was already BIM-enabled. Furthermore, the project was under construction at the time of the case study and we could have the real participants of the project in our study. This made it possible for them and for us to have a direct evaluation of our proposed VR-integrated workflow, with their actual workflows used in the project.

6.4.2 Case specific Methodology:

The phenomenological study was adopted for this research. The goal of qualitative phenomenological research is to describe a "lived experience" of a phenomenon. As this is a qualitative analysis of narrative data, methods to analyze its data must be quite different from more traditional or quantitative methods of research [130]. Data collection was performed by the description of participants of their lived phenomenal experience that was possible through conversations with them and semi structured interviews. Furthermore, a questionnaire was filled by the participants right after the experience. The reason for this was to document their first-hand impressions and feelings.

We designed the questions to be as less directive as possible, without suggesting or leading towards particular answers. We also tried to put together different types of question such as multiple choices, ratings and open answer question and the participants were also asked to describe freely their general impression of the experience. Moreover, we relied on qualitative data obtained by our direct observations during the session. Assuming that the phenomena of interest have not been purely historical, some relevant behaviors or environmental conditions will be available for observation. Such observations serve as yet another source of evidence in a case study. As during the session other colleagues of the participants who were immersed in VR were present in the room, we also heard their observations. These were the main sources of the case study evidence.

6.4.3 Case Study objective

Through this case study, we evaluate one of the research hypotheses which is the integration of digital technologies in architecture through BIM. The case also focuses on BIM collaboration as a key factor in a successful BIM implementation and visualization which is at the heart of the BIM collaboration. The qualitative data obtained will help answer the research questions and contribute to the overall purpose of the research. The notion of integration here is to be able to use these technologies in daily practices of architectural firms, eliminating the need for outsourcing and extra times and costs. This requires that these new technologies fit in the technological pipeline of an architectural firm. BIM-enabled practices have already been digitalized to some extents which facilitates the integration. As in BIM we create a digital model enriched with data, it can be used in numerous ways. Visualization of a BIM model is one the main use cases in BIM-enabled practices. If we can create high quality renders directly from our BIM model, or send it with a click of a button to a VR environment without extra developing and creation of separate models, then we have integrated these innovative technologies in our practice.

There has been an evident move from software developers, whose products could be utilized in the AEC sector, to use BIM models as a source of information in their products. For example, game engines such as Unity and Unreal, have been used to create platforms for BIM collaboration. They can import the geometries coming from file formats such as Revit or IFC, and visualize them in the platform. The performance of such tools depends heavily on hardware components, specially the GPU. As BIM-enabled practices have already powerful computers to handle BIM software such as Revit, they are often able to utilize the mentioned.

An objective of the case study was to evaluate a virtual environment where a design review, collaboration and project decision communication session could be conducted. The characteristics of the collaboration method included its fitting in the current workflows of the participants' firms and being integrated in their technological pipeline. Therefore, the VR scene and related activities were based on the BIM models and processes the participants employ in the development of a project under construction in Barcelona at the time of our experiment.

The case study tries to document the participants' experiences during the sessions in VR, their perception of the content that was presented to them with which they could interact in VR, their impression of the nature of VR, their comfort during the session and their final thoughts about its practicability in their everyday practice. For this reason, the hardware and software utilized during the experience were constant factors.

6.4.4 Theoretical ground

The environment in which collaboration sessions take place is a major factor determining the efficiency and success of collaborative workflows. A number of underlying processes, tools and technologies are fundamental to the success of a lean and BIM project, as has been demonstrated by some of the completed projects [131] [132]. BIM model visualization technology is the core and the engine around which most of BIM collaboration tools have been developed. Visualization is done by different methods and on different mediums, ranging from smart phones to rooms equipped with large screens such as the concept of BIM Big Room. The "Big Room" in construction refers to a large facility supporting the colocation of the entire project team which was described in previous chapters. The Big Room framework has been proven to improve trust, collaboration and communication amongst stakeholders [133]. However, today's practice of using "Big Room" has some challenges [134]. A problem is that it demands the physical presence of project participants hence making it difficult specially for long-distance project teams.

In this case study, we evaluate a BIM-enabled workflow based on virtual reality technologies, as the medium in which BIM models are visualized. It provided an environment where collaboration sessions can take place without the need of the physical presence of the project participants. BIM research needs to pay more attention to the people, process and their overarching interaction with technology and therefore participants' feedback was essential in this study. Social theory and behavioral science theory have been applied in understanding the decision-making processes of geographically dispersed design teams who used game-like virtual reality systems for collaboration [135]. People will be more encouraged to engage in collaborative workflows if such activates are of a more stimulating and amusing nature, in contrast with burdensome and mundane processes. The issue can be addressed by the use of more attractive activities, such as being in a VR environment.

As a medium, VR has three defining characteristics, it is interactive (users can interact with models), spatial (models are represented in three spatial dimensions), and real-time (feedback from actions is given without noticeable pause) [136]. VR provides a spatio-visual representation of the design object and has the potential to become a highly effective instrument for exploration of digitally modeled architecture. The use of stereoscopic head-mounted displays (HMDs) allows stereovision and thus a depth perception in digital environments. The degree of immersion is directly related to image quality and the reaction rate of the HMD. Because the computer records the head and body movements, the display responds to the user, giving the impression that he is immersed in the environment that surrounds him. The result is a spatio-temporal experience and the sense that the user is present in the virtual environment. This sense of presence is positively correlated with the user's level of interaction with the virtual world [137].

During the design process of a building, the outcome depends on the involved people's interpretations, perceptions, and prejudices [138]. This is aligned with one of the main concepts of BIM, to involve the project stakeholders in early stages of the design, and VR can be an appropriate medium for this purpose. A common case in construction projects is that some stakeholders are not from AEC sector, and have no familiarity with conventional construction documents. A prevalent problem is that the information and design concepts are not presented in such a way that all stakeholders can perceive them well. In this context, real-time visualizations and VR have been shown to offer an efficient communication platform [139]. VR lets us experience and discuss something that does not yet exist with a common perspective. Instead of speaking in abstractions, VR gives us a more tangible frame of reference. As a result, it tightens the understanding gap between clients and architects, and between visual and non-visual thinkers.

6.4.5 The experiment

The Virtual Environment

To define the virtual environment, we initially had to evaluate the necessary tools, i.e. hardware and software capable of visualizing a BIM model in VR. Previous studies have found VR displayed on Oculus Rift DK2 Head Mounted Display (HMD) to be a promising media platform for visualizing and demonstrating complex spatial 3D models, especially for non-experts untrained in reading technical drawings. At the time of the case study workshop, the commercial version of Oculus has been introduced to the market alongside other kits such as HTC VIVE. In terms of performance and quality the two products are pretty much rated in the same range [166].

They feature two OLED panels boasting a combined 2,160 x 1,200 resolution. Thus, each eye gets its own 1,080 x 1,200 resolution display to mindlessly gaze at. With a 90Hz refresh rate on both headsets and asynchronous spacewarp on the Rift for 90 fps VR, this means there are 233 million pixels, making for a grown-up VR experience versus the 60Hz Samsung Gear VR. HTC Vive and Oculus Rift also have a wider 110-degree field of view (measured diagonally). This results in a virtual reality world that is felt as if it truly wraps around one's head. The HTC VIVE headsets are slightly bigger in size and it's technically heavier at around 555g without headphones included. Oculus is 470g by comparison and throws in headphones. Hence, there was not a remarkable preference over one to another HMD for the purposes of our case study.

We had the chance to use facilities of UPCschool, which is a division of Polytechnic University of Catalonia (UPC). We were given two HTC Vive devices and two high-end computers to handle the heavy task of the VR scene rendering. The two PC units were equipped with the following hardware: Intel® Core™ i7-7700K Processor (4-Cores, 8MB Cache, Turbo Boost 2.0, Overclocked up to 4.4GHz, NVIDIA® GeForce® GTX 1080 with 8GB GDDR5X 16GB DDR4 at 2400MHz; up to 64GB (additional memory sold separately). These specifications are slightly higher than the characteristics of a desktop computer recommended by the HTC company [167] as the minimum hardware requirements for supporting its HMD. Today in the market there are several software available that are able to import geometry and information from different file formats utilized in AEC practice, and visualized them in a VR scene.

Software choice

Depending on the features and tools these software packages offer, users can have different sort of interactions with the model or scene. Therefore, to determine the suitable software for the case study we considered the software features and their required workflow for creating a VR scene, and the software used by the participants so that their file formats could work with the VR software. One of the software that currently has the most features for VR and is compatible with many file formats used by BIM enabled practices, is Fuzor. The justification for this choice are mainly the software capacities that this platform offers. The most important features for the purposes of the case study were the ability to measure and move the model elements in the VR scene and the ability to host a multi-user collaboration session in VR. At the time of the experiment, other available VR platforms in the market such as "Autodesk Live", "InsightVR" and “Enscape” lacked such capacities which were important to the experiment. This means two or more users are able to be present in the same VR environment simultaneously through internet or LAN connection. Moreover, the performance and the ability to handle large models, and the graphic quality of the VR scenes were considered for selecting the software among available choices in the market.

Participants

The Catalonia government, whose project was used for the case study, encourages the application of BIM in its construction projects. It was a tremendous opportunity to utilize one of their under-construction projects which is BIM-enabled. The participants of the case study were the real stakeholders of this project called Campus Generalitat, an office building to host the new headquarters of the Catalonia government. The BIM models were being developed in Revit which then could be exported to the VR platform with its element's information, geometries and materials included in the model.

Members of the architectural discipline (Batlle i Roig) and of the development company (Hines) were invited to participate in a session of the experiment, to conduct an architectural design review of the project. We also collaborated with CT engineers, an engineering firm from Barcelona, as they oversaw the BIM coordination and modeling of the MEP systems of the project, working with another firm which was in charge of the design and installation of the systems. The other part of the experiment involved a collaboration session in VR between these two parties.

The BIM contents

The project was being developed by various stakeholders and teams. As the client required the delivery of the project in BIM, all the teams who were not already BIM enabled, had to collaborate with an external firm to develop the BIM model and implement the related processes for them. The project works had been divided in 10 parts or batches, 4 parts of which had been developed at the time of the experiment. The remaining parts whether did not require a BIM model or were not developed yet.

The models are coordinated in Autodesk Navisworks Manage 2017. To do this, the models in the formats RVT, NWC and IFC are merged weekly, and the IFC format is used to audit the models. CT engineers uses several models to create its BIM content and some more to coordinate with other disciplines. In addition, they use Navisworks both internally and externally to evaluate the work and resolve collisions.

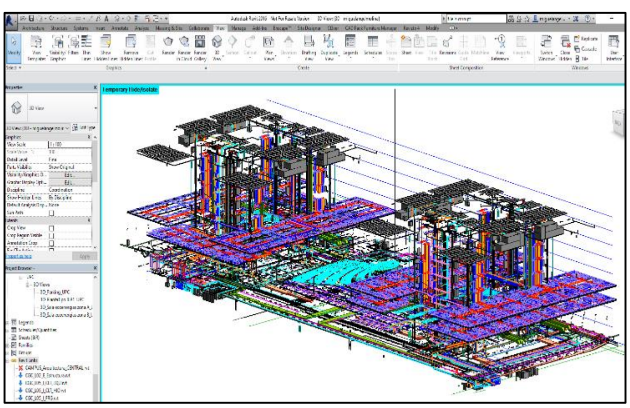

Figure 53 All MEP systems models loaded.

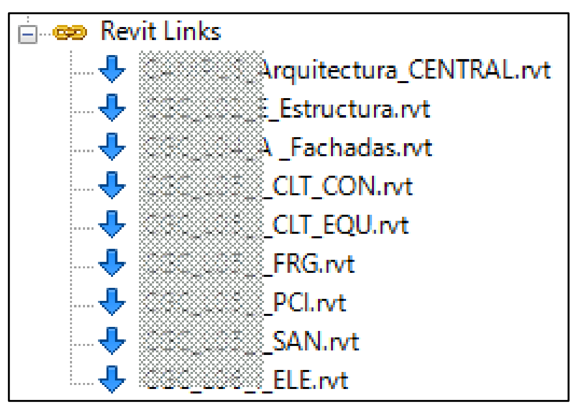

Figure 52 Revit Tree showing loaded linked models.

After the approval of all project stakeholders we received 10 models, most of which contained the MEP elements and we merged them with the main structure and architecture models to be placed in context. The total volume of these models was up to 2GB and our computers could load them all as links. By installing the Fuzor VR collaboration software on the machine, it installs its plug-in on Revit which lets the user export the geometries to Fuzor to be visualized in VR. Almost 40 million polygons were exported to the platform from Revit which was a long and time-consuming process, taking up to 50 minutes. Once imported, the model can be saved in Fuzor file format (*.CSV) which is then quick to load and using that file the user does not have to export the geometry every time. There is also a bidirectional synchronization between Revit and Fuzor meaning the changes done in either platform, will be reflected to the other one while synchronization is active. This feature prevents the need for re-exporting after every change.

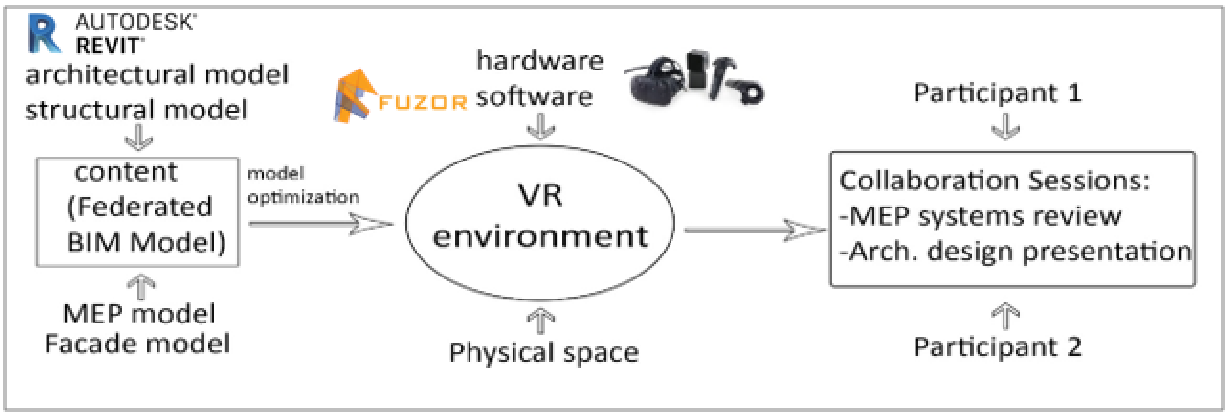

Figure 54 The VR-integrated collaboration workflow

Tasks and processes

Prior to the day of experiment, we met with some of the participants in four sessions in order to practice working with VR, revise the models, check the performance and prepare the hardware and software. These measures were crucial to take in order to assure the experiment would go smooth and without problems and crashes. In the case of crashes and the obligation of restarting the platforms, we would have needed to cease the experiment for some time. The main problems that arise when exporting a BIM model into a VR scene are related to the heavy task of rendering VR scene in every frame. It is important to keep the model files in a reasonable range to reduce the pressure of rendering in the computers. It can be done by removing and hiding the elements that are not important in the collaboration session and by exporting only the parts of the models that are of interest. Given the tight agenda and the timetable assigned to different participants during the day, it was important to avoid such incidents, as it is in real life meetings.

6.4.5.1 First Experiment: MEP Coordination

The case study had two main sessions, the first one was a MEP systems review that was led by the BIM modeler and was addressed to one the MEP installers. The two participants were immersed in VR in two rooms that were adjacent and there was a moveable partition wall between the two room. The partition had to be placed in such a way that the two pairs of HTC VIVE tracking sensors would not interfere with each other, yet the participants could hear each other and communicate verbally. In case of the participants being in distant location, Skype or similar tools could be used for communications.

As there was a high density of the mechanical equipment in one of the service rooms in -1 parking level, the objective was to check the position and the space between the MEP elements in that room. This is especially important for the maintenance of these equipment which require regular inspections and replacements of the components. Viewing the model in 1:1 scale also allows for model checking itself and to find modelling errors which can affect the accuracy of data output from BIM models.

The two participants in this session collaborated in VR for about 20 minutes, they appeared as avatars in the VR scene and could follow each other in the model and review the MEP systems. It was evident that visualizing the model in VR could clarify some obscure parts of the project that are not clearly visible in conventional 2D drawings or even 3D scenes viewed by monitors.

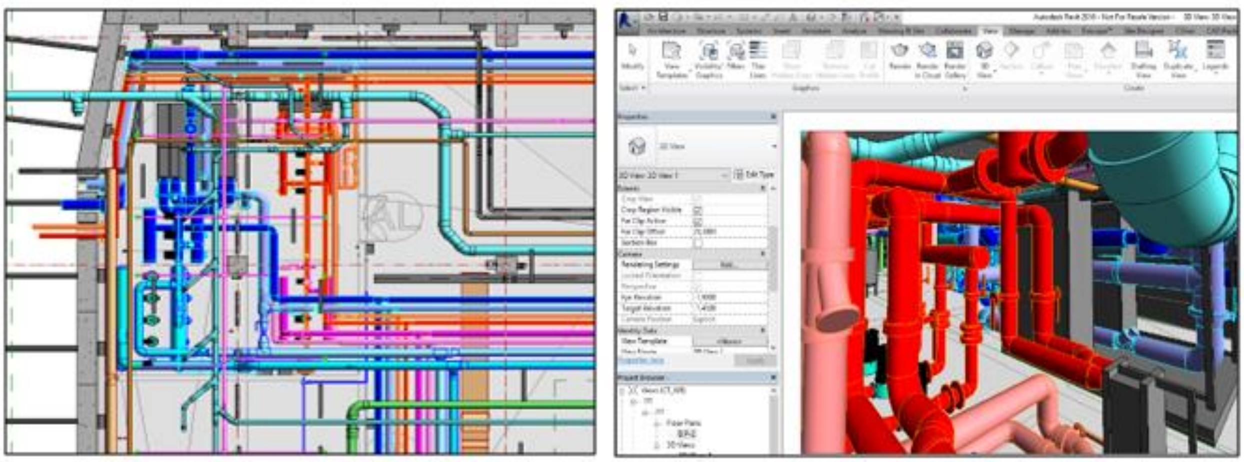

Figure 56 Plan and 3D view of the MEP room.

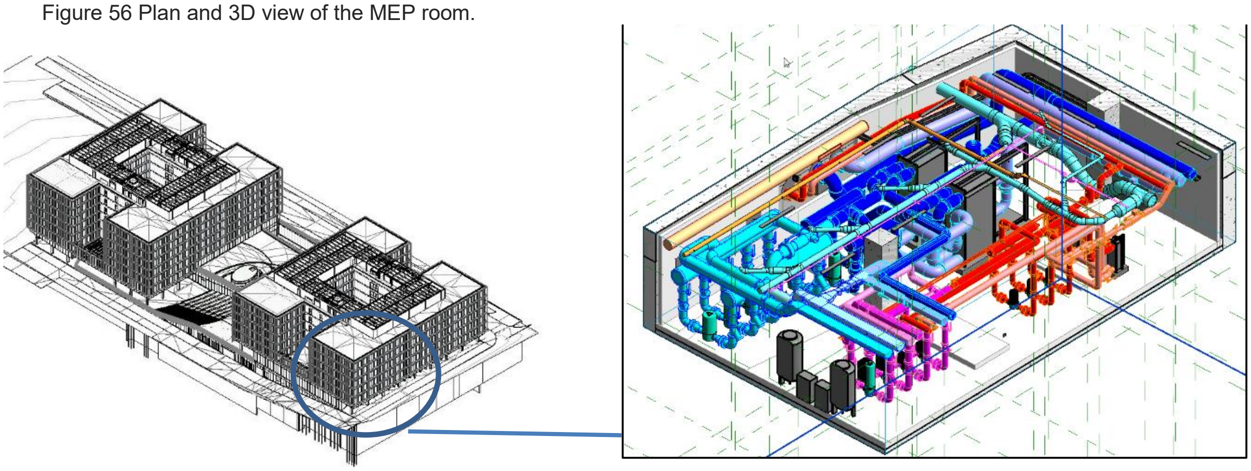

Figure 55 The federated model, including all disciplines. The MEP room is located in P -1 level

One main advantage was that the participants could sit and move in the model and see pipework conditions that are difficult to realize otherwise by conventional review methods. They could see the installations together with the structure and architecture models loaded in the scene, which helped with the clash detection between the disciplines.

The measurement tool allowed measuring the distance between two points to check the spaces necessary for maintained maneuvers. The movement tool of the platform granted the participants the ability to move in the VR space the elements by selecting them with HTC VIVE joysticks which was a sort of simulation of a real component replacement procedure. The execution of this task with the joysticks was easy and needed some precedent practice. These two main participants had practiced before the session started for

Figure 57 Two participants collaborating in the same VR scene

about half an hour. Other colleagues of them who were present in the room then also tried the VR experience as well and were also interviewed later. This simulation of a real-life situation in which the collaboration was taking place, could only be done in VR, and no other collaboration method.

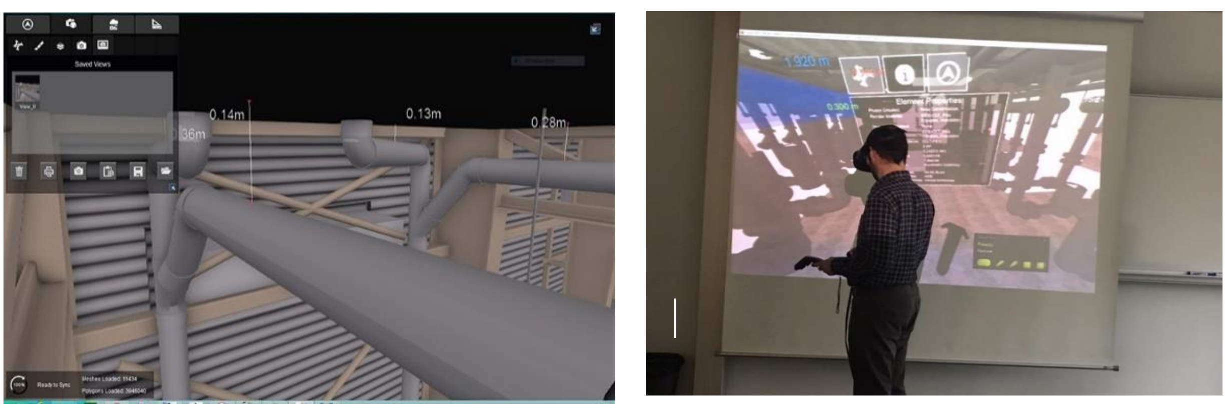

Figure 58 Measurements placed in VR

6.4.5.2 Second Experiment: Architectural Design Review

The second session was focused on an architectural design review. The participants from the architecture team of the project and from the project development entity were immersed in VR to review the architecture design of the project. A part of the model was chosen for the session that included the entrance area with several voids and skylights which was architecturally more interesting to be reviewed and experienced in VR. Moreover, the exterior areas and facades and the entry to the building from the courtyard were reviewed. The architecture firm indicated that they do not load all the materials and textures on their Revit models, as it will increase the volume of the Revit files. This could cause an inferior performance of their computers. It is noticeable that on today's average computers, loading large sized Revit files may run the computer into crashes or slow performance, hence the models are often divided into smaller models or are segmented by Revit worksets.

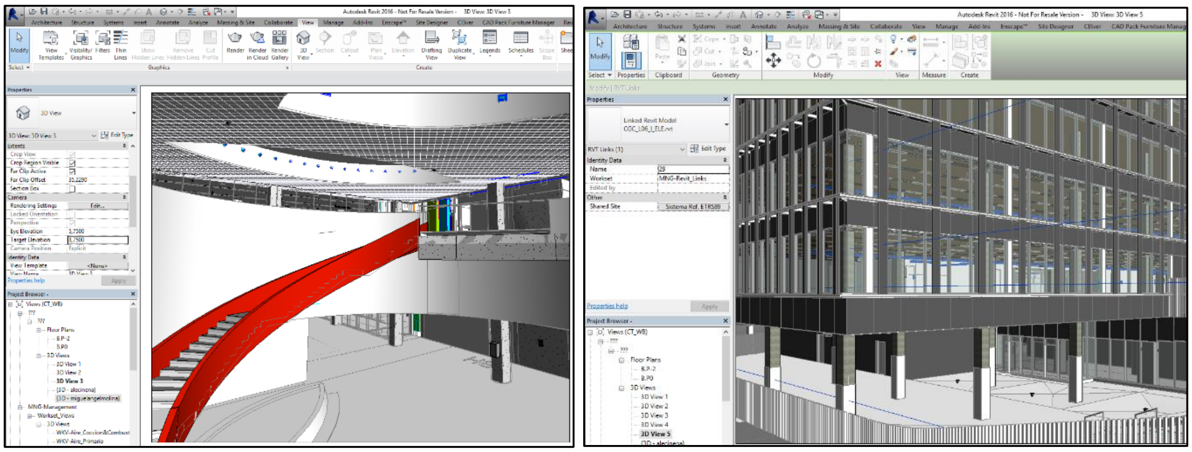

Figure 60 Views of the parts of the building visualized in VR.

Figure 59 Project stakeholders observing the Architectural design review.

The software allows for two rendering modes of draft and realistic, and as it was about the architectural design review, we used the realistic mode. This would impose a tougher task on the computers Graphic Processing Units (GPUs). There could be risks of crash, but as during this session only one user was in the VR scene, the experience was smooth. It was exciting for both the designers and the client to be immersed in the model and review the design with realistic feel of scale, dimensions and proportions. This level of perception of spatial relations before a project is built, is unique to VR as well.

6.4.6 The results and discussions

6.4.6.1 Observation from the experiment

During the preparation stage, we learnt that it is extremely important to check the hardware and software of the computers to have an acceptable performance. In our first experiments, there were some degrees of latency in image rendering in the HMD which made it almost impractical. After updating graphic card drivers, we adjusted the settings of the HTC VIVE units to apply direct mode which ensures that the HMD is not recognized as a monitor. In addition, we replaced the analog connectors with HDMI ones for the output to the video projectors and the performance improved considerably.

One common problem during VR practices can be the crash of software handling the VR scene, especially when the models are quite large. To avoid this, we applied section boxes in the Fuzor software, so only the parts of the model that were of our interest for specific activities were rendered. It can be said that the average hardware available in the market and the software currently able to run VR scenes for AEC file formats, are at an edge of operability. The computers that meet these preconditions can be quite costly and the averagely priced desktops or laptops currently used by consumers are not able to handle a VR experience. This can be considered as one the obstacles for the wide adoption of VR-based workflows in AEC.

Participants were fairly quick to learn how to interact with the model, and in a period of five minutes most of them were already comfortable with the devices and could perform the activities. The new collaboration environment also seemed to enhance the participant engagement in collaboration activates. Often shortly after starting the experiment, we could receive feedbacks and suggestions about the experience. The participants expressed what features and additions to the software could help them with performing activities in VR. We reported these feedbacks to the software company and they approved that they are working on implementing them for the coming releases. The newly released version of the software included a markup tool, one of our suggestions.

The practicality and advantages of a design review in VR was obvious to most of the participants, but there were doubts about its adoptability as a daily practice. A main concern was about the workflows of exporting a Revit model to a VR scene as they imagined there is a need for a great deal of preparation. They were informed that in fact, by available tools in the market this workflow has been simplified, some creating a VR scene with 1-click solutions directly from Revit. Actually, extensive efforts in software development companies are focused on homogenizing the workflows and processes in BIM enabled practices. Interoperability between software and automation of processes and easy-to-achieve outputs like renders and data are all helping AEC professionals doing more in their work. These measures are facilitating the integration of digital technologies in the architectural practices and other sectors in the AEC industry.

Codes from observations:

The following codes are extracted from the direct observations during the preparation and execution of the experiment. Together with the codes from interview, they will form the codes of this case study.

People: Learning new skills – Activity Engagement

Process: design review environment – model visualization workflow – virtual communication

Product: hardware/software compatibility – computer performance- IT infrastructures – Technology immaturity

6.4.6.2 Interview results

To achieve the first-hand feedbacks from the participants, they were interviewed right after each one's experience. A survey was conducted in the format of interview and a web-based questionnaire. We asked about the participants' and their firms' background, the experiment with VR and their thoughts about BIM collaboration using this digital technology. We gathered feedback from nine participants who wore the VR HDMs and experienced the scene who were from various AEC disciplines.

All the users had experience with BIM to some extend and near half of them are working in fully BIM enabled practices (Figure 61).

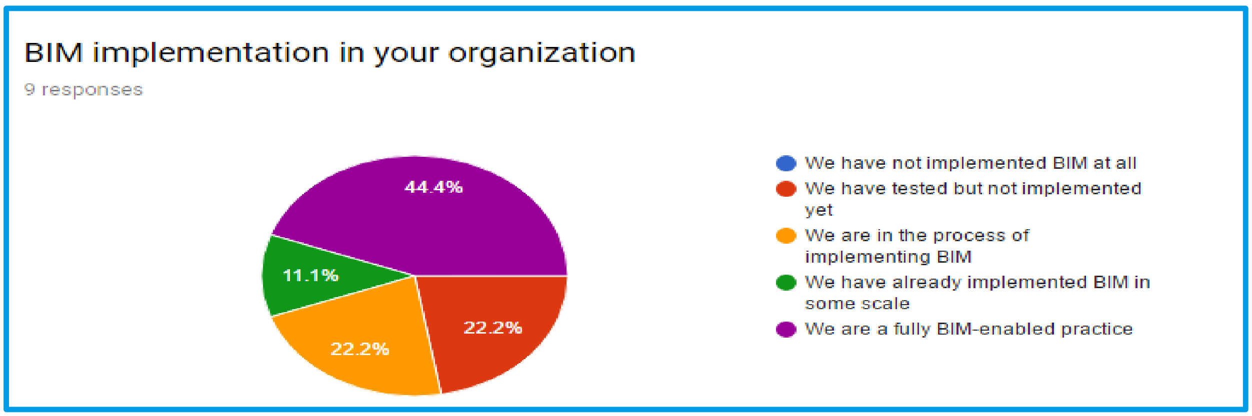

Figure 61 BIM implementation statistics

The majority of the participants had no or little experience with VR before, and nearly all rated the experiment as very interesting. One of our important questions was how practical do the participants see the daily use of VR in their offices. The average response was to some degree and for particular uses,

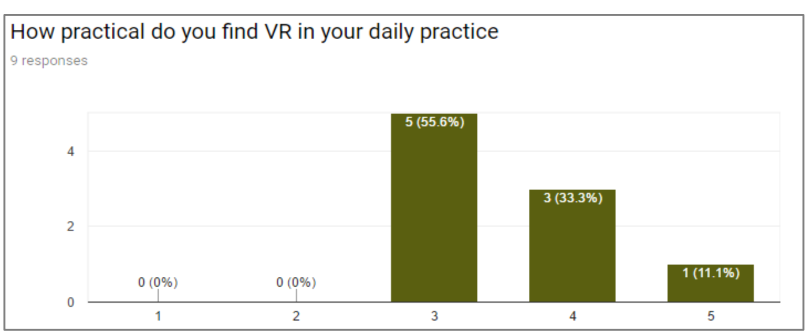

Figure 62 The applicability of VR chart.

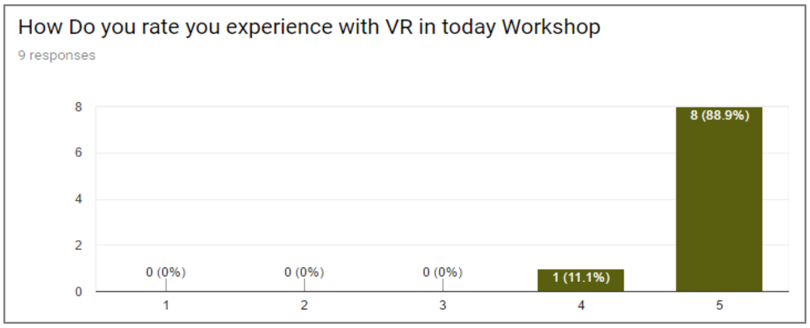

Figure 63 The experiment impression chart.

while nobody found it not practical at all (Figure 62). The responses came from a variety of professionals with very different daily tasks, also their level of knowledge about creating VR scene workflows could affect this response. They were also asked about their impression of the conducted experiment which was mainly satisfactory (Figure 63).

Some of the disadvantages usually mentioned with the use of VR are its discomfort, the physiological difficulties it may cause and the process of getting used to it. In this experiment, almost all the participants indicated that they were quickly, in a range of under five minutes, feeling adopted to the VR environment. About more than half of the participants felt very comfortable during the whole experience.

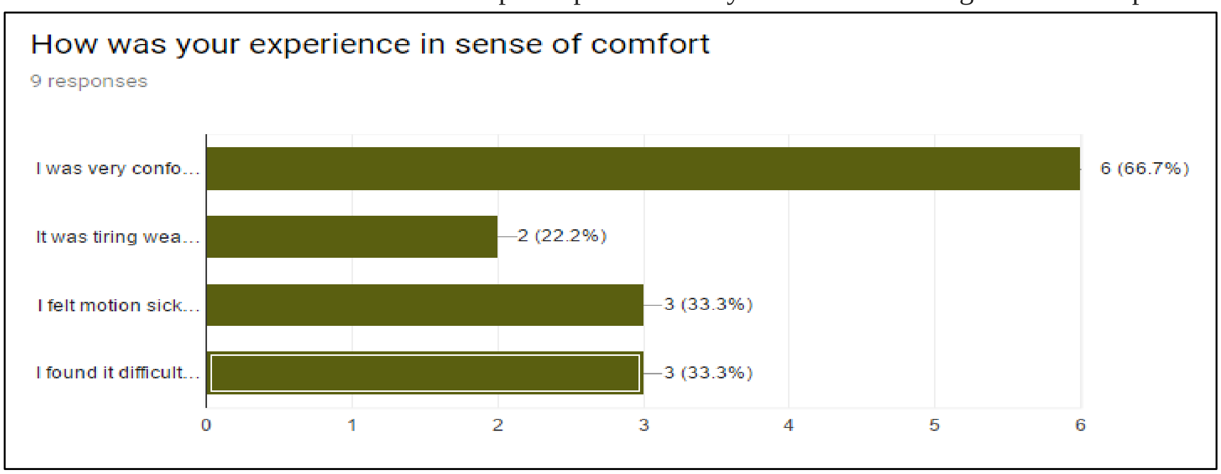

Figure 64 Comfort feeling chart

The rest had felt some degrees of motion sickness, have felt tired after some time wearing the HMD or found it difficult to move around with the device. About less than half of the participants found the process of getting used to the VR environment and devices very easy, while others expressed some degrees of difficulties for the process (Figure 64).

The participants were asked to describe what features of the experiment were more impressive to them. Most of the answers were implying on the sensing and perceiving the space in real scale or as one

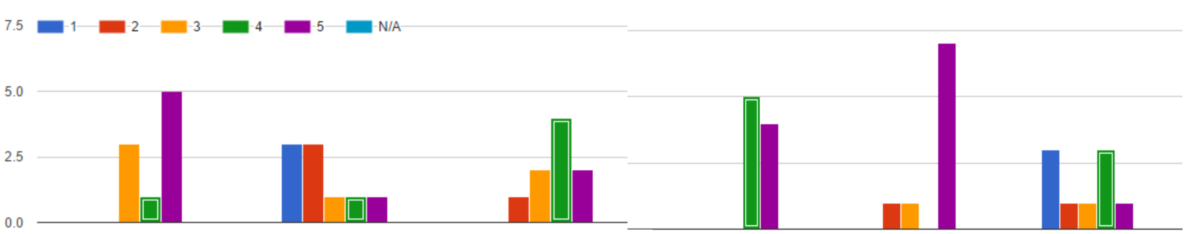

Figure 65 VR use cases chart

participant said ‘’ the sensation of being inside the building’’. It is on the grounds that in VR the users not just visualize and view the model, but are inside or around it, resulting in a level of immersion is not possible by any other mediums. Having the ability to view the building elements information in VR and the speed and ease of movement inside the model were other impressive features to the participants.

Another important aspect of VR that we asked about, is its use cases and applications in different areas of AEC professionals’ activities. The participants were asked to rate the applicability of VR from not recommended to highly recommended in the following use cases: Internal design review with colleagues, personal use in office, internal collaboration, collaboration with other project teams, presentation to clients, project decision communication to site workers, simulation of a project issue (handicap access, etc.). The highest ranked use case was the presentation to the clients use case. Also, collaboration with other teams and internal design review were use cases they would recommend the use of VR (Figure 65).

Given that the participants were of different backgrounds with different levels of acquaintance to the VR software and tools available in the market, we asked them how they see the workflow of visualizing a BIM model in VR from 0 being easy and straightforward to 5 being difficult and burdensome. The majority indicated 3 in the range of difficulty and the rest found it easy and straightforward, with no one rating it as difficult and burdensome.

Following the questions about the experiment and the applicability of VR in AEC practices, we asked the participants what are the main obstacles for adopting VR as a tool in their activities. Some choices were given and moreover, they could express their own opinion about what they see as an obstacle. The highest rate goes to the software and hardware costs associated with VR implementation (figure 66). No One saw its lack of application as a hurdle and some indicated the ‘’resistance to change from personnel and firms’’ or the need of ‘’knowledge of the technology and its scope’’ can be considered as barriers to the implementation of VR-based practices.

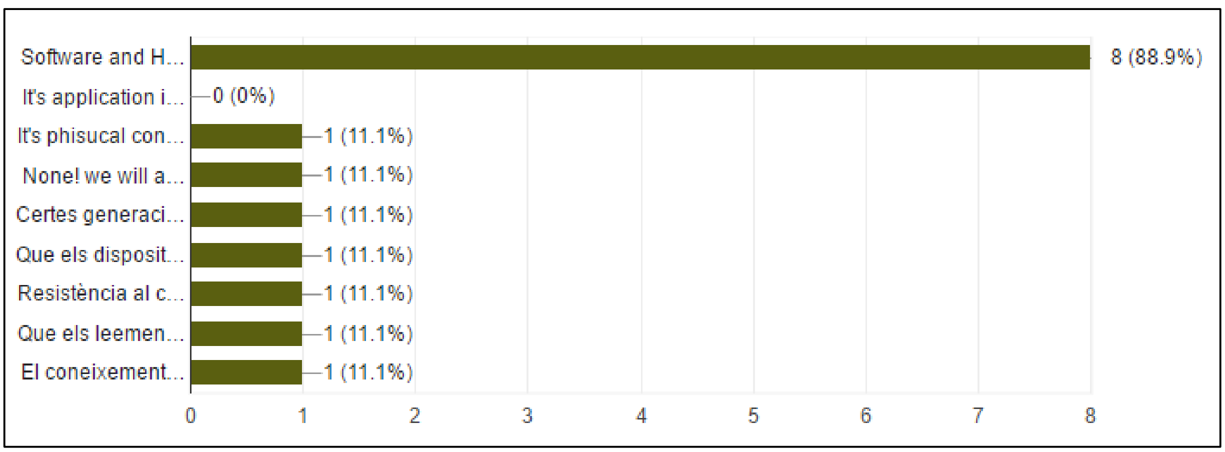

Figure 66 Obstacles in VR adoption chart

Our last question was about what features the participants would like to see in future VR tools. Some comments regarded the software we used for the experiment which were communicated to the software company, and some regarded what can be interesting to have in VR tools in general. One of the comments was on the ‘’simulation of the behaviors of the building’’, for example the structural wind resistance being mapped on the model. Simulation and visualization of data on the model are currently practiced in BIM processes, most commonly are the solar and daylight studies or solar heat gains that can be visualized on a Revit model by available plugins, and to be able to see these kinds of visualizations in VR is definitely an added value.

When asked about the BIM-enabled collaboration in VR different opinions were expressed. As one said: ‘’collaborative session can be tiring, but the fun element of VR can help with that’’. The co-location requirement of BIM collaboration rooms is also another problem that can addressed with the virtual presence of the participants. Coordination model of projects can be complicated and being immersed in them can help with a better understanding. Client engagement was another important point perceived in this method. Instead of 2D drawings or 3D models that can be hard to read, clients can have a better understanding in VR. As one participant said: ‘’in this way we can bring clients easier into the collaboration sessions’’. The impact of implanting BIM for a VR collaboration is simply the ease of its integration into daily practices. As a participant mention: ‘’ we would never have tried technologies such as VR or 3D printing if it wasn’t for its easy workflow in our BIM environment’’. We see here some issues that were difficult to work on in traditional methods, is addressed by the integration of advanced ICT tools.

Codes from the interviews:

People: training – awareness – motivation – co-location

Products: BIM maturity – software functionality – software/hardware cost

Processes: decision communication – joint decision making – collaboration environment – efficient workflows

6.4.7 Case Study Results

This work addresses two issues of conventional BIM collaboration methods. First, the need of physical presence in methods such as Big BIM room and second, the lack of full immersion in model visualization. Through a lived experiment, we evaluated a VR integrated collaboration workflow in a real project. The collaboration sessions had two goals. One was testing a workflow which could enable us to perform a clash-detection of disciplines via simulation. The evaluation was on some innovative features of a VR software, allowing for virtual presence of multiple users and simulation of on-site tasks. The other part was about project design review, where the architects of the project presented some parts of their design to the client.

An aspect of this work that makes it distinct from other experiments was that the participants were asked to perform tasks that they were already involved with at that time in their firms. Only that they were require to perform the tasks with VR as the visualization medium. This allowed them to do a direct and sensible comparison between a VR enabled workflow and their conventional ones. The project, their BIM ecosystem, the participants were constants of the real-life project while the variable was the use of VR as the collaboration environment. Using this method, the architects can be virtually present in interdisciplinary collaboration sessions contributing to the efficiency of such sessions.

A common problem in the maintenance of building systems is the accessibility to the MEP elements and the ease of repairing and replacing them. Through this live experiment we found out that VR has a practicality of addressing this issue by simulating a real situation. Although previous research might have suggested assumed use cases for VR in AEC, the particular feature of this software allowing for such simulation was put into an academic case study for the first time at the time of the experiment. It was resulted from the interviews participants believe such simulation can be practical in addressing the issue, although they suggested some software functionality to make it more practical. New releases of the software included features such as a permanent markup tool based on our suggestions. In addition, we found out that the awareness factor, also highlighted as a major factor in BIM adoption, also play a key role for employing VR tools in AEC practices. Most of our participant had no or little experience with VR and did not consider it a functional tool in their practice. The interview results showed that after their experience they would consider the use of VR in their workflow.

Statements

BIM promotes new technologies to be integrated in daily practices

As we witnessed this experience, many participants had not tried Virtual Reality tools before this experiment. One reason for that is the assumption that it would require enormous amount of time and effort to create a VR scene. Once we showed them how easily they can publish their BIM models in VR, many agreed that it can be part of the daily practice. Here we want to highlight the importance of integration and interoperability. The more software and tools can work together and interoperate, the more efficient BIM implementation becomes and it is a key factor to favor the implementation of BIM. The idea is once a digital replication of the building has been created, it can be used for other technologies such as VR, 3D printing, block chain, generative design and other ones.

BIM helps architect with the design process itself

As one of the main characteristics of BIM, the design takes pace in a 3D environment. This helps architects to have instant prototypes of their designs with a click of a button. The integration a VR with BIM, allows architects to view and explore their designs in a 1:1 scale. They can walk in the building as if it has been built. Therefore, the important notion here to consider is that BIM does not only provide an infrastructure for project delivery, but it helps in creative processes of an architect as well. In this case, VR helps with the space perception and understating of design, allowing for better inputs from clients.

BIM helps with problem solving through simulation of real-life situations in collaboration sessions.

A very exciting feature of our experiment was the simulation of an on-site task to validate the MEP room design. The participants in the collaboration session in VR, had the ability to move and relocate the MEP element, and therefore simulate a maintenance task. It allowed them to see if the distances between these elements allowed for an accessible maintenance.

The required investment and the lack of awareness are main obstacles in BIM employment

One evident result of the case study was that the participants new a little about the possible application of new technologies in their practice. It emphasis the importance of awareness factor. If principals of an architectural firms all well aware of tools and technologies that help them achieve more with their BIM implementation, they tend to use them. Therefore, unawareness is an important factor that prevents the utilization of BIM based technologies. On the other hand, it is true that some technologies like VR, need potent computers and they often require an investment on the hardware and software used by architectural offices. This is another main obstacle in utilization of these tools. it is then critical to have a long-term vision on the return of investment. BIM implementation requires a long-term vision.

Codes from the statements:

People: awareness – design perception

Products: interoperability – software functionality – technology integration –software/hardware cost

Processes: efficient workflow

6.4.8 Conclusions

At the heart of the BIM collaboration workflows lays the visualization of a 3D model based on which the AEC professionals can review the designs, encounter clashed and errors and visually communicate project decisions to other stakeholders. BIM authoring tools such as Revit are meant to be used for creating and authoring the models. It means they are not always suitable for visualizing the model for presentational and design review purposes, due to their slow performance while interacting with model. Furthermore, for model privacy concerns it is not always desirable to share the model file. Third party software should be usually used for specific visualizing purposes.

Creating the virtual environment relies heavily on the software and hardware available in the market and the features they offer. The more the software are adoptable and compatible with current BIM workflows and file formats used by a firm, the higher their practicality. The functionality of VR tools for AEC practices, depends on the tools and features the software offer. Some tools are merely visualizers of a BIM model, while others allow degrees of interactions with model and the ability to draw or add elements in the VR scene. It is important for the software companies to have a correct understanding of AEC needs to develop tools that meet those requirements.

Besides, Investment in software and hardware is an essential step towards the adoption of VR. Computers with highly potent GPUs, that cost considerably, are necessary for handling VR scenes. Most of the software available are monthly or yearly subscription based and cost per user. The need for these investments often is an obstacle of VR adoption.

VR is a whole new realm in the cyber world and future works must be focused on realizing its capabilities and the opportunities it brings. By understanding the AEC needs and practices and developing software with features responding to those needs, the potential advantages of VR implementation in AEC can be discovered and evolved. However, at this moment hardware and software requirements are too demanding to generalize its use. But seeing the technological progress that is being made in this field, this should be solved in 5 years, which allows us to assure that the game-changing VR phenomenon is already here.

On the other hand, we have seen how VR environments allow us to establish a new field for collaboration. Not only is it fun, it is also efficient and allows doing tests that previously were only possible on site.

From the point of view of the leadership of the use of VR, it seems logical to ensure that the architect can be its main promoter, since traditionally it has been concerned with the visual aspect of its design.

This circumstance could make them adopt this technology first (something that is already happening now) and therefore, the one that later illustrates the rest of stakeholders on its use beyond visual simulations. But, for that you must start thinking outside the box and find out what other uses can add value to the rest of the participants in the project. For example, as general coordinator of a design contract, they can access to the shard models from the other consultants and use them to improve the design by facilitating future maintenance works. Also, they can use VR in the construction management in order to interact with the contractors in a more direct and understandable way, as seen in this case study. This implies the acquisition of new capacities, both technical and infrastructural. It also implies the assumption of a more client-focused role because the use of VR entails that the customer gives feedback about the design in a direct non-filtered, way.

For all this, future works in the field must be focused on two aspects, improvements and education. Improvements are needed in VR software to run on more conventional computers and to handle more complex models with acceptable performance. Research in the field of computer graphics done by the industry or academics can considerably contribute to such improvements. The education aspect refers to the importance of awareness within the professionals and current students. Architectural and engineering education and in particular BIM education must include topics on the potentials of VR and other innovative visualization tools from which AEC industry can benefit. With more practical tools and advanced taught skills, we will be able to see new workflows and possibilities in the industry practices.

Coding results of the case study:

By aggregating all the codes from observation, interviews and statements the following charts are created. The frequency of codes will be important in the final research analysis.

Codes from the observations:

People: Learning new skills – Activity Engagement

Process: design review environment – model visualization workflow – virtual communication

Product: hardware/software compatibility – computer performance- IT infrastructures – Technology immaturity

Codlings from the interviews:

People: learning – awareness – motivation – co-location

Product: BIM maturity – software functionality – software/hardware cost

Process: decision communication – joint decision making – collaboration environment – efficient workflows

Codes from the statements:

People: awareness – design perception

Product: interoperability – software functionality – technology integration –software/hardware cost

Process: efficient workflow

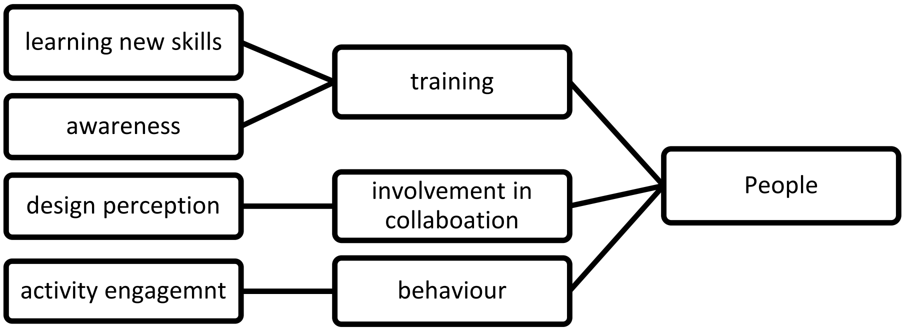

Figure 69 Code and categories of the People theme

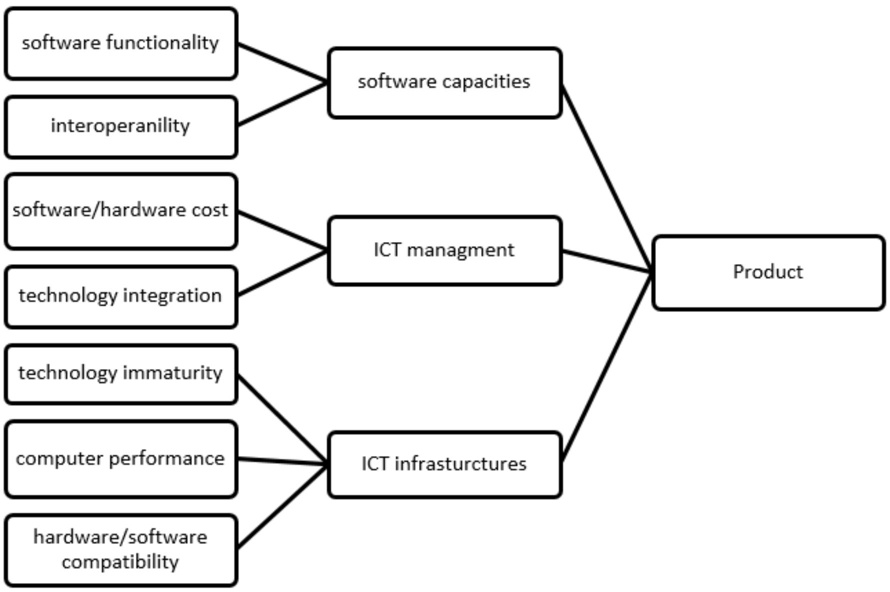

Figure 68 Codes and categories of the Product theme

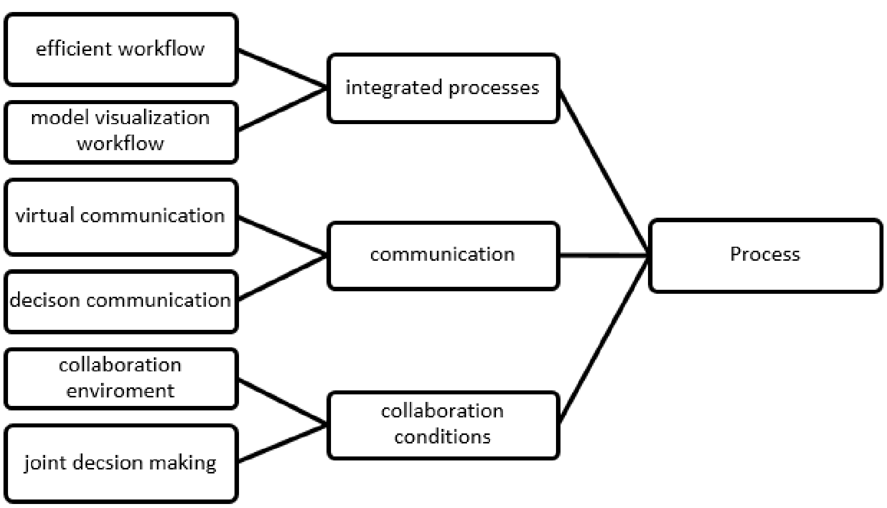

Figure 67 Codes and categories of the Process theme

6.5 Case Study 3: Battle I Roig architects

The last case studies in the research is an investigation about a post-BIM-implemented architectural practice. Following the first case about a non-BIM-enabled project, the second case that was about a recent BIM-implemented project, this case is about a practice that already has been developing projects in BIM for some years. To conduct this case study, we have utilized Pennsylvania state university guide for research on BIM through case studies [128] . The guide includes general guidelines and semi-structured interviews with staff of an organization. This is done in order to understand the impact of BIM implementation in a practice. In the following, we present the case study methodology, the semi-structured interviews and the analysis of them and the artefacts. Eventually, we present our learnings from the studies.

6.5.1 Reasons for undertaking this case

For the purposes of our research, we needed to study a BIM-enabled architectural practice. One that already has some years of experience with BIM which could share with us their perception of their BIM implementation. As one of the major architectural practices in Barcelona with some years of experience with BIM, we had the possibility to work with Battle I Roig office. We already had collaborated with them for case study 2, and we were relatively acquainted with their practice. I addition, we had the chance to work directly with the BIM manager of the office, which would provide us with the opportunity to study their BIM implementation through the person who implemented the firm's BIM strategy. For these reasons, Battle I Roig was a suitable choice for studying a BIM-enabled architectural firm.

6.5.2 Methodology

The following outlines the methodology that will be used to conduct and document case studies of organizations. The methodology includes collecting background knowledge of the organization, leading focus group meetings, conducting semi-structured interviews with operating unit heads and unit members, and performing artefact analysis of the organization. At the conclusion of the case study, we will prepare a report with a summary of the observations.

The report will include a background of the organization, a background on the organization's implementation of BIM, a summary of the methodology used on the case study, an analysis of the BIM Planning Elements for Organization and conclusions. The planning element analysis will document the mission and goals; uses and tasks; processes; information needs; legal considerations, infrastructure and personnel. The personnel section will include the organizations hierarchy, roles and responsibilities, and change readiness.

Analysis of Organizational Background

Before any on-site studies are initiated, an analysis of the organization's internal structure should be conducted. it should be determined and documented the purpose of the organization and their current public BIM use. This will be completed through the analysis of organizational websites and other publications. This will help to ensure that the organization's internal processes are understood allowing for interviews to be as productive as possible. The BIM Manager should verify the organizational background and add information if necessary.

Meeting with the BIM Manager

Early in the process an informal meeting with the BIM manager, the lead contact for the organization, should be conducted. In this meeting the researcher will review the methodology for the case study and establish a more detailed plan and schedule. The goals of the case study will also be distinctly defined during this meeting. Additionally, the BIM manager will be asked to begin locating artifacts of the organization including products and publications. It is important to understand the background of the organization's BIM Use and whether or not they have a documented BIM Plan. If they have a BIM plan what are their goals for BIM Use as they relate to the mission of the organization. After the informal meeting with the BIM manager is completed, an outline of the case process should be given.

Semi-Structured Interviews:

To help study the BIM implementation in the organization semi-structured interviews will be conducted. The goal of the interviews is to understand the impacts of the implementation and the consideration for future use of BIM. The question will be based around the organizational BIM planning elements and outcomes. Once the interviews are completed, the responses will be summarized along with other analysis and will be confronted with the research hypothesis.

Observational Analysis

In addition to artifact analysis, the researcher will spend time observing the tasks and processes of each operating unit. While observing the process, we will try to get a better understanding of the tasks by observing the operators and supervisors. We will be looking at processes which we do not understand and tasks that may be unproductive or information heavy. During the observation period we will try to learn if there are any inconsistencies between the artifacts of the organization and the observed behaviors. In other words, do the processes and goals layout within the literature of the organization match what is actually being performed by the organization? The observational analysis will also help to determine how ready to organization is adopt BIM technologies into the daily operations of that unit.

Anticipated Outcomes

At the conclusion of the case study, we will present a summary of the observations, interview results and the analysis of them. It will include a background of the organization, a background on the organization's implementation of BIM, a summary of the methodology used on the case study, an analysis of the BIM Planning Elements for Organization and conclusions. The planning element analysis will document the mission and goals; uses and tasks; processes; information needs; legal considerations, infrastructure and personnel. The personnel section will include the organizations hierarchy, roles and responsibilities, and change readiness. The overall goal of the case study is to perform a study on the impacts of BIM implementation

6.5.3 Case Description

Background of the organization

The organization has a history of almost 35 years and has been offering architectural services for different kind of projects. The projects mainly include landscape, buildings and urban planning. It is a private entity that was originally founded by two partners, Architect Battle and Architect Roig. In recent years two new partners have joined who are landscape and building directors.

- Enric Batlle Durany
  PhD Architect & Landscape Architect. Founding Partner

- Joan Roig Durán
  Architect. Founding Partner

- Albert Gil Margalef
  Architect. Partner & Building Director.

- Iván Sánchez Fabra
  Architect. Partner & Landscape Director

- Elena Puigmal Crespo
  Architect. Managing Director

Background of the organization implementation of BIM:

The organization started implementing BIM since 2013. This included hiring a BIM manager, Maria Duran, who was in charge of defining the of BIM implantation strategy, BIM standards and libraries, staff training and other BIM-related workflows for the practice.

Case Study Procedure:

For this study, we conducted semi-structured interviews with the BIM management unit. We also studied some artifacts such as the BIM models they have produced for two different projects. It gave us an insight into the quality of models, how they are organized and their levels of definition. We also worked with them and other project teams for the Campus Generalitat project, as mentioned in the case study 2. Apart from the specific purposes of that experiment, it helped us understand the workflows and BIM-related procedures of the practice which will be useful for this case study.

BIM planning elements for organizations:

A general guideline for implementing BIM and training the staff accordingly was the initial elements of the BIM planning. It followed by developing the practice-specific BIM assets. It included libraries of smart building elements and Revit families which were created according to the practice's standards. In addition, the definition of templates, sheets and tables and other graphical standards to be used in Revit projects were other tasks in the initial planning.

Mission and Goals:

As we read in the office manifesto it is:

Batlle i Roig Arquitectura is committed to providing its services to clients with rigor, efficiency and the guarantee of excellence in the results. In order to accomplish these goals, we have established a structure, a process, and a methodology. These, combined with the "know how" and professionalism of our team allow us to achieve top quality products.

Batlle i Roig Arquitectura has an integral management system according to ISO 9001, ISO 14001 AND ISO 14006 standards establishing several procedures to constantly improve the services and activities, prevent environmental pollution and satisfy the clients. The whole team is committed to achieving the goals set out by this management policy.

Batlle i Roig current strategic guidelines are:

- Attention to the client's needs. Deadlines and budget: Gain customer loyalty, providing all services within architecture's realm satisfying the customer's needs beyond their expectations and initial requirements, observing agreed deadlines and budgets to guarantee their maximum satisfaction.

- Using the best digital tools: Maintaining a constant effort in the development of services and activities that allow us to improve processes and the quality of our projects, as well as our brand's position in the architecture service market, through the use of the best and most innovative digital tools available.

- Sustainability and environment: Proposing environmental design improvements in project development, preventing pollution generated by buildings along their whole life cycle, reducing the negative environmental impact and avoiding impact among different stages of this cycle.

- Respecting environment reducing consumption, diminishing waste and pollution, and fostering recycling, reuse, and reversible actions: Observe current legal regulations regarding quality and the environment.

-

The practice's Road Map is:

- A constant consideration of the team member's motivation, personal, and professional development, as a formula for their involvement in multidisciplinary teamwork. That is the goal of the plots and plans allowing the team members to expand their education, seize responsibilities, and satisfy personal, professional, and creative aspirations, always under the notion of a continuous teamwork.

- Adapt its structure to the market's different situations, providing responses to the business environment requirements.

- Providing continuous training for team members to provide better services.

6.5.3.1 BIM implementation

BIM Mission Statement and Goals:

The BIM management unit of the company indicated that the main mission of the BIM implementation is to improve the quality of deliveries. The goal is to have tailored solutions for implementing BIM on each project. To train the staff about the goals and to have them follow the specifications of each project are other BIM related goals.

How BIM Goals Support the Organizational Mission and Goals:

One of the main guidelines of the office, as mentioned above, is the utilization of digital tools in their practice. This is in order the keep up their position in the competitive market and delivering better services. In this sense, the BIM goals absolutely stay in the guidelines of the office and support its achievement.

Current BIM Uses and Organizational Tasks:

The office is fully BIM-enabled, meaning they use BIM internally and for external collaborations. They use BIM Products, Processes and People internally for all their projects and if asked, they can extend the BIM implantation in working with other project stakeholders. If other project teams also use BIM, they are ready to work with them and if it is not asked by the client, they still use BIM for internal purposes. All projects include the development of their proper BIM models.

Processes

The office is organized by thematic work teams -Edification, Landscape, Planning, Urbanization- that develop their work collaborating with specialists in other fields. They may form efficient multidisciplinary teams that face the different challenges of each of the projects to be able to guarantee the quality and professionalism required by the clients. Some teams that are organized by thematic, which are not understood as watertight elements, but as parts of a flexible and dynamic set that is structured from the exchange of information and collaboration with disciplines so diverse as are the engineers of facilities, structures, facades, mobility or urbanization, also of the urbanistic right or of the sciences of the environment like the agronomy, the biology or the geology.

Information Needs

The standard libraries, families, sheets, templates, BIM objects and drawing sets are the main data used in the practice. This data is stored in a central server with high security levels. On the BIM management unit can modify the elements in this storage, but everyone has access to the shared information. The main file formats are those related to Revit.

Legal Considerations

This differs from project to project. Sometimes a client requires the implantation of BIM and dictates the related requirements. Sometimes it is up to the office to improvise the BIM related considerations.

Personnel

The BIM related personnel operate within the BIM management unit. Currently, there is a BIM manager, Maria Duran, and her assistant in this unit. They oversee the definition of BIM standards, BIM implementation in each project and BIM related training.

6.5.4 Semi-structured interviews

In the following, the transcript of our interviews with the BIM management unit with the leadership of the BIM manager Maria Duran is presented. This comes from a number of interview session conducted in the *Battle I Roig office.*

Mission and Goals:

- What is the mission of the operating unit?

Our operating unit is BIM management team, our mission is to create the structure of BIM implementation in each project. We create the templates and standards so the colleagues can follow. We create the families and libraries and store them in a single place so everyone can refer to during a project. This allows us to have control over such data, and others will not have permission to create or modify the objects. This is one of the main missions of our unit, to have a central database of information to be used in projects, while we maintain control over the data, to guarantee quality and to save time.

- Do you also oversee the technical parts like software and hardware?

We have a different unit that takes care of the technical issues but we work with them on matters such as licenses, how many of them we need and for what tools and software. This depends on what we need for each project and we decide in our unit about such issues.

- What are the goals of the operating unit?

Of course, we have many goals which sometimes are hardly achieved. One of the main goals is to train and educate staff to get them on board. We are about to start classes every two weeks of about an hour to explain specific matter about using Revit or Navisworks, in a very clear and specific way. It is about teaching the staff the manners of using these tools in Battle I Roig office. Everyone who joins the team will have some training on how we use and implement BIM in the office, they need to know how we do things here. Another goal is to have specific drawing lists with template ready to be used while we are developing the drawings. These sheets contain the layout and views to include and a lot of the work is done so the final outputs are consistent and under control. Another goal is to develop specific codes for dynamo for our needs in order to automate and speed up processes. We still have not had enough time to develop as we are also helping with the projects themselves, but this is a goal we are working on.

- So, you also work with Revit in your unit?

Yes, we also get involved in actual project development in Revit.

- How does the operating unit's mission and goals support the goals, mission, and purpose of the Organization?

Well, our ultimate goals have been to improve the quality of outputs and to improve the productivity. We have achieved the quality improvement for sure but we have not had analysis on productivity to see before and after BIM implementation. We believe that we are improving a lot but not that sensible until now because we needed a lot of time to create the BIM families and objects and define our internal processes. Another factor that slows down the process is when we hire a new employee because they are often familiar with Revit but not with actual project experience and we need to train them about our internal methods, working with others and etc. it is often not possible to find someone with all the skills and software knowledge we need, so training is a critical part of the process.

- How does it work to get new employees on the track?

In each team there are seniors that are quite experienced and there are usually one of the seniors available to help anyone in need in the office.

- What are some additional goals that have not yet been attainable due to current organizational processes?

Mainly the training sessions we talked about. We can already see that our projects are being done very efficiently and it is sensible for us in our unit if not for some other team members.

- How long have you already been implementing BIM?

It is almost five years since the initial implementation of BIM. I joined the office because of the decision of using BIM in a project and I have been involved in the BIM journey of this office from the beginning.

Tasks (Uses):

- What are the tasks, duties, and responsibilities of this operating unit?

The main daily task that is probably the most time taking is to help people use BIM in the office, especially when it comes to something complicated and difficult. When they don't know certain processes or methods of doing works me and my colleague help them get things done. Lately, we have been investing a lot of time to train our landscape unit to use Revit and implement BIM, which is a very tough process. Apart from that we also do some developments and work on the actual project. This helps us a lot as we can see their need on the first hand. For example, we can see if a family is missing or a template has issues directly by being involved in the project development. This is important to keep in touch with the project part as well and not only be enclosed in our operating unit.

Processes:

- How does this operate unit function?

As mentioned before, we define standards for the office and specific projects and then we train the staff on how to utilize them. So, our main functions of creating a methodology and implement it on actual projects.

- What is the process for each of the major tasks?

Apart from training we also have ongoing development of the data and assets we already have to improve them. Finding new software and tools to implement in our practice and trying to improve methods of working helps us achieve our task. About the training, we also try to find ways to train staff in a way to be easier for them to understand. We try to make things easier for people working on a project which eventually helps us achieve our goals.

Information Needs:

- What information does this operating unit manage?

The main data and information we manage is regarding the libraries and templates. Another type of information we receive and manage is about the issues of ongoing projects, where we hear the staff about their problems or the solutions, they think might be useful. We also collect the feedbacks about the current implemented methodology. This sort of information helps us improve the current practices and by being involved in project development we can see collect this sort of information at first hand.

- How do you treat a new project coming to the office?

Usually, we are the ones who offer the use of BIM in a project, not that we are asked to. As we already are a BIM-enabled practice and we always use BIM in our projects. In some projects we have certain BIM requirements so that needs some studies in order to adjust our practice with those requirements. It can be that our software is not cable enough to handle some task and things like that. For example, in our collaboration with Barcelona F.C we had challenges as their BIM standards and requirement are of very high levels. For us, these kinds of projects which have BIM requirements that are highly defined are more difficult to do. It is due to the fact that our definitions and templates might not match the ones required by the client so it takes us extra efforts to meet their requirements.

- What do you use to manage this information?

We have a central server which has a protected part where only our team has access to and can modify the data. In the case of libraries for example, everyone in the office has access to but to modify, remove or create those assets we only have the permission.

- Software

We don't use a certain software to manage the information.

- Hardware

The server hard drive is where most of the management occurs.

- Number of Users

We are two people in the BIM management unit who manage them and the rest of the office have access to it.

- Why did you choose this option?

Because it was the way it used to be done in the office before BIM, and now we just adopt the method for BIM implementation.

- Do they share/receive info from other departments?

Usually, other users outside of our unit have only access to use the information we create, but sometimes we have expert users and modelers that might create families. We receive this kind of data and check them to fit with our standards before putting them on the servers.

- Is the work/information duplicated anywhere?

Yes, the main server is highly protected but still, we make copies of the information. Like we had a serious problem with viruses some time ago, so the new server has a higher security level and we also make copies.

- Do the staff keep copies of the data on their computer?

No, they only access the data, libraries, objects etc. from the server. When they need something specific, they can modify the object and save it on the project folder that is on the server as well. Users are forbidden to save anything on their computers.

Collaboration processes:

- What are the issues regarding sharing/duplicating information?

We had some issues with parameters when they were duplicated and we had some issues when working with other team models and families. Sometimes problems occur when over positioned multiple models from different disciplines which need to be addressed in BIM execution plans.

- How is a facility handed over?

We usually deliver both printed drawings and digital copies. In case of BIM-enabled projects, we deliver the Revit models, or it might be that we agree on a certain format, like IFC, and we handle those files.

- What are your primary steps for handing over building data/information?

It depends on each project. For example, if the contractor, the owner and everyone on the team is using BIM, we make agreements on how and when to exchange data, but it usually is once a week. If it is only us using BIM, then such a process does not make sense.

- How do you manage as-built and record drawings?

It is usually not included in our responsibilities to create as-built documents. We always update the model during the construction so it is usually the same as the built. But if a client asks a LOD 500 model for maintenance reasons, it is usually the contractors' responsibility. It usually takes to create a separate model with high LODs as Revit does not have the capability to increase the LOD of a model. We try to make models that are relevant during all the project phases, this is something we are leaning over time. In the beginning, we used BIM mainly for our needs as others were not really using it, but now with contractors and others also using BIM, we need to create the models considering their needs as well.

- Is "as-maintained" documentation kept for the facility?

It can be, though we are not responsible for that. Usually, it is the contracted who takes care of these parts. Now we are starting to hear more of facility management needs and now we are starting to get more involved in this part. Now it happens that during the construction phase, the maintenance people come to our meeting to talk about their needs and we and the contractor try to consider their needs. we are starting to learn what information the maintenance people need and we try to get them what they need which is usually an excel file and some IFC file formats.

Legal Considerations:

- How are projects procured, DBB, DB, CM, etc.?

We are usually involved from the start of a project until the facility hand over. Projects may come to us directly from the client or we get a project by winning a competition. As for most cases, the owner contracts a contractor so our projects are usually produced by DBB (Design-Bid-Built).

  - Why are they procured that way?

This is a way that usually market and clients are comfortable with so we must follow.

- What is the level of participation?
  - Is the owner actively involved in overseeing the project?

Yes, the owners are usually involved. The level of participation is usually more during the construction phase. Sometimes they are not directly involved by through a construction manager that they hire.

  - Is the operations and maintenance considered during the planning stage?

As mentioned before, now we are getting to consider the operation and maintenance from the beginning. But previously these considerations would take place during the construction and delivery of the projects. Obviously, this is beneficial to have these considerations earlier on because then it can affect the design and we would do things differently in order to meet their requirements.

  - Does the operations and maintenance group have input in the design?

As I said not yet that much but we are trying to get them involved during the design phase.

- Is there any contracts or documentation requiring BIM to be used on projects?

Yes, each project has a document. In the case of Campus de la Generalitat we had a BIM execution plan which was not very much defined. It was kind of flexible because of being a new experience for them and not putting a lot of pressure on the teams to follow certain requirements. This way for us is also better as we can have our own flexibility and fewer concerns about adopting their plan.

Another point in this project was that the BIM requirements came in play only during the construction phase so a lot of stuff had already been closed. As we anyways use BIM for our projects, we were already BIM-enabled but as the BIM requirements came late it did not have a huge effect on our processes. Of course, there were some requirements and we followed them but it was fine for us as we had our flexibility.

- Would you add it to the contract if you knew what to say?

I think in case of project delivery with BIM it is important to be specific about LOD and scope of services. We have had some projects that we agreed to deliver a BIM model but later their requirements were more than what we assumed and it cost us extra time and money. A well-defined BEP and contract can help prevent these sorts of issue.

- What about cases that they require you conventional DWG files and not a Revit Model?

As we are internally BIM enabled, we follow our processes and we develop a project with Revit, then we do exportations of DWGs.

- What about pricing? Have you increased your service prices after implementing BIM?

No, implementing BIM is advantageous both for us and client and we can deliver a higher quality product, but our service fees have remained the same.

Personnel:

- What are the personal and personnel types or categories within your operating unit?

Well basically I have been running the BIM management unit alone from the beginning and now I have another colleague working with me and we pretty much share the works, being related to BIM management or to actual project development. We report to the office directors and the owners directly.

- What are the roles and responsibilities of each type of personnel within your operating unit?

I am the one who is responsible of this unit and I report to the directors.

Education and Training:

- What is the education and training program for BIM and in general?

We try to hire people with some BIM knowledge and with Revit skills. We sometimes even invest on new employees and we pay for some courses so they can improve their Revit or BIM skills. Then we also educate them in about our office ways of working. We try to make groups of 2,3 and we train them like in *a class. We try to find people with experience but we found it pretty difficult to find people with BIM experience.*

Infrastructure:

- What are some of the infrastructures that you have?

We have an IT department here which takes care of such things. we have internal networks, computers and typical equipment of an office.

General Questions:

- What issues do they experience with their facilities?

Our main issues regard the correct utilization of families, information and the correct implementation of our BIM strategies. Also, things like keeping the correct order of views and etc. we want everyone to follow the correct workflows and we can keep things under control.

- What would assist them in doing their job more efficiently?

As mentioned, we are investing time to make more automated processes and by that we reduce the errors and development times. Besides that, training the staff for specific matters.

Codes from the interviews:

People: Training – Software skills – Collaboration skills – Responsibility – Collaboration experience

Product: Central database – Data accessibility levels – Software interoperability – File formats – Software functionality – ICT infrastructure

Process: Data accessibility – Office Protocols – Standards – Issue tracking – Standard compatibility – BEP specifications – BIM requirements conflicts – Contracts – Data exchange – Data requirement – Early involvement – Client involvement – Joint decision making

6.5.5 Case Study results

In this section we present our analysis of the information obtained from interviews, studying the practice's background and their artifacts such as their delivered projects. Our interview with the BIM manager of the office gave us an overall understanding of how BIM is implemented in the practice. The BIM manager was involved in the BIM implementation journey of the practice from the beginning. Therefore, she was well aware of the challenges, of the current needs, and of the future direction the office should take to improve their BIM practice. In the following, we will highlight some of the main statements understood from the interview, and we try to confront them with our previous discussions in the literature review sections.

BIM implementation is not a one-fits-all approach.

Talking with the BIM manager, we repeatedly heard her talking about the specific ways they implement BIM for their office. At the beginning of their utilization of BIM, they had a plan of how they are going to implement BIM, together with a set of standards and datasets to be used in their projects. In the market and academic world, there are a handful of BIM Execution Plan (BEP). What was highlighted in this case study is that each firm has to adopt its BEP, considering their needs, their change readiness, their investing budget and other factors.

Not only each firm has to tailor a BEP according to its needs, but every single project needs such curing. Having talked with *BiR* staff and other project stakeholders in the project of Campus de la Generalitat, we noticed the importance of a BEP for each project, so that the services are well defined and the responsibilities are clear. These requirements may well be reflected in legal contracts. In case of large-scale projects such as Campus, a BIM managing entity might be necessary to be appointed to oversee the project BIM implementation and to verify during the project that the requirements are met.

We must highlight the importance of creating a BIM implementation plan in the organizational level and a BIM execution plans in the project level. Each firm has to initially consider its capacities and needs in order to define the scope of BIM implementation. Each project requires its own BIM execution plan considering the client needs, the project requirements and the project teams' capacities. Failure in creating a proper plan will lead to confusions and inefficiencies in implementing BIM in a firm and eventually in the projects they are involved in.

Training the People for new roles and skills is essential.

As mentioned above, it is important for architectural firms to have their own manner of implementing BIM. This creates the urge for new comers in an office to be trained about the BIM strategy of that firm. The ways of getting the works done can differ dramatically from one practice to the other, even if the practice is BIM-enabled. The BIM manager mentioned they run training sessions for their employees to keep them updated. As BIM implementation is always evolving and with new tools or software being employed, it is crucial to keep the staff up-to-date.

Training the staff means spending time and money. Therefore, and architectural practice must consider such a long-term investment on their staff, apart from the initial investment needed to implement BIM. The BIM manager also mentioned they might pay some classes for their staff to attend. She indicated that it is often difficult to find staff who are already familiar with a professional application of BIM in projects. They might have software skills, but not the experience of working with BIM in actual projects. This leads us to the next conclusion.

BIM is new, so skilled people are few! The need for BIM education.

BIM is a relatively new domain in the AEC industry and yet BIM education is often not included in architectural education curriculums. Most of the professionals have learnt about BIM by attending extra-curriculum classes or specialized courses or self-learning. This means most of the architecture students that graduate from university have not been trained about BIM. This leads to the issue mentioned above, which is the difficulty of finding skilled BIM people. Therefore, universities should begin considering the inclusion of some BIM topics in architectural education.

BIM success relies on the contract and specifications, be careful about conflicts!

BIM requirements and scope must be clearly indicated in the early stages of a project and reflected in legal contracts. As we discussed how BIM implementation should be specified for each firm, the lack of clear BIM requirements for a certain project may lead to confusions and issues. Therefore, it is crucial that besides a BEP for a project that outlines the requirements of BIM implementation, we have such requirements reflected in legal contracts. Although it is important to notice that a project-specific requirement for a project might be very different from a firms' workflows. This might cause a firm to have to change their methods of working which leads to a reduction their efficiency. As indicated by the BIM manager in the case of Campus Generalitat, the BIM requirements were minimal and basic and that left their hands open to follow their own workflows.

BIM success relies on the project delivery method and the role of the owner.

Another important aspect in a successful BIM implementation relies on the delivery method an owner chooses for a project. As discusses broadly in previous sections, some project delivery methods are more compatible with BIM implementation. In this regard and for its collaborative nature, IPD and Architect-led Design-Build methods can be considered the most compatible ones. BIM models during the Design-Build delivery method opens up the opportunity to fully leverage tools and practices, but the most valuable benefit is having a constructible design. Incorporating a building information modeling toolset into any aspect of the IPD process enables project teams to use information in an integrated environment, increasing efficiency and enabling new ways of working. So, it is crucial for the owner to have a proper vision while bidding a project to facilitate a successful BIM-enabled project delivery enabled by BIM collaboration approaches.

BIM Collaboration approach brings other stakeholders inputs early on the works of the architects

Being relevant during a project whole life cycle is a main characteristic of BIM. Considering this point, architectural practices are including inputs during their early design stages that previously had less relevance. Operation and maintenance phase is a part of a building lifecycle that is being considered early-on thanks to the BIM implementation. As the BIM manager indicated, they are paying more attention to this phase by involving the operation people in their meetings during the design phase. This might impact their design and they try to include the data that will be useful in that stage. Furthermore, the implication of BIM to work collaboratively and to get all project stakeholders involved in the project development puts an emphasis on such considerations. As we see in this case, the early involvement of other project stakeholders is often initiated by the architectural practice. As they receive inputs form others early on, it allows them to have a global vision on the project and therefore giving them the merit to lead the collaborative processes yet making decisions jointly.

BIM implementation is an always evolving process, have a big picture in mind.

The BIM manager mentioned many times how their BIM journey evolves with time considering the practice's new requirements, refining their processes, training staff and incorporating new tools. This is due to two facts. First, BIM itself is relatively new and is evolving. New products are introduced to the market and processes and politics are evolving. Second, each firm's experience with BIM can lead them to refine and improve their BIM implementation. Therefore, BIM managing units need to stay up to date with the latest trends and apply what they find beneficial for their practice. In the case of *Batlle i Roig*, the BIM manager indicated that they are trying to implement Dynamo scripts to automate the processes. It is essential to look at the big picture of BIM implementation, and not trying to implement everything in the beginning. By implementing the basics and adding what brings value along the way, a practice can assume a successful BIM implementation.

Codes from the statements:

People: Training x2 – Software skills – collaboration leadership –client involvement

Product: Software functionality

Process: Office Protocols –BEP specifications – BIM requirements conflicts – Contracts x3 — Data– Early involvement – Client involvement – Joint decision making

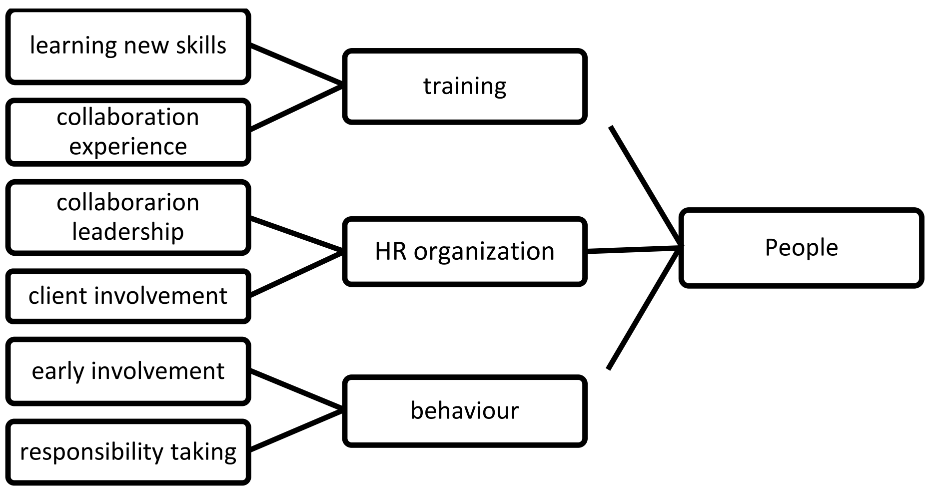

Figure 71 Codes and categories of the People theme

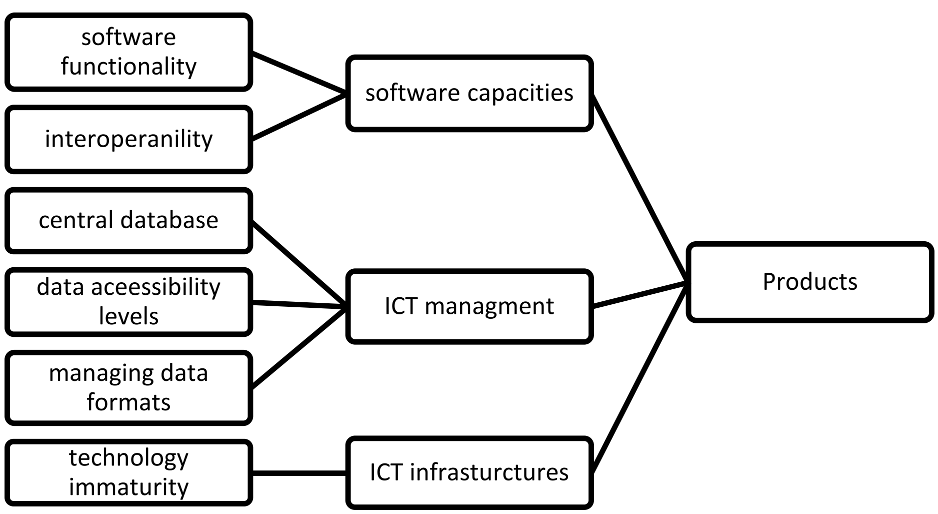

Figure 70 Codes and categories of the Products theme

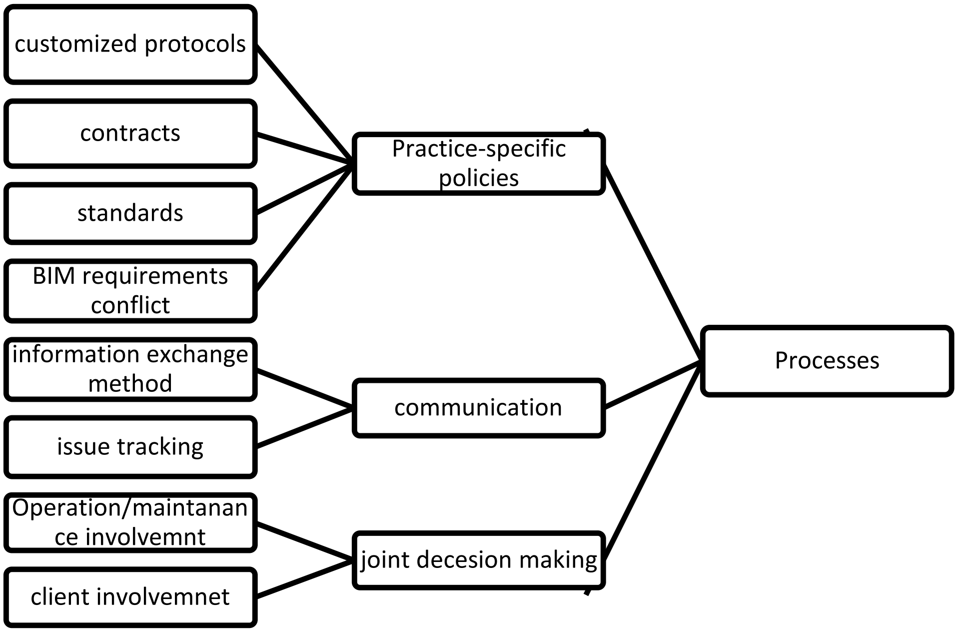

Figure 72 Codes and categories of the Processes theme

6.5.6 Conclusions

In this Study case, we have seen how an architect assumes the role of BIM Manager, both at the organizational and project level. At the organizational level, this role implies establishing BIM implementation policies in the company and all that this entails, such as the training of personnel, technological innovation, changes in processes or the provision of adequate technological equipment for each case. Besides that, BIM implementation is an always-evolving process, so this activity is continuously updated in order to keep the organization up-to-date.

It's evident that this kind of responsibilities differ from the traditional picture that we have about an architect and as a matter of fact, all the BIM-enabled architectural firms must have this kind of role in their organization. At the project level, this case shows us how the BIM Manager architects must assume a variety of roles different than the conventional ones. First, they are usually responsible for preparing the BEP, which is a contractual document that sets the way in which the client's requirements are reflected in the project using BIM. In case of not being the main provider of BEP, they should participate in its writing since this document is an agreement between all the parties regarding the objectives, use and scope of BIM in the project.

This contractual approach makes the architect play a more precise role in terms of compliance with the client's requirements, since BIM establishes a set of objective ways for assessing the degree of contract compliance. Usually, the architect focuses more on the formal and functional aspects of their assignment and not as much on the procedural aspects of its development and the characteristics of the deliverables. However, with the implementation of BIM the format and characteristics of the BIM deliverables has a great importance, prevailing over what the traditional deliverables describe (sheets, memories, etc.). This means that they must pay much more attention to what and how to deliver compared to before.

Finally, the role of the architect in collaborative processes is relevant. This case study demonstrates how they naturally positions themselves as a negotiator between the parties, whether they have such an intention or not. In my experience, the other stakeholders hope that they resolve the coordination problems between the different disciplines and the client. This is especially relevant in the increasingly common collaborative contracts. This is closely related to the incremental and iterative development that BIM demands, since the different disciplines have to develop their part of the assignment in parallel. In order to interact between them and find solutions to the complex problems they face, they must design a development plan that makes it possible. In order to do that, it is necessary to prioritize the development of each part in a logical order from the global point of view, not from the point of view of the interests of each party itself. This is different from what happens traditionally, where each consultant thinks about his own design process and what they need for it from others. For example, it is common for MEP engineers to wait until the architectural design is reaches a certain level of definiton before starting their task. This obviously causes problems of coordination and design because often the architectural and structural previous design cannot satisfy its space and dimension needs. Instead, the collaborative processes promoted by BIM require that MEP engineers participate from the beginning by proposing and modeling space allocators and draft systems. In addition, also architects often have to take decisions about MEP much earlier than they normally did in conventional methods.

7 *Qualitative data analysis*

Interviews have been the main information gathering method in the case studies. In addition to that, observations and studying the documents have been utilized to gather supplementary data depending on the case being studied and objectives. As most of the information comes from the interviews, in this section the method for analyzing them and the results are presented. To systemically analyze the data obtained from the case study, a Thematic Analysis method is adopted and explained in the following.

7.1 Thematic analysis

Thematic analysis is one of the most common forms of analysis within qualitative research. It emphasizes pinpointing, examining, and recording patterns of meaning (or "themes") within data. A theme represents a level of patterned response or meaning from the data that is related to the research questions at hand. Braun & Clarke [140] provide a six-phase guide which is a very useful framework for conducting this kind of analysis:

Phase 1: Become familiar with the data. The first step in any qualitative analysis is reading, and re-reading the transcripts. While working verbal data such as interviews, the data will need to be transcribed into written form in order to conduct a thematic analysis.

Phase 2: Generating initial codes. The second step in the thematic analysis is generating an initial list of items from the data set that have a reoccurring pattern. This phase then involves the production of initial codes from the data. Codes identify a feature of the data (semantic content or latent) that appears interesting to the analyst.

Phase 3: Searching for themes. Searching for themes and considering what works and what does not work within themes enables the researcher to begin the analysis of potential codes. This phase, which re-focuses the analysis at the broader level of themes, rather than codes, involves sorting the different codes into potential themes, and collating all the relevant coded data extracts within the identified themes.

Phase 4: Reviewing the themes. This phase requires the researchers to search for data that supports or refutes the proposed theory. This allows for further expansion on and revision of themes as they develop. At the end of this phase, you should have a fairly good idea of what your different themes are, how they fit together, and the overall story they tell about the data.

Phase 5: Defining and naming themes. At this point, the researcher then defines and further refines the themes that you will present for your analysis, and analyze the data within them.

Phase 6: producing the report. After final themes have been reviewed, researchers begin the process of writing the final report. While writing the final report, researchers should decide on themes that make meaningful contributions to answering research questions which should be refined later as final themes.

In the following sections, the results of taking the above mentioned steps are presented.

7.2 Codes obtained from the qualitative data

In this sections, all the codes from the case studies are presented in the following tables. In order to generate conclusions from the coded data it is helpful to compare the identified codes regarding their importance. Therefore, a value is necessary to rank each code in respect to its relevance. As a measure of relevance the term frequency can be used. It implied on the frequency of a term by counting its occurrence within the information sources. In qualitative data analysis, such counting leads to the further step of interpreting the pattern that is found in the codes [141].

Reflecting on the codes from the information sources it is evident that some share common characteristics, therefore in the tables below they might be put in different categories than the initial ones presented in the end of each case study. The codes and their categories or concepts have interdependencies and influences on each other. To explore the factors related to collaboration and the impacts of BIM implementation on them, these relations are investigated in the analysis section to draw conclusions.

Codes related to People theme											
Categories		Attitude			Training			Human Resources (HR) Organization			
Case	Source / codes	Collaborative mindset	Willingness to share data	Responsibility taking	Learning new skills	Collaboration experience	Awareness	Leadership	Clear roles and responsivity	Work ownership	Involvement in collaboration
CS1	Document	2	1	1		1		1			
	Interviews	1	2	1		1		1	1		2
	Statements		1					1	1	1	
CS2	Experiment	1			2			1		1	3
	Interviews	2	2		3	2	3		1		2
	Statements						1				1
CS3	Interviews	1	1	2	3	1		1	2	1	2
	Statements				3			1			2
Code frequency		7	7	4	11	5	4	5	5	3	12
Category frequency		16			20			25			

Table 7 Codes and their frequency of People theme

Codes related to Products theme											
Categories		Software capacity		ICT management				ICT infrastructure			
Case	Source / codes	Software functionality	Interoperability	Central database	Technology integration	Data accessibility	Information exchange management	Technology maturity	Computer performance	ICT costs	Related hardware/soft ware
CS1	Document	2	1	2	1	2	1	1			1
	Interviews	1	1	2		2	2	1			1
	Statements	2	1	1		1	1	1			1
CS2	Experiment	2	2		1		1	2	3		1
	Interviews	3	4		3			2	1	4	3
	Statements	1	2		2		1	1	1	2	
CS3	Interviews	1	2	1	1	2	1	1		1	1
	Statements	1									
Code frequency		13	14	6	8	7	7	9	5	7	8
Category frequency		28		28				29			

Table 8 Codes and their frequency of the Products theme

Codes related to Processes theme														
Categories		Communication			Collaboration conditions					Collaboration Policies			
Case	Source / codes	Data exchange method	Decision communication	Issue tracking	Collaboration environment	Joint decision making	Early involvement	Efficient workflow	Direct participant leadership	Protocols	Contracts	Standards	BIM require-ments conflict
CS1	Document	2	1	2		1	1		2	1	1	1	
	Interviews	3	1	2		2		2	2			1	
	Statements	1											
CS2	Experiment		1	1	2	1		1			1	1	
	Interviews		2		3	3		2			1		
	Statements				1			1	1				
CS3	Interviews	2	1	1		1	2			2	1	2	1
	Statements					2	1		1	2	3		1
Code frequency		8	6	6	6	10	4	6	6	5	7	5	2
``		20			32					19			

Table 9 Codes and their frequency of the Processes theme

The data gathering techniques used in the case study revealed insights about the concept of collaboration and the impacts of implementing BIM on it. Conducting semi-structured interviews contributed to this insight by benefiting from the opinions and experiences from the professionals of the field. This process resulted in 32 codes which are grouped together in 9 categories. These categories fall well within 3 themes of People, Products and processes which were initially introduced in this research as the dimensions of a BIM ecosystems. We discussed implementing BIM will impact these dimensions and using the frequency of the codes and categories shown above, we will discuss the more crucial factors in BIM collaboration in the following.

7.2.1 People theme

The categories belonging to the people them are further interpreted in their importance order based on the category frequency:

1- Human Resources (HR) organization:

The codes belonging to this category emerged as the most frequent ones in the People them. The study showed that the involvement of individuals in collaboration is crucial for its success and positively contributes to the whole project. The implementation of BIM requires all project stakeholders to collaborate from the initial stages of a project development. Some teams such as operation and maintenance that in traditional project development methods had little impact are brought into collaboration encouraged by BIM implantation. Client involvement can also be facilitated in BIM enabled projects as the client can have a better input in collaboration when a 3D model is used that helps with understanding the issues compared to 2D drawings.

Implementing BIM requires new roles to be defined and responsibilities must be clearly attributed to individual to prevent confusions. Froese [142] reports that few project participants have explicit responsibility for overall coordination, though well-defined task is fundamental to construction industry dealing with complexity. Avoidance of responsibility is prevalent in project team, which impedes the collaboration among project participants. However, it is unlikely that the roles need to be fundamentally changed in an architectural practice once BIM is implemented as the participants in CS3 suggest. Nevertheless, new roles such as BIM specialists and experienced BIM modelers might be required which can contribute to the size of the practice. The participants expressed the rarity of experienced individual in the field of BIM and other literature also confirms that [143]. This will lead us to the importance of the next category that is Training.

2- **Training**:

The importance of training was repeatedly highlighted in the 3 case studies. Collaboration requires particular skills and improves by experience. Learning new skillsets is even more crucial in BIM-enabled collaboration due to the paradigm shift in working methods and the utilization of advanced ICT tools. Perseverance training and education ensure frontier professionals understand the BIM process and be able to collaborate with other team members. The lack of such training may cause resistance to change among the personnel of an organization. This has been highlighted in the literature related to change management as well [144]. In top management levels of organizations, training leads to awareness. As we realized in CS2, awareness of the benefits of new technology in management levels will lead to their implementation in organizations. Then it is crucial to train other staff about how to benefit from such technologies.

As we learnt from the studies, BIM implementation can be achieved through different approached and in different scales. Each practice may develop their own specific workflows and protocols. Therefore, even experienced professionals who are hired in an organization might need specific training to fit well in their job. The interview BIM manager confirmed that they always train new comers to the office about their specific BIM approach. Another point about BIM skills relates to the different generations of professionals which their BIM experience level might be in contrast with their overall career experience. A trend is seen that young professionals are more eager to learn emerging tools and technologies. This trend might result in the trend that a young staff member with little experience can be skilled with BIM tools while a very experienced veteran has to rely on him to operate BIM functions due to his/her lack of skills of BIM software. Being the second most important factor in the People theme, it emphasis the need for adequate BIM-related training of future architects in academic and industry level.

3- **Attitude**:

Attitude and behavior ended to be the least important factor in the People aspect of collaboration in the study. It was unexpected as in the initial studies this factor seemed to be the most important one in this theme. Nevertheless, the lack of collaborative attitude will impact negatively the two other factors in this theme. Meaning, if the experienced professionals with BIM collaboration skills do not adopt a collaborative mindset and are redundant to share information, they will have an adverse effect on the whole collaborative activities. This will hurt the flow of information between project stakeholders that in our study resulted to be a crucial factor in collaboration.

Another Use of new technology generates the needs for change. Individuals may increase their fear of the unknown when facing such change due to new technology implementation. Individuals may be resistant to change when confronted with technological change [145]. By BIM implementation, the architectural practices are required to drastically change their workflows and tools they use. Thus, it seems natural that some resistance arises within their organizations which may contribute to the problem of lacking collaborative mindset. This is something that can be addressed by training and awareness which again highlights the importance of the training subject. Taking new responsibilities was also highlighted in our study. With BIM comes new tasks that the employees might be unfamiliar with. This can cause them to be resistant towards these new responsibilities which will negatively affect the collaborative processes.

7.2.2 Products theme

1- **ICT infrastructures:**

Implementing new digital technologies requires organization to establish capable infrastructures. The literature review revealed the costs associated with creating the infrastructure as one of the main obstacles of adopting BIM [69] and it was confirmed in our studies. BIM collaboration tools usually use a 3D visualization engine that requires potent computers to allow a smooth performance. Some tools such as VR require expensive hardware to run and conventional computer have to be replaced or updated to perform well. The software cost is also a concern in adopting such technologies. The lack of such infrastructure prevents exploiting the full capacities of BIM.

Technology maturity is the main factor related to this category based on the frequency of codes. A mature technology is a technology that has been in use for long enough that most of its initial faults and inherent problems have been removed or reduced by further development. The technological aspect of BIM relies on recent innovation in the ICT sector and their reliability requires time and trials to be fully adopted in organizations. This factor contributed to the BIM maturity level that is crucial for achieving full collaborative benefits of BIM. The literature review in previous sections showed how the integrated BIM level is relied on the use of web based technologies which enable the full collaborative approach. Therefore, technology maturity as confirmed in our study is crucial for effective collaboration.

2- **ICT management:**

Human-to-human and human-to-computer interactions occur during the project management process. The latter is more efficient than the former one. As the degree of project complexity rises, it gets harder to ensure the adequacy of the information flow through human-to-human communication [146]. Traditional construction practices require the same information to be used multiple times by multiple organizations. BIM models solidify the information in a digital file which is the core of BIM. In CS1 we witnessed the lack of central database affected the information distribution negatively and caused difficulties in decision making processes. As with BIM the initial level of information created is relatively high, the management of this information is crucial for the project success. It is so to the extent that some suggest the use of BIM acronym for Building Information Management. The coding results reveal that the integration of ICT in architectural practices is crucial for information management.

3- **Software capacity**:

BIM comes with constellation of tools and software that are tailored for specific uses. The functionality and features of software can provide the architects with abilities to perform efficient collaboration. For example, the visualization of a BIM model in web browsers allows for new collaboration approaches. Or in our study, the certain features of the VR tool provided unprecedented collaborative approach by simulating real-life tasks. Awareness of such functionalities is crucial in the selection of software. In the BIM adoption section of the literature review, we discussed that vendors can claim about functionalities but it takes an extensive examination to realize the real benefits of a tool for architects. There is no certainty that the new particular technology will bring the promised profits.

Interoperability on the other hand, is the most crucial factor in collaboration related to the Products and technology aspect based on the extracted codes. Interoperability can be interpreted as the enabler of computer-to-computer interaction. BIM interoperability has been defined as the ability to manage and communicate electronic product and project data between collaborating firms and within individual companies' design, construction, maintenance, and business process systems [147]. It allows for smooth exchange and processing of data and its lack causes defects and delays in project collaborations. In case study 3 it was highlighted that it is important to include interoperability concerns early on in contracts and BEPs of each project to prevent conflicts. Therefore, it relates to both Products and Processes themes in the coding analysis.

7.2.3 Processes theme:

1- **Collaboration conditions**:

This category was ranked in the first place after grouping a number of codes that relate to the conditions in which collaboration take place. The most frequent code in this category was ‘’Joint decision making’’ which refers to a condition that allows or decisions to be made collectively by the project team members. Joint decision-making can avoid poor decisions made by individuals, which may fail to consider alternatives to maintain a good relationship of team members. Joint decision-making involves information exchange, resources allocation, conflict management and communication [148]. Therefore, it becomes even more crucial in the case of conflicts between project stakeholders. Based on the case studies, data accessibility and information exchange management were codes that affect joint decisions making. Implementing BIM requires the involvement of all stakeholders early on in the collaborative processes and therefore allows for decisions to be made jointly.

As we saw in CS2, the environment in which collaboration takes place also impacts its effectiveness. A virtual environment in that case was suggested in response to deficiencies of a BIG BIM room method. As for human interaction, such environments can promote engagement or in the contrary can be burdensome and affect the collaboration negatively. The concept of leadership also resulted from the coding process to be influencing the conditions of collaboration. Leadership in collaboration is crucial as the project have a need for leaders who can bring the team together and complete the work collaboratively which was specially highlighted in CS1. The emergence of BIM changes the collaborators per task and intensity of collaboration. Therefore, leadership is needed for coordinating between different participants. Although naturally emerging leadership is more effective than assigned leadership, some owners introduce the role of BIM consultants in their project management because they think that parties with BIM execution capability are scarce. However, if the leadership comes from within the project team members who are already familiar with the designs it will be more effective. In this sense, architects as the authors of the project with their comprehensive vision of the client needs and their own design tend to be the appropriate figure to assume this role.

2- **Communication**:

Traditionally, the way data is transferred in isolated files via blueprints, work reports and minutes of periodic meetings was linear. There are lots of possibilities for coordination to be missed in this process, especially with specialists with different disciplines, who often do not think about the other disciplines' responsibilities. In CS1 we witnessed how the lack of specialized and effective channels of communications contributed to project delays. BIM implementation changes the way information is processed and exchanged and the case studies confirmed its effective influence in this respect. The availability of information helps with collective decision making.

In CS2 the application of advanced digital technologies opened the way for innovative ways of communication. Although implementing such new technologies comes with resistances that we argued above, such issues can be addressed by effective training. Effective collaboration channels also contribute to joint-decision making. Traditionally, some project team members did not have access to collaborative processes. BIM and its specific communication tools allow all project team members have input and give feedbacks that based on the project organization can be available to other project team members.

3- **Collaboration policies**:

The importance of project policies that affect collaboration was many times mentioned in the interviews. Implementation of BIM can bring about complicated processes. It was highlighted that each organization needs its own specific standards and protocols. Therefore, working with others with different BIM approaches can cause conflicts. In this respect, it is crucial to foresee the collaborative consideration early in the contracts and project BEPs. This is also influenced by software interoperability as discussed above. The contractual issues are sometimes barriers to achieving integrated teams. Legal and contractual obligations often restrict potential collaboration with other parties. Specifying ownerships, defining clear roles and responsibilities and an appropriate project organization are crucial factors in this respect and were also highlighted by the frequency of the codes. The lack of such consideration can even make the BIM collaboration less effective than traditional methods as the amount of information to be handled is remarkably higher. Also employing experienced BIM specialist is an effective measure to take in preventing above mentioned issues.

7.3 Discussions:

BIM has been implemented in the different stages of construction and different organizational levels to facilitate collaborative work. Successful collaboration based on ICT in any context requires change management which relies on the successful execution of and dedication to three main components of technology, people and process. This is equivalent to the three main dimensions of a BIM ecosystem suggested at the beginning of this work which are Products, People and Processes. This was further confirmed in our qualitative research as the codes and categories fit in the three mentioned themes. These three dimensions are complementary and synergistic. Given the complex dependencies between products, processes, and people in the BIM ecosystem, it is important that the evolution and growth across each dimension remain compatible. Although any of these dimensions can be implemented independently, this will have a less effect on the success of the project. These factors are not independent. A model of BIM collaboration effects is developed here to provide practical insight into the BIM collaboration effects.

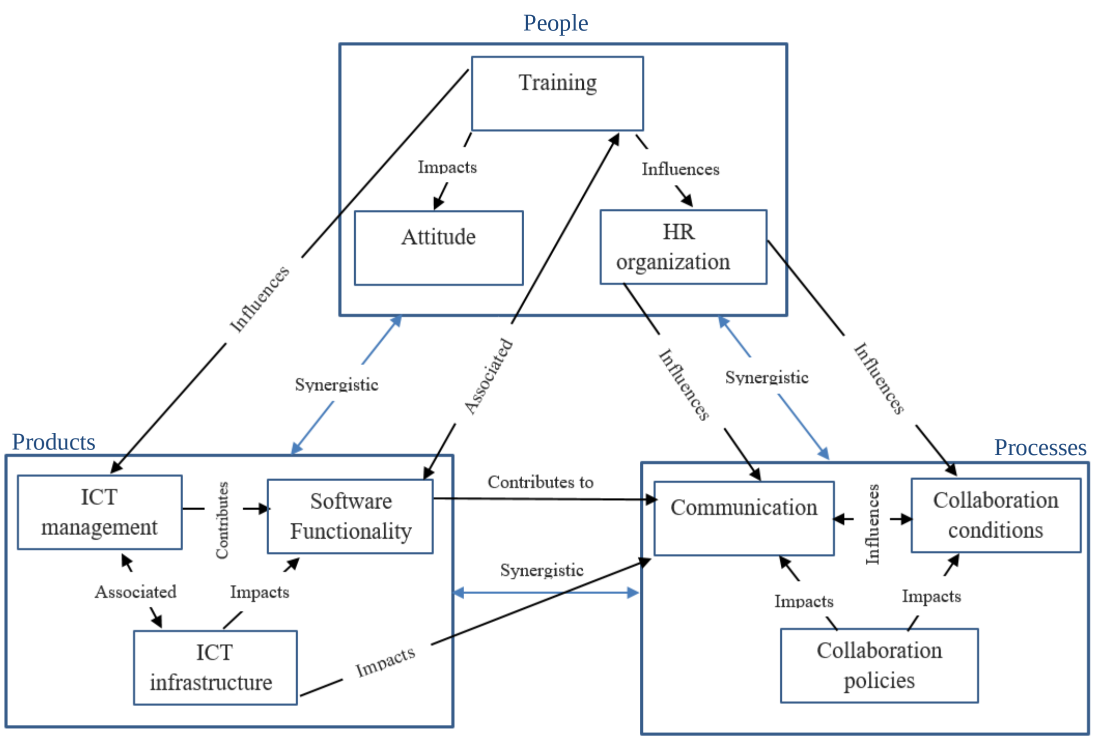

Figure 73 Model of BIM collaboration effects

The figure above depicts the relationships between the categories or concepts within the themes of People, Products and Processes. These categories were grouped based on the codes created in the qualitative data analysis and are factors related to collaboration and BIM implementation in architectural practices. The categories that impacts another category have a remarkable effect on that category meaning the impacted category condition is dependent on the impacting category. The categories that influence another category suggest a slighter level of impact, meaning the effect is not remarkably great but still has influence on the other category. The associated categories have a direct bilateral effect on each other, meaning they are adjusted by each other and a change in one requires a proper change in the other one. Categories that contribute to each other have a positive effect in flourishing the other category. These relations were based on the discussions on the categories presented above.

7.3.1 Crucial Concepts in BIM collaboration

In coding qualitative data, the frequency associated with a code is regarded as its relative importance in the data set: important items are those that are repeated more frequently [152]. The following categories or concepts in collaboration are recognized as being the most effective in determining the success of collaboration. In the interpretation for determining the ranking of importance, firstly the frequency of codes within that category was considered and secondly, the relation of that category with other categories was taken into account. Therefore, not necessarily the most frequent categories have been resulted as the most important ones. The following are the results of the importance ranking of the categories or concepts in BIM collaboration.

Training impacts Attitude and influences HR organization and ICT management

The professionals involved in collaboration are required to have a collaborative mindset. Achieving such a mindset will lead to willingness to share information and take responsibilities necessary to perform collaboration. BIM implementation emphasizes the need of a collaborative mindset as the professionals are required to participate more and earlier in collaboration. The project team members need to be trained to have an attitude that facilitate working with others. Training also decreases the resistance that comes with adopting of new workflows and technologies. Rezgui [149] highlights the need for continuous training in order to improve the level of awareness and maturity for new technology adoption. Individuals who are provided with the necessary training for new technology adoption are able to respond to such change [150].

Employing new staff to be part of BIM projects requires specific training within the organizations. Its importance was highlighted and discussed earlier. In the category of HR organization, involvement in collaboration resulted as the most frequent code. Training people to have a collaborative attitude therefore has a positive influence in the involvement of team members in collaboration. Although the category of training did not result the most frequent in coding analysis, based on its relation with other categories we can claim that training is the most important category in People them of this study.

ICT infrastructure impacts software functionality and communication

Technology maturity as the most frequent code in ICT infrastructure category is the enabling factor in the adoption of BIM software and tools. The functionality of many software used in a BIM ecosystem relies on the ability of ICT infrastructure to handle an acceptable performance. Because of the costs associated with implementing adequate infrastructures, it is considered a barrier in literature and was confirmed in our case studies. The advanced ICT tools that are used in BIM collaboration often rely on potent computers. Implementation and adoption of a technology aspect of BIM for interdisciplinary collaboration requires an understanding of the communication maturity and project specific contingencies within individual organizations [24]. The software capacity category has a positive contribution to the communication category by enabling interoperability and allowing the use of software functionalities. Therefore, based on the coding results and the relation of this category to other categories providing the appropriate ICT infrastructures results to be the most important category related to the product them in this study.

Collaborating policies impact Communication and Collaboration conditions

The adoption of appropriate collaboration protocols and standards and foreseeing the concerns in contracts is crucial to prevent conflicts and complication in BIM-enabled projects. In contracts many aspects must be seen that impact the collaboration conditions. For instance, the leadership role in contracts has to be defined attributed to the appropriate project stakeholder for a more effective collaboration. The adoption of appropriate collaboration protocols facilitates the information exchange and distribution that help with joint decision making. Joint decision-making is a determinant of collaboration performance within collaborative procedure. Early involvement of team members in collaborative approaches was also discussed to be a key factor in an effective collaboration. The combined knowledge and expertise determines the value of engineering during the early stage of construction and decisions made jointly at this period have the greatest effect [151]. Although the collaboration policies may not be directly impacting all the factors within Collaboration condition and communication category, it has a considerable impact on the overall collaborative process. However, in determining the most important category within the Processes theme, “Collaboration conditions” has been considerably more referred to in our studies based on the codes that fall in this category.

7.3.2 Crucial factors in BIM collaboration

To have a more detailed insight on the factories influencing BIM collaboration, it is worth analyzing the most frequent codes within each them. These codes or factors, might be within the most important categories or concepts or not. Therefore, analyzing them individually will also help us with finding the patterns effective within the context of BIM collaboration. In the following these individual analyses are presented.

Involvement in collaboration

This code was ranked as the most frequent in the category of HR resources and in the theme of People. The participants in the case study repeatedly talked about the importance of involving more people and the importance of involving them early in the collaboration processes. However, even though achieving BIM's full capabilities relies on effective collaboration among the team members in BIM-based construction projects, it is still a struggle for these members to collaborate [153]. Nonetheless, in the case studies, we saw how implementing BIM encourages a more involvement of project stakeholders in collaboration. In CS1, we recognized the barriers to such an involvement. Factors like the lack of access to information and information not getting to the right person due to the lack of a structured data distributions were mentioned as barriers to getting people involved in collaboration. In CS2, we witnessed the environment that the collaboration takes place has a positive impact on involving more people in collaboration. Being immersed in VR helped the clients have a more contribution on the designs as he would better perceive the project.

In CS3 we heard how implementing BIM has required people in the end of a construction project cycle be involved in the very beginning of collaborative processes.

Involvement in collaboration as mentioned above is encouraged by BIM implementation. However, Within the BIM-enabled settings, maintaining collaboration among members coming from multiple disciplines and organizations has proved problematic [154]. This exposes BIM-enabled projects to a wide range of risks, among others, misunderstandings, misinterpretation of data and increased rework [155]. Therefore, getting people involved and maintaining that involvement is crucial for a successful collaboration and contributes to a successful project delivery. Team members in BIM-enabled projects come from various organization, with different organizational structures and hierarchies. Furthermore, each team member may have a different understanding of BIM collaboration requirements. This implies on the importance of leadership in involving people in collaboration, maintaining them and guiding them through the collaboration in different phases of a project.

Interoperability

This code was ranked as the most frequent in the category of software capacity in the Products theme. As it is the enabler of the machine-to-machine interaction, its importance is highlighted in a BIM ecosystem where a constellation of different software and tools are utilized. In CS1 we saw how each organization used an internal system for data distribution that was not compatible with the systems used by other teams. This contributed to confusions and the lack of necessary information for decision making. In CS2, we witnessed the interoperability between the BIM authoring tools and VR collaboration tools allowed for this technology to be used and integrated in the participant organizations workflows. In the participants' statements of the CS3, it was mentioned that how they try to use innovative tools such as Dynamo to enable a better interoperability and automation in their daily tasks. This allows for extracting data quickly from the models and making it available to collaborators such as facility management people.

The challenges of interoperability and exchange of information through BIM tools and software cross the project phases and life cycle are regarded as major hindrances to BIM collaboration [153]. This observation finds support in arguments by Hu et al. [155] who argued that information exchange in IFC formats is problematic, the reason being that existing collaboration tools have inadequate interoperability in different project phases. These tools must be simpler, more secure platforms in which data ownership and interoperability concerns have been alleviated, and the requirements of an efficient common data environment (CDE) have been satisfied. If the data is universal and open that any other system can use the data, then such interoperability can reduce the cost of information processing and promote integration.

Joint decision making

This code or factor resulted to be the most frequent in the category of collaboration conditions in the theme of processes. It closely relates to the above discussed factor of involvement in collaboration. If the conditions of involvement in collaborations are met, it positively contributes to a joint decision making. Joint decision-making is a determinant of collaboration performance within collaborative procedures. On the other hand, the lack of necessary information and difficulties to access it negatively affects a joint decision making which was seen and discussed in CS1. In CS2, a condition where project team members could be virtually present in collaboration without the need of their physical presence positively affected the process of joint decision making. In CS3, the early involvement of project stakeholders in collaborative processes was mentioned to be enabled by BIM implementation. This involvement contributes positively to a condition where joint decision making can take place.

Joint decision making is considered as an important aspect of collaborative relationship [156]. Joint decision making involves information exchange, resources allocation, conflict management and communication [157]. It is common that people working on a project have conflicts, which impedes successful organizational collaboration. This is another implication on the importance of leadership. A leadership role that comes within the project design teams who has a comprehensive understanding of project goals, can facilitate achieving solutions in the case of conflicts. This was evident in CS1 where agreeing on a solution was troublesome in absence of conditions that positively affect the joint decision-making procedure. Another concern regarding this factor, is the authority of people involved in collaboration to make decisions. The lack of this ability will delay a joint decision making as the person must refer to his/her boss to obtain permission or ask for the decision.

7.3.3 Conclusion

The vision of BIM is that all parties in the project collaborate based on the same source of information, and make better decisions with improved reactions of others, allowing participants to define and communicate their requirements better, diminish rework on site, and remove unnecessary waste in the process. The ability to enhance collaboration within a network of professionals involved in a construction project is one of BIM's best-selling points and is seen as a prerequisite for success in BIM-enabled projects [157]. Collaboration within BIM is therefore of paramount importance in construction project developments.

There are many factors involved in a successful BIM collaboration. Prior to studying these factors, we discussed that ICT has proven to benefit the collaboration processes [26]. To efficiently integrate ICT or the digital transformation of organizations, a change management procedure must take place [27]. To be effective, the change management process must take into consideration how an adjustment or replacement will impact processes, systems and employees within the organization. These three areas that need to be changed are similar to the dimensions of a BIM ecosystem as described in this work. Therefore, we argued that understanding the factors within these three dimensions that relate to collaboration, we lead us to understand the factors influencing a successful collaboration based on ICT tools that are integrated in architectural practices through BIM. Hence, the case studies tried to evaluate the factors that were recognized based on the literature review and the case study coding results.

Reflecting on the final codes, we could categorize them in three themes of People, Products and Processes. Similar to the dimensions of the BIM ecosystem. This confirms our initial claims that BIM is an ecosystem because its elements have synergy and work together and grew together. This is evident due to the interdependencies between these factors as was revealed by our study. For example, "Learning collaboration skills" in the People theme, impacts the "Software functionality'' in the products theme. "Software functionary'' is dependent on the "Technology maturity'' which in turn impacts '' Data exchange method'' within the Processes theme. Another example is "Awareness'' that helps people with technology acceptance that leads to "Technology integration" within the Products theme that influences factors within the Processes theme such as "Issue tracking" and decision communication. Thus, we can conclude that by understanding these inter-dependencies we can recognize the crucial factors enabling an advance collaboration based on ICT through the implementation of BIM.

Regarding the People theme, the factors grouped under the category or the concept of “training” resulted to be the most influential. In the study by Oraee et. Al [153] it was also indicated that even those organizations currently implementing BIM still struggle with training and access to employees who possess the skills to use BIM to manage and collaborate. In our study, it was revealed that training also greatly impacts the attitude of the people involved in collaboration that leads to facilitating the flow of information and therefore impacting other factors such as joint decision making. This implied on the need for education within academia for the training of the next generation of architects to possess the necessary skillsets and mindsets for effective collaboration. This is also highlighted in the work of Zhang et al. [158] among others. Although the category of HR organization was ranked as the most frequent in People them, we discussed that training has a greater impact on the overall success of BIM collaboration. However, the most important factor related to People was recognized as “collaboration involvement” that falls in the category of “HR organization”.

Regarding the products theme, the factors belonging to the concept of “ICT infrastructure” summed up to make this category as the most important in this theme. ICT infrastructures will enable the utilization of software capacity and impacts the ICT organization which includes important factors such as data exchange management that were recognized as impacting other important factors such as joint decision making. This category also includes the important factor of technology maturity, as it has been discussed to be an essential requirement for BIM implementation and contributing to BIM maturity levels [24]. Despite recent advancements, inefficient ICT-based solutions, such as cloud-based collaboration and data management platforms, are still not sufficiently effective in providing technical features to support information sharing, process management, exploration space, privacy and flexible system configuration [160]. Therefore, the effectiveness of such technologies in collaboration also depends on their maturity. Our study revealed the most important factor in this them is “interoperability” that falls in the category of “software capacity”.

Regarding the processes theme, the concept of “collaboration conditions” resulted to be the most important. It is due to some of the most frequently mentioned codes or factors within this category that puts it in this position. This includes the second most frequent factors such as “direct participant involvement” which was discussed above and highlighted in the work of Liu et al. [161] and will be discussed further in addressing the research primary hypothesis. “Collaboration conditions” is impacted by the concept of “collaboration policies”, which was discussed as an effective concept, and has numerous relationships with other concepts which implies again on its importance. “efficient workflow” factor with its high frequency also contributes to the importance of this concept which in our study was revealed to be an enabler and a motivation for utilizing ICT advance tools within collaborative process. The most frequent factor of the processed theme “joint decision making” is another factor within this category. The Processes theme has the most overall rank in the number of factors frequency in our study and also contains the most overall frequent concept which is “collaboration conditions” which indicate the importance of this theme in the overall success of BIM collaboration.

8 *Final Conclusions*

8.1 Undertaken activities in this research

This research was designed to investigate the crucial factors for an effective collaboration based on advanced ICT and enabled by BIM with respect to architectural practices. The concerns about the move toward adopting BIM by architectural firms was reviews and its influential factors and barriers were discussed. The term ecosystem was adopted to describe the nature of BIM and the reason for which was described. To further constitute the BIM ecosystem, its dimensions of People, Product and Process were presented in detail with respect to collaborative procedures and their impact on the Architects' role. It included the delineation of a number of BIM policies and protocols, tools and technologies, roles and skills which are all related to and suitable for architectural practices in their interdisciplinary collaboration.

An extensive literature review was conducted to identify the areas of interest to the author and the research, and the gaps in the existing literature. In addition to that, my collaboration with the industry and professional experiences contributed to the identification of those areas. It was found that the question of digitalization of architectural practices through BIM that would allow an advance collaboration approach is an area on which the research must focus. The role of digital technologies in collaboration as a key success factor in BIM-enabled projects was set to be investigated. Thus the case studies were designed to investigate the issues of traditional collaboration methods and if BIM with the utilization of advanced ICT can address them. Different qualitative data gathering methods were utilized to achieve the most amount of information possible for further analysis and interpretations.

Through the three case studies, the research questions and hypothesis were put into investigation. The first case study focused on collaboration issues in a non-BIM project where the architectural consultant faced difficulties to find a solution for a particular problem in parking levels. By studying the communications and documents about the situation and conducting interviews with project team members, some issues were identified. Then a review was conducted to determine how a BIM ecosystem could address those issues. The elements of the ecosystem regarding Products, People, and Processes were chosen to model the situation in a BIM ecosystem. this served as a pilot project to help gain knowledge and experience for the next case study and provide us with some qualitative data.

The second case study focused on a BIM-enabled project. The participants in the case study were the real actors of a project under construction in Barcelona. The goal of the case study was to evaluate the integration of VR as a cutting-edge visualization technology in the daily practices of project stakeholders. The study paid special attention to BIM collaboration and architectural presentation activities. The results were based on the pre-studies to prepare the case, observation of the lived experiment, and conducting interviews with the participants. the collaboration with a software company for the case allowed us to test some of their latest product features, emphasizing on the role of IT companies to enter the construction industry.

Finally, the third case study, focused on post-BIM experiences, meaning the evaluation of an architectural firm after years of utilizing BIM. This helps the research by reviewing its questions and hypothesis and determining the areas for future works and research in the field of BIM in architectural practices.

8.2 Review of the Research questions

Question 1: What are the most crucial factors in an effective BIM-enabled collaboration?

Based on the coding the results it was revealed that the concepts of "HR organization", "ICT infrastructure" and "collaboration conditions" are the most frequently impotent concepts in BIM collaboration. However, further interpretations resulted that the concept of "training" plays a more important role than "HR organization" and an efficient training can moderate organization effects.

To recognize the most crucial factors in BIM-enabled collaboration, we refer to the most frequent ones within the concepts and the themes. The most important factors within the concepts of "training", "ICT infrastructures" and "collaboration conditions" result to be "learning new skills", "technology maturity" and "joint decision making". Referring to the themes of ''people", "products" and "processes" the most frequently mentioned factors are "involvement in collaboration", "interoperability" and "joint decision making". Therefore, the factor of "joint decision making" results to be the most important both within the concepts and themes. We argued that because of the influence of "leadership" on "joint decision making", the factors of "leadership" and "leadership" and "direct participant leadership" are also recognized as crucial factors determining an effective BIM-enabled collaboration.

Question 2: What information and communication technologies are more effective in BIM-enabled collaborations?

In regard to the "products" theme which refers to technologies, hardware and software, the "data accessibility" and "information exchange management" have remarkable influence on "joint decision making" which was recognized as the most important factor in collaboration. Therefore, considering the information and communication technologies that are influential on these factors will help with answering question 2. The flow of information between project stakeholders and its accessibility when required in critical moments such as decision making would be facilitated by "cloud technologies". For this matter, a CDE must be cloud-based and managed in a way to provide access to the right people at the right time. Therefore, we can recognize "cloud technologies" as the most important one enabling an effective collaboration in a wide range of industries including AEC.

With regard to BIM-enabled collaboration, an effective way of coordination between project stakeholders is doing so based on the BIM 3D model. This allows for effective "issue tracking", which was revealed as an important factor in our analysis, better understanding of situation ad exploiting the potentials of innovative collaboration environment such as VR. Therefore, "3D visualization technologies" such as WebGL, real-time rendering and game engines and AR/VR technologies have remarkable use in collaboration. Although each of the "cloud" and "visualization" technologies are important and have their own use cases, the combination of the two results to be the most effective ICT-based tools for collaboration. Therefore, cloud environments that host data storage and can visualize the BIM 3D models are the most compelling tools enabling a successful BIM collaboration. Such tools have a positive influence on factors such as "involvement in collaboration", "central data base", "data accessibility" issue tracking" among other factors recognized in the case study data analysis.

Question 3: How the role of architects is impacted by implementing BIM-based collaboration?

The participants of the case studies agreed that the role of architects will fundamentally change by implementing BIM. However, BIM-based collaboration brings about some opportunities for architects to play a more influential role in project delivery in order to prevent changes to their design intends. The importance of "leadership" factor in collaboration was highlighted because of its influence on factors such as "joint decision making" and concepts of "collaboration conditions" and "ICT management". The participants also indicated that leadership that comes from project participants is more effective than a 3rd party leadership, a case that is common in BIM-enabled projects. We discussed that because of the architects comprehensive understanding of the project needs, this leadership role fits their position in the project. Therefore, implementing BIM in collaborative procedures provides the opportunity for architects to stand in a leadership position.

8.3 Addressing the research hypothesis and key findings

Principal hypothesis: BIM implementation essentially changes the architect's role and responsibility in projects' collaboration and coordination processes.

The ultimate product delivered in a construction project is a building. A collaborative approach specifically aims to increase the success of teams as they engage in collaborative problem solving. Better solutions will eventually lead to a better project delivery. The three dimensions of the BIM ecosystem described in this research all work together to encourage collaboration. BIM collaboration Products are specifically designed to streamline collaboration between various project teams, with reference to a 3D data enriched model. BIM Processes do so by including factors that ask for collaboration in the protocols and contracts to implement collaborative policies. People engaged in BIM-enabled projects are required to collaborate on early stages of design and to share their works to avoid creating silos.

In case study 1, we saw how all the coordination issues could be addressed using BIM if somebody leads the adoption of a collaborative ecosystem that allows to centralize communications and refer them to a tangible support such as the BIM because the lack of a single leading party in collaboration and multiple coordination units in the project level had contributed to confusions. This actor should be the architect, since he is already responsible for the overall design coordination. But for that they should want to do it and train themselves properly. Otherwise, given that the advantages of the BIM in this field are already widely known, another actor will take care of it, relegating the architect to a mere specialist. This means that the architect must assume general coordination roles within the BIM if he does not want his current field of action to be reduced.

In this case study the ''leadership'' factor resulted to be an important factor within the crucial concept of "HR organization" that also influences the crucial factor of "collaboration involvement". In addition, the "direct participant leadership" was another factor revealed to confirm the importance of leadership from one the project stakeholders i.e. the architects. An effective leadership also contributes to an effective "joint decision making", the factor reveled to be the most significant in a successful BIM collaboration.

From case study 2 we could draw the conclusion that the architectural firm that participated in the experiment could offer the VR service to its clients for the project review and as an added value for the subcontractors in the construction phase. This widens its field of action, allowing to expand its business model. This also allowed for engaging the client more actively in collaboration as the VR environment provides a better perception of designs. This more engaging environment highlights another important factor revealed in the study which is ‘’Collaboration involvement” and positively contributed to the factor of ‘’collaboration environment’’.

In case study 3, we hear from the interviewee that implementing BIM has led them to collaborate with facility and maintenance people early on in the design development. This means peoples involved in two ends of a project life-cycle are encouraged to collaborate required in their BIM ecosystem. It helps with foreseeing the future needs of the building before major decisions are concreted. It again highlights the crucial factor of ‘’collaboration involvement’’ and “early involvement” which positively contributes to the most crucial factor of “joint decision making”. Another example in the case study was the use of scripting in order to automate some time taking tasks, such as specific scheduling. Once an architectural firm is freed from time taking manual tasks, they can focus more on the design process itself and leading others toward the goal of delivering a better product. It relates to the factors of “efficient workflows” which positively contributes to the most crucial factor of “joint decision making”. This implies the assumption of a new role, that of BIM Manager, inexistent until now. Although not all architects must act as BIM Manager, of course, it is true that in each project and each organization there must be one of them. Therefore, this collective will agree that this position will be occupied by one of its own guild.

The research concludes that although implementing BIM brings about a paradigm shift in working methods of architectural practices, it does not necessarily change their role as the “project authors”. Studying the situation in the architectural firm subject to the case study 3, we realized that the main architects still initiate the design process as it was before BIM implementation. Although the rest of the office utilizes BIM and develop and deliver their initial design in their BIM ecosystem. The role of ‘’project authors’’ still remains the same, albeit the fact that this authorship is now involving other project stakeholders more than ever. While the nature of the role remains the same, the architects can assume a more influential position on the whole project development BIM-enabled projects as “leaders” in collaboration procedures. This leadership, however, must adopt a negotiating spirit, since collaboration implies that the interests of all agents must agree on a design that has a shared responsibility among all.

Nevertheless, we must take into consideration that this hypothesis is valid in the case of a true and an effective BIM collaboration. Meaning, the crucial factors for that must be satisfied. Here the concept of “collaboration policies” can be specially highlighted based on the CS3 participant’s statements. This concept that strongly impacts the most crucial concept of “collaboration conditions”, includes the factors such as “contracts”, “protocols” and “standards”. The role of architects as BIM collaboration leaders must be specified in legal contracts and agreements and must be reinforced by factors affecting the concept of “HR organization”. It is only when all these conditions are met we can expect the architects to assume a leadership position and of the historical idea of master builder who balanced between art and science and oversaw all aspects of design and construction for an entire project.

Secondary hypothesis: Implementing BIM allows various digital technologies to be integrated in the technological pipeline of architectural firms.

As discussed in previously, this research finds the phrase ‘’ecosystem’’ the most comprehensive one to describe BIM. It is important to notice that here BIM stands for ‘’Building Information Modelling’’ and not a “Building Information Model”. The latter one is an output of the act of Building Information Modeling. The research adopts the three main dimensions of People, Product and Process to establish the BIM ecosystem. The findings from qualitative data analysis confirmed the strong inter-dependencies between the factors and concepts within these three dimensions or themes. It relates to the nature of an ecosystem that is consisted of elements that are dependent on each other and work together. A defect or unnatural grow in any of these dimensions negatively effects the whole ecosystem. An example of the factors that relate to these hypotheses and the idea of the ecosystem is as the following: For example, “learning collaboration skills” in the People theme, impacts the “software functionality’’ in the products theme. “Software functionary’’ is dependent on the “Technology maturity’’ which in turn impacts ‘’ data exchange method’’ within the Processes theme. Another example is “awareness’’ that helps people with technology acceptance that leads to “technology integration” within the Products theme that influences factors within the Processes theme such “issue tracking” and “decision communication”.

This research finds that the provided BIM ecosystem in this work can facilitate the integration of digital technologies supported by our initial argument that was confirmed by the case study analysis results. To efficiently integrate ICT or the digital transformation of organizations, a change management procedure must take place [27]. To be effective, the change management process must take into consideration how an adjustment or replacement will impact processes, systems and employees within the organization. These three areas that need to be changed are similar to the dimensions of a BIM ecosystem as described in this work. Therefore, we argued that understanding the factors within these three dimensions that relate to collaboration, we lead us to understand the factors influencing a successful collaboration based on ICT tools that are integrated in architectural practices through BIM.

Apart from the results of the case studies, the study of today’s BIM situation also supports this hypothesis for the following reasons:

BIM adoption in the industry: ‘*’BIM is now a necessity in modern construction projects* [162].’’ Over the past few years, the construction industry has seen an increase in BIM adoption. Apart from the awareness of the professionals about its benefits, it has been pushed further by government requirements around the world. For instance, in the UK, the following chart depicts the adoption rate in the last few years. Therefore, the industry acceptance of BIM can provide a standard basis for digital technology providers to enter the AEC industry. As many perceive it [163] and this research confirms, BIM adoption is the first step towards digitalization in architectural practices.

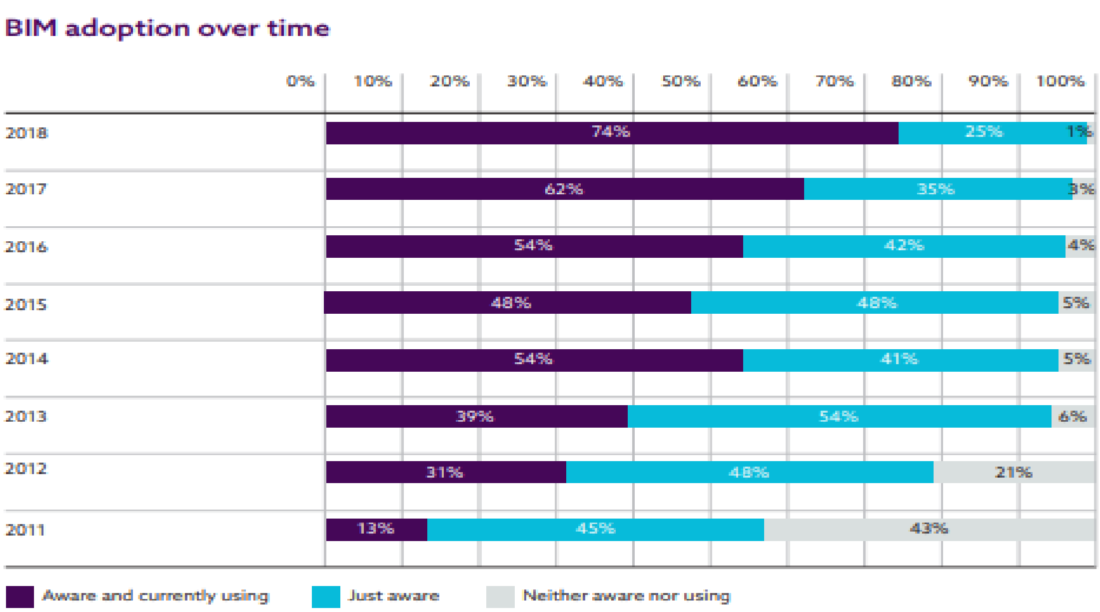

Figure 74 UK BIM adoption. The NBS. (2018)

- The response of technology providers: as for the author's professional experience and observations from the market, many technology providers are trying to enter the construction market through BIM. This is through adopting file formats used in BIM ecosystem or by accessing the Application Programming Interface (API). The example of the VR integration case study discusses this concept in detail.

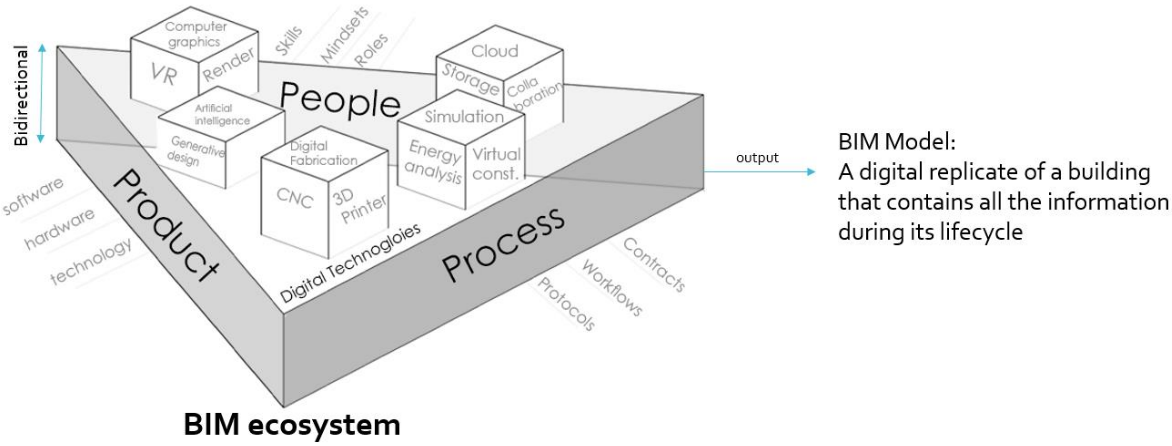

Figure 75 The BIM Ecosystem and the intergration of ICT

Digital technologies include all types of electronic equipment and applications that use information in the form of numeric code. The advances in computer sciences, whether in the field of hardware or software, have made these technologies available to the public more than ever before. This availability that comes with affordable expenses, has allowed them to enter the construction industry. BIM itself is an example of such a notion. Creating and working on 3D models that contain large amount of information requires potent computers. Therefore, it was due to the availability of such computers with reasonable prices to make BIM adoption logical regarding the Return on Investment (ROI).

The relation between BIM and digital technologies is a bidirectional one. One is to utilize inputs received from technologies such 3D scanning or artificial intelligence to create a BIM model, the other is to use a BIM model to prefabricate building parts, or to visualize it in a VR environment. The research concludes that the integration of these technologies means that this bidirectional relation takes place within an architectural practice technology pipeline. It means no additional work to create data is required to make this relationship possible. It happens fluently and quickly because of the interoperability between these technologies made possible by BIM. The factor of "interoperability" as the most crucial factor in the Products them and the "technology integration" and "efficient workflows" are some of the factors that relate to this topic.

8.4 Study limitations

Despite initial planning's, efforts, and support from the thesis supervisors to organize the case studies, the research faced some inevitable difficulties. To name some limitations we can mention:

- In the first case study about Vanak project, the author received enormous support from the project developer. They allowed access to the project documents and communications regarding the issue in the parking levels. We were also able to interview some team members from the project coordination office, however, our access to other project team members was limited. Furthermore, the main limitation we faced that the project stopped only sometime after our case study initiation. We hoped to be able to interview more people and evaluate our proposed BIM ecosystem together with the project stakeholders, but the project development never resumed again to this date.

- It is very difficult to find companies who are willing to collaborate on such academic projects. This is due to two reasons: one is that they are strict on disclosing their working methods and designs, and the other is that the time and costs that is associated with such collaborations. In fact, we had initial talks with a number of companies and organizations that showed some positive signs, who eventually withdraw from allowing us to study their case. Therefore, we had to stick with the 3 possibilities we had to address the thesis hypothesis. The fact is BIM is a novel concept in the construction industry and there are not many companies and projects that implement it.

- Another limitation was that even with the companies who agreed to collaborate, we had limited time and access to the personnel and their materials. For instance, in the case study 2, we needed to acquire permission from several entities involved in the construction project to utilize their BIM models and study their workflows. we also needed to acquire software license and only use the equipment's available in the university. We then needed to perform the experiment in one day as it was extremely difficult to gather the numerous participants on a specific day, making it almost impossible to repeat the experiment. In case study 3 we also faced limitations for accessing the firms' artifacts and personnel to interview.

Despite the limitations, the research has tried to employ multi-methods of data gathering to acquire the most amount of information. Based on such data collection and analysis the thesis hypothesis has been addressed and conclusions have been made.

8.5 Further works and Recommendations

The research finds some areas of interest for future works. They are whether based on the limitation of this research which did not allow for their investigations, or areas found during this research to require more studies.

- Due to the limitations mentioned above, the case study 1, we could not deploy our BIM ecosystem on the project with its real project stakeholder. Comparative research as such to compare different aspects of conventional project development with BIM –enabled one are of great interest to the academic and professional world. This requires the development of two projects of identical characteristics, one through traditional methodologies and the other using BIM with actors with a sufficient degree of BIM capabilities.

- The importance of the "training" factor was highlighted and discussed in this work. It has remarkable influences on many other factors that contribute to a successful BIM collaboration. Therefore, the research finds out that the area of BIM education needs to be further addressed. Including BIM subjects in architectural education curriculum to train the next generation of architects who are aware of BIM potential for the profession is important. The way to apply such training requires further research. This is also highlighted in the work of Zhang et al. [158] among other.

- On the industry side, further research and efforts are required to improve interoperability between BIM software. This is a key point for the integration of digital technologies in architectural practices. the research finds out that the focus should be more on better defined APIs for the access of other developers, rather than accepting file formats. IFC and openBIM concepts have been introduced to enable a better interoperability. However, from the practice world, construction practitioners have argued that they are not confident in IFC data exchange [164]. The importance of the factor "interoperability" was highlighted in this research as the enabler of machine-to-machine interaction and research in this filed will contribute to the further integration of technological systems that consists an important dimension of a BIM ecosystem.

- The impacts of BIM implementation on existing and emerging roles within the AEC industry is another area that requires research. For instance, "digital leadership" refers to the strategic use of a company's digital assets to achieve business goals. The idea of leadership in digitally transformed organization is an emerging topic that can be applied to the AEC industry as well. Or Project managers need specific updates on the scope of work, and on their roles and responsibilities in implementing BIM on their projects, resulting in a new paradigm of project management termed by Ma et al. [165] as "BIM-based project management (BPM)". The emergence of these roles in new working environment bolds again the need for education and training as discussed earlier.

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10 *List of Publications*

Scopus Journal Publication:

Zaker, R. Coloma, E. Zamora, J. (2018) *Virtual reality-integrated workflow in BIM-enabled projects collaboration and design review: a case study*. Visualization in Engineering. SpringerOpen.

Conference Publication:

Zaker, R. Coloma, E. Zamora, J. (2018) *Virtual reality-integrated workflow in BIM-enabled projects.* Conference Paper accepted for ‘’Forming technologies in Architecture’’ Conference, Glasgow - 2017

Zaker, R. Coloma, E. Zamora, J. (2018) *Virtual reality-integration in AEC practices.* Poster accepted for the IAARC 3SSettlements conference - TUM Munich - 2018