Sistemas de evaluación de la vivienda hacia ciudades sostenibles. Análisis de su impacto en el edificio y en el entorno urbano

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Para Diana Carolina

Tú, que has vivido a mi lado todo este camino.

Este compendio es para ti, mi compañera, te amo.

Para Héctor Bautista

Para ti, mi pequeño artista.

Espero que lo implícito en esta publicación… sirva para que vivas en un mundo mejor.

Resumen

En la última década, se ha dirigido una atención prioritaria hacia la obtención de sostenibilidad en la vivienda; la cual, ha sido señalada como un ente capaz de mitigar los problemas ambientales causados en los núcleos urbanos. La relación entre esta y la ciudad es inherente, por lo que las repercusiones que puede tener un determinado entorno urbano sobre una determinada construcción habitacional, o viceversa, deberían de ser consideradas por cualquier proceso de evaluación que se realice en el sector residencial. Sin embargo, la situación actual de los sistemas de evaluación de la sostenibilidad en la vivienda (SESV) muestra que existe un claro desvío hacia la obtención de eficiencia energética, lo cual, desde la perspectiva abordada en esta tesis, obstaculiza la obtención de una evaluación más holística que acrecente el desarrollo sostenible de las ciudades. A tenor de lo anterior, el objetivo principal de este documento fue el de auxiliar en la consecución de una evaluación más robusta de la sostenibilidad de la vivienda, así como en el logro de una comprensión más amplia de los problemas conocidos en los mecanismos actuales de evaluación y del nexo vivienda-ciudad, con el fin de obtener una aproximación al cuestionamiento sobre si el uso de los SESV vigentes, coadyuva al desarrollo de ciudades sostenibles de forma coherente con el significado de sostenibilidad. Para su consecución, se analizó el estado de los SESV con mayor aplicación y difusión en el ámbito internacional, así como los criterios implícitos en sus indicadores, y el impacto que tiene el uso de los mismos en el edificio y el entorno urbano. El documento se presenta en la modalidad de compendio de publicaciones, por lo que los aspectos metodológicos contienen distintas implicaciones, teniendo como característica común el enfoque comparativo. En este, los análisis incluyeron a los SESV: Passivhaus, BREEAM, LEED, GBI, AQUA-HQE, BEST, CASA, BERDE, Green Homes, y LOTUS, así como también al programa mexicano de financiamiento para soluciones habitacionales. Por

otra parte, cada uno de los artículos expuestos, presenta entornos o temáticas que abordan vacíos o brechas considerables en el conocimiento existente. En el primer artículo, se analizó la factibilidad del uso del estándar Passivhaus en el clima mediterráneo. En este, a pesar de que los resultados indican que la aplicación de los criterios del estándar es rentable, y permite reducir las demandas de energía y las emisiones de CO_2, se observó que los indicadores utilizados tienen una contribución mínima o incluso inexistente en el entorno urbano; en el segundo artículo, se muestran los resultados de las evaluaciones realizadas a través de los SESV más reconocidos internacionalmente, en diferentes viviendas construidas bajo el programa mexicano de financiamiento para soluciones habitacionales. Entre los principales hallazgos, se señaló que el modelo de evaluación del programa mexicano, que prioriza los aspectos del entorno urbano por encima del resto de parámetros considerados, puede representar un nuevo paradigma hacia el logro de la vivienda social sostenible; en el tercer artículo se realizó un análisis comparativo de los indicadores de vivienda utilizados por los SESV de viviendas unifamiliares; en los que, el entorno urbano residencial influye en los puntajes de certificación de las vivienda. Los resultados revelaron que el porcentaje de influencia que estas pueden lograr mediante éstos indicadores es relativamente bajo. Además, se encontró una ausencia significativa de éstos indicadores para las evaluaciones de criterios obligatorios, y que, la metodología establecida podría ser de utilidad para la búsqueda y definición de nuevos indicadores sostenibles. Finalmente, se pretende que los resultados implícitos en esta tesis, promuevan la sostenibilidad urbana a través de la construcción y evaluación del parque de viviendas nuevos y existentes, que faciliten la obtención de ciudades sostenibles.

Abstract

In the last decade, priority attention has been directed towards obtaining sustainability in housing; which, has been pointed out as an entity capable of mitigating the environmental problems caused in urban centers. The relationship between it and the city is inherent, so the repercussions that a given urban environment can have on given housing construction, or vice versa, should be considered by any evaluation process carried out in the residential sector. However, the current situation of the housing sustainability rating systems (HSRS) shows that there is an apparent deviation towards obtaining energy efficiency, which, from the perspective addressed in this thesis, hinders the obtaining of a more holistic assessment than increasing the sustainable development of cities. In the light of the foregoing, the main objective of this document was to assist in the achievement of a more robust assessment of housing sustainability, as well as in achieving a broader understanding of the problems known in the current mechanisms of evaluation and in the nexus housing-city, in order to obtain an approximation to the question of whether the use of existing HSRSs, contributes to the development of sustainable cities in a way consistent with the meaning of sustainability. To achieve the objective, the status of the HSRSs with the more significant application and dissemination in the international ambit was analyzed, as well as the criteria implicit in their indicators, and the impact that their use has on the building and the urban environment. The document is presented in the form of a compendium of publications, so that the methodological aspects contain different implications, having the comparative approach as a common characteristic. In this, the analyzes included the HSRSs: Passivhaus, BREEAM, LEED, GBI, AQUA-HQE, BEST, CASA, BERDE, Green Homes, and LOTUS, as well as the Mexican funding program for housing solutions. On the other hand, each one of the exposed articles presents environments or issues that address considerable gaps in the existing knowledge. In the first article, the feasibility of using the Passivhaus standard in the Mediterranean climate was analyzed. In this, although the results indicate that the application of the criteria of the standard is profitable, and allows to reduce energy demands and CO2 emissions, it was observed that the indicators used have a minimal or even non-existent contribution to the urban environs; In the second article, the results of the evaluations carried out through the most internationally recognized HSRSs are shown, in different homes built under the Mexican funding program for housing solutions.

Among the main findings, it was pointed out that the evaluation model of the Mexican program, which prioritizes aspects of the urban environment over the rest of the parameters considered, may represent a new paradigm towards the achievement of sustainable social housing; in the third article a comparative analysis of the housing indicators used by the HSRSs of single-family homes was carried out; in which, the residential urban environment influences the housing certification scores. The results revealed that the percentage of influence that these can achieve through these indicators is relatively low. Besides, a significant absence of these indicators was found for the evaluation of mandatory criteria, and that, the established methodology could be useful for the search and definition of new sustainable indicators. Finally, it is intended that the results implicit in this thesis promote urban sustainability through the construction and evaluation of the new and existing housing stock, which will facilitate obtaining sustainable cities.

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INTRODUCCIÓN

"Es esencial para el arquitecto saber ver; quiero decir, ver de manera que no se sobreponga el análisis puramente racional" ***—Luis Barragán—***

Capítulo I

Introducción.

Organismos internacionales como las Naciones Unidas (ONU), o el Banco Mundial, han puntualizado la trascendencia que puede tener la vivienda en la obtención del desarrollo sostenible en los asentamientos humanos. Con la finalidad de garantizar la contribución de las viviendas existentes y futuras en la consecución de ciudades sostenibles, el sector residencial y la industria verde, han elaborado una amplia gama de sistemas de evaluación de la vivienda. En la actualidad, millones de casas alrededor del planeta se han edificado bajo los criterios instaurados en los sistemas de evaluación vigentes, lo cual, se ha traducido en la disminución de gases de efecto invernadero y limitación de los impactos ambientales producidos en cada una de las etapas del ciclo de vida de estas viviendas; representando así, una mejoría significativa en su diseño, en su edificación, en su gestión y en su demolición. Sin embargo, existen diversas teorías que sugieren que los paradigmas modernos de evaluación establecidos por la plétora existente de sistemas, fallan en el cumplimiento de una evaluación holística y coherente con el concepto de sostenibilidad.

En esta tesis se busca obtener una comprensión más amplia de los sistemas de evaluación vigentes, así como mayores respuestas a los cuestionamientos realizados por otros investigadores, con relación a la forma en que éstos sistemas coadyuvan a la obtención de ciudades sostenibles, por lo que se exploran temáticas con vacíos o brechas considerables en el conocimiento existente. La modalidad del presente documento corresponde al compendio de publicaciones, estableciendo como unidad temática, al análisis de la repercusión que tiene el uso de un determinado sistema de evaluación, en una determinada vivienda y su contribución en la obtención de ciudades sostenibles.

1.1. Contexto y justificación.

El cambio climático y la degradación de la capa de ozono representan dos de los mayores desafíos ambientales a los que se enfrenta la sociedad global [1,2], señalándose entre los principales causantes de éstos: a los asentamientos humanos [3-5]. Por otra parte, las estimaciones recientes advierten que en el año 2030, el planeta contará con más de un billón de personas de las que actualmente lo habitan [6], y, si se considera el impacto que causa la actividad humana en el cambio climático y en la degradación medioambiental [7,8], así como la persistente tendencia a la urbanización del planeta [9,10]; es ineludible el hecho de que la humanidad deberá afrontar el reto de integrar el concepto de sostenibilidad, como una cualidad intrínseca en las ciudades [11].

Bajo la hipótesis de que la actividad de la sociedad y su desarrollo, son dependientes de un entorno habitable [12], las acciones dirigidas hacia la obtención de un desarrollo sostenible suponen un componente primordial en los objetivos establecidos por la comunidad global en sus diferentes escalas: regional, nacional, e internacional [13-15].

La definición de desarrollo sostenible surgió en el reporte realizado en 1987 por la comisión mundial del desarrollo y medio ambiente (WCED siglas en inglés) "our common future", en el que se estableció como: "El desarrollo que satisface las necesidades del presente, sin comprometer la capacidad de las generaciones futuras para satisfacer sus propias necesidades" [16]. Sin embargo, desde su exposición, el confirmar que se han realizado acciones dirigidas hacia el desarrollo sostenible dentro el ámbito de la construcción, ha generado distintos puntos de vista entre sus diversos actores [17,18].

En 2015, la ONU aprobó la agenda 2030 sobre el desarrollo sostenible [19], en la cual, los países adheridos a esta organización, acordaron determinar 17 objetivos de desarrollo sostenible (ODS), con la finalidad de proporcionar un paradigma que guíe a la humanidad hacia una prosperidad compartida en un mundo sostenible [20]. En la búsqueda de soluciones que guíen este nuevo paradigma, es que investigaciones recientes señalan que la vivienda tiene un rol fundamental para que las ciudades se beneficien de cualidades capaces de promover el desarrollo sostenible [21-24], lo cual se encuentra en sintonía por lo especificado por la ONU-Habitat (**Fig. 1.1**).

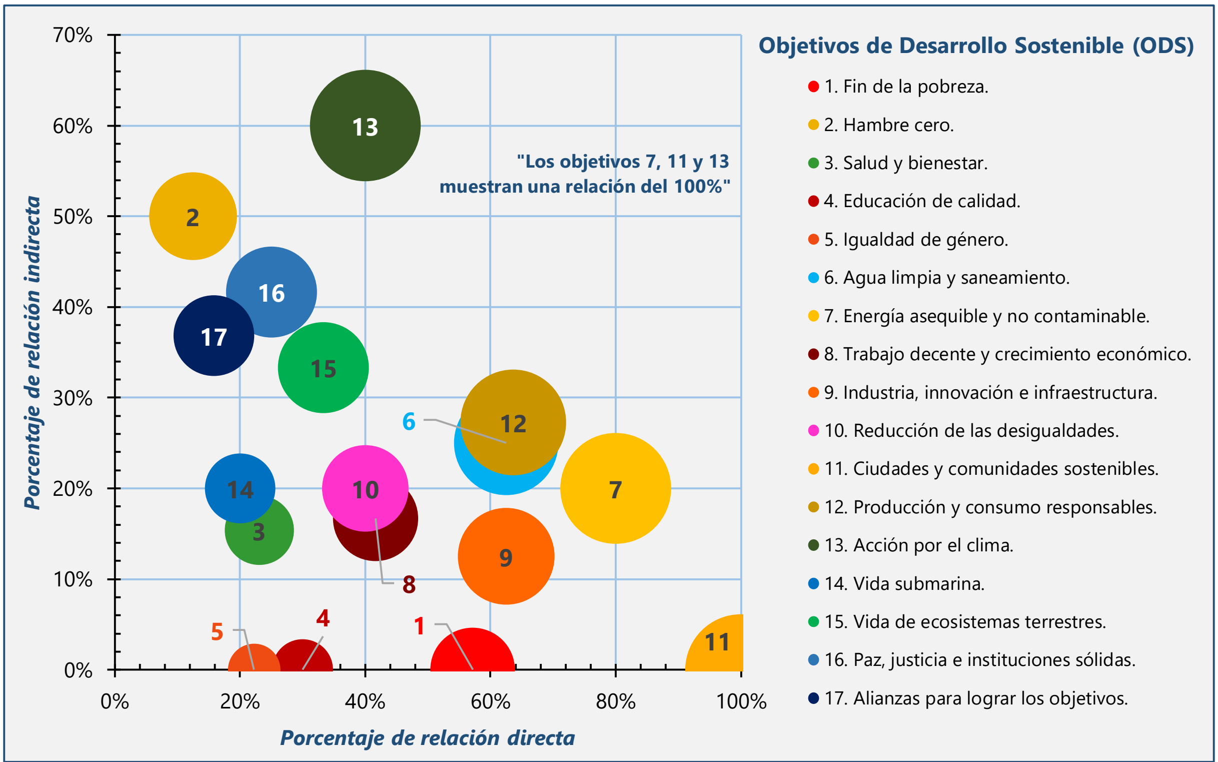

Fig. 1.1. Porcentaje de relación directa o indirecta entre las metas planteadas en cada uno de los ODS y la vivienda. El tamaño de los círculos corresponde al porcentaje total de relación, mientras que los números mostrados al centro, corresponden al número del ODS al que hace referencia el porcentaje de relación. **Información basada* en *[25].*

Barbosa et al. [26] mencionaron que, si la humanidad requiere aplicar la sostenibilidad en el ámbito de la construcción, es necesario que sea capaz de medirla; por consiguiente, en el sector residencial se han elaborado diversos sistemas de evaluación que permiten cuantificar el grado de sostenibilidad con el que cuenta una vivienda —los SESV—. En éstos sistemas, se pueden destacar dos hitos trascendentales en su desarrollo y difusión:

- En 1990 se dio el lanzamiento del Método de Evaluación BREEAM (Building Research Establishment Environmental Assessment Method, definición en inglés), al ser el primer sistema que consideró el desempeño ambiental de un edificio de oficinas [27].
- En 1992, mediante la Conferencia de las Naciones Unidas sobre el Medio Ambiente y el Desarrollo (UNCED siglas en inglés), se firmó Agenda 21, la cual estableció textualmente en su apartado 40.4: "Es preciso elaborar indicadores del desarrollo sostenible que sirvan de base sólida para adoptar decisiones en todos los niveles y que contribuyan a una sostenibilidad autorregulada de los sistemas integrados del medio ambiente y el desarrollo" [28].

De acuerdo con Seemann [29]: "nunca en la historia de la arquitectura ha entrado una nueva idea en el mercado tan rápida y exhaustivamente como la sostenibilidad." Entre los SESV con mayor uso y difusión en los últimos años por la industria de la construcción, existen principalmente dos tipos de enfoques [30-32]: (i) el que se fundamenta en el análisis cualitativo del edificio —Evaluación de Calidad Total (ECT)—; (ii) el que se fundamenta en el análisis cuantitativo del edificio —Evaluación de eficiencia energética, emisiones o Análisis de Ciclo de Vida (ACV)—.

- En lo correspondiente a los SESV basados en el análisis cualitativo, LEED y BREEAM son considerados como los más reconocidos tanto por el sector académico, como por la industria de la construcción [33-38]. De acuerdo con Doan et al. [39], BREEAM fue el primer sistema de evaluación de la sostenibilidad en la construcción en el mundo, mientras que LEED se considera como el sistema con mayor presencia en el ámbito internacional.
- En cuanto a los SESV basados en el análisis cuantitativo, el Sistema Passivhaus ha tenido una gran repercusión en el mercado inmobiliario durante los últimos años [40-44]. De acuerdo a sus inventores, el sistema se caracteriza por un enfoque holístico, que combina varias medidas en un marco coherente [45]. Ismaeel [46], señala que el estándar Passivhaus es el sistema de evaluación de eficiencia energética con mayor aceptación en Europa.

Por otra parte, a pesar de que la gama existente de SESV permite adaptar los esquemas de evaluación a sus respectivos contextos, también complica el análisis comparativo entre las distintas metodologías [47]; por consiguiente, la complejidad que se presenta para evaluar la sostenibilidad supone diversos argumentos, pero en lo que concuerda la literatura existente es que el factor de éxito depende en gran parte de los indicadores utilizados [36,48-55].

En 1997, Rennings y Wiggering [56], señalaron que los indicadores son un requisito previo para la aplicación de la sostenibilidad en las decisiones políticas, sin embargo, éstos deben reflejar hasta qué punto el uso real de los recursos naturales está lejos de este objetivo. Un indicador se puede definir como un parámetro o valor que provee información sobre un fenómeno en específico [57], entre sus definiciones más completas se encuentra la de la Guía Metodológica de Indicadores Energéticos para el Desarrollo Sostenible [58], en la que se definen como: "Aquellos valores que se extienden más allá de las estadísticas básicas para proporcionar una comprensión más profunda de los temas principales y para resaltar las relaciones importantes que no son evidentes utilizando estadísticas básicas."

Durante las próximas décadas, se estima que el uso y la creación de nuevos sistemas de evaluación se incremente dentro del sector residencial [30,34,36,59,60], debido a que el conocimiento del estatus de sostenibilidad en las viviendas será de gran relevancia para las naciones que consideren dentro de sus prioridades gubernamentales, el concepto del desarrollo sostenible [61]; de acuerdo con el consejo mundial de la edificación verde (World Green Building Council), las viviendas que siguen los principios establecidos por los SESV, pueden establecer las bases para el cumplimiento de nueve, de los 17 ODS, incluido el objetivo de crear ciudades y comunidades sostenibles [62].

A pesar de que es innegable que la utilización de los SESV ha contribuido de forma significativa en la mejora de la industria de la construcción, y a la par en la limitación de las emisiones de gases de efecto invernadero (GEI) [33,40,59,63-66]; publicaciones previas han señalado que los SESV vigentes no permiten evaluar en su totalidad el índice de sostenibilidad con el que cuenta una vivienda [34,35,67-69]. Lo anterior, representa la principal justificación para la realización de los artículos que constituyen el presente documento.

Entre las distintas teorías, se consideró que, a pesar de la repercusión que puede tener la vivienda en la obtención de ciudades sostenibles, su papel como ente transformador no ha sido aprovechado para cumplir el objetivo de obtener o promover la sostenibilidad en las ciudades, y, por el contrario, la pesquisa siguió el entendido de que la vivienda es hoy en día, uno de los principales asuntos a resolver por la humanidad, en la búsqueda de opciones que permitan limitar las emisiones de GEI y los problemas relacionados con el cambio climático que se producen en las ciudades.

Considerando que más del 65% de la superficie de las ciudades corresponde al sector residencial [70], es que esta tesis justifica su desarrollo en la búsqueda de respuestas a los cuestionamientos realizados en los últimos años, con referencia a la contribución que puede tener el uso de un determinado sistema de evaluación, o en su caso, la adaptación de sus indicadores en cualquier etapa del ciclo de vida de la vivienda, en la obtención de ciudades sostenibles.

Por otra parte, durante la Conferencia de las Naciones Unidas sobre la Vivienda y el Desarrollo Urbano Sostenible, celebrada en Ecuador en octubre de 2016 (Hábitat III), se señaló que la vivienda no ha sido integrada correctamente en las políticas de desarrollo y planeación urbana de la mayoría de los gobiernos actuales adheridos a las Naciones Unidas [70]. En la presente tesis, se considera, que esta falta de integración, responde en gran medida a que los encargados del diseño y gestión del sector residencial han direccionado sus prioridades hacia la obtención de viviendas energéticamente eficientes, en vez de edificar o evaluar viviendas que cumplan con un nivel de sostenibilidad de forma más holística. Lo cual, se encuentra en sintonía con otras investigaciones realizadas en los últimos años [71,72].

Lo señalado en el párrafo anterior, se puede sustentar en que la mayoría de los SESV presentan un claro desvío hacia la asignación de las ponderaciones más elevadas a las cualidades que tienen que ver con la eficiencia energética [36,38,73-75]. Ante esto, Mateus y Bragança [76], señalaron que los aspectos relacionados con la planificación urbana sostenible en la vivienda, normalmente se limitan a los municipios y las autoridades regionales y, por lo tanto, es más racional y directo establecer el límite del sistema físico al edificio mismo, tal y como sucede en la mayoría de los SESV.

Por otra parte, se ha establecido que las estrategias necesarias para mitigar los gases de efecto invernadero y conseguir una eficiencia energética, así como una mejor adaptación al cambio climático en las ciudades; pueden ser obtenidas del análisis pormenorizado de la relación entre el edificio y el entorno urbano que lo circunda [34,77-81]. Lo anterior también representa una de las principales líneas de investigación que se abordaron en el presente documento.

Las circunstancias que condicionaron la realización de los artículos que componen este compendio, se establecen en el argumento de que las acciones realizadas en la configuración y caracterización de los SESV: representan un rol crítico en la obtención de un desarrollo sostenible. Asimismo, se espera que la información expuesta en cada uno de los capítulos, y los resultados obtenidos, sirvan para formular medidas en las que se involucre la vivienda, con el fin de aprovechar los recursos con los que cuenta el sector residencial, de manera que se impulse el desarrollo sostenible de las ciudades.

1.2. Delimitaciones de la investigación.

Como acotación general de esta tesis, se puede señalar que los estudios realizados se enfocaron exclusivamente en los sistemas de evaluación: Passivhaus, BREEAM, LEED, GBI, AQUA-HQE, BEST, CASA, BERDE, Green Homes, LOTUS y en el programa mexicano de financiamiento para soluciones habitacionales. Las delimitaciones de la investigación correspondientes a cada uno de los artículos publicados, son señaladas a continuación:

- **The Passivhaus Standard in the Mediterranean Climate: Evaluation, Comparison and Profitability.** Este artículo limitó el análisis hacia la tipología de vivienda adosada. Asimismo, las características de los casos de estudio, correspondieron a las consideradas como convencionales en el ámbito de construcción español, en acuerdo con las condiciones climatológicas correspondientes al clima Mediterráneo.
- **Sustainable social housing: The comparison of the Mexican funding program for housing solutions and building sustainability rating systems.** Se acotó la pesquisa en las tipologías de vivienda social unifamiliar y multifamiliar. Asimismo, las características de las mismas correspondieron a las delineadas por el programa mexicano de financiación para soluciones habitacionales. En el cual, los casos de estudio se ubicaron en el Noroeste de México. Por otra parte, en el análisis comparativo se seleccionaron los sistemas: BREEAM, LEED, GBI y AQUA-HQE, en conjunto con el programa mexicano.
- **Housing Indicators for Sustainable Cities in Middle-Income Countries through the Residential Urban Environment Recognized Using Single-Family Housing Rating Systems.** A diferencia de los artículos anteriores —en los que existieron casos reales de estudio—, la demarcación en este manuscrito direccionó el estudio hacia las metodologías establecidas por los SESV, específicamente en el análisis de los indicadores del entorno urbano residencial que influyen en la etiqueta o certificación final de las viviendas; considerando las versiones enfocadas en la vivienda unifamiliar. Asimismo, los resultados se justificaron en lo establecido por los sistemas: BREEAM, LEED, BEST, CASA, GBI, BERDE, Green Homes y LOTUS.

1.3. Objetivos.

El objetivo global de esta tesis fue el de obtener una aproximación que permita esclarecer el cuestionamiento sobre si el uso de los SESV coadyuva a la obtención de ciudades sostenibles. Asimismo, uno de los objetivos principales que se plantearon en la realización de cada uno de los artículos, fue el de auxiliar en la consecución de una evaluación más robusta de la sostenibilidad de la vivienda, así como en el logro de una comprensión más amplia de los problemas conocidos en los sistemas actuales de evaluación.

Por otra parte, con la finalidad de incrementar la calidad de los SESV que se utilizan en la actualidad, es que se exploraron entornos y temáticas con vacíos o brechas considerables en el conocimiento existente.

Los objetivos específicos del documento, correspondieron en este caso, a los delimitados por los artículos realizados durante la elaboración de las pesquisas:

- **The Passivhaus Standard in the Mediterranean Climate: Evaluation, Comparison and Profitability.** Obtener la viabilidad y la disminución de los impactos ambientales que significa la aplicación del standard Passivhaus a una vivienda convencional del ámbito español, con un énfasis específico en el clima Mediterráneo.
- **Sustainable social housing: The comparison of the Mexican funding program for housing solutions and building sustainability rating systems.** Comparar el programa mexicano de financiación para soluciones habitacionales en un contexto global, con las regulaciones especificadas por los sistemas de evaluación de la sostenibilidad en los edificios de más alto rango en la industria de la construcción, a través de sus parámetros de evaluación. Permitiendo así que los parámetros de evaluación del programa mexicano, sean examinados, evaluados y comparados, con el fin de obtener hallazgos científicos que conduzcan a la integración real del concepto de vivienda social sostenible en la construcción mexicana, así como proveer una guía para la obtención de vivienda social sostenible en diferentes países de ingresos medios.
- **Housing Indicators for Sustainable Cities in Middle-Income Countries through the Residential Urban Environment Recognized Using Single-Family Housing Rating Systems.** Identificar indicadores de viviendas unifamiliares con respecto a las características del entorno urbano residencial, reconocido como verde, ecológico o sostenible por los sistemas de calificación de viviendas unifamiliares. Con la finalidad de que estos indicadores sean de utilidad para los encargados de configurar el entorno urbano residencial, en la búsqueda de asentamientos humanos más seguros, más inclusivos, más resilientes y más sostenibles en los países de ingresos medios. Paralelamente al objetivo principal, se espera que este estudio proporcione una imagen de la situación actual en la que los sistemas de evaluación de la vivienda unifamiliar de los países de ingresos medios consideran el impacto que tiene el entorno urbano residencial en la clasificación de un hogar verde, ecológico o sostenible.

Finalmente, a pesar de las características implícitas en cada uno de los artículos realizados, la unidad temática del documento se centró en el análisis de los sistemas vigentes con mayor difusión en el ámbito internacional, y su contribución hacia la obtención de ciudades sostenibles. Buscando que los resultados expuestos en este documento, sean de utilidad para el sector de la construcción, así como también para los organismos encargados del desarrollo y gestión de las ciudades, y de los mismos sistemas de evaluación.

1.4. Estructura.

La estructura de esta tesis corresponde a la modalidad de compendio de publicaciones, dividiéndose en cinco capítulos y los anexos, en los que se incluyen otros productos realizados de forma paralela a la elaboración de los artículos que constituyen este compendio:

- **Capítulo I.** Consiste en la introducción de la pesquisa: señalando el contexto y la justificación; las delimitaciones implícitas en los resultados obtenidos; los objetivos, tanto el global, como los específicos de cada uno de los artículos expuestos; y, finalmente se detalla la estructura del documento.
- **Capítulo II.** Presenta el primer artículo: "The Passivhaus Standard in the Mediterranean Climate: Evaluation, Comparison and Profitability." Publicado en la revista Journal of Green Building en el 2015. Actualmente, este artículo cuenta con 3 citas de acuerdo con la base de datos de SCOPUS. Asimismo, el factor de impacto de la revista en el año de publicación del artículo fue de 0.34 (CiteScore).
- **Capítulo III.** Presenta el segundo artículo publicado, "Sustainable social housing: The comparison of the Mexican funding program for housing solutions and building sustainability rating systems." Publicado en la revista Building and Environment en el 2018. Actualmente este artículo cuenta con 12 citas de acuerdo con la base de datos de SCOPUS. Asimismo, el factor de impacto de la revista en el año de publicación del artículo fue de 5.60 (CiteScore con datos calculados al 30 de abril del 2019).
- **Capítulo IV.** Presenta el tercer artículo publicado, "Housing Indicators for Sustainable Cities in Middle-Income Countries through the Residential Urban Environment Recognized Using Single-Family Housing Rating Systems." Publicado en la revista Sustainability en este año. Actualmente, el artículo no cuenta con citas de acuerdo con la base de datos de SCOPUS. Por otra parte, el factor de impacto de la revista aún no se conoce debido a que la publicación es de este año; sin embargo, en 2018 fue de 3.01 (CiteScore con datos calculados al 30 de abril del 2019).
- **Capítulo V.** Señala las conclusiones de la tesis, y se especifican los lineamientos que pueden seguir las líneas de investigación futuras. Asimismo, se señalan los productos obtenidos durante la duración del doctorado, de forma transversal a lo comprendido en este compendio.

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CAPÍTULO II

THE PASSIVHAUS STANDARD IN THE MEDITERRANEAN CLIMATE: EVALUATION, COMPARISON AND PROFITABILITY.

Saldaña-Márquez, H., Gómez-Soberón, J.M., Arredondo-Rea, S.P., Almaral-Sánchez, J.L., Gómez-Soberón, M.C., Rosell-Balada, G. (2015) “THE PASSIVHAUS STANDARD IN THE MEDITERRANEAN CLIMATE: EVALUATION, COMPARISON AND PROFITABILITY“ ***Journal of Green Building***. 10 (4): 55-72.

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THE PASSIVHAUS STANDARD IN THE MEDITERRANEAN CLIMATE: EVALUATION, COMPARISON AND PROFITABILITY

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INTRODUCTION

One of the main environmental problems faced by the global community in the twenty-first century is unquestionably the reduction of greenhouse gas emissions (Fuller and Crawford 2011). To face this challenge, the European Union (EU) has set the so-called 2020 Horizon as one of its main objectives: limiting the emission of greenhouse gas emissions by 20%, satisfying 20% of all energy needs through renewable sources, and improving energy efficiency by 20% (The European Union 2012). The last projection forecast in 2012 by the European Environmental Agency (EEA) established that Spain was one of the countries in the EU furthest from reaching these objectives (The European Union 2013). As a result, implementing measures devised to meet the 2020 objectives is currently a priority for the Spanish government.

In recent decades, the housing sector has played a decisive role in increasing global energy demands and greenhouse gas emissions (Nejat et al. 2015). In 2014 Spain's housing sector's energy consumption needs represented 19% of total national consumption and 31% of the electricity demand (IDAE 2013). Starting from the design phase, reduction in energy consumption per square meter has become a prerequisite for the majority of buildings (Parameshwaran et al. 2012; Koo et al. 2014).

The importance and urgency exhibited by the EU housing sector in achieving the government objectives outlined in the 2020 Horizon have led the energy market to show a clear trend towards buildings with higher energy performance in the future (Shimschar et al. 2011). Similarly, the success factor of energy efficiency initiatives will depend to a large degree on the method or the indicators used when measuring energy performance in each building (Abu Bakar et

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* A significant value in the Spanish housing sector, the total consumption of isolated houses is double that of block houses; in the specific case of heating consumption, the proportion is 4 times greater, exceeding 6 times in the Mediterranean zone (IDAE 2011).

** According to Asdrubali et al. (2008), the isolated house is the least favorable in Spain.

al. 2015; Day and Gunderson 2015). As a result, selecting one energy evaluation methodology over another can be decisive in the path taken by Spain, change the current perception of the country, and increase Spain's standing within the EU.

Several studies (Feist et al. 2005; Schnieders and Hermelink 2006; Mahdavi and Doppelbauer 2010; Mlakar and Strancar 2011; Hatt et al. 2012; Dahlstrøm et al. 2012; Dequaire 2012; Proietti et al. 2013; Ridley et al. 2013; Stoian et al. 2013; Moran et al. 2014; O'Kelly et al. 2014) indicate that the Passivhaus standard (PS) can be used as a highly effective tool in both limiting greenhouse gas emissions and increasing building energy efficiency.

Other studies (Audenaert et al. 2008; Moeseke 2011; Allacker and De Troyer 2013; McLeod et al. 2013; Mlecnik 2013; Stephan et al. 2013) challenge the adoption of the PS because they consider other options within the energy market to be better from both environmental and financial perspectives. Nonetheless, the precursors to the PS claim that the benefits of the standard can be replicated in any part of the world through its use during the design phase (Feist 2014; Passive House Institute 2010, 2015; Passipedia 2015).

The main objective of this study was to analyze the viability of using PS through the Passive House Planning Package (PHPP) tool in the Spanish housing sector, focusing on its use in the Mediterranean climate in the Province of Barcelona. To that end, we selected an isolated semidetached home, that exhibits the typical characteristics of current Spanish housing so that any possible deficiencies or virtues of adopting the PS are easily observable.

The study was conducted using 3 construction proposals (PC, P1, and P2); the initial proposal (PC) is defined by conventional construction technology, while the remaining 2 proposals (P1 and P2) offer different construction alternatives focused on optimization (window glass, the building envelope, and improved installations), enabling evaluation of the PS criteria compliance. To test the ease of obtaining PS compliance without the need for changing the architectural design of the project, the design and space distribution of the PC alternative remained the same for the P1 and P2 options.

KEYWORDS:

passivhaus standard, energy efficiency, PHPP, Mediterranean climate, construction costs

THE PASSIVHAUS STANDARD

The Passive House (PH) concept was first developed in Sweden from collaboration between Bo Adamson of Lund University and Dr. Wolfgang Feist (Proietti et al. 2013). This concept is characterized by a holistic approach, combining several measures into a consistent framework (Feist 2005). More specifically, PH refers to "a building, for which thermal comfort can be achieved solely by post heating or post cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions" (Passipedia 2015). One of the main advantages of PH is that even though building a PH implies a higher construction cost, the additional expense will be recovered in a few years by the energy savings (Stoian et al. 2013).

According to Schnieders and Hermelink (2006), "the standard has been named 'Passive House' because the 'passive' use of incidental heat gains—delivered externally by solar irradiation through the windows and provided internally by the heat emissions of appliances and occupants—essentially suffices to keep the building at comfortable indoor temperatures throughout the heating period." The standard fundamentally consists of three elements: an energy limit, a quality requirement and a defined set of preferred passive systems that allow the energy limit and quality requirement to be met cost effectively (EERG 2015).

The combined heat and electric energy demand of a building is the Primary Energy demand (PE). Therefore, the PS includes a requirement for the PE (see methodology) to prevent the space heat demand from being reduced at the expense of large internal gains from electric appliances and to discourage direct electric heating (Feist 2005).

With approximately fifty thousand Passive Houses in use worldwide (2012 data), the Passivhaus standard is rapidly spreading all over the world (Passipedia 2015). Several authors (Feist 2005; Schnieders and Hermelink 2006; Hatt et al. 2012; Moran et al. 2014) claim that PH can save up to 50% of the total primary energy consumption.

The Passive House Institute (2015) stated that "the PH concept itself remains the same for all of the world's climates, as does the physics behind it. Yet while Passive House principles remain the same across the world, the details do have to be adapted to the specific climate at hand."

A comparison of PH and low-energy houses revealed that PH CO_2 emissions were approximately 25-40% lower than low-energy houses, with a 5% increase in initial construction costs (Mahdavi and Doppelbauer 2010). Another investigation by Audenaert et al. (2008) concluded that a PH costs 16% more than a standard house; the insulation and ventilation are the main causes for this extra cost. They also noted that "when energy-saving buildings are to be promoted at a large scale, governments should aid with larger subsidies to make passive houses more attractive to individuals planning projects in the residential sector."

The existing situation might determine which design strategy should be pursued more actively to achieve better energy performance. However, the large number of elements in the market today makes it necessary for architects to have a tool to assist them in identifying the best combinations for any specific situation (Ochoa and Capeluto 2008; Kallaos and Bohne 2013; Chen et al. 2015). This study sought to clarify some aspects regarding the adoption of the PS criteria in the Mediterranean climate during the design phase for the Spanish context. The research discussed in this paper investigated the PE, CO_2 emissions and profitability.

METHODOLOGY

The PHPP V-1.2.1 software was used to evaluate the PS among the study samples (PC, P1 and P2). According to Mlecnik et al. (2010), "the tool was developed independently of German building legislation and the German implementation of the Energy Performance of Buildings Directive (EPBD). The accuracy of the PHPP tool as a predictor for energy use has been validated on several demonstration projects. Its main advantage compared with other design and evaluation tools is that is has been specifically created as a design and certification tool for passive houses and that it regularly incorporates new research results in its calculation procedures."

To obtain more conclusive results on the implementation of PS in Spain, a parallel assessment was performed in PHPP; the energy efficiency assessment of the proposals was run in CERMA software, which is an application recognized by the Ministry of Industry, Energy and Tourism and the Ministry of Public Works, that obtains the qualification energy efficiency in new construction buildings for the entire Spanish territory (MINETUR 2015).

The PS is only favorable when it is in compliance with its specifications (Feist 2013): a maximum value of 15 kWh/(m^2a) in the specific heating demand or a maximum of 10 W/m2 in the heating load; a maximum value of 15 kWh/(m^2a) + 0.3 W/(m^2aK) * Dry degree hours[3] (DDH) in the specific cooling demand or a maximum of 10 W/m2 in the cooling load; and a maximum specific primary energy demand (including domestic electricity) of 120 kWh/(m^2a). Therefore, proposals P1 and P2 were forced to comply with the PS requirements (using alternative construction systems). As a result of these study variables, external criteria were required to facilitate equivalence between them (and with respect to the PC proposal).

In this study, we selected an economic assessment and cost-effectiveness as the comparative criteria of the study samples because these are considered the usual parametric criteria in the construction sector; these criteria were used as discrimination or rejection variables for the equivalent alternatives (Georges et al. 2012; Allacker and De Troyer 2013; Alam et al. 2014; Galvin 2014). With the use of financial and energy evaluations of the variables, we were able to compare the results and assess the cost-effectiveness of changing from a PC system to the P1 or P2 system; this comparison allowed us to determine trends, draw parallels and identify optimum action alternatives.

The proposals for the modifications studied did not affect interior spaces, the project geometry, volumes or the established uses of each space. To prevent uncontrolled variables from affecting the results of the study, no variations or modifications in the building surroundings or orientation were allowed.

Energetic assessment

Because primary energy can be produced on the building site by renewable energy, the boundaries between total energy demand, delivered energy and primary energy are difficult to define (Dequaire 2012). Therefore, the values referring to occupation, equipment, and energy consumption were limited in accordance with the guidelines established in the PHPP, for which the following considerations were made:

- Data entered into the PHPP concerning the climate for the proposed location were determined by the software Meteonorm V-6.1.0.23 (°N Lat: 41.668, °E Long: 2.255, Altitude: 282, Time Zone: 1, Random Seed: 1-5, Albedo: Automatic, Diffuse and Tilt Radiation Model: Perez, Temperature Model: Standard (hour), Period Radiation: 1981-2000, Period Temperature: 1996-2005).
- The typology and properties of the ground were considered as clays and silts: Thermal conductivity: 1.5 W/(mK), Heat capacity: 3.0 Mj/(m^3K), Floor slab area: 115.4 m^2, Floor slab perimeter: 46.4 m, U-Value for PC: 3.521 W/(m^2K), U-Value for P1 and P2: 0.447 W/(m^2K); the U-value varies between proposals because the P1 and P2 have insulation in the slab construction system that contacts the ground. The depth of the groundwater table was 3 m, and the groundwater flow rate was 0.05 m/d.

- The maximum of the supply and extract air demands was 363 m^3/h, and the supply air per person was assumed for dwellings: 30 $m^3/(P*h)$. For summer ventilation, the ratio of time during which the windows are opened to total time was 50% at night and 70% during the day. The preceding parameters are useful to assess the energy consumption from forced ventilation and air conditioning.
- The solar collector that provided hot water was assumed to have a deviation from north of 180º, an angle of inclination from the horizontal of 40º and a collector field height of 1.04 m.

  The assumptions of the appliance electricity consumption in the home were as follows: Clothes Washing: 1.25 kWh/Use, for a standard 5 kg wash load and considering the most unfavorable consumption. Clothes drying: 4.00 kWh/Use, assuming a standard 5 kg wash load and considering the most unfavorable consumption. Dishwashing: 0.92 kWh/Use, assuming a standard load of twelve place settings and considering common consumption. Cooking with electricity: 0.20 kWh/Use considering the PHPP value for an induction ceramic cooktop. Refrigerating: 0.31 kWh/Use considering common consumption. Freezing: 0.64 kWh/Use considering common consumption. Consumer electronics: 80 W considering the PHPP value for residential use.

Economic assessment

The budgets used were based on the quantification of various items included on every construction proposal (PC, P1 and P2) for which the Bank BEDEC of the Institute of Construction Technology (ITeC) was used (ITEC 2015). Determining the basic prices is necessary for the construction or realization of each unit of work (quantities of raw materials used, commitment length of operators, equipment and tools, and auxiliary means required).

Once the basic prices of each item have been obtained and multiplied by the total volume, the Execution Material Budget (EMB) was obtained. This budget will increase with (by applying the usual coefficients) indirect costs (2%), overhead costs and industrial benefit (13% and 5%, respectively), and finally taxes (10%, reduced rate), resulting in the Contract Execution Budget (CEB) (State Agency 1987) using 2013 prices.

An identical treatment was applied to each proposal studied, only changing the alternative building system improvements proposed in P1 and P2; therefore, the budget variances that are identified relate to the environmental certification in economic terms.

The economic assessment corresponding to operational energy accounted for a 20-year period, for which the following considerations were made:

- The energetic demands were considered by the PHPP results.
- To determine the potential future increases in the annual kWh price, the reported average percentage in the five years previous to 2013 was used.
- The price and taxes for electricity (0.146230 € and 5.11%, respectively) and natural gas (0.050789 € and 0.23%, respectively) were established for April 2013. Therefore, we considered an annual rate of increase of 4.1% and a monthly flat fee of 7.65 € for electricity and an annual rate of increase of 2% and a monthly flat fee of 2.42 € for natural gas.

[3] Time integral of the difference between the dew-point temperature and the reference temperature of 13 °C throughout all periods during which this difference is positive (Feist 2013).

- The price of pellets (0.484848 €) was established by their consumption in kg and was determined using 2013 values. Therefore, we considered an annual rate of increase of 2%; we did not consider a monthly flat fee and taxes because these are subsidized by the government.
- A VAT of 21% was considered for electricity, natural gas and pellets.

Profitability

Two common and widely used indicators were used in the economic assessment: the Internal Rate of Return (IRR) and the Net Present Value (NPV). Both indicators were determined using spreadsheet software. For these calculations, a number of periods (n = 20 years) was used, and the initial investment cost was calculated as the difference in CEB between the PC alternative and the other two proposals (P1 and P2).

The cash flow or the predicted annual income from alternatives P1 and P2 was determined based on the savings from reduced energy consumption. Finally, the IRR calculation was made starting in the fifth year, and the NPV calculation considered three different inflation scenarios: 2%, 4% and 6%.

DESCRIPTION OF THE OBJECT OF STUDY

The project is a 3-story building (see Figure 1 and Figure 2) that includes two housing units, with each unit covering 223.14 m^2 of useful area; both units are symmetrical and have the same distribution of spaces and use (see Table 1 and Table 2). The main orientation of the homes is north-south; the glass surface of the northern facade represents 11.25% of the total surface, while the southern facade has 61.42% glass coverage. Due to the descending slope of the lot on which they were built, their basements begin to diverge from the ground in a southerly direction.

FIGURE 1: Project description.

FIGURE 2: Project render.

TABLE 1. Useful Areas and Treated Floor Areas (PHPP)

Floor	Useful Areas		Treated Floor Areas	
	1 Unit	2 Units	1 Unit	2 Units
BS (m²)	68.39	136.78	28.10	56.21
GF (m²)	92.00	184.00	80.40	160.80
FF (m²)	62.75	125.50	55.34	110.68
TOTAL	**223.14 m²**	**446.28 m²**	**163.84 m²**	**327.69 m²**

TABLE 2. Area groups (PHPP)

Area Group	Surface
Exterior wall (m²)	336.87
Partition wall (m²)	100.90
Accessible roof (m²)	148.5
Non-accessible roof (m²)	111.0
Basement ceiling (m²)	115.36
Floor slab (m²)	157.30
TOTAL THERMAL ENVELOPE	**982.26 m³**

The horizontal and vertical structural members of the buildings consist of monolithic unidirectional reinforced concrete beams and columns; the foundations consist of spread footings and isolated footings according to the location of the columns and retaining walls.

GENERAL FEATURES

The project is located in the town of l'Ametlla del Vallès, which is part of the province of Barcelona (41°40'5.24"N, 2°15'20.03"E), and the plot covers 1053 m^2 (39 m x 27 m), with a mean slope of 20% at 282 m above sea level. According to the Koppen-Geiger scale, the climate region corresponding to the location is "Csa" (C: Warm temperate, s: Summer dry, a: Hot summer) (Kottek et al. 2006). Before evaluating the project based on PS criteria, the PC alternative of this study and the construction variations that result in P1 and P2 are all subjected to meticulous compliance with all construction codes and regulations typical of the Spanish construction sector (see Table 3).

Specific features

The basic initial data for the PHPP included the calculated U-values (the thermal transmittance of the materials used in the envelopes) and their corresponding thicknesses because these

TABLE 3. Legal Framework

Normative	Description	
Technical Building Code (TBC) Article 3 of law 38/1999	DB-HR	Noise protection.
	DB-HS	Sanitation.
	DB-SI	Safety in case of fire.
	DB-SE	Structural safety.
	DB-SUA	Safety in use and accessibility.
	DB-HE	Energy saving.
EHE-08	Compliance requirements: Reinforced concrete.	
REBT	Low voltage electrical regulations, Royal Decree 842/2002 of August 2, 2002.	
RITE	Rules of installation: Thermal installations in buildings, Royal Decree 1027/2007.	
Decree 68/2010:	Processing and approval of technical documents recognized by the technical edification code.	
Decree 135/1995	Accessibility Code of Catalonia.	
Decree 21/2006	Adoption of environmental criteria and eco-efficiency in buildings.	
Municipal scope	General Urban Plan (14/01/1987).	

are some of the main parameters that control energy consumption and energetic efficiency in residential buildings (see Table 4).

TABLE 4. Description of U-Values

Building elements	Building assembly Description	Proposal (s)	U-Value [W/(m²K)]	Thickness (cm)
Exterior wall	Coating (20 mm) + gero brick (140 mm) + air chamber (50 mm) + expanded polystyrene panel (50 mm) + totxana brick (70 mm) + gypsum plaster (15 mm)	PC	0.448	34.50
	Coating (15 mm) + thermal clay (190 mm) + gero brick (100 mm) + expanded polystyrene panel (80 mm) + totxana brick (40 mm) + gypsum plaster (15 mm)	P1	0.310	44.00
	Coating (15 mm) + thermal clay (190 mm) + gero brick (100 mm) + expanded polystyrene panel (120 mm) + totxana brick (40 mm) + gypsum plaster (15 mm)	P2	0.230	48.00
Partition wall	Gero brick (140 mm) + expanded polystyrene panel (50 mm) + gero brick (140 mm)	PC, P1 and P2	0.476	33.00
Accessible roof	Reinforced concrete slab (300 mm) + expanded polystyrene panel (80 mm) + perlite (50 mm) + mortar (20 mm) + ceramic tile (20 mm)	PC	0.370	47.00
	Reinforced concrete slab (300 mm) + expanded polystyrene panel (120 mm) + perlite (50 mm) + mortar (20 mm) + ceramic tile (20 mm)	P1 and P2	0.260	51.00
Non-accessible roof	Reinforced concrete slab (300 mm) + expanded polystyrene panel (80 mm) + perlite (50 mm) + gravel (70 mm)	PC	0.370	50.00
	Reinforced concrete slab (300 mm) + expanded polystyrene panel (120 mm) + perlite (50 mm) + gravel (70 mm)	P1 and P2	0.260	54.00
Basement ceiling	Reinforced concrete slab (300 mm) + gypsum plaster (15 mm) + marble flooring (20 mm)	PC	2.460	33.50
	Reinforced concrete slab (300 mm) + gypsum plaster (15 mm) + marble flooring (20 mm) + perlite (80 mm)	P1 and P2	0.424	41.50
Floor slab	Reinforced concrete slab (250 mm) + gravel (50 mm)	PC	3.520	30.00
	Reinforced concrete slab (250 mm) + gravel (50 mm) + perlite (80 mm)	P1 and P2	0.447	38.00

The terms "Gero and totxana" brick are used in Catalonia. For more information, see the UPC (2015).

For the carpentry details corresponding to envelope openings (windows), improvements were proposed for the types of glass used, their number on each element, their thickness, and the characteristics of their insulating chamber according to each one of the proposals: PC, P1 and P2 (see Table 5).

TABLE 5. Description of Windows

Windows characteristics	PC	P1	P2
Winter / Summer reduction factor of north orientation (average value)	63% / 47%	62% / 46%	62% / 46%
Winter / Summer reduction factor of east orientation (average value)	81% / 65%	43% / 55%	52% / 55%
Winter / Summer reduction factor of south orientation (average value)	61% / 35%	68% / 36%	68% / 36%
Winter / Summer reduction factor of west orientation (average value)	27% / 30%	43% / 55%	52% / 55%
Window/Glazing Area of north orientation (m²)	18.24 / 15.70	18.24 / 11.60	
Window/Glazing Area of east orientation (m²)	1.80 / 1.50	7.56 / 5.00	
Window/Glazing Area of south orientation (m²)	75.03 / 68.20	75.03 / 59.50	
Window/Glazing Area of west orientation (m²)	13.32 / 11.60	7.56 / 5.00	
Total (Window / Glazing) Area (m²)	108.39 / 97.10	108.39 / 81.00	
U-Value of glazing (W/m²K)	2.90	1.10	0.60
U-Value of frames (W/m²K)	3.30	0.97	0.97
G-Value (Perpendicular radiation)	0.77	0.56	0.54

Different installation systems were used for each of the proposals in compliance with indoor air quality requirements to satisfy indoor comfort and improve heating and cooling for the different study variables, in addition to those necessary for the solar energy contribution to useful heat, as shown in Table 6.

TABLE 6. Description of Facility Systems

Facility systems	Description	PC	P1	P2
Ventilation data	Effective heat recovery efficiency	0%	50%	
	SHX efficiency		100%	
	SHX heat recovery efficiency		62%	
Heating and cooling load	Heating load (W)	18,195.00	5,034.00	3,943.00
	Specific heating load (W/m²)	55.50	15.40	12.00
	Cooling load (W)	8,345.00	4,464.00	4,146.00
	Specific max. cooling load (W/m²)	25.50	13.60	12.70
Hot water provided by solar	Estimated solar fraction of DHW production	64%	60%	84%
	Solar contribution to useful heat (kWh/m² year)	17.00	18.00	26.00
Heat generation	Ratio of heat generator space heat run	101%		139%
	Ratio of heat generator DHW run	132%	135%	
	Ratio of heat generator, DHW and space heating	103%	116%	

SHX: Subsoil Heat Exchanger; DHW: Domestic Hot Water.

Based on the specific characteristics of the PC, P1 and P2, the EMB varied by submitted proposal. The facade, facilities, insulation and cover were the budget lines that presented more variations between the different projects (see Table 7).

TABLE 7. Breakdown of the Contract Execution Budget (CEB)

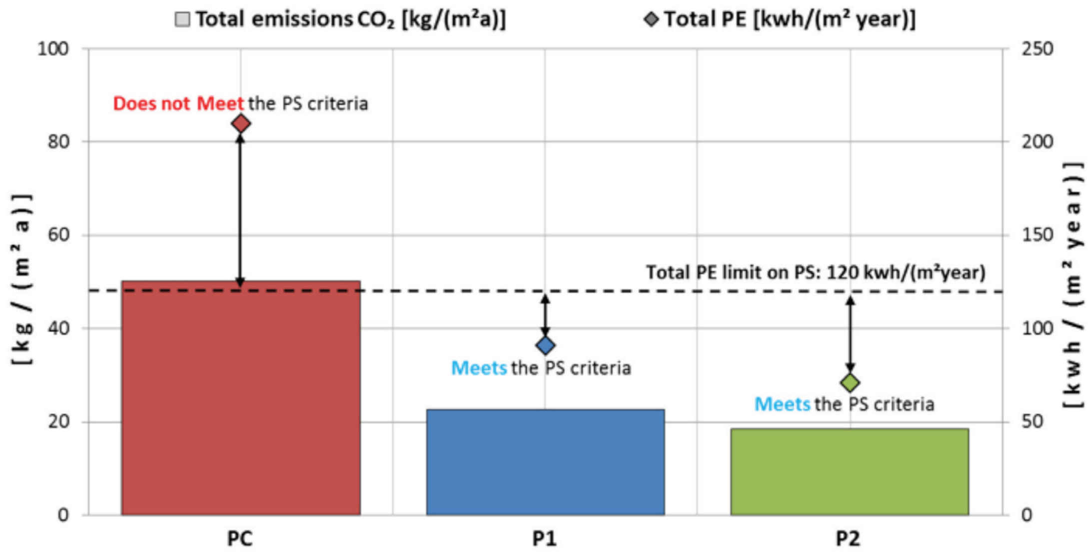
Data	PC	P1	P2
Ground preparation	18,493.25 €		
Foundations	37, 557.94 €		
Structure	93,751.10 €		
Coating	110,129.58 €		
Waste management	6,012.29 €		
Quality control	2,927.79 €		
Health and safety	17,186.97 €		
Signaling	16,824.60 €	16,825.50 €	
Urbanization	76,327.31 €	76,537.05 €	
Partitions	32,116.82 €	32,338.17 €	
Facade	78,474.62 €	99,542.30 €	100,365.45 €
Facilities	54,498.30 €	70776.53 €	100,317.91 €
Insulation	9,910.94 €	18,404.15 €	19,241.22 €
Cover	23,583.53 €	27,319.51 €	27,319.51 €
Execution Material Budget (EMB)	***577,795.02 €***	***627,802.13 €***	***659,003.72 €***
Overhead costs and industrial benefit	*109,781.05 €*	*119,282.40 €*	*125,210.71 €*
Value Added Tax (VAT)	*68,757.61 €*	*74,708.45 €*	*78,421.44 €*
Contract Execution Budget (CEB)	**756,333.68 €**	**821,792.99 €**	**862,635.87 €**

RESULTS

Energetic assessment

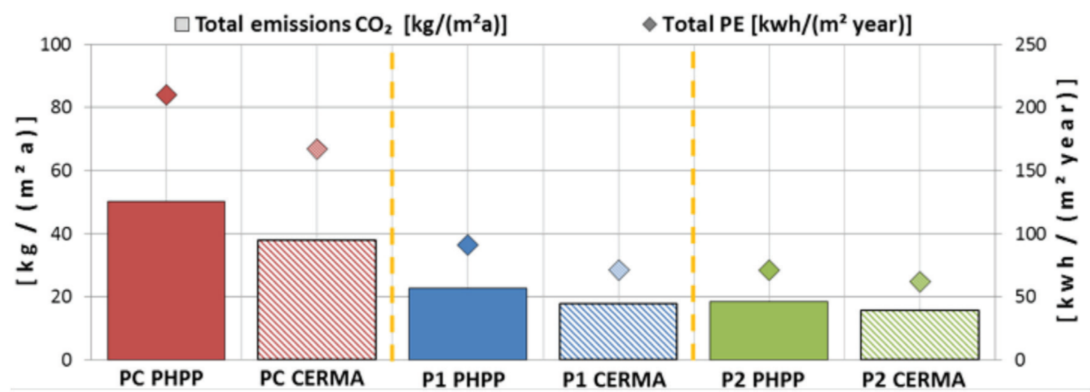
Once the data of any given proposal were introduced, the operational energy was evaluated and a comparison was made between each proposal. The PHPP verified the behavior of the 3 study alternatives; the values obtained by the PHPP highlight that proposals P1 and P2 (which meet the PS criteria) exhibit much lower PE and CO_2 emissions than the PE and CO_2 emissions of the PC (which does not meet the PS criteria), as shown in Figure 3.

FIGURE 3: PHPP results



These results show that the PE was reduced by 57% in P1 compared to PC, while P2 showed a greater reduction of 66%, which is within the estimated range of other studies (Feist 2005; Schnieders and Hermelink 2006; Hatt et al. 2012; Moran et al. 2014). The results show a 22% reduction for P2 compared to P1. The CO_2 emissions generated by PC are reduced by 55% using P1 and 63% using P2. The results show an 18% reduction for P2 compared to P1. The energy efficiency assessments from CERMA software show the values of total PE and CO_2 emissions of proposals P1 and P2 and demonstrate a large reduction compared to PC. A comparison between PHPP and CERMA shows a minimum differential range that varied between 13% and 20% for PE and 16% and 25% for CO_2 emissions on each proposal, as shown in Figure 4.

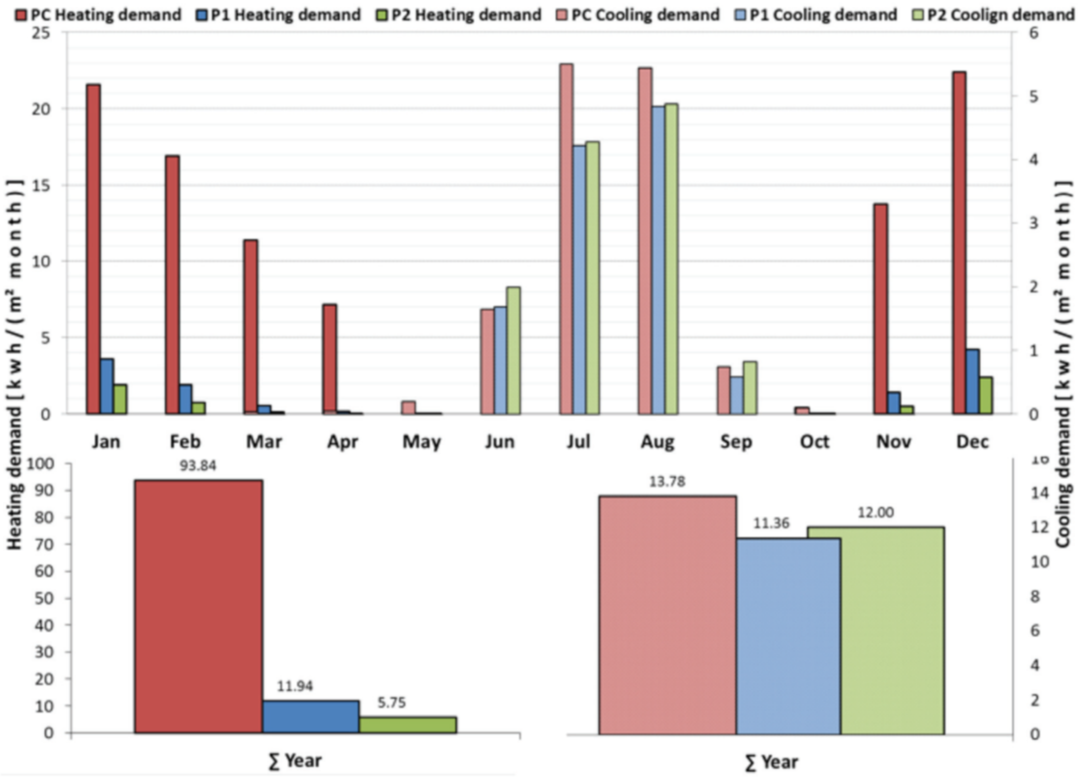
FIGURE 4: Results of the PHPP and CERMA



A comparison with other software reinforces the veracity of the PHPP results and obtains more conclusive findings. As a product of the changes made to each of the proposals (as given in the description of the study object) and following the assessment results, P2 is the most environmentally efficient proposal, followed by P1 and finally PC with a very large difference from the other two proposals.

Some researchers have argued that the problem with the PS assumption is that the standard mainly focuses on heating demand (McLeod et al. 2013; Mlecknik 2013; Stephan et al. 2013) by switching the importance of the repercussions of cooling demand. The result of this particular case study shows that this argument is valid because the modifications made under the PH concept have indeed produced greater reductions in heating demand and very limited reductions in cooling demand (see Figure 5).

FIGURE 5: Specific heating and cooling demand



P1 and P2 presented significant reductions in heating demand with respect to PC, with P2 reducing heating demand by 94% and P1 reducing heating demand by 87%. The most significant reductions were those registered in the period from November to April. The P1 and P2 proposals also showed reductions in cooling demand; however, in contrast to the specific heating demand, the cooling demand had more moderate reductions, with P1 reducing the cooling demand by 18% and P2 reducing cooling demand by 13% compared to the PC. The months during which the cooling demands are critical are July and August.

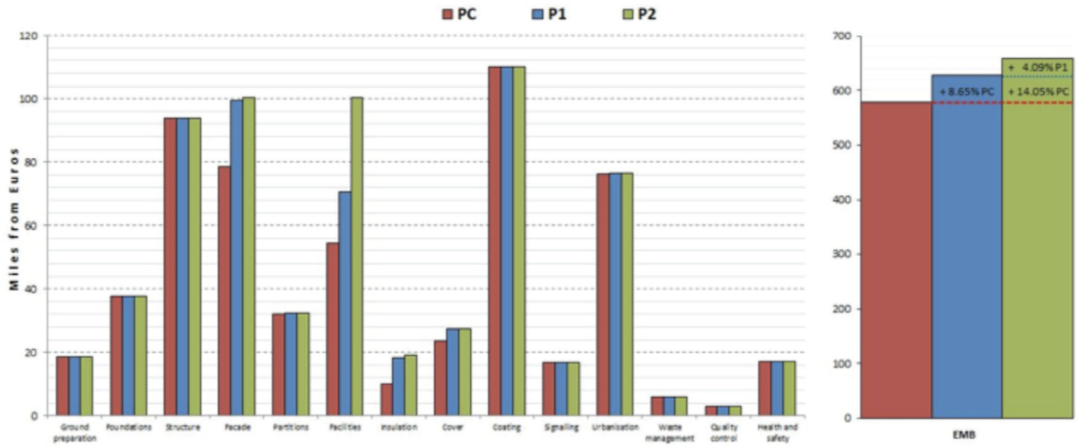
With further developments and diffusion of the Passivhaus standard, requirements to limit the energy used for space cooling are now taken into account (Dequaire 2012). The PS parameters are clearly more focused on reducing the specific heating demand, but to obtain better results in specific cooling demand, the PS parameters are changing. Feist (2013) mentioned that "the criteria for cooling and dehumidification apply provisionally and may possibly have to be adapted with advances in knowledge." In fact, some authors (Santamouris and Kolokotsa 2013; Kubota and Toe 2014) have shown various heat dissipation techniques that can be taken into account for the PHPP software, with the prospect of reinforcing the cooling demand assessment.

Economic assessment

A good residential building project depends not only on the available energy improvements, new and innovative materials and the construction quality. The economic aspect must also be evaluated because an improved project will be more expensive than the original, and whether this increased cost is worthwhile should be determined.

P1 shows an increased cost of 8.65% with respect to the PC, with the main variations resulting from the facade, insulation, facilities, and cover. Similarly, P2 shows an increased cost of 14.05% with respect to PC, with the main variations resulting from the same sources as those in P1. However, P2 costs 4.90% more than P1, with the main variation resulting from the insulation, as shown in Figure 6.

FIGURE 6: EMB budget line variations of the proposals



In terms of the EMB budget lines distribution of the proposals (see Figure 7), facilities play a greater role in P1 and P2 and show the highest increase compared to the other modifications. Regarding PC, the facilities are located in the medium range of the EMB. Moreover, coating represents the biggest line of the EMB on each of the proposals: 19% for PC, 18% for P1 and 17% for P2.

With initial inversion and the total amounts of energetic demands by year (see Table 8), the economic assessment of the proposals shows that improving PC to achieve compliance with the PS is cost-effective in P1 and P2 (see Figure 8). P1 becomes more cost-effective after the seventh year, while P2 begins to be more cost-effective after the ninth year compared to the initial investment and the energy cost of the PC alternative over time. However, P2 becomes more cost-effective than P1 after the seventeenth year.

FIGURE 7: EMB budget lines distribution of the proposals

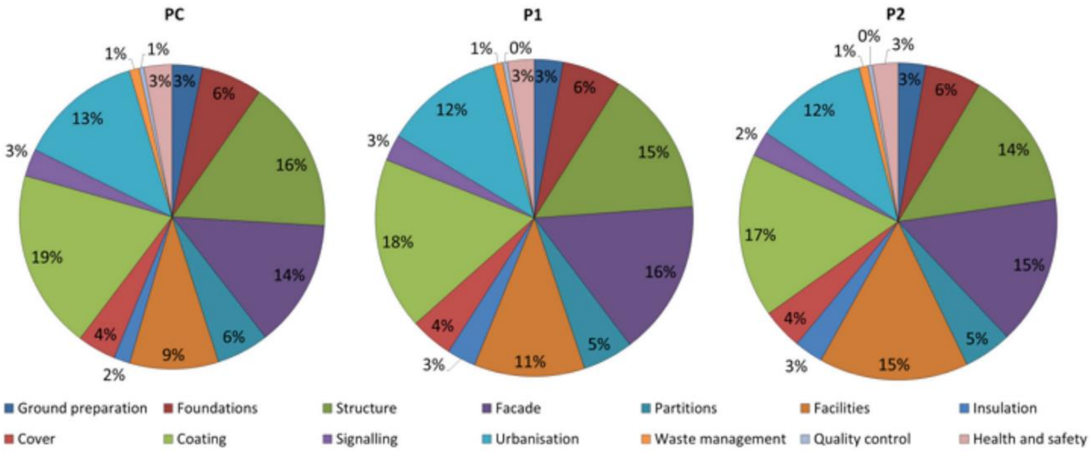
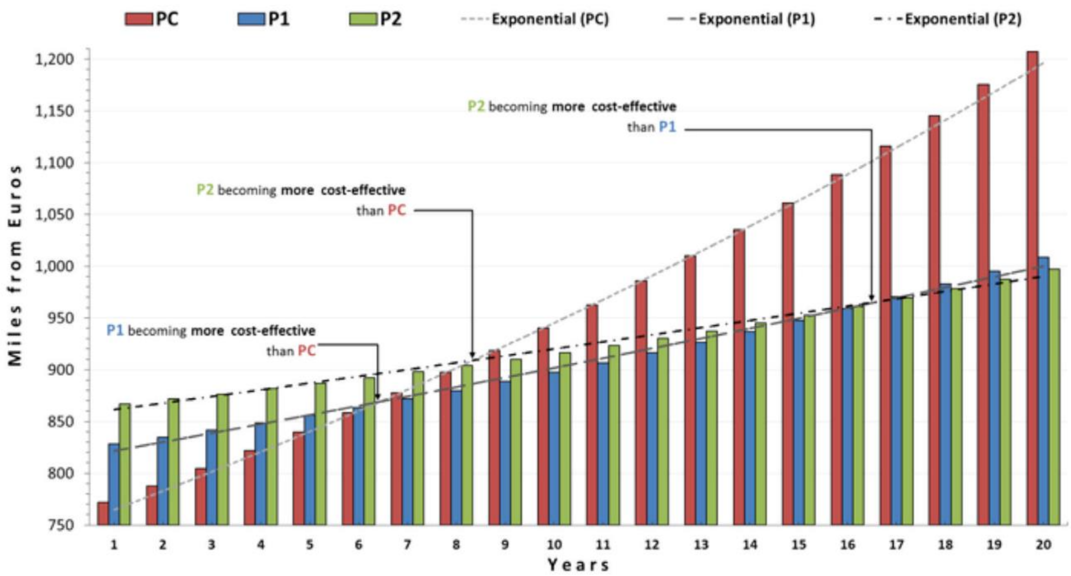


TABLE 8. Energetic consumption and initial inversion of the proposals.

Proposals	Initial inversion (€)	Total amounts of PE and Natural gas or Biomass* (€)	Year 1 (€)	Year 7 (€)	Year 9 (€)	Year 17 (€)	Year 20 (€)
PC	*756,333.68*	*15,481.04*	771,814.72	877,717.87	918,586.32	1116,309.27	1207,173.16
P1	*821,792.98*	*6,337.14*	828,130.11	871,662.40	888,534.10	970,591.17	1008,491.41
P2	*862,635.87*	*4,484.85*	867,048.71	898,059.08	910,158.25	969,481.20	997,091.27

*Notes: The table shows only the most representative years; *during the first year, increases described in methodology are projected in subsequent years.*

FIGURE 8: Accumulated economic costs of energy demands.



Profitability

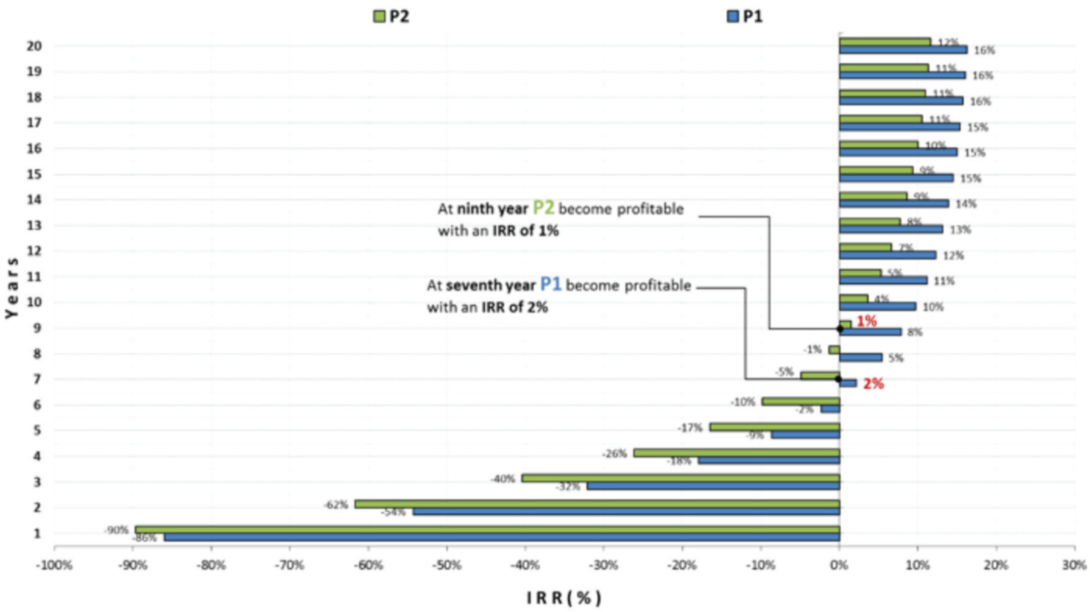
The benefit to the investor depends on the payback period. The IRR evaluation criterion used in proposals P1 and P2 confirms that P1 is profitable after the seventh year and P2 is profitable after the ninth year (see Table 9 and Figure 9). At the end of the study period (20 years), P2 reaches an IRR of 16.24% and P2 reaches an IRR of 11.67% (the change in behavior of the proposals occurs between the third and seventh years). Therefore, P2 is the most profitable proposal.

TABLE 9. IRR of P1 and P2.

Proposals	Year 1	Year 4	Year 7	Year 9	Year 15	Year 20
P1	-86.03%	-17.93%	2.18%	7.87%	14.50%	16.24%
P2	-89.66%	-26.17%	-4.90%	1.47%	9.38%	11.67%

Notes: The table shows only the most representative years.

FIGURE 9: IRR of P1 and P2



With respect to the NPV of P1 and P2 (see Table 10 and Figure 10), P1 becomes profitable in 9 years. The evaluation of the NPV criterion is sensitive to predicted inflation rates (inexact and estimated data), which have a direct and incrementally ascendant relationship. However, the investment is safe even in the most unfavorable case; that is, in the hypothetical case in which one must decide between investing in a Passivhaus project and investing in a long-term financial product with an inflation rate of 6% for 20 years, after the ninth year, the P1 investment is more profitable than the financial product.

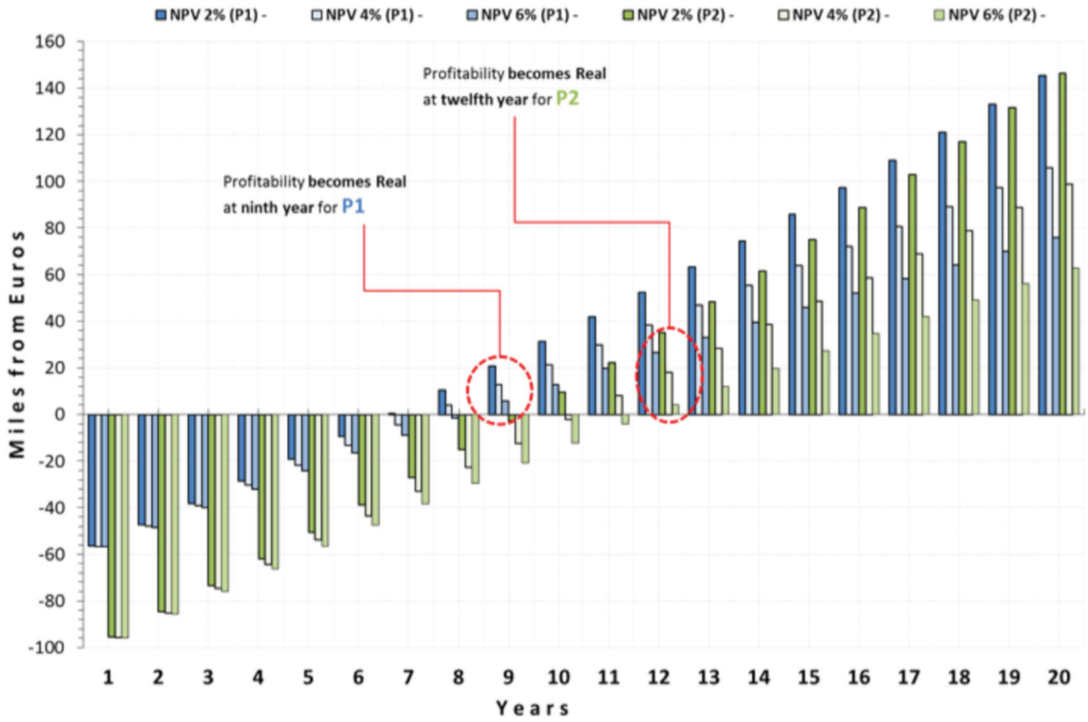
The results for proposal P1 also apply to P2; however, because the initial investment for P2 (see Table 8) is 5% higher than that for P1, the maximum period for the investment to become profitable is 12 years. Therefore, after that period of time, P2 will become more profitable than the financial product.

TABLE 10. NPV of P1 and P2 considering 2%, 4% and 6% inflation.

Proposal	Inflation	Year 1	Year 7	Year 8	Year 9	Year 15	Year 20
P1	*2%*	-56,494.69	472.13	10,526.06	20,748.67	85,826.49	145,377.55
	4%	-56,667.08	-4,486.55	4,120.82	12,704.30	73,736.23	105,708.87
	6%	-56,832.97	-8,905.43	-1,514.66	5,716.55	45,962.89	75,765.56
P2	*2%*	-95,521.61	9,647.96	22,308.59	35,179.17	75,094.26	146,239.69
	4%	-95,728.93	-2,202.78	8,022.87	18,218.17	48,629.40	98,774.62
	6%	-95,928.43	-12,366.72	-4,074.07	4,037.96	27,334.24	62,940.32

Notes: The accumulated amounts are in Euros. The table shows only the most representative years.

FIGURE 10: NPV of P1 and P2 (applying the inflation rates of 2%, 4% and 6%).



CONCLUSIONS

According to Abu Bakar et al. (2015), "the purpose of building energy analysis is to study the performance of energy consumption, perform system comparison and identify alternatives for improvement." The current investigation has shown that the PS is an effective tool when used during the design phase, reducing CO_2 emissions and increasing energy efficiency in the housing sector.

The results indicate that for a conventional home to obtain the PS certification, a final budget increase of only 8.65% is required (P1). However, with a slightly higher cost increase of 14.65% (P2), CO2 emissions can be reduced by up to 63% and the PE can be reduced by 66%. Similarly, the study also shows that using the PS is profitable, with profitability achieved for the P1 and P2 proposals in the ninth and twelfth years, respectively.

Based on this study, the use of the PS in the Spanish housing sector would help the country achieve the 2020 Horizon objectives prescribed by the EU. However, stating that this standard should be used in the entire country remains a largely theoretical and unpractical assertion. Additional studies similar to the one presented in this article still need to be conducted to determine how best to meet 2020 Horizon objectives.

Careful attention must be paid to the specific cooling demand (in the Mediterranean climate). This is clearly an area of study with great opportunities, which may help drive adoption of the PS in climates such as the one presented here. The reductions shown in the cooling demand are particularly visible compared to the reductions exhibited in the specific heating demand.

The results obtained may be more conclusive given that the variable established as "orientation" in the original project made the initial proposal (PC) less energy consuming. Similarly, the intent of preserving the design and distribution in proposals P1 and P2 demonstrates that obtaining the PS in a conventional home is fairly viable simply by modifying certain project characteristics, such as the type of glass, envelope, facilities, and equipment. More research is needed to obtain a wider understanding of behavior or adequacy of the standard in a global context, especially the viability and implications of the current limits that define the PS.

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CAPÍTULO III

SUSTAINABLE SOCIAL HOUSING: THE COMPARISON OF THE MEXICAN FUNDING PROGRAM FOR HOUSING SOLUTIONS AND BUILDING SUSTAINABILITY RATING SYSTEMS.

Saldaña-Márquez, H., Gómez-Soberón, J.M., Arredondo-Rea, S.P., Gámez-García, D.C., Corral-Higuera, R. (2018) "Sustainable social housing: The comparison of the Mexican funding program for housing solutions and building sustainability rating systems" ***Building and Environment***. 133 (4): 103-122.

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Sustainable social housing: The comparison of the Mexican funding program for housing solutions and building sustainability rating systems

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ABSTRACT

In the last decade, Mexico has been prominent among the Upper-middle-income countries (UMC) due to the application of its Funding Program for Housing Solutions (FPHS) in dealing with social housing.

This paper shows the results of the evaluations carried out, through the internationally recognized Building Sustainability Rating Systems (BSRS), on different housing units built under this program. It was necessary to carry out a normalization criteria process (NCP) due to the particular characteristics of each BSRS and the complexity they presented in carrying out a comparative analysis.

Case studies indicate that housing developed by the FPHS obtained low qualifications according to internationally focused BSRS, with significant deficiencies concerning materials, energy efficiency, indoor environmental quality, and management. However, this study provides indicators of its possible integration in the social housing of countries with characteristics analogous to those of Mexico. Among all indicators, that those referring to the urban environment are capable of being integrated into the social housing.

Among the findings, some aspects of the FPHS evaluation process impede the integration of sustainable characteristics in Mexican social housing. On the other hand, the FPHS evaluation model, which gives priority to urban environment aspects above all else, may represent a new paradigm towards the achievement of the sustainable social housing (SSH).

1. Introduction

Housing is one of the intrinsic conditions that determine living standards, the wellbeing of people and their environment [1]; it is often considered indispensable for achieving sustainable global development. This industry is an essential factor in the global increase in energy demand and Greenhouse Gas (GHG) emissions [2–4]. Despite this, different researchers [5,6] note that housing could act as a useful system which may lead to a reversal of these effects.[1]

From the different types of housing in existence, this study focuses on SSH –considering only those financed by some public or private body–, as they are optimal for experimenting with new solutions based on the principle of achieving low-cost and energy-efficient quality housing [7,8].

Regarding the UMC, Mexico has emerged as a reference in the search for solutions to SSH [9–12], as its housing policies have focused on finding solutions for the lowest income groups [11,13,14]. Partly due to the need to satisfy growth rates, as well as by the limited resources available for each inhabitant.

According to Turok [15], "Housing decisions need to be bolstered by institutional reforms to facilitate coordination and capacity-building"; likewise, several pieces of research [8,15–22] conclude that SSH must undergo a comprehensive analysis during the design phase, with an analysis of the urban context of its location being of particular

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[1] Abbreviations: BSRS: Building sustainability rating systems, COM: Competitiveness, CONAVI: National housing commission, DH: Detached house, ENE: Energy, FP: Fulfillment percentage, FPHS: Funding program for housing solutions, HIC: High-income country, IBP: Incentive to best practices, IEQ: Indoor environmental quality, MAN: Management, MAT: Materials, MCI: Multi-criteria indicators, MH: Multi-family house, NCP: Normalization criteria process, NMA: New macro-areas, OCI: Obligatory-criteria indicators, OCI_{Opt}: Optional-criteria indicators, $PDim^{Avl}$: Available scores of dimension, $PDim^{Max}$: Maximum scores of dimension, $PMCI^{BSRS}$: Maximum points of MCI according to BSRS, $PNMA^{Max}$: Maximum scores of NMA, SIT: Site, SSH: Sustainable social housing, TRA: Transport, UMC: Upper-middle-income country, $VMCI^{Case}$: Values of MCI according to study cases, $VMCI^{Max}$: Maximum values of MCI, WAT: Water, WDim: Weight of dimensions, $WDim^{Real}$: Real WDim, WNMA: Weight of NMA, WST: Waste.

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Sustainable social housing: The comparison of the Mexican Funding Program for Housing Solutions and Building Sustainability Rating Systems

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A B S T R A C T

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Keywords: *Social housing; building sustainability rating systems; comparative approach; housing program funding; certification; green building rating systems.*[1]

1. Introduction.

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According to Turok [15], "Housing decisions need to be bolstered by institutional reforms to facilitate coordination and capacity-building"; likewise, several pieces of research [8,15–22] conclude that SSH must undergo a comprehensive analysis during the design phase, with an analysis of the urban context of its location being of particular importance. In Mexico, the National Housing Commission (CONAVI) implements these ordinances through the FPHS (previously known as "Esta es tu casa"), which aims to mitigate the social housing problem through a holistic approach [23].

The FPHS offers the low-income population various schemes (acquisition of a new or used home, self-production, improvement or expansion, and land acquisition) that make it easier for them to acquire a house to improve their quality of life, granting them economic support that will help them complete the cost of the housing solution; the program focused on households whose monthly payment does not exceed US $ 615. For the acquisition of a new house, each beneficiary may obtain a subsidy for up to US $4300 depending on the price (from US $ 7400 to US $ 19460) and the score reached by the housing solution [23].

In the last decade, Mexican social housing has acquired an essential role in the construction industry, due to the percentage (82%) that it represents in the Mexican housing stock [9]. The Mexican government's actions in providing more sustainable housing employing the FPHS have been considered exemplary regarding good sustainable practice on a global level. However, the need to reduce energy consumption in the residential sector is urgent [19,22,24,25], as it emits 49 million tons of CO_2 per year [26], and consumes 15.4% of the country's total energy [27].

Of the many tools used for accrediting a building as sustainable, the BSRS multi-criteria approach stands out as an instrument for measuring sustainability in the construction industry [28–38], contributing to the improvement of the housing construction sector. According to Rodriguez, et al. [39] "In Mexico no methodologies have been developed to assess the sustainable level of all housing stock", however, the FPHS (which concentrates on social housing) is a tool with a methodology similar to that of the BSRS.

Several authors [32,36,39–42] state that the analysis of information arising from the different approaches of the BSRS constitutes a little-studied area of research; establishing it would favor a new way of evaluating housing, especially in countries with similar housing characteristics to Mexico's. In addition, Buckley et al. [12] established that "A closer look at the design and characteristics of these programs can provide some preliminary indications as to their potential in creating scaled and pragmatic solutions that address housing affordability challenges".

This paper shows that the methodology used by the FPHS in obtaining SSH has principles that may be replicated by other UMC; this work aims to analyze the FPHS in a global context, with the regulations specified by the highest-ranking BSRS in the construction industry through their evaluation parameters. Thus allowing the SSH parameters (as established by the FPHS), to be examined, evaluated and compared to obtain scientific findings that will lead to the real integration of the concept of SSH into Mexican construction, as well as acting as a guide for obtaining SSH in different UMC.

To achieve this objective, a comparison was made of the FPHS evaluation methodology and that of several, globally recognized, BSRS such as Leadership in Energy & Environmental Design (LEED) [43], Building Research Establishment Environmental Assessment Methodology (BREEAM) [44], Green Building Index (GBI) [45] and Alta Qualidade Ambiental-Haute Qualité Environnementale (AQUA-HQE) [46]. The analysis was carried out on two different types of housing: Detached (DH) and Multi-family (MH) with a maximum of three levels; these were spread over 24 housing units (from a universe of 214 units).

Estimates indicate that Mexico needs to build up to 600,000 new housing units each year over the next decades [47]. Therefore, the characteristics and configuration of future housing will have a significant environmental impact on a global level, which makes it necessary to establish clear sustainable guidelines for them.

2. Method and data.

This study proposes (as its primary focus) a comparison of the FPHS and the BSRS: LEED, BREEAM, AQUA-HQE and GBI, as they have been used widely with good results in several previous studies [34,40–42,48–54] to obtain comparable results in both qualitative and quantitative terms.

The first step was to carry out a selective analysis of the different BSRS in the residential sector; comparative methodology was used and, as in previous works [34–36,42,48,51,55,56], an NCP was carried out. Finally, to validate the application, 24 real housing units were evaluated and compared regarding the FPHS and BSRS chosen, applying the methodology stipulated for each system and using the established NCP.

The comparison process allows us to decide whether the evaluation methodology established by the FPHS is sufficient for obtaining SSH which complies with the sustainability requirements at international levels. Additionally, the process means that the indicators omitted in the FPHS may be of interest to the Mexican government or, as the case may be, for any sustainable certification process in other UMC whose primary objective is to achieve SSH.

2.1 BSRS selection.

Regarding the BSRS to be included in the study, only those that were most representative and whose practical application was most feasible were selected; consequently, a database search was carried out in October 2016. SCOPUS [57] was chosen as the search engine, due to its wide range of scientific content relating to the building industry [58]; the search included the following configuration as a strategy: *TITLE-ABS-KEY: "rating system" OR "assessment tool" OR "rating tool" OR "assessment system" AND housing OR residential OR residences OR homes.*

From the previously obtained results, the number of references was limited by three restrictions: *SUBJAREA: mult OR ceng OR chem OR comp OR eart OR ener OR engi OR envi OR mate OR math OR phys; 2009 > PUBYEAR < 2017;* and*, DOCTYPE: "ar", "cp", "re".*

The search produced 381 documents; of which only those with more than five citations (a guarantee of their proven validity, widespread acceptation and harmony with current works) were chosen as candidates for the research analysis. The documents had to mention the BSRS from a multi-criteria approach, to include different quantitative and qualitative criteria that affect the accessibility of housing as well as its sustainability [20], both considered “ideal” for an excellent start to the sustainability certification process [59], sufficient for a majority of the UMC.

As a result, 14 references identified 17 different BSRS from around the world. Between these, three selection criteria were applied to define the BSRS to be included in the present study (see Table 1). The first criterion was that, within their specifications, they contained a version applicable to a UMC, thereby guaranteeing that the comparison of the different BSRS was within the methodology framework with characteristics representative of these countries; the second was based on the number of times these BSRS were cited in the references, allowing those that had more recognition within the scientific field to be chosen; the third criterion was based on the availability of access to the latest version of the BSRS, thereby guaranteeing that the UMC could access the different methodologies (via the Web).

Table 1

Description of BSRS

BSRS	Country	Applicability in a UMC	References[A]	On-line Availability	Comply with criterion one and three
BEAM Plus (HK BEAM)	Hong Kong	No	4	Yes	No
BREEAM	United Kingdom	Yes	10	Yes	Yes
CASBEE	Japan	No	7	Yes	No
CSH	United Kingdom	No	1	Yes	No
DGNB	Germany	No	3	No	No
Green Building Label	China	Yes	2	Yes	Yes
Green Building Index	Malaysia	Yes	2	Yes	Yes
Green Globes	Canada	No	3	Yes	No
Green Mark	Singapore	No	2	Yes	No
Green Star	Australia	Yes	3	No	No
ITACA	Italy	No	1	No	No
LEED	United States	Yes	13	Yes	Yes
LiderA	Portugal	No	1	Yes	No
SABA	Jordan	Yes	1	No	No
SB Tool	International	Yes	4	Yes	Yes
SBAT	South Africa	Yes	1	No	No
SPeAR	United Kingdom	Yes	1	No	No

[A]Key references: [34,40,48,55,56,60–68].

The BSRS were chosen from Table 1: LEED [43] and BREEAM [44] because they fulfil the established criteria, both having the highest number of citations in the references; GBI [45] was also chosen as, unlike SB Tool [69] and Green Building Label [70] –which also comply with the criteria– it was developed by a UMC; GBI also has characteristics that most resemble the reality of the case studies analyzed and evaluated (in contrast with SB Tool and Green Building Label).

In order to compare the FPHS with a BSRS whose evaluation characteristics include aspects of the Latin-American housing sector, it was decided to include the AQUA-HQE [46] system; despite being developed in France, its bases are closer to the Mexican reality than the rest of the BSRS (see Table 2) due to the similarities between Mexico and Brazil in terms of their characteristics [71]. Highlighting between these two the representativeness they have in Latin America [72], as well as the resemblances between its housing programs subsidies [12,73] and their inversion in sustainability through their social housing initiatives [10].

Table 2

Countries characteristics according to selected BSRS

Country (BSRS)	CO_2 emissions (kt)	Total population – Cities[A]	Climatic Zones	GDP (Current US$, trillion)	GINI index[B]	Household size	Housing Expenditure (%)
Mexico (FPHS)	480,270.657	130,019,231 - 11	9	1.047	48.200	3.7	21
Brazil (AQUA-HQE)	529,808.160	210,105,023 - 15	8	1.796	51.300	3.3	20
Malaysia (GBI)	242,821.406	31,860,882 - 2	3	0.296	46.300	4.6	24
U. K. (BREEAM)	419,820.162	66,389,639 - 1	21	2.648	41.00	2.3	24
U.S.A. (LEED)	5,254,279.285	325,670,538 - 13	17	18.624	34.100	2.6	18

*Key references: [14,74–78]; [A] with more than 1 million of people; [B] of inequality in the distribution of family income in a country.

According to the above paragraph, the integration of AQUA-HQE in this work enabling a comparison with a practical application in the Brazilian ambit. This BSRS has carried out certifications since 2007 [79] and has more than 44,000 certified housing units in 104 housing developments [80].

2.2 Development and execution of the NCP.

Each BSRS chosen showed different specifications and requirements, depending on the type of building and the year of its version. Table 3 shows the study parameters used for each of the BSRS considered, highlighting the difficulty in performing a direct comparative analysis due to the lack of uniform criteria; therefore, a comparable normalization process is needed to determine the degree of sustainability of the FPHS housing, as well as the significance of each aspect studied within the sustainability evaluation.

Table 3

Description of selecting BSRS

BSRS	Version and modality	Scoring and Rating system	Dimensions[B]	Adoption
FPHS	2017 - Acquisition of newly house [23]	**Points:** Pass= Obtaining subsidy (from 650 onwards) – Highest subsidy (from 900 onwards)[A]	Basic elements of Housing & Development (BHD) - Basic elements for strengthening Social Cohesion (BSC) - (EUE) Efficient Use of Energies - Reduction in drinking Water Consumption (RWC) - Solid Waste Management (SWM) - Location (LOC) - Equipment and Services (EQS) - Density (DEN) - Competitiveness (COM) - Incentive to Best Practices (IBP)	National (MEX)
BREEAM	SD233 1.0 (2016) – Residential: Single and Multiple (Partially fitted)[81]	**% Score:** Unclassified (<30) - Pass (≥30) - Good (≥45) - Very good (≥55) - Excellent (≥70) - Outstanding (≥85)	Energy (ENE) - Healthy & wellbeing (HEA) - Materials (MAT) - Management (MAN) - Land use & ecology (LE) - Innovation (INN) - Transport (TRA) - Waste (WST) - Pollution (POL) - Water (WAT)	Global

LEED	V4 (2013) - Homes and multifamily low rise [82]	**Points:** Certified (40 to 49) - Silver (50 to 59) - Gold (60 to 79) - Platinum (≥80)	Energy & atmosphere (EA) - Indoor environmental quality (EQ) - Location & Transportation (LT) - Water Efficiency (WE) - Materials & Resources (MR) - Sustainable Site (SS) - Innovation (IN) - Regional Priority (RP) - Integrative Process (IP)	Global
GBI	RNC V3.1 (2014) - Landed and low rise [83]	**Points:** Certified (50 to 65) - Silver (66 to 75) - Gold (76 to 85) - Platinum (≥86)	Sustainable Site planning and Management (SSM) - Energy Efficiency (EE) - Indoor Environmental Quality (EQ) - Materials & Resources (MR) - Water Efficiency (WE) - Innovation (IN)	National (MYS)
AQUA-HQE	Residential buildings under construction (2016) - Detached and multifamily [84]	**Stars:** Global (all base) - Pass (4) - Good (5 to 8) - Very good (9 to 12) - Excellent (13 to 15) - Exceptional (≥ 16)	Environment (EN) - Energy & Savings (ES) - Comfort (CF) - Health & Safety (HS)	National (BRA)

[A]Varies according to housing category and location [23]; [B]Dimensions= area, categories, main issues, headings, etc.

The exclusive indicators in each dimension defined by each BSRS were separated into obligatory-criteria indicators (OCI) and multi-criteria indicators (MCI), in order to obtain more detail and minimize any ambiguities (caused by an exclusive comparison of each of the BSRS' methodologies) in the results, establishing the similarities and divergences of each of the BSRS; the same occurred with the MH and DH typologies. Then the NCP was performed, using the concept of new macro-areas (NMA) [34]; this involves identifying common elements among the BSRS, then regrouping them (each BSRS has its methodologies, occasionally with dimensions established by one BSRS corresponding to categories found within one single dimension in another BSRS).

Starting from the premise that it is impossible to eliminate subjectivity through the NCP on different BSRS [28,34,35,37,38,42,48,51,55,56,60] and with the aim of defining the NMA, the dimensions used in previous investigations in this field [34,37,38,42,48,51,55,56,60], along with similar approaches to this study, were itemized in addition to the BSRS chosen (see Fig. 1). The breakdown revealed those used in more than one study and present in more than one BSRS; from the results obtained, only those indicated by the academic scope and the construction industry were considered. Consequently, Fig. 1 shows the eight chosen for use in the NCP: Energy (ENE), indoor environmental quality (IEQ), management (MAN), materials (MAT), site (SIT), transport (TRA), water (WAT), waste (WST).

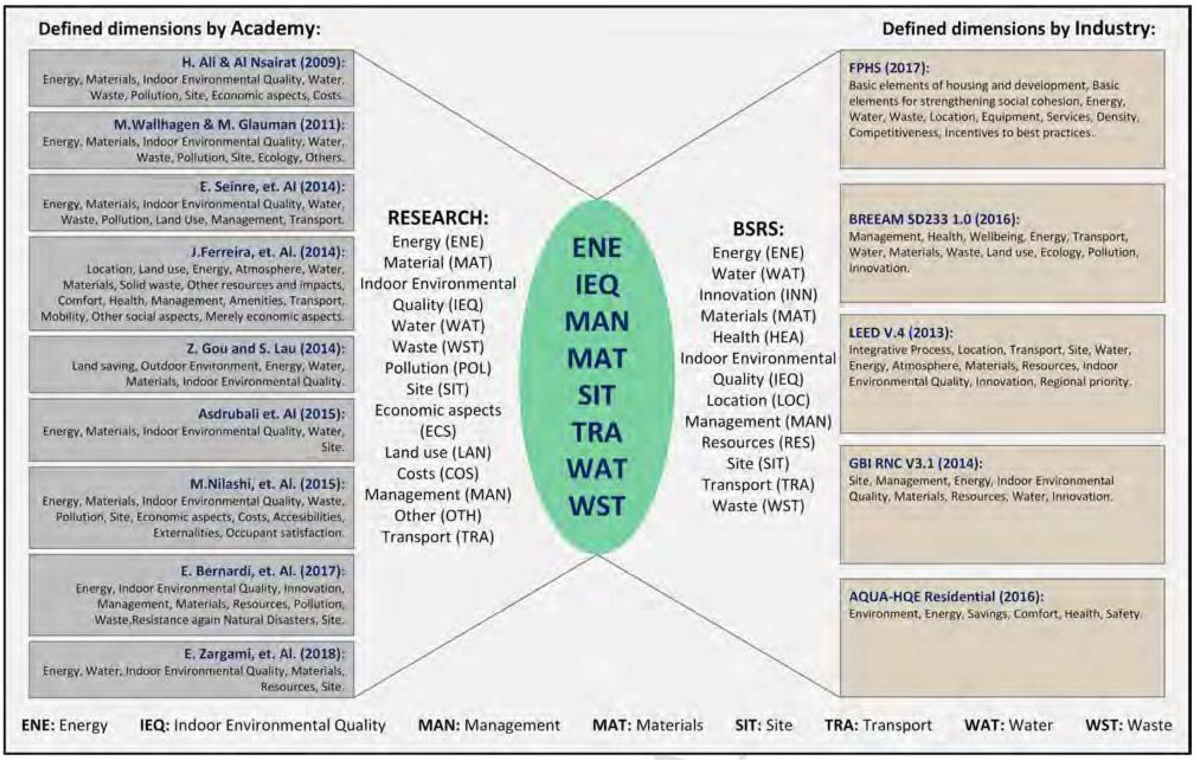

Fig. 1. Breakdown dimensions and definition of the NMA.

The maximum values corresponding to the NMA come from the NCP referring to the OCI and MCI. Once the maximum values of the NMA were defined for both types of housing in each of the BSRS, a comparative analysis of the BSRS was carried out. This, in turn, enabled concerning the characteristics of the FPHS, ascertaining the degree of sustainability of the buildings complying with this methodology, as well as the significance of each indicator that the system evaluates and the differences regarding the others.

2.2.1 NCP of the OCI.

The analysis of the application of the OCI is of great importance as they establish the conditions essential for a particular system to be assigned the qualification of sustainable [35]. Despite this, each BSRS shows peculiarities in terms of the quantity of criteria established or the dimensions in which they are located, which has made it necessary to use evaluations that permit comparison.

The main similarity of the OCI established by each BSRS lies in their assessment, based on their compliance or noncompliance, and not by means of a numerical value that would establish a hierarchy among them. However, with the aim of obtaining results in quantitative terms, a numerical value of one was assigned to each OCI, except in the case of FPHS, in which a value of two was given to the criterion corresponding to the neighborhood promoter, due to being considered preferable to the others [23]. On the other hand, the conditions that establish minimum points for any dimensions were also considered as OCI.

For their part, BREEAM and AQUA-HQE possess different qualification methodologies to the rest of the BSRS (see Table 3), resulting in the following considerations: in the case of BREEAM, the indicators vary in function of the qualification desired, and so to achieve its assimilation into the study only those considered essential for achieving the certification of "Pass" were considered. For AQUA-HQE, the "Base" values defined were considered like the OCI.

AQUA-HQE has one peculiarity in relation to the other BSRS, in that there are optional criteria (OCI_{opt}) within the range established as "Obligatory" or "Base"; these depend on the housing having some specific features to be considered [84], so it was decided the annulment of their participation in the NCP in order to reduce the subjectivity that might arise from the comparison of the case studies.

The NCP consists of three phases (see Fig. 2): in the first phase the scores corresponding to the OCI are identified (as well as the OCI_{opt} in the AQUA-HQE case) in each category in which the dimensions considered for each BSRS are based; in the second phase, the values identified are reorganized in the NMA; finally, the third phase obtains the maximum scores corresponding to each of the NMA ($PNMA^{max}$), as well as their weight ($WNMA$) in relation to the others (see Fig. A.1).

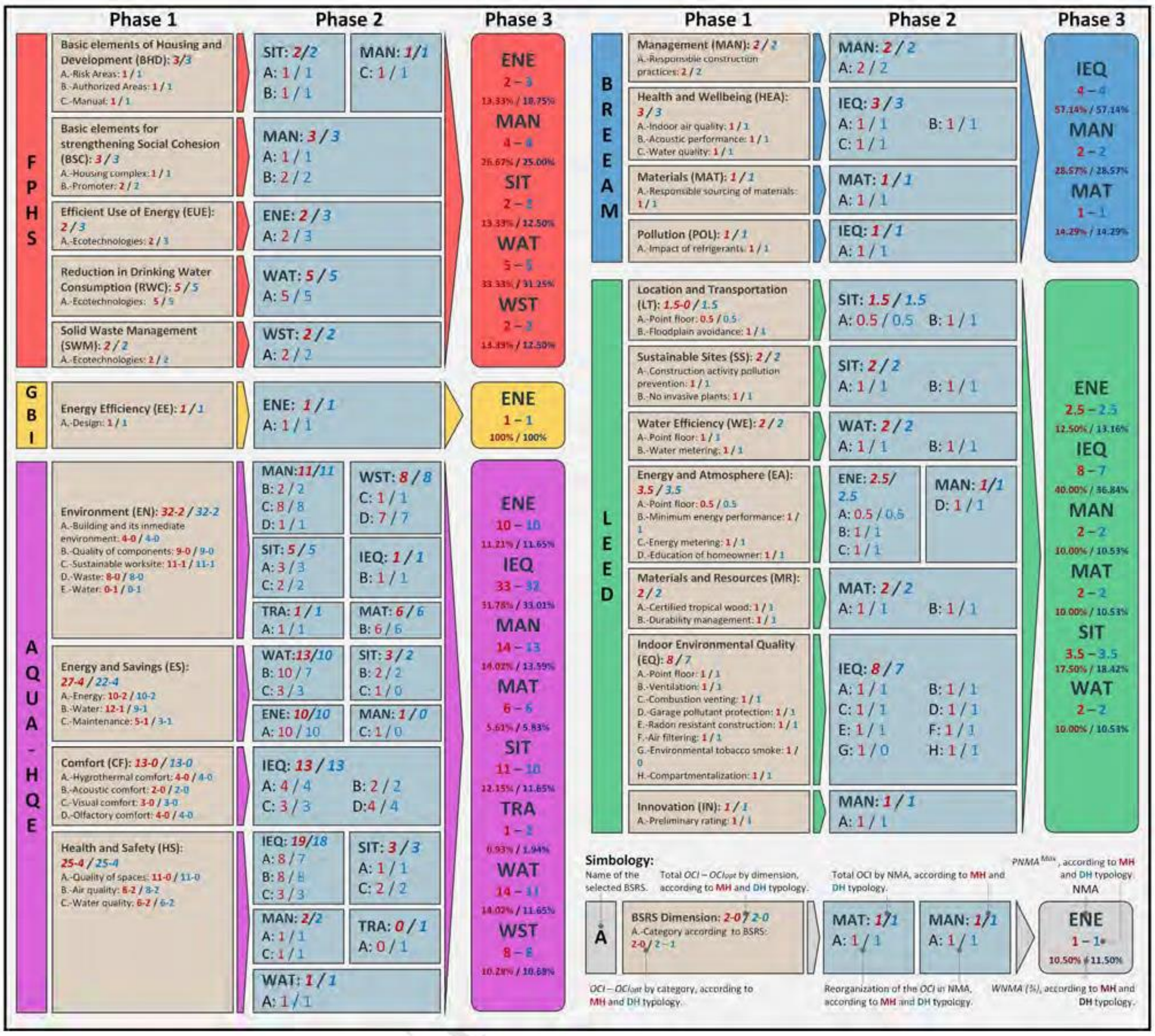

Fig. 2. NCP scheme according to OCI.

When the *PNMA*^{max} and *WNMA* for both types of housing are obtained it can be seen that, in the desired normalization of the comparative proposal, there are BSRS showing extreme differences to the group studied (see Fig. 3); for example, the GBI deals with only one dimension, evaluating only one indicator. AQUA-HQE, on the other hand, with only four dimensions, manages to evaluate up to 100 indicators for the MH and 96 for the DH.

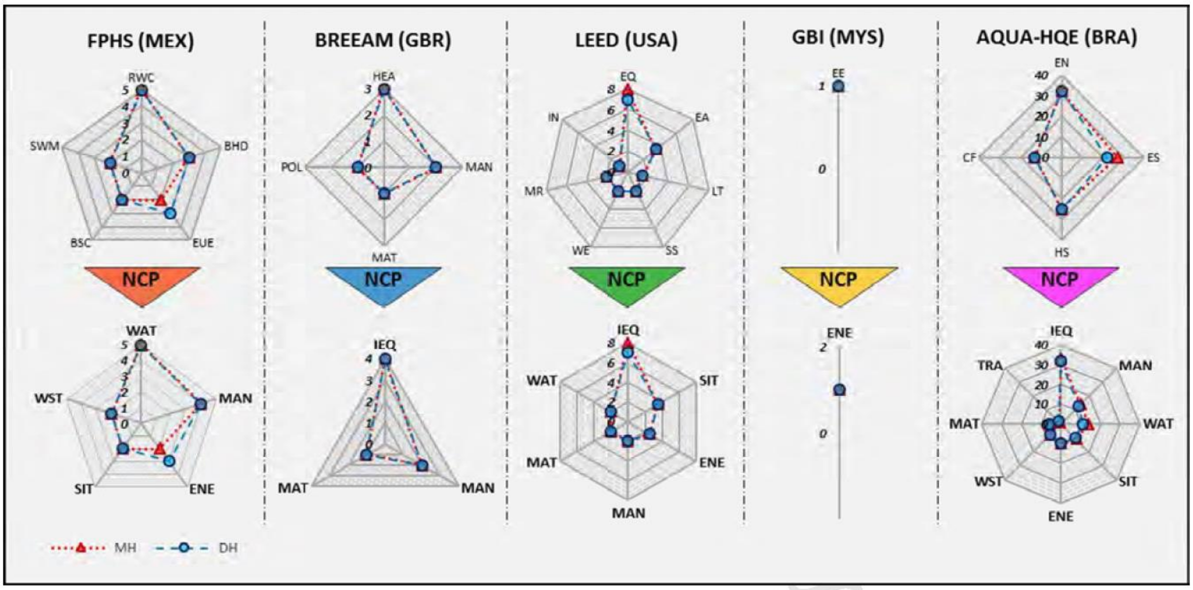

Fig. 3. Total *OCI* and *PNMA*^{max} distribution according to BSRS and NCP.

Another critical aspect of Fig. 3 is that no NMA is evaluated by all of the BSRS analyzed; however, the BSRS created in a high-income country (HIC) –BREEAM, LEED and AQUA-HQE–, are differentiated from the BSRS created in a UMC –FPHS and GBI–. It can be seen in the former, that the characteristics related to the IEQ have the highest ranking among those considered essential for a housing unit to be classified as sustainable, while in those developed in a UMC this area is not given such importance –often showing great variations between both systems–. This reflects the priority needs of the housing sector of each country; on the one hand, GBI only considers characteristics related to the ENE as essential for classifying a house as sustainable, while the FPHS lays a greater emphasis on the characteristics relating to WAT, as well as ENE, MAN, SIT and WST.

2.2.2 NCP of the MCI.

A Project can be carried out in several ways, therefore the options that minimize adverse environmental impact become fundamental in attaining the sustainable goals [85]. In consequence, the analysis and comparison processes of the different MCI of the BSRS may provide a theoretical base with a real application, to define the indicators to be evaluated in an emerging BSRS.

Regarding the comparative process of the different MCI, some particular considerations were needed to permit their assimilation, among which were AQUA-HQE, which is the BSRS showing most significant differences in its multi-criteria evaluation process (see Table 3). Consequently, it was decided that the values defined as necessary for obtaining the "MP" level would be considered as the maximum particular scores for each dimension ($PDim^{max}$). Likewise, it was decided that the weight assigned to each dimension ($WDim^{AQUA\text{-}HQE}$) would be calculated according to this level.

The main similarity of the BSRS is that their initial values are based on points. Each BSRS has a maximum and an available score in each of its dimensions (*PDim*^{max} and *PDim*^{Avl}; see Fig. 4). AQUA-HQE is the only one that shows different ranking in each dimension, although similar in the MH and DH; the FPHS stands out as having the dimensions with greater differences (COM and IBP) (the same as with MH and DH). GBI does not present different values, BREEAM only shows differences between its typologies and LEED shows slight differences in comparison with AQUA-HQE and FPHS (but similar scores in MH and DH). This shows the margin of manoeuver each system offers the industry in choosing the MCI.

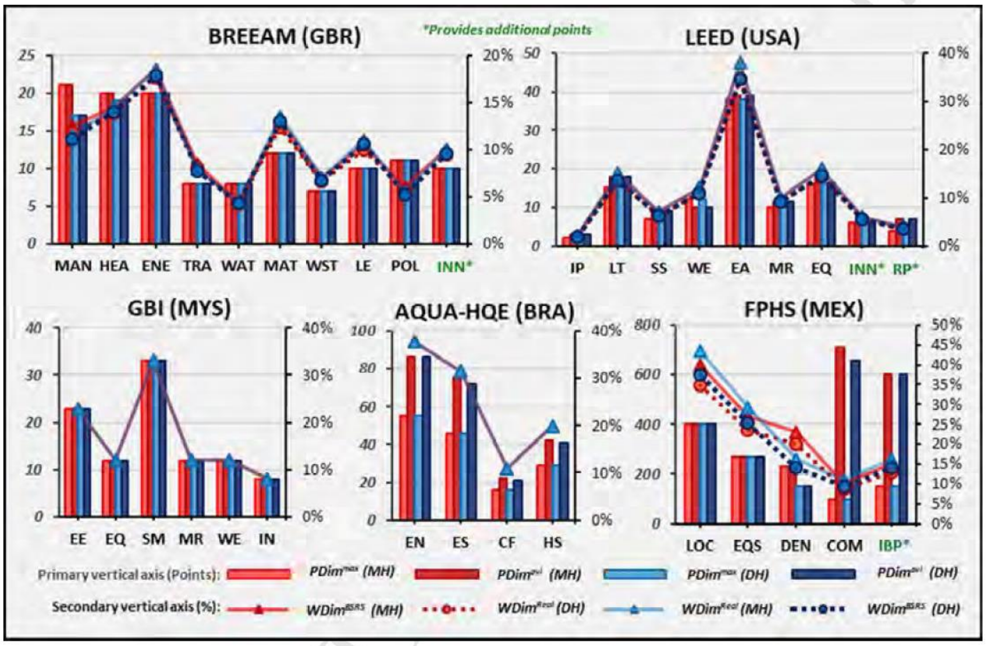

Fig. 4. Maximum and available points; and maximum and real weights according to BSRS.

Additionally, BREEAM, LEED and FPHS include dimensions that are classified as additional or extra (see Fig. 4). However, to obtain the real weight of each dimension corresponding to each BSRS (*WDim*^{Real}; see Eq. 1 and Fig B.1), the *WDim*^{BSRS} are maintained (see Eq. 2 and Fig. B.1), with the aim of respecting the ranking imposed by each BSRS on the maximum score established for each indicator (*PMCI*^{BSRS}). In the case of GBI and AQUA-HQE, the *WDim*^{Real} = *WDim*^{BSRS}, as neither of them have dimensions which warrant extra points (see Fig. 4). Also, in the case of BREEAM, the *WDim*^{BSRS}, was defined by the own system (see [81]).

$$WDim_i^{Real}(\%) = PDim_i^{Max}/SC^{Total} \quad \text{(Eq. 1)}$$

Where: SC^{Total} is the maximum score defined by the BSRS, including the additional dimensions.

$$WDim_i^{BSRS}(\%) = PDim_i^{Max}/SC^{Max} \quad \text{(Eq. 2)}$$

Where: SC^{Max} is the maximum score defined by the BSRS, excluding the additional dimensions.

Once the $PMCI^{BSRS}$ and the $WDim^{Real}$ have been defined, the maximum values corresponding to each indicator in the NCP ($VMCI^{Max}$; see Eq. 3) are determined.

$$VMCI_i^{max} = \left((PMCI_i^{BSRS}/PDim_i^{max}) \times WDim_i^{Real}\right) \times 100 \quad \text{(Eq. 3)}$$

The NCP of the MCI consists of three phases (see Fig. 5): In the first, the $PDim^{Avl}$ are identified, and the points per category in each BSRS are itemized; in the second phase the $PDim^{Avl}$ of each category ($PCat^{Avl}$) are redistributed in the NMA and the respective $VMCI^{Max}$ corresponding to each NMA are obtained; finally, in the third phase the $PNMA^{max}$ and WNMA are obtained from the $VMCI^{Max}$.

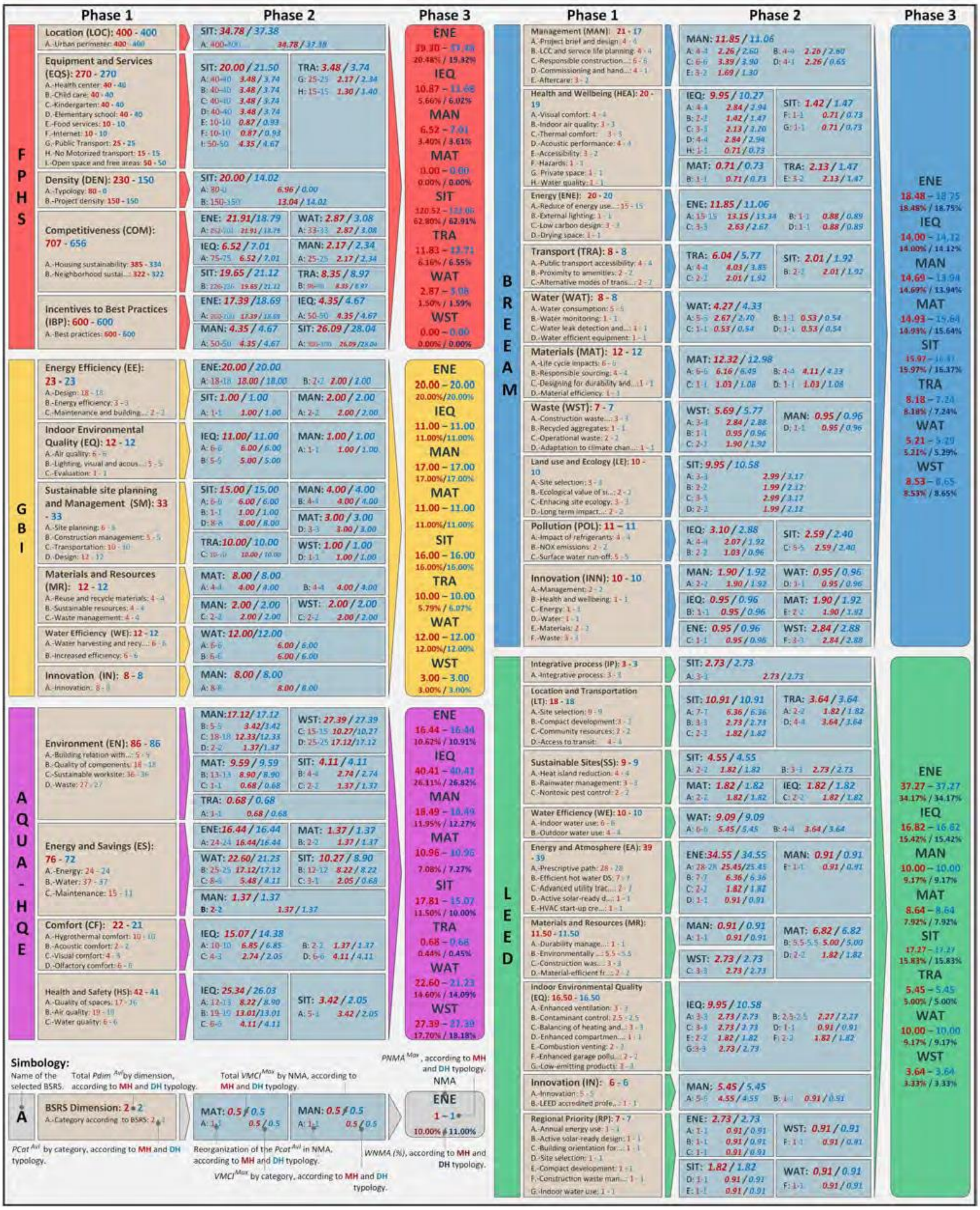

Fig. 5. NPC scheme according to MCI.

The NCP shows a better general balance of the MCI in comparison with the OCI (see Fig. 2 and Fig. 5). In this case, BREEAM, LEED and GBI consider the indicators in all of the NMA; this is not the case of the FHPS and AQUA-HQE (both applied in Latin America) in which the former does not consider the MAT and WST dimensions, while in the latter the dimension corresponding to TRA may be considered null, as it represents only 0.44 and 0.45% in MH and DH respectively.

The BSRS showing greatest disparity between the weights assigned to each of the dimensions is the FPHS (see Fig. 6), in which the SIT dimension has the highest weight, 62%; in the others, the same dimension has weights that vary between 10 and 16%.

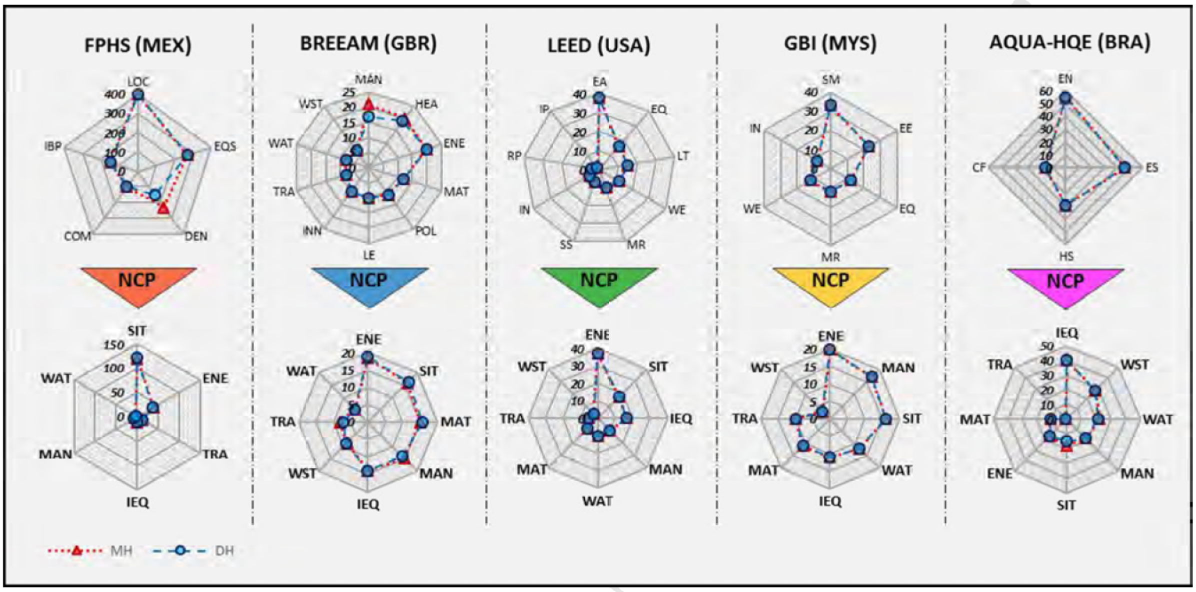

Fig. 6. *$PDim^{max}$* and *$PNMA^{max}$* distribution according to BSRS and NCP.

Although the Mexican government ensures that the methodology implanted by the FPHS provides an integral evaluation, the distribution of the values relating to each dimension established by the NCP shows that only those corresponding to the ENE are above 10%. Thus, if one of the aims of the FPHS is for its housing validation to be considered holistic, a redistribution of its weighting should be considered a fundamental priority.

2.3 Case studies selection and description.

The case studies come from four different housing development companies; all were required to have been built between 2013 and 2015 (a guarantee that similar version of the FPHS was applied) and that their design and construction process had been conceived with the FPHS methodology.

Of 214 possible housing units, 10 MH and 14 DH units were chosen as the study group for this research. To prevent duplication of the evaluation results, the cases studied were those that showed different characteristics to the rest of the study group. A hierarchical process allowed the selection of each case to be established, and in total six decision phases were necessary for their establishment; typology, neighborhood, gross floor area, building site area, front door location and exclusive area. (see Fig. 7).

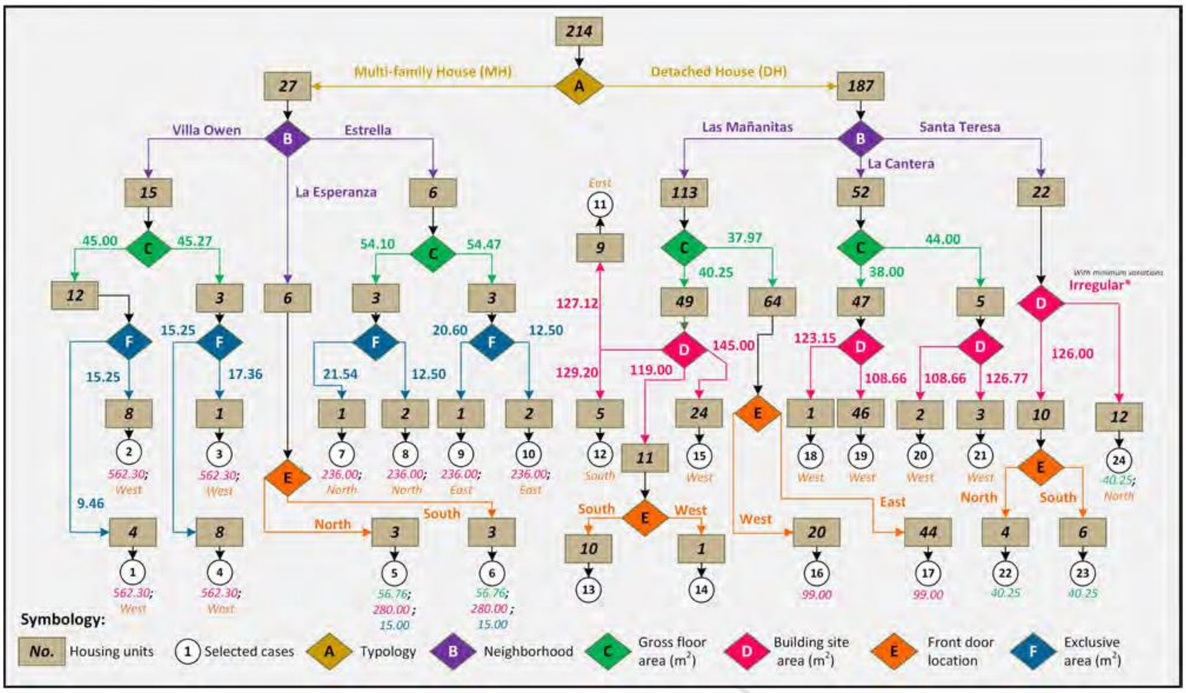

Fig. 7. Process of selecting cases.

Although the case studies satisfy the requirements established by the FPHS and have sustainable attributes [86], their characteristics, as well as their building type, may be lead them to be considered as "conventional buildings" in developed countries [13,19,87]. Table 4 provides descriptive data of the principal characteristics considered in the research for each case chosen (in addition to those shown in Fig. 7 and Fig. 8); this data comes from the determination of their parameters and their specific study.

Table 4

Characteristics of housing units

Cases	TFA[A] (m²)	Construction year	Rooms	Cost[B] (MEX)	Category (CONAVI)	Density (du/ha)[C]	DUC[D] (km)	PDL[E] (%)	Uses[F] (800 m)	Bus Routes	E.R.[G] - M.S.[H] (Yes/No)
1 and 2	37.18	2014	1	$245,000	II	83	2.25	89	12	3	Yes - Yes
3 and 4	37.68	2014	2	$300,000	II	83	2.25	89	12	3	Yes - Yes
5	44.07	2014	3	$305,000	II	66	2.83	80	10	4	Yes - Yes
6	44.07	2014	3	$325,000	I	66	2.83	80	10	4	Yes - Yes
7 and 8	44.14	2015	3	$290,000	II	83	2.18	97	15	5	No - Yes
9 and 10	44.16	2015	3	$325,000	I	83	2.19	97	15	5	No - Yes
11	35.58	2014	2	$330,000	I	46	2.91	71	8	2	No - Yes
12	35.58	2014	2	$320,000	I	46	2.96	66	8	2	No - Yes
13	35.58	2014	2	$310,000	II	46	3.00	62	8	2	No - Yes
14	35.58	2014	2	$310,000	II	46	2.94	66	8	2	No - Yes
15	35.58	2014	2	$350,000	I	83	3.13	46	7	2	No - Yes
16	33.41	2013	2	$251,500	II	46	3.54	49	7	2	No - No

17	33.41	2013	2	$310,000	II	46	3.55	28	3	2	No - No
18	33.47	2015	2	$283,000	II	48	5.29	15	2	2	Yes - Yes
19	33.47	2015	2	$283,000	II	48	5.07	15	3	2	Yes - Yes
20	38.75	2015	2	$388,000	I	48	5.27	15	2	2	Yes - Yes
21	38.75	2015	2	$388,000	I	48	5.18	15	2	2	Yes - Yes
22	35.58	2015	2	$340,000	I	83	3.48	63	7	3	No - Yes
23	35.58	2015	2	$340,000	I	83	3.49	62	7	3	No - Yes
24	35.58	2015	2	$340,000	I	83	3.50	61	6	3	No - Yes

[A]Treated floor area; [B]According to construction year; [C]Dwelling units per hectare; [D]Distance to urban center; [E]Previously developed land (considering a radius of 800 m from the center of the housings); [F]According to LEED (BSRS which consider more uses); [G]Ecologist report; [H]Management support (refers to seasonal commissioning).

Fig. 8 shows the general architectural distribution of each case in the study, as well as the technology installed and the thermal transmission values corresponding to their cladding; as the building complexes are of social interest, they are usually composed of houses with similar geometry.

U-values*			
Cases	Floor (W/m²K)	Roof (W/m²K)	Wall (W/m²K)
1 & 3	1.93	0.39	2.40
2 & 4	0.39	0.39	2.40
5	2.30	2.87	1.79
6	2.71	0.71	2.47
7 & 9	2.30	2.90	1.83
8 & 10	2.71	0.71	1.83
11 to 17	2.60	0.71	1.72
18 to 21	2.60	0.71	1.64
22 to 24	2.60	0.71	1.72

* All windows have values of 5.7 (W/m²K)

Lighting technologies				
Cases	Indoor LED-Compact	P-density (W/m²)	Outdoor LED-Compact	Public With LED's?
1 & 2	5.00-0.00	1.34	1.00-1.00	Yes
3 & 4	6.00-0.00	1.59	0.00-2.00	Yes
5 to 8	6.00-2.00	1.95	0.00-2.00	No
9 & 10	6.00-2.00	2.24	0.00-2.00	No
11 to 15	6.00-0.00	1.68	0.00-2.00	Yes
16 & 17	0.00-6.00	2.33	0.00-2.00	No
18 & 19	6.00-0.00	1.79	0.00-2.00	No
20 & 21	6.00-1.00	1.88	0.00-3.00	No
22 to 24	6.00-0.00	1.68	0.00-2.00	Yes

Water technologies					
Cases	Toilet (lt)	B-tap (lt)	K-tap (lt)	Shower (lt)	Water heater (lt/min)-Efficiency
1 to 4	4.80	10.40	8.70	6.40	6.00-93%
5 to 10	3.80	10.40	8.70	4.10	4.20-88%
11 to 15	3.80	10.40	8.70	4.10	6.00-93%
16 & 17	4.80	12.00	12.00	6.40	6.00-93%
18 to 21	3.80	12.00	12.00	6.40	4.20-88%
22 to 24	3.80	10.40	8.70	4.10	6.00-93%

Abbreviations: P-density: Power density; B-Tap: Basin tap; K-tap: Kitchen tap

Fig. 1. Case studies plans, thermal transmittance and technologies.

All the case studies are located in the city of Los Mochis, Sinaloa (see [88]), which give the study a solid local representation. Similarly, the cases comply with the specifications of the Housing Construction Code [89] and the local building regulations [90], thus guaranteeing a real and current constructive situation of the ambit of the study.

During the selection process of the cases, specifications provided by the developers and kindly elaborate open software [91] were used in the analysis. In situ visits were also made to the area of each case, evaluating within a radius that ranged from 250m to 1000m, thereby allowing precise and up to date data to be obtained about the housing units' environment (regarding the urban installations). Additionally, calculation tools and graphics software were used for making diagrams [92] and in the analysis of the architectural plans [93].

2.4 Case studies comparison.

In order to carry out the comparison of the cases studied it was necessary to previously evaluate each one under the methodology employed by the BSRS selected, also conforming to the NCP. In general, each evaluation was carried out independently for the OCI and MCI; as the case studies showed a very limited level of energetic performance, the majority will in all likelihood not comply with the minimum total required by the BSRS. On the other hand, and due to the differences that are shown between the evaluation of the OCI and MCI of each BSRS (see Fig. 3 and Fig 6). Focusing on an exclusive comparison of the OCI and the MCI, acquires a fundamental role, allowing a deep analysis of the OCI, which is essencial towards obtaining SSH and due to the restrictions that this housing typology has.

2.4.1 Case studies comparison according to OCI.

After the preliminary evaluation of each of the BSRS, in the analysis of the results those corresponding to the NCP were also obtained; due to their quantity, only the average values obtained by the total of each typology were considered.

In both methodologies (BSRS and NCP), the fulfillment percentages (*FP*) were obtained for each typology; i.e., according to the BSRS (see Eq. 4), the values obtained for each case of study (OCI^{Case}), divided by the values corresponding to the *Total OCI* –omitting the values of OCI_{opt} in AQUA-HQE–; according to the NCP (see Eq. 5), the values obtained for each case of study ($PNMA^{Case}$), divided among the $PNMA^{max}$.

$$OCIFP^{BSRS}(\%) = Total\ OCI^{Case}/Total\ OCI^{BSRS} \quad \text{(Eq. 4)}$$

$$OCIFP^{NCP}(\%) = Total\ PNMA^{Case}/Total\ PNMA^{Max} \quad \text{(Eq. 5)}$$

Finally, regarding the NCP, the *OCI-FP* obtained in each *NMA*, from the $PNMA^{max}$ ($OCI\text{-}FP^{NMA}$) were evaluated (see Eq. 6).

$$OCIFP^{NMA}(\%) = PNMA^{Case}/PNMA^{Max} \quad \text{(Eq. 6)}$$

2.4.2 Case studies comparison according to MCI.

Because of the differences that each BSRS shows concerning the MCI, the comparative analysis consists of two processes: one for the established methodology and the other for the NCP.

With regard to the methodology established for each of the BSRS, first the results were obtained for the corresponding case study and then the FP; in which the total MCI obtained for each case of study were considered and were divided among the total of $PDim^{max}$ established for each BSRS ($MCI\text{-}FP^{BSRS}$), respecting the upper limits established for each BSRS.

Concerning the methodology established in the NCP for each of the BSRS, emphasis was on the *VMCI* obtained from the case studies ($VMCI^{Case}$; Eq. 7) corresponding to each NMA, from the total of $PNMA^{max}$ ($MCI\text{-}FP^{NCP}$).

$$VMCI_i^{Case} = \left((PMCI_i^{Case}/PDim_i^{max}) \times WDim_i^{Real}\right) \times 100 \quad \text{(Eq. 7)}$$

Finally, regarding the NCP, the *MCI-FP* obtained in each *NMA*, from the $PNMA^{max}$ ($MCI\text{-}FP^{NMA}$) were evaluated (see Eq. 8).

$$MCIFP^{NMA}(\%) = PNMA^{Case}/PNMA^{Max} \quad \text{(Eq. 8)}$$

3. Results and discussion.

The results obtained show the divergences in the BSRS in terms of the characteristics necessary for a building to be considered sustainable. Therefore, though all of the studied BSRS managed to increase the level of sustainability of a determined house, it also seems unlikely that the construction industry will agree upon homogenized building standards that include these characteristics, at least in the short term. This should not, however, be considered wholly negative, as each country has different needs and priorities, which must be dealt with in the most appropriate manner possible.

Although it is true that the evaluations carried out by each BSRS provided information that allows the sustainability level of a building to be established, the comparative analysis of the results obtained from the NCP emphasize, amongst other things, the updates that the Mexican government should make to obtain SSH conforming to the global concept of sustainability as shown in the other BSRS; alternatively, it can establish the arguments showing how to obtain SSH in different UMC through the methodology established by the FPHS.

On the other hand, the NCP when obtaining the $VMCI^{Max}$, evidences the FPHS as the BSRS that has lower requirements among the OCI and have greater freedom of choice among the MCI, considerably reducing the *MCI-FP* of the case studies about that established by the system itself (see Fig. 9).

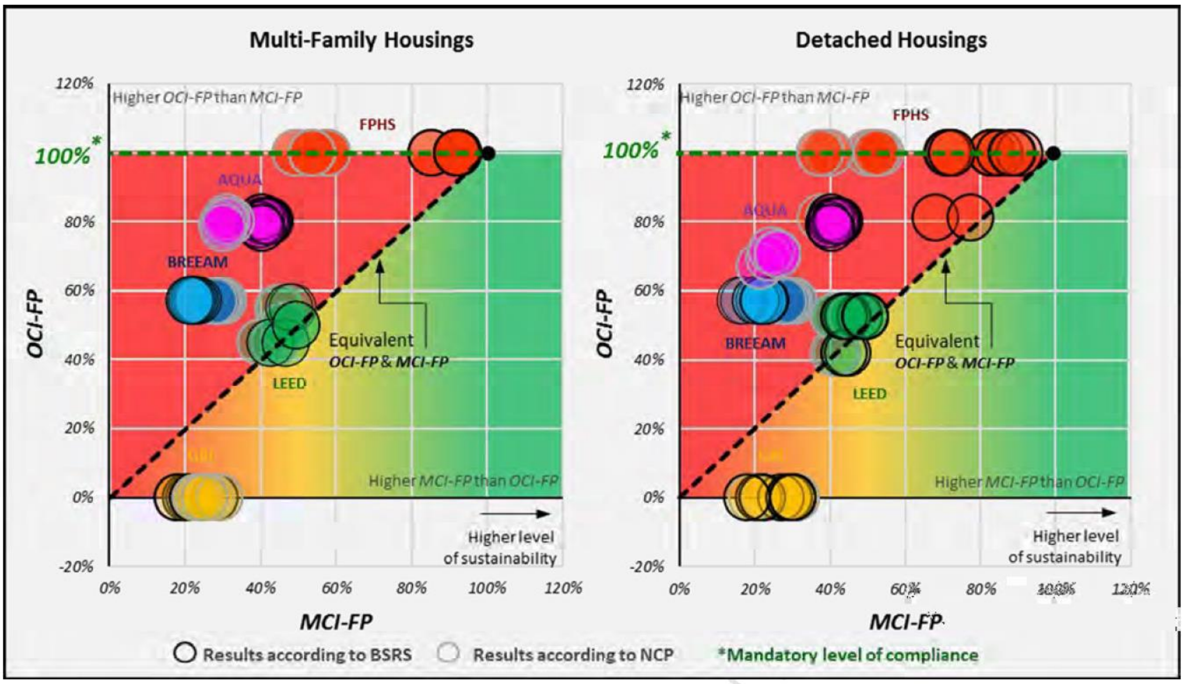

Fig. 9. *OCI-FP* vs *MCI-FP* of the case studies.

Additionally, Fig. 9 shows that LEED is the BSRS that has greater equivalences between the OCI and the MCI concerning the case studies, highlighting the case of GBI as the only one in which the MCI-FP predominates over the *OCI-FP*; this is because it only considers one OCI in its evaluation methodology, as opposed to the others, which have a more holistic and integral evaluation.

Regarding the FPHS, the identification of the $PDim^{Max}$ and $PDim^{Avl}$ in the COM and IBP dimensions, as well as the results of the case studies obtained in the NCP and their comparison with the system's methodology, shows that despite the FPHS focusing on different indicators found close to the other BSRS, its evaluation methodology allows housing developers to evade a considerable number of indicators located in various NMA (see Fig. 10). If the $PDim^{Max}$ were to be reorganized in each of the dimensions established by the FPHS, or, failing that, new dimensions established in order to reduce the possibility of evasion; this would considerably increase the level of sustainability of the new buildings being added to the Mexican housing stock.

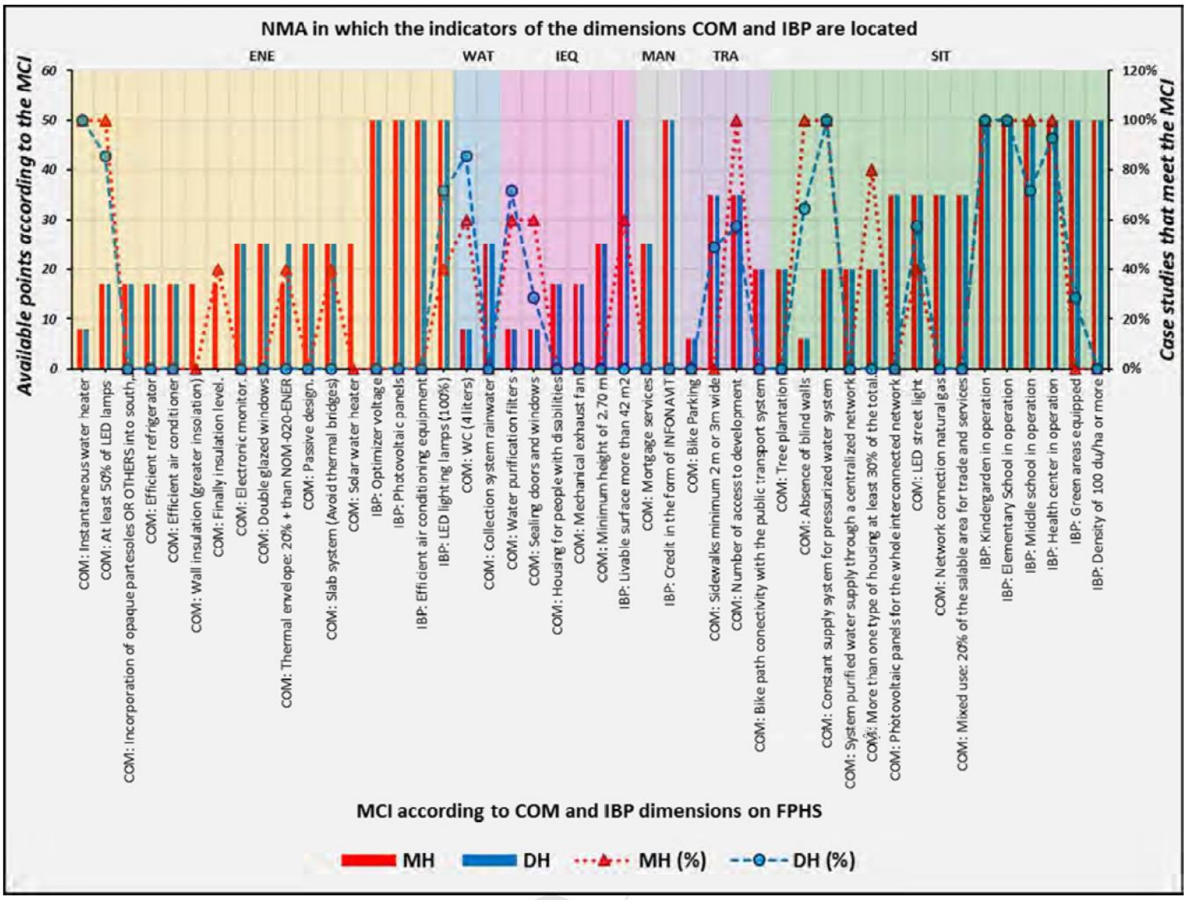

Fig. 10. Location of the MCI (COM and IBP dimensions) in FPHS according to NCP and percentage of the case studies that meet the criteria.

3.1 Results and discussion according to OCI.

The results obtained from the evaluations conform to the established methodology of each BSRS (see Fig. 11), showing that no housing unit complies fully with the OCI required by BREEAM, LEED, GBI and AQUA-HQE. Only the FPHS attains 100% in MH and 86% in DH; explainable by the fact that these are conditioned by the requirements indicated by the FPHS, which in turn is conditioned by the prevailing economic situation of the construction industry.

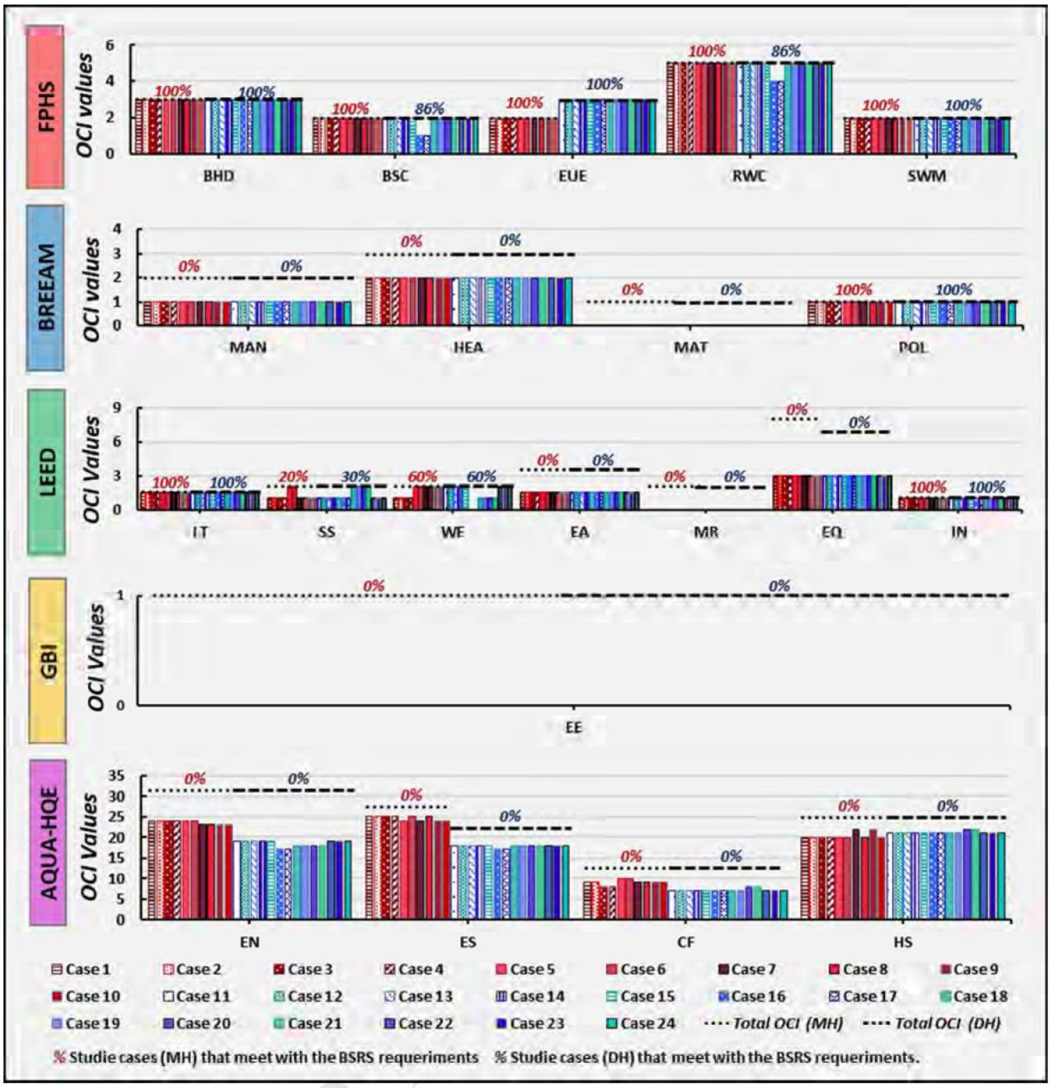

Fig. 11. Results of the case studies according to BSRS.

Fig. 11 shows that BREEAM has less OCI than the FPHS; however, its compliance requirements in the dimensions of MAN, HEA and MAT are more demanding. No case study complied with the OCI in these dimensions and POL stood out as the only one that all the case studies fulfilled. LEED has a higher number of OCI than the FPHS, and is the most demanding of the BSRS chosen. The dimensions in which cases complied with the OCI were LT, SS, WE and IN, especially LT and IN, which had 100% compliance. GBI is the system furthest from the BSRS that are used globally, as it evaluates the EE dimension with only one OCI; however, it is more demanding than the FPHS. Consequently, no case study can be validated with this BSRS. In the case of AQUA-HQE, despite being the system with most OCI, it is less demanding than the others and may be considered as having more affinity to the FPHS, due to the close levels of compliance shown in each of its dimensions.

As notable cases in the study, numbers 16 and 17 received the minimum scores of the dimensions studied in comparison with the rest of the cases (when they were not identical); the reason for this is that they were built in 2013 (according to the requirements established by the FPHS in this year). This shows that the recent improvements in the OCI of the FPHS raise the degree of sustainability of the Mexican buildings applying for the subsidy, also bringing them closer to the minimum international standards.

Performing the NCP, as well as evaluating the average results of the case studies, accentuates the differences between the different BSRS (similar curve trends between FPHS and AQUA; and between these two with respect to LEED and BREEAM serious discrepancies. See Fig. 12), in which the variations shown in the NM are drastic, but less so in those presented according to housing type (except WST in AQUA-HQE).

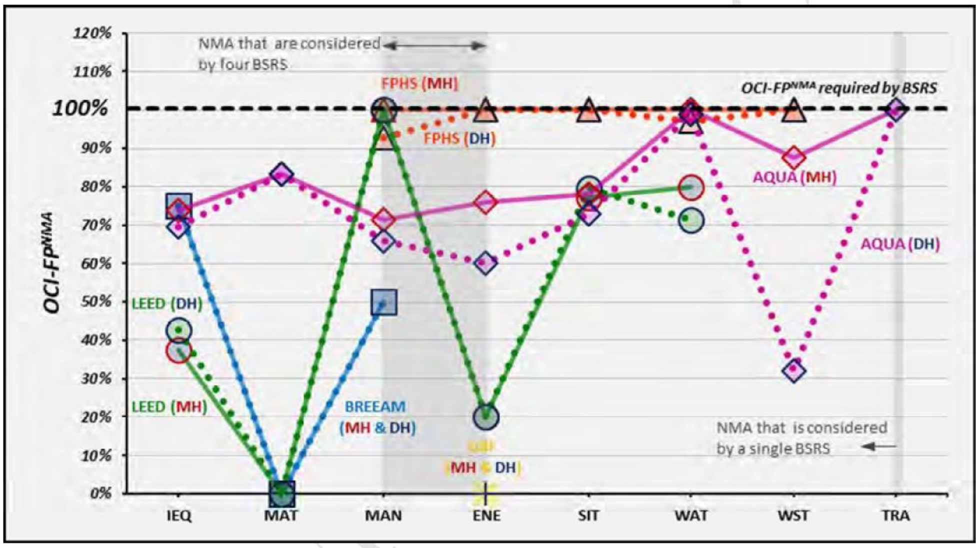

Fig. 12. Average results of the *OCI-FP^NMA^* according to case studies.

In the analysis of MH and DH (see Fig. 12), it can be seen that the former are better placed than the latter, one reason for this being the inclusion of a local developer and water sectioning valves, which are not evaluated in some cases of DH. The sectioning valves, but not the local developer, are also considered essential in AQUA-HQE, despite ranking above other criteria in the FPHS and not representing a characteristic to be evaluated in the study of the BSRS. Regarding BREEAM and GBI, they do not show different ranges between MH and DH.

In the case of LEED, aspects related to IEQ, SIT and WAT show attenuated differences, in which WAT stands out (with MH having the best behavior); in this case the point floor is identified as the main reason for these differences. The best compliance with the *OCI-FP^NCP^*, in the case of IEQ and SIT, is obtained by DH. In the specific case of IEQ, the differences are caused by the MH having to comply with more indicators than the DH; and in the case of SIT, the differences are due to the percentage of case studies that included non-invasive (native) plant species.

Finally, AQUA-HQE shows the *OCI-FP*^{NCP} with most significant variations in the NMA; however, the TRA and WAT are the only ones in which both the MH and DH comply 100%, and in general terms they show a higher degree of compliance in MH.

Regarding the comparison of the FPHS and the other BSRS, Fig. 12 confirms that AQUA-HQE has the highest affinity (mainly in the MH), as well as showing the case of GBI, which despite having only one indicator, is so demanding that no case study could achieve compliance. In the case of BREEAM and LEED (the best known BSRS), IEQ and MAT are shown as the NMA that the FPHS omits in its evaluation process, with the emphasis on MAT, where no case study was able to comply with any OCI.

With the aim of increasing the sustainability characteristics established as essential for the global BSRS, while also bringing FPHS closer to the intrinsic global standards of the construction industry, Table 5 shows the criteria that none of the case studies were able to fulfil in the BSRS used. It also identifies those that could be assimilated by the FPHS, within the existing limitations of its industry and the requirements established by the CONAVI.

Table 5

Non-fulfillment cause of the case studies in the BSRS and possible assimilation by the FPHS.

NMA	*BSRS*-DIMENSION	Non-fulfillment cause	Possible Assimilation?
ENE	LEED-EA	• Fulfillment of the requirements of ENERGY STAR for Homes, version 3 (U values).	No
		• Gas meter.	Yes
	GBI-EE	• Fulfillment of the requirements as stipulated in MS 1525 (U Values).	No
	AQUA-ES	• Estimation about energy consumption covering 5 factors (heating, cooling, lighting, domestic hot water (DHW) and auxiliaries).	No
		• Use of local renewable energy.	Yes
IEQ	BREEAM-HEA	• Early design advice on acoustic performance.	Yes
	LEED-EQ	• Fulfillment of the requirements for local exhaust and outdoor air ventilation.	No
		• Whole-unit ventilation system.	No
		• Air filters.	Yes
		• Smoking ban in common areas.	Yes
		• Blower door test.	No
	AQUA-CF	• Early design advice on acoustic performance.	Yes
		• Architectural and technical solutions to limit the effects of sources of unpleasant odors from outside, taking into account prevailing winds.	Yes
		• Ventilation system.	No

	AQUA-HS	• Recommendations about furniture provisions.	Yes
		• Identification of external pollution sources.	Yes
		• Identification of internal pollution sources along the life cycle of the building and the degree of health risk attached to these sources.	No
MAN	BREEAM-MAN	• Arguments to know whether timber and timber based-products used during the construction process are legally harvested and traded timber.	No
	AQUA-EN	• Specifications in contracts about the use of products listed in-group one of the carcinogenic substances classification as defined by the IARC.	Yes
		• Fulfillment of the requirements related to construction, demolition waste management and recycling.	No
		• Achievement of certain minimum rates of processing of waste generated in the project.	No
		• Managing water and energy resources during construction.	Yes
MAT	BREEAM-MAT	• Arguments to know whether timber and timber based-products used on the project are legally harvested and traded timber.	No
	LEED-MR	• Arguments to know if all wood in the building were non-tropical, reused or reclaimed, or certified by the Forest Stewardship Council, or USGBC-approved equivalent.	No
		• Fulfillment of the requirements of ENERGY STAR for Homes, version 3.	No
	AQUA-EN	• Substantiation of the origin of the natural resources employed.	No
SIT	AQUA-SIT	• Clarity as to how the analysis helps to meet the objectives set by BSRS (prevailing winds, rainfall, local resources, materials, infrastructure, etc.)	Yes
		• Dedicated space to the improvement of the quality of life.	Yes
WST	AQUA-EN	• Waste classification according to their nature and recovery potential.	Yes

*Key references: [23,81–84]

The criteria that could be assimilated by FPHS have been established, assuming the following aspects to be possible: The implementation of new eco-technology; the evaluation of possible variable characteristics, broader in their design phase than the current ones (such as analysis of the prevailing winds, natural light, etc.); the inclusion of new obligations for the verifier, e.g., in the case of resource and residue management during construction; and the inclusion of new clauses in the contracts and users manuals.

In general terms, the comparative analysis of the evaluation methodology of the chosen FPHS and BSRS indicate that the case studies analyzed according to the FPHS approach showed compliance with the indicators of the NMA: TRA and WAT. On the other hand, the characteristics related to MAT require complex solutions concerning their standardization with the rest of the BSRS, with the same occurring in ENE, IEQ and MAN; their solution would represent a significant advance for the Mexican construction industry.

3.2 Results and discussion according to MCI.

Based on each BSRS's own methodology, the case studies show different ranges among the BSRS (see Fig. 13): in GBI no house achieves the minimum qualification for basic compliance. In LEED and AQUA-HQE there are cases of minimum compliance (and others where the qualification was superior to the certification requisites); in

BREEAM only 50% of the MH cases were awarded a certification of "Pass". Finally, compliance in FPHS went from 100% obtaining the highest possible qualification in MH, to only 28.5% in DH.

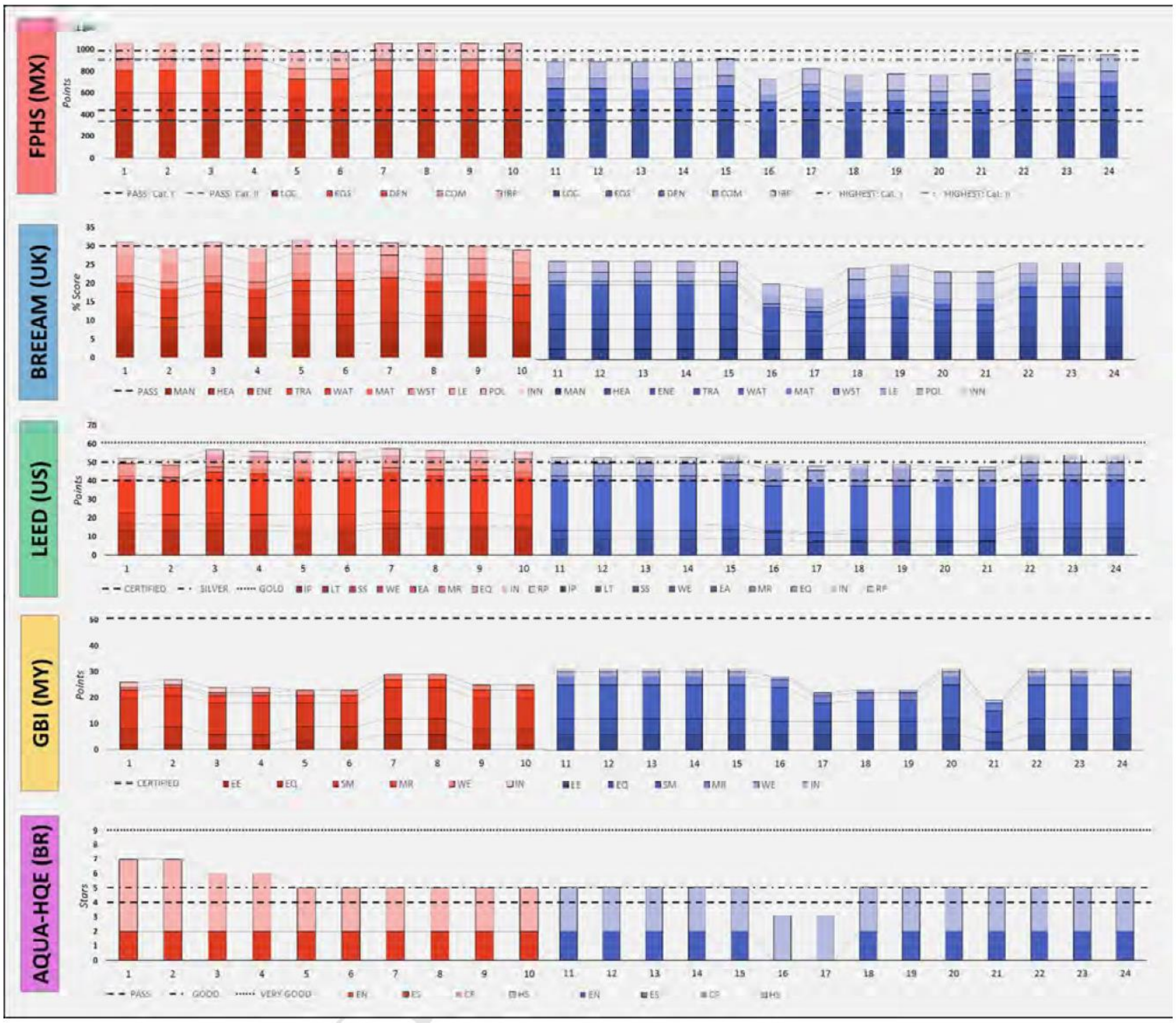

Fig. 13. Results of the case studies according to MCI of the BSRS.

If the results are evaluated in terms of the type of housing studied, MH has better results than DH in FPHS, BREEAM, LEED and AQUA-HQE, with only GBI showing DH with better values than MH. Another aspect to highlight is that LEED shows greater uniformity in the results obtained by both typologies. Therefore, the established methodologies –separately– show the difficulty of establishing correlations that allow a comparative analysis to be performed, due to the disparity shown in the results of the case studies (see Fig. 13).

The results obtained by means of the NCP, like those of each BSRS, also have difficulty in establishing correlations in the BSRS (see Fig. 14); however, they permit ENE and SIT to be identified as the NMA in which the case studies achieved $MCI\text{-}FP^{NCP}$ of over 50% in the BREEAM (only in MH) and LEED systems. The case of ENE in

LEED is particularly interesting, where the range of compliance of the case studies is due to the size of the houses as opposed to the design, type of installations or quality of the surrounding area in each case.

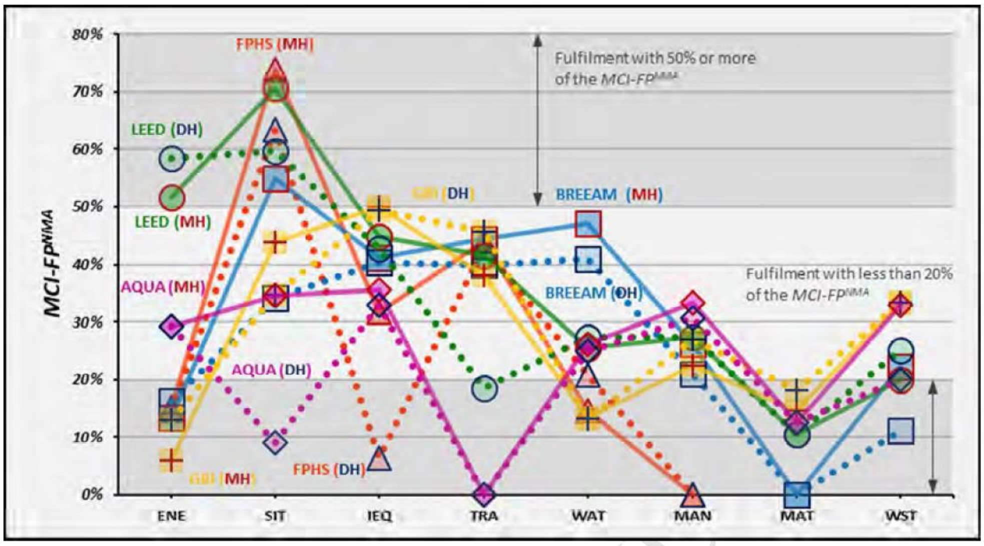

Fig. 14. Average results of the *MCI-FP*^{NMA} according to case studies.

Fig. 14 also shows MAT as the NMA in which none of the case studies manage to achieve more than 20% in any BSRS; this could be explained by it not being considered in the FPHS, which proves the need to actively involve this NMA in the Mexican system and thereby obtain more sustainable housing.

Of the difficulties in establishing possible correlations, two stand out: on the one hand the BSRS that were developed considering a global adoption, and on the other hand those in which only local (national) characteristics were considered.

For the correlation of the global adoption group (LEED and BREEAM), the main differences are found in ENE, MAT and WAT; the first two have better scores in this research in LEED, while on the contrary WAT scores better in BREEAM. When the types of housing are analyzed, the most significant differences are present in the characteristics related to ENE (for LEED), and SIT (for BREEAM) (see Fig. 14).

Regarding the correlation of the national group (GBI and AQUA-HQE), the results of this work only consider them similar in MAN and MAT, showing greater disparity when compared with the global adoption group; as for the greater differences among the typologies, these are established in the characteristics relating to the SIT (see Fig. 14).

The NCP also shows that the NMA that includes the characteristics related to the SIT is to be found among those that obtained the highest *MCI-FP*^{NMA} (except for AQUA-HQE in DH; see Fig. 14), in accordance with the FPHS operational rules, which emphasize projects that encourage orderly urban expansion [94]. However, although the FPHS has to deal with the paradigm that the characteristics of the environment play a significant part in the sustainable qualities of the housing, the WNMA of the case studies referring to SIT in the FPHS do not coincide with those obtained by the rest of the BSRS (see Fig. 15).

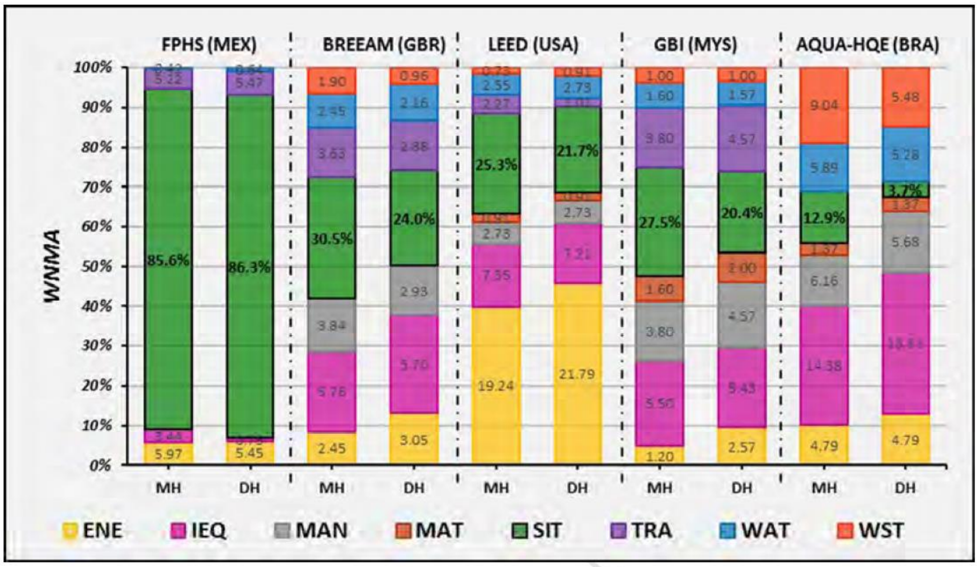

Fig. 15. *WNMA* percentage according to average results of the case studies.

The divergence shown in Fig. 15 about the weight of SIT is due to the FPHS awarding very high percentage scores to the characteristics of equipment and services located close to the housing, in particular those relating to education. E.g. if a house is located near a childcare center, kindergarten, elementary school and middle school it can obtain up to 27% of the maximum score awarded by the FPHS, while in the other BSRS the evaluation of the equipment and services that should be located near the housing are significantly different with regard to the values assigned as well as the types of installations and services envisaged in the evaluation (see Table 6).

Table 6

Considerations criteria by the BSRS according to Equipment and Services indicators.

BSRS	Equipment and Services Considerations by the BSRS	Maximum distances[A]	Available points	Maximum weight
FPHS	1. Health center; 2. Child care; 3. Kindergarten; 4. Elementary School;5. Middle School; 6. Food or super market; 7. Open space and free areas.	1, 2 and 2.5 Km	220 370[B]	22% 37%[B]
BREEAM	1. Appropriate Food Outlet; 2. Access to cash; 3. Recreation or leisure facility for fitness or sports; 4. Outdoor open space; 5. Publicly available postal facility; 6. Community facility; 7. Over the counter services associated with a pharmacy; 8. Public sector doctor's surgery or general medical center; 9. Child care facility or school.	0.5 and 1 Km	2	2.125% (MH) 2% (DH)
LEED	1. Open space; 2. Food; 3. Clothing store or department store selling clothes; 4. Convenience store; 5. Farmers market; Hardware store; 6. Pharmacy; 7. Other	0.8 Km	3	3%

	retail; 8. Bank; 9. Gym, health club, exercise studio; 10. Hair care; 11. Laundry, dry cleaner; 12. Restaurant, café, diner; 13. Adult or senior care (licensed); 14. Child care (licensed); 15. Community or recreation center; 16. Cultural arts facility (museum, performing arts); 17. Educational facility (including school, university, adult education center, vocational school, community college); 18. Family entertainment venue (theater, sports); 19. Government office that serves public on-site; 20. Place of worship; 21. Medical clinic or office that treats patients; 22. Police or fire station; 23. Post office; 24. Public library; 25. Public park; 26. Social services center.			
GBI	1. Bank or ATM; 2. Playground or Public Park; 3. Religious Centre (Mosque, Surau, Temple, Church, Kuil); 4. Restaurant or Coffee Shop; 5. Supermarket or Grocery Store or Mini-market or Wet Market; 6. University or College or School or Crèche or Kindergarten; 7. Community Center or Assembly Hall; 8. Hair Saloon or Barber Shop; 9. Hardware Store; 10. Hospital or Medical Center or Clinic or Pharmacy; 11. Laundry; 12. Library or Book Store or Newsagent or Stationery Shop; 13. Police Station or Police Pondok; 14. Post Office.	0.75 Km	4	4%
AQUA-HQE	None	None	0	0%

[A]Varies according to equipment or service, see [23,81–84]; [B]Considering the extra-points dimension: IBP

It should be pointed out that the distance measuring criteria presented in Table 6 is not comparable within the BSRS; the FPHS, for example, uses a straight line between two reference points whereas the others measure distance by following the walking distances. This goes to show that the real comparable distances in FPHS are higher, requiring motorized transport and therefore having a greater environmental impact [95].

Among the notable aspects of the housing built according to the FPHS approach, several common characteristics have been established among all the BSRS, which are also considered fundamental in evaluating sustainable housing globally (see Table 7); they are practical in their construction and they contribute to improving the Mexican housing stock. Additionally, they represent an example of good practice for countries similar to Mexico and who are studying BSRS proposals, thereby permitting their replication.

Table 7

Maximum fulfillment with the established criteria by the BSRS.

NMA	Causes for which case studies fulfilled the established criteria by the BSRS*.
ENE	• Energy star qualified water heater.
	• High-efficacy lighting.
	• There is no exceed the maximum allowable pipe length.
IEQ	• All habitable rooms meet the minimum requirements of ventilation rate in the local building code.
	• A nominated percentage of the habitable rooms has a Daylight Factor of minimum 0.5%.
	• All public and circulation spaces being naturally lit.
MAN	• Person on the ground who act as the point of contact to relay information concerning environmental aspects of the building site and to oversee the implementation of the contractor's commitments.

	• Contracts specifications with external companies: They must handle the storage or sorting of building-site waste to existing local chains.
	• Justified and satisfactory provisions to optimize logistics, sorting and waste grouping in the worksite.
	• Ensure the fiscal and labor formality of 100% of construction company subcontractors, and other service providers involved in activities on the work site.
	• Manual for the future occupants and maintenance.
MAT	• Use of building products or materials that have been extracted, harvested or recovered, as well as manufactured, within Mexico for 50% or 75% (based on cost) of the total material value.
SIT	• Previously developed land or avoidance of sensitive land.
	• Location within ½ mile (800 meters) of a publicly accessible or community-based open space that is at least ¾ acre.
	• Fulfillment of the dwelling unit per acre of buildable land area density.
TRA	• Fulfillment of the Accessibility Index determined by the BREEAM.
WAT	• Reduce on the consumption of potable water for sanitary use from all sources through the use of water efficient components and water recycling systems of more than 12.5% of the conventional buildings.
	• Water meter with a pulsed or other open protocol communication output to enable connection to an appropriate utility monitoring and management system, e.g. a building management system (BMS), for the monitoring of water consumption.
WST	• Dedicated area(s) and storage for collection of non-hazardous materials for recycling are provided during construction.

*Key references: [23,81–84]

4. Conclusions.

The findings of this study show advances made by the CONAVI by adjusting its criteria in order to accredit its standards to those established internationally by the construction industry; the ultimate objective being to achieve more SSH. However, although the case studies scored highly in the FPHS, when they were evaluated according to global standards (the BSRS studied), the results showed intervals of compliance significantly different to the FPHS, with lower levels of the basic requirements considered necessary for validating compliance with those systems.

The results of the case studies show that the qualification that a specific house can obtain using the FPHS criteria will vary significantly according to the approach used for its evaluation, showing as the only common degree of sustainability that these have, to the specifications that the same program establishes. Seen from the global perspective of sustainability, and emphasizing the intrinsic details that characterize a sustainable housing unit, none of the case studies can be considered as such, as the characteristics relating to MAT, ENE, IEQ, and MAN are not comparable with the requirements established by the other systems.

Regarding the characteristics of the MCI, the study shows that the FPHS has a wide range of evaluation indicators and parameters, the majority of which are not applied by the housing developers, due to laxity in the granting of the evaluation process. The priority for the FPHS is to establish an evaluation methodology with homogenous proportionality in the aspects for assessment, or failing that a weighting of the values assigned to each indicator, with the aim of obtaining a housing unit that puts contextualization before industrialization.

Those indicators considered essential in the internationally recognized BSRS were established, with the emphasis on those that could be integrated into the methodology established by the FPHS under the current characteristics of the sector. Implementation would lead to an increase in the level of sustainability of the Mexican housing stock, and given the preponderance of this type of housing in the country, would reduce both the energy demand and GHG emissions of Mexican residential areas.

The case studies provide indicators of possible application with the possibility of integrating sustainable characteristics within the configuration of social housing in countries with similar characteristics to Mexico. The study indicates that the sustainable characteristics with the best chance of integration into this type of housing are those related to the urban environment; as this is usually the responsibility of the public sector, as opposed to the private, its application is more feasible.

Finally, although the evaluation model established by the FPHS shows room for improvement in several areas (some of them detailed in this study), prioritizing the characteristics related to the urban environment, above all other categories, may represent a new paradigm for evaluating social housing. This is especially true for the UMC, where there is a need to improve the habitat of this type of housing, with more and more countries seeking an evaluation system which will help them improve their housing stock.

5. Future scope.

Future research could focus on the analysis of a more significant number of BSRS created in a UMC, which would allow obtaining better arguments to draw relevant conclusions regarding the differences in the conceptualization of the concept of sustainability that the different countries have. Likewise, it would be interesting to analyze the possibility that acceptance criteria such as sustainable construction were established as a global acceptance, as well as a broader analysis of the OCI and their possible establishment as global standards.

Concerning the NCP, it would be interesting to establish new standardization equations by considering certifications different from those used in the present work. Regarding the Mexican residential sector, an in-depth analysis of the characteristics related to MAT, ENE, IEQ, and MAN is essential to obtain solutions that are consistent with the particularities of the Mexican environment.

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Appendix A. A calculation example of the $PNMA^{Max}$ and *WNMA* for a particular NMA according to the OCI.

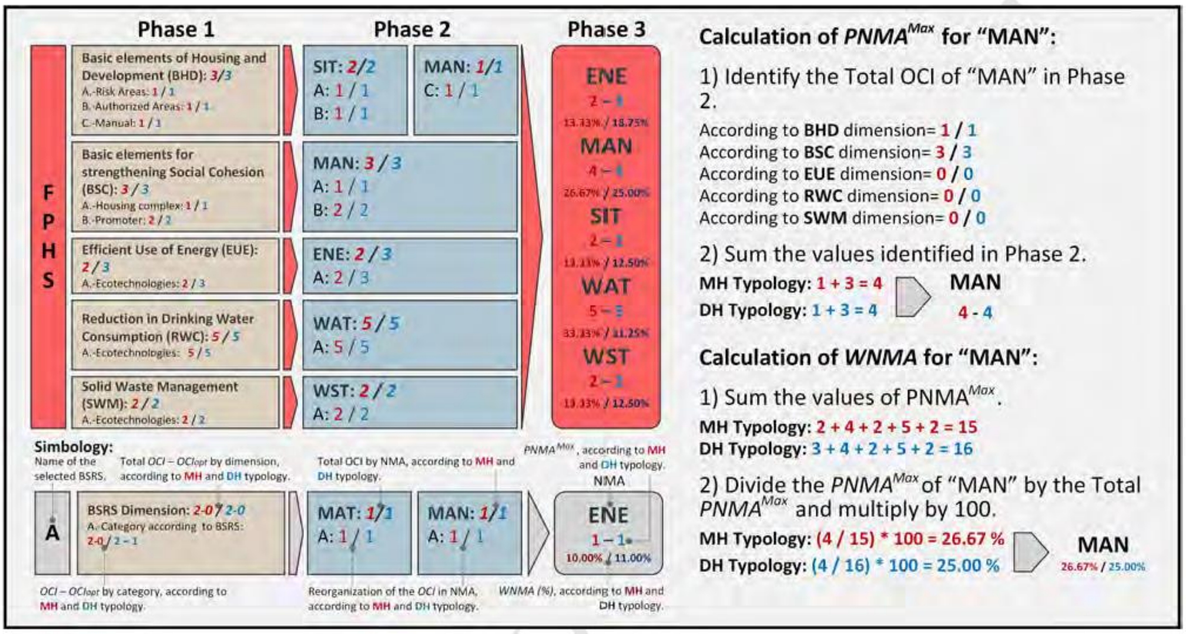

Fig. A.1. $PNMA^{Max}$ and *WNMA* calculation example.

Appendix B. A calculation example of the $WDim^{Real}$ and $WDim^{BSRS}$.

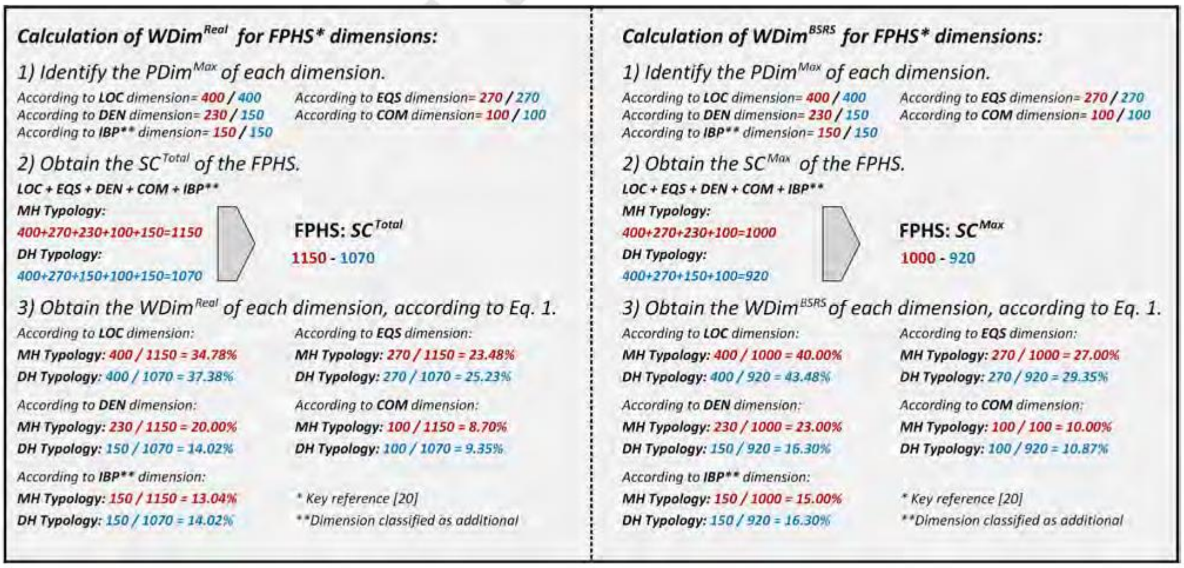

Fig. B.1. $WDim^{Real}$ and $WDim^{BSRS}$ calculation example.

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CAPÍTULO IV

HOUSING INDICATORS FOR SUSTAINABLE CITIES IN MIDDLE-INCOME COUNTRIES THROUGH THE RESIDENTIAL URBAN ENVIRONMENT RECOGNIZED USING SINGLE-FAMILY HOUSING RATING SYSTEMS.

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Article

Housing Indicators for Sustainable Cities in Middle-Income Countries through the Residential Urban Environment Recognized Using Single-Family Housing Rating Systems

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Abstract: This study presents a comparative analysis of the housing indicators used by the single-family housing rating systems (SHRSs), in which the residential urban environment (RUE) influences buildings' certification scores, emphasizing the relationships of six systems developed by middle-income countries (MICs)—BEST, CASA, GBI, BERDE, Green Homes, and LOTUS—and the two most-recognized rating systems, BREEAM and LEED. The aim is to provide new housing indicators that are capable of bringing the concept of sustainability into the cities of MICs. The results reveal that the percentage of influence that single-family housing (SFH) can achieve in the metric established by each system is relatively low. However, considering all of the identified indicators, this influence could increase to 53.16% of the total score in multi-criteria evaluations. Furthermore, a significant lack of indicators for mandatory criteria evaluations was found, with CASA being the only system that considers their inclusion. This paper identifies 37 indicators for multi-criteria assessments and two for mandatory-criteria assessments, providing new perspectives on several topics. Furthermore, the methodology established to obtain the indicators could be useful for other researchers in the identification of new sustainable indicators.

Keywords: housing indicators; residential urban environment; rating systems; single-family house; sustainable cities; residential sector; comparative approach; middle-income countries

1. Introduction

1.1. Background and Research Objectives

According to recent estimates, the planet will be populated by over 8.5 billion people in 2030 [1]. Considering the enormous impact of human activity, e.g., climate change and environmental destruction [2–4], as well as the constant trend toward urbanization [5,6], the unavoidable truth is that humanity must face up to the challenge of creating livable and sustainable urban habitats while maintaining and developing cities [7–9].

Housing indicators are resources that make it possible to study the issues and conditions of human settlements, as well as providing the basis for their monitoring [10]. They are also considered as useful resources to help in promulgating sustainable political decisions [6]. It is important to consider these indicators during the planning process of cities because the qualities of residential urban environments (RUEs) can seriously affect their livability [11–15].

Several researchers have recently applied housing indicators in order to achieve or enhance sustainability [16–23]; some of these investigations refer to social housing [17,18,21,22]. Among the indicators that were analyzed are those referring to household vulnerability; these studies found that social housing tends to be inhabited by people with below-average incomes [18,21] who are vulnerable to energy poverty. To solve this issue, Llera-Sastresa proposed a methodological approach based on indicators that improves energy management in social housing [21]. In this sense, Monzón et al. [17] developed a system of indicators to detect multifamily dwellings that have weak energy, acoustic, and accessibility performance. Similarly, Morganti et al. [20] proposed an indicator called building mass, which may contribute to the reduction of energy demand. Other works have proposed social and economic indicators that can help to predict the origin of mortgages as well as housing prices [16]. On the other hand, some researchers have studied indicators for green housing [19,23]. Among these, the most recognized global rating systems (BREEAM, LEED, GBTool, CASBEE) and their implications on sustainability indicators have been evaluated [23].

The relevance of the study of the indicators recognized by rating systems is that these systems, among the plethora of existing instruments used to evaluate building sustainability, have become commonly used in the building industry [24–28]. The flexible framework of these methods makes them receptive to covering more sustainability aspects [29], connecting the neighborhood and community, and thus contextualizing them on a broader scale [30]. One of the virtues of rating systems is their ability to evaluate a wide variety of different indicators as a whole, even though these might have different units of measurement [31]. This makes them a unique method by which to obtain indicators that have been proven in the construction sector in different regions around the world, and which in turn, have the support of experts who have participated in the development of each of the systems.

The comparison of the level of the indicators in rating systems comprises a minor part of the studies carried out in the academic field using a comparative approach [32]. However, this level of detail is recommended to obtain results for a specific aspect [32]. In contrast to other studies that focus on the level of the indicators [33–37], this work has centered on the initial situation of RUEs during the SHRS criteria scoring process. The significance of focusing on the study and acquisition of indicators has been shown in several publications, in which it is argued that the success of any evaluation process depends mostly on the indicators used [31,38–41].

The primary aim of this paper is to identify single-family housing indicators concerning RUE characteristics (SHI^{RUEs}), recognized as green, ecological, or sustainable by the single-family housing rating systems (SHRSs). The objective is that these indicators will be of use to those in charge of configuring RUEs in the pursuit of safer, more inclusive, resilient, and sustainable human settlements in middle-income countries (MICs).

In parallel with the primary aim, it is expected that this study will provide a picture of the current situation in which the SHRSs of MICs consider the impact that RUEs have on a home's classification as green, ecological, or sustainable. Moreover, although the findings are directed toward obtaining useful indicators for MICs, the discussion of the results provides new perspectives about different topics. This may prove helpful for others involved in the development of a SHRS, as well as in carrying out policies related to the residential sector and to single-family housing (SFH).

1.2. Why Address Single-Family Housing of the Middle-Income Countries through the Residential Urban Environment?

In the United Nations Conference on Housing and Sustainable Urban Development (UN-Habitat III), held in Ecuador in October 2016, it was pointed out that "housing has not been appropriately integrated into urban policies in spite of residential land use occupying between 65 and 75 percent of the surface of a city." [42]. This situation is most evident in the MICs, in which the need for the prioritization of these issues has been established in several previous studies [43–48].

One of the main causes of the lack of integration between housing and the RUE is that priority has been given to the search for efficient buildings, instead of providing an environment that integrates both elements [49,50]. This, by analyzing the relationship between the building and the qualities of its immediate environment, can provide strategies to achieve energy efficiency, mitigate greenhouse gases, and improve adaptation to climate change in cities [24,51,52].

Single-family housing (SFH) is the most representative housing type in the MICs and has the most significant environmental impact [53–55]. Furthermore, most housing stock financing is still dedicated to it [56]. According to the World Bank, more than half of the places that will be urbanized by 2030 have not yet been built [57]; it is expected that a significant number of these constructions will be in the MICs [58]. Therefore, the characteristics and configurations that these countries establish as intrinsic to defining sustainable housing (green or ecological housing) will have a decisive impact on the cities since more than 65% of their surface corresponds to the residential sector [42].

Research, such as that of Papargyropoulou et al. [59], suggest that the use of rating systems should be a mandatory requirement in the planning process of the buildings in the MICs. Nevertheless, the findings of this study reveal an urgent need to either redesign the weighting of the SHI^{RUEs} used or to contemplate integrating a more significant quantity. This coincides with the concerns of several international bodies, such as the United Nations and the World Bank, to give priority attention to themes related to how the construction industry comprehends the current and future situation of the RUE in the developing countries.

The features of the SFHs in developing countries will have a significant environmental impact on a global scale, which makes it necessary to establish clear and sustainable criteria for them [60]. Therefore, the significance of this study lies in the search for a way to achieve urban sustainability in the residential sector of MICs; this will be achieved by modifying the current paradigms with which the construction industry evaluates and builds millions of sustainable homes around the world.

2. Research Method

Four processes were developed to obtain housing indicators that would allow the concept of sustainability to be assimilated into the MIC's cities using the characteristics of the RUE. The first defined the rating systems that were used as the basis for the analysis; the second selected the indicators that were the targets of the study; the third obtained the values of each of the chosen indicators; finally, the fourth performed a comparative analysis and obtained the total of the SHI^{RUEs} with their respective descriptions and influence percentage ranges.

2.1. *Definition of the Rating Systems*

The definition of a SHRS considered those that are recognized by both the construction industry and the academic sector (Figure 1). The SHRSs were obtained from two independent processes. On the one hand, six systems were identified from the analysis of the 52 green building rating systems (GBRSs) recognized by the World Green Building Council (Figure 1a; [61]); on the other hand, a systematic review was carried out in which five systems were identified from the analysis of 226 articles published in journals indexed in Scopus (Figure 1b).

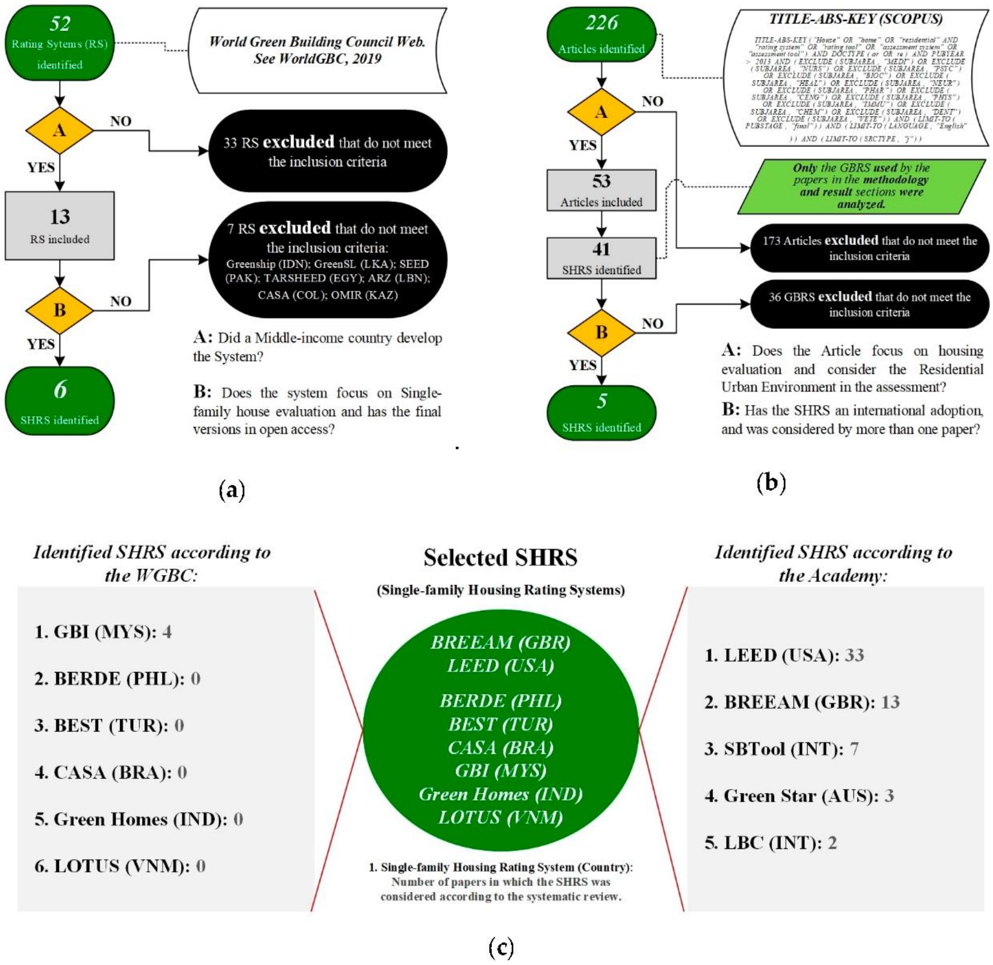


Figure 1. Flowchart of the single-family housing rating systems (SHRSs) definition: (**a**) the SHRSs identification by a decisive hierarchical process according to the systems identified by The World Green Building Council, (**b**) the identification of the SHRSs with an international adoption through a systematic review, and (**c**) definition of the SHRSs.

The rating systems' definition process shows the significance of LEED and BREEAM as the most recognized schemes in the academic sector (Figure 1), which is in accordance with what has been shown by various studies [26,32,62,63]. Likewise, researchers show a clear lack of interest in the SHRSs developed by the MICs, given that just 7.5% of the studies analyzed in the systematic review only considered the GBI rating system [37,60,64,65].

The analyzed versions of each of the SHRSs correspond to those currently used by the construction industry (Table 1). Here, it is possible to identify three classes of systems: (i) those developed by a high-income country (HIC) with an international adoption, (ii) those developed by an upper-middle-income country (UMC) with a national adoption, and (iii) those developed by a lower-middle-income country (LMC) with a national adoption.

The SHRSs selected include contexts drawn from different regions of the planet; the East Asia and Pacific region show greater representativeness in this study with the consideration of the systems developed in Malaysia, Philippines, and Vietnam (Table 1). Moreover, the consideration of BERDE, BEST, CASA, Green Homes, and LOTUS provides added value to this work because they can be studied as a novel contribution to the knowledge in this subject developed thus far (Figure 1c).

Table 1. Description of the SHRSs.

SHRS	Version–Year	Country–Income Level	Adoption	Scoring: Rating System
BREEAM	SD233 2.0–2016 [A]	United Kingdom (GBR)–HIC	International	% **Score**: Pass (≥ 30), Good (≥ 45), Very good (≥ 55), Excellent (≥ 70), Outstanding (≥ 85).
LEED	V4 BD+C–2013	United States (USA)–HIC	International	**Points**: Certified (40–49), Silver (50–59), Gold (60–79), Platinum (80+).
BEST	1.0–2018	Turkey (TUR)–UMC	National	**Points**: Approved (45–64), Good (65–79), Very good (80–99), Excellent (100).
CASA	CASA–2017	Brazil (BRA)–UMC	National	**Points**: Certified (40–49), Silver (50–59), Gold (60–79), Platinum (80+).
GBI	RNC 3.1–2014	Malaysia (MYS)–UMC	National	**Points**: Certified (50–65), Silver (66–75), Gold (76–85), Platinum (86+).
BERDE	NC 2.2.0–2018	Philippines (PHL)–LMC	National	**Stars**: 1 Star (51–60 points), 2 Star (61–70 points), 3 Star (71–80 points), 4 Star (81–90 points), 5 Star (91+ points).
Green Homes	2.0–2012 [B]	India (IND)–LMC	National	**Points**: Certified (38–44), Silver (45–51), Gold (52–59), Platinum (60–75).
LOTUS	Homes V1–2017	Vietnam (VNM)–LMC	National	**Points**: Certified (32–43), Silver (44–51), Gold (52–59), Platinum (60+).

References: [66–73]. [A] Only "partially fitted" was considered. [B] Includes Addendum of October 2016 and January 2014 [74,75].

2.2. *Selection of the Single-Family Housing Indicators That Focuses on the Residential Urban Environment*

The chosen indicators (SHI^{RUEs}) correspond to those showing incidences in specific areas of the RUE around the SFH, i.e., in all the indicators in which the characteristics of the urban environment enable the housing to obtain a specific score. On the other hand, the analysis excluded all those indicators in which the required compliance criteria are performed in the private space of the dwelling, or in which there is a possibility of compliance through some activity carried out in the residence. The selection process is described in Figure 2, which ends with the consideration of four types of indicators: (i) $SHOCI^{RUEentirely}$; (ii) $SHOCI^{RUEpartially}$; (iii) $SHMCI^{RUEentirely}$; and (iv) $SHMCI^{RUEpartially}$.

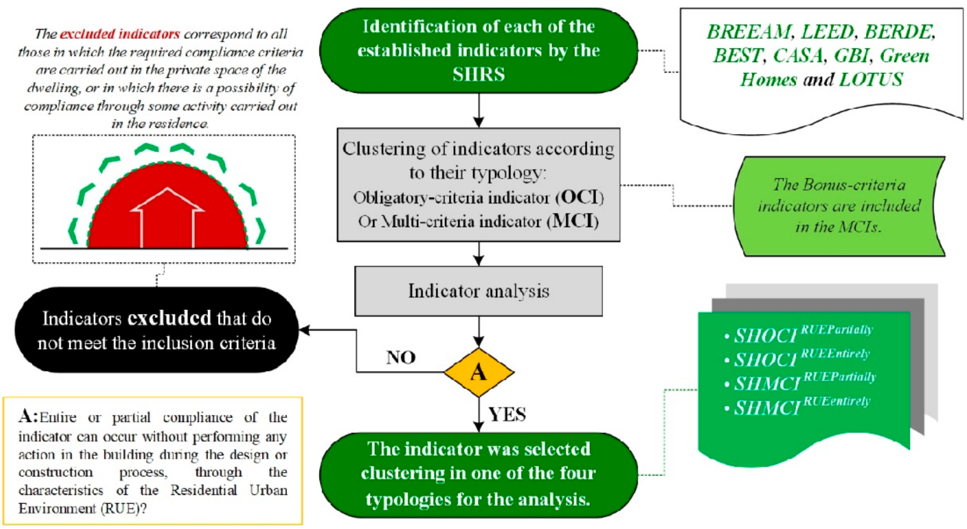


Figure 2. Flowchart of the selection of the SHI^{RUEs}.

The severance of the obligatory-criteria indicators (OCI) and the multi-criteria indicators (MCI) has been carried out in previous studies [60,76,77]. These showed that one of the advantages of following this process is that it produces results that refer directly to the green or sustainable characteristics considered intrinsic to each GBRT, while also allowing the analysis of the dispensable features without any constraints.

The determination of the partial and entire typologies was made because there are a considerable number of indicators in which only some of their compliance criteria focus on the qualities of the RUE. Likewise, there are also indicators in which all of their compliance criteria are related to the urban environment that surrounds the home.

2.3. Obtainment of the Values of the SHI^{RUEs}

The current range of SHRSs allows the evaluation schemes to be adapted to their respective contexts; however, this complicates the comparative analysis of the different methodologies [78]. To overcome this impediment, this paper proposes the extraction of the corresponding values for each of the $SHOCI^{RUE}$ and $SHMCI^{RUE}$.

To obtain the values that each SHRS assigns to each type of SHI^{RUE} in relation to the other indicators, two equations are studied (Equations (1) and (2)), both in the $SHOCI^{RUEs}$ and in the $SHMCI^{RUEs}$:

$$SHI^{RUE_{entirely}} = \left(I^{Max}/C^{Max}\right) \times WC^{I} \quad (1)$$

where I^{Max} is the maximum value assigned to the indicator by the SHRSs; C^{Max} is the maximum value assigned to the category in which the indicator is located; and WC^{I} is the weight of the category in which the indicator is located.

$$SHI^{RUE_{partially}} = \left(SHI^{RUE_{entirely}}/IR^{Total}\right) \times IR^{RUE} \quad (2)$$

where IR^{Total} is the total number of requirements established by the SHRS for the compliance of the indicator and IR^{RUE} is the number of requirements that can be met through the RUE.

Regarding the WC^{I} of each indicator, the one defined by each SHRS was used, except in those cases where the tool did not specify the weighting of each category; in this case, the values were obtained through Equation (3):

$$WC^{I} = C^{Max}/\sum C^{Max} \quad (3)$$

During the score obtainment process, all of the $SHOCI^{RUEs}$ were considered to have a value of one. Moreover, only 50% of the value of the indicators was considered in cases in which the SHI^{RUEs} showed criteria that the house must necessarily meet in conjunction with the RUE (these indicators were considered as $SHI^{RUEpartially}$), e.g., materials, where the RUE is required to have an infrastructure capable of providing a defined percentage of the dwelling. Additionally, some consideration was given to the different rating systems, as specified in Table 2.

Table 2. Considerations made in the selected SHRS.

SHRS	Special Considerations
BREEAM	BREEAM allows the weights of each category to differ regarding the location of the home in which the certification is to be made. Therefore, to obtain a quantitative analysis with the least possible bias, all the WC^{I}s were obtained using Equation (3). On the other hand, the OCIs vary according to the rating level desired; however, for this analysis, those required for a "pass" level were addressed. In addition, the $SHMCI^{RUEs}$ indicated in the innovation category were considered to be independent of the categories to which they refer to respect the weight that should correspond to them.
LEED	The point floors were discarded.
BERDE	The four OCIs presented by this tool are located in the categories of management (MN), and use of land and ecology (LE). In the MN category, the OCIs were located in the commitment to sharing resource data, and compliance with building and environmental laws, regulations, and mandatory standards. The other two OCIs were located in the LE category: distinct and clear boundaries, and initial site assessment. Finally, each OCI was considered with a value of 0.25.
BEST	The available points in Table 1 (see Reference [68]) were considered to obtain the maximum values granted by the SHRS for each indicator.
LOTUS	The categories of innovation (INN) and best practice credits (BPC) were discarded, both in the OCIs and in the MCIs, because the tool does not consider a specific weight for this category.

Note: There are no special considerations in the SHRS: CASA, GBI, and Green Homes.

Obtaining the values of each SHI^{RUE} makes it possible to ascertain the maximum influence that the RUE has on each rating system (through quantitative data); this, in turn, allows the comparative analysis of the different systems to be carried out.

2.4. Comparative Analysis and Description of the SHI^{RUEs} Identified

Li et al. [32] state that there are four levels of comparison among the rating systems: (i) general, (ii) category, (iii) criterion (sub-category), and (iv) indicator. This work focuses on the comparative analysis corresponding to level four. In this case, the criteria established by the systems are compared in each of the indicators, obtaining both the existing relationships between the different schemes, as well as those indicators of exclusive consideration by each of the systems, allowing new indicators to be identified and described.

The establishment of relationships among the rating systems means that any discussion of the results must involve a certain amount of complexity and subjectivity [79]; this uncertainty may be reduced by applying a criteria normalization process [24,60,80], which consists of reorganizing the selected indicators into new macro-areas (NMAs).

The process of clustering the indicators into the NMAs was based on the relationships between the SHRSs concerning the categories in which the SHI^{RUEs} were identified. Once the indicators have been relocated in the NMAs, it was possible to discern their relationships, as well as to see the peculiarities that each SHRS establishes in its evaluation methodology.

Once the relationships were established between the SHI^{RUEs} located in each NMA presented by each system, the maximum and minimum percentages of influence of each indicator were obtained. Additionally, the schemes that establish more rigorous compliance criteria were identified, as well as the more accessible compliance criteria.

3. Results and Discussion

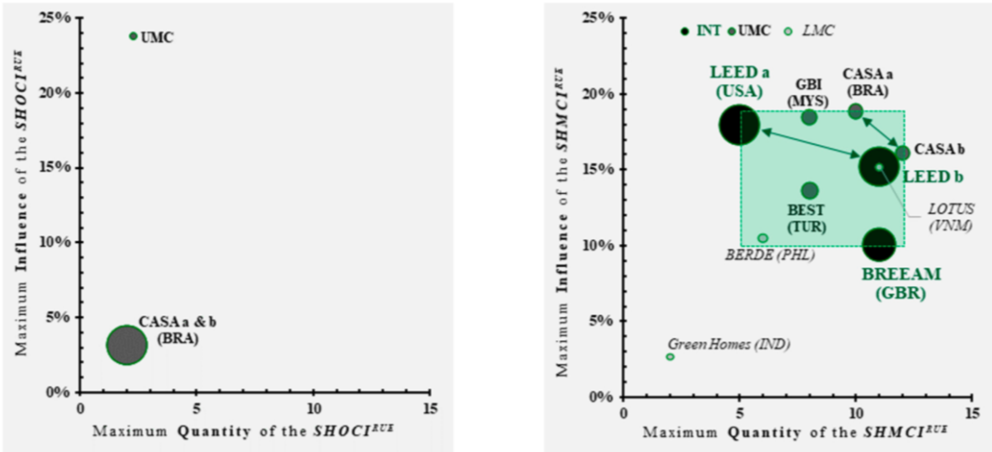
The results and their discussion are presented in two sections: First, it shows the current situation of the conception that rating systems have of the RUE that surrounds the SFH, as well as the similarities and divergences among the systems. Second, it presents the identified indicators and their integration possibilities in the MICs, outlining the advantages that their use would have for these countries.

3.1. The RUE Recognized by the SHRSs: Their Influence and Relationships among the Schemes

This study notes that the urban environment recognized by the SHRSs needs to be addressed in a better way to provide housing that allows the sustainability of cities in the MICs to be improved. Based on each rating system's own scheme, the maximum percentage of the RUE influence on the score of the housing varies according to the SHRS used. However, it is possible to establish a significant absence of the $SHOCI^{RUEs}$ among the rating systems, with CASA being the only system that considers the inclusion of this type of indicator, with a maximum influence of 3.15%. Furthermore, the study shows that none of the systems analyzed could achieve more than 18.86%, referring to the $SHMCI^{RUEs}$ (Figure 3).

Among the peculiarities of the SHRSs selected, LEED and CASA gave two paths to follow (performance—a, prescriptive—b); therefore, both scenarios were considered within the comparative analysis to reduce the sensitivity and uncertainty.

Table 3 shows the distribution of the indicators according to each of the typologies considered. It was found that the type corresponding to the $SHI^{RUEentirely}$ provides the most weight to the maximum percentage of influence. However, there are tools in which this does not occur. In CASA, the $SHOCI^{RUEpartially}$ were the only indicators; in LOTUS, the $SHMCI^{RUEpartially}$ made up more than double the value of the $SHMCI^{RUEentirely}$; in Green Homes, the percentages between both types of $SHMCI^{RUEs}$ were equal. This highlights the weakness of the SHRSs of some MICs concerning the consideration of the RUE.



(**a**) (**b**)

Figure 3. Maximum influence and quantities according to the single-family housing indicators concerning RUE characteristics (SHI^{RUEs}) identified on the SHRS: (**a**) results according to the $SHOCI^{RUEs}$, and (**b**) results according to the $SHMCI^{RUEs}$. The size of the points corresponds to the GNI per capita [81] of the country in which the system was developed.

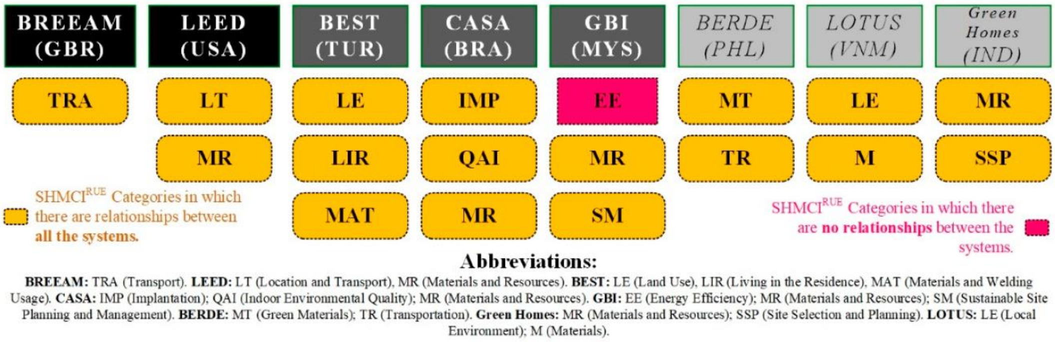
Table 3. Quantity and weight of the SHI^{RUE} identified in the SHRSs.

SHRS	Adoption	$SHOCI^{RUEpartially}$		$SHMCI^{RUEpartially}$		$SHMCI^{RUEentirely}$	
		Qty.	% *	Qty.	% *	Qty.	% *
BREEAM	International	-	-	6	2.25	5	7.81
LEED (a)		-	-	1	0.68	4	17.27
LEED (b)		-	-	1	0.68	10	14.55
BEST	National in a UMC	-	-	3	3.64	5	10.00
CASA (a)		2	3.15	6	4.32	4	14.55
CASA (b)		2	3.15	6	4.32	6	11.82
GBI		-	-	2	1.50	6	17.00
BERDE	National in an LMC	-	-	2	2.50	4	8.00
Green Homes		-	-	1	1.33	1	1.33
LOTUS		-	-	8	10.19	3	5.00

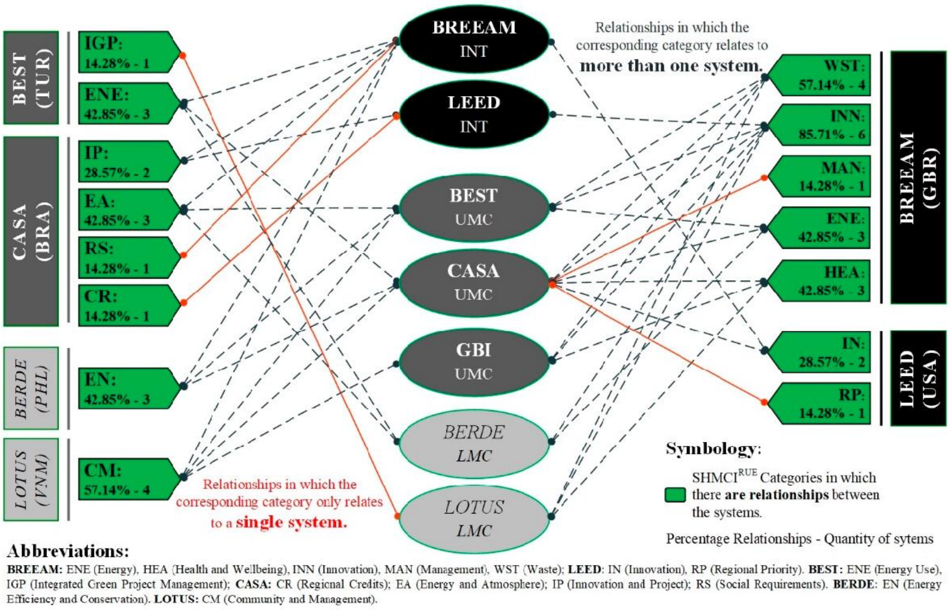
* Maximum percentage of influence that can be achieved with the compliance of the indicators. (a) and (b) refer to the performance and prescriptive paths, respectively.

Among the SHRSs developed by a MIC, CASA stands out as the only system that considers both $SHOCI^{RUEs}$ and $SHMCI^{RUEs}$. This may be a reflection of the practices implemented in Brazil in recent years, especially in social housing projects [22], where dwellings that have obtained more sustainable labeling have shown a high correlation of compliance with indicators related to urban quality [77]. In contrast to CASA, Green Homes was a system in which the RUE exerts the least influence on the housing score assigned for obtaining certification. This was possibly due to there being 0.23 accredited planners per 100,000 people in India [42], so the priorities of the residential sector can be unintentionally directed toward other areas. The aforementioned is of the utmost importance because India is considered one of the three countries where the highest world population growth will occur during the next 30 years [58].

Regarding the relationships among the SHRSs, most of the systems consider the categories associated with location, materials, and transport (Figure 4a). Moreover, most of the SHRSs exhibit more categories related to two or more systems than categories that are related to one or no systems (Figure 4b). Additionally, Figure 4 exhibits the case of GBI, which possessed the only category without any relationship with another system.



(a)



(b)

Figure 4. Relations between the categories established by each SHRS and the remaining systems: (**a**) categories in which there are relationships between all systems and in which there are no relationships, and (**b**) categories in which there are relationships between the systems.

Each of the SHRSs has its own conception about how the urban environment impacts the labeling of housing and its maximum influence on the score; despite this, performing the normalization criteria process (NCP) allowed the identified indicators to be clustered into six new macro-areas (Figure 5): energy (ENE), innovation (INN), location (LCT), materials (MAT), transport (TRA), and waste (WST).

The clustering of the SHI^{RUEs} into the NMAs (Figure 6) shows that BREEAM and CASA (b) included all the NMAs proposed, and Green Homes was the system with the lowest inclusion of the areas, considering only LCT and MAT. On the other hand, the percentages of distribution among the NMAs shown by each system varied significantly, with LEED (b) and BEST, and GBI and BERDE, being the rating systems that showed a closer distribution.

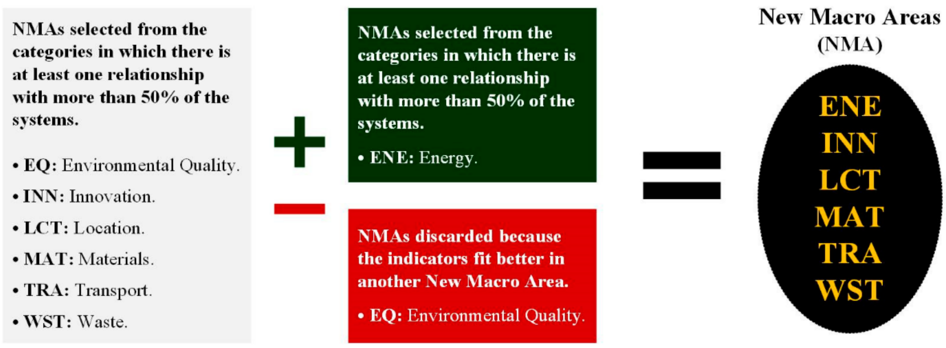


Figure 5. Scheme of the normalization criteria process (NCP).

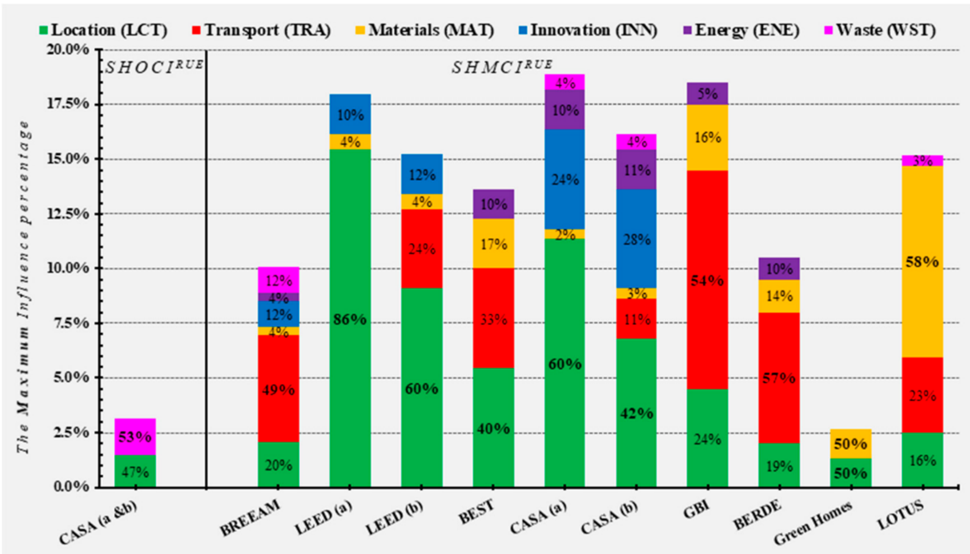
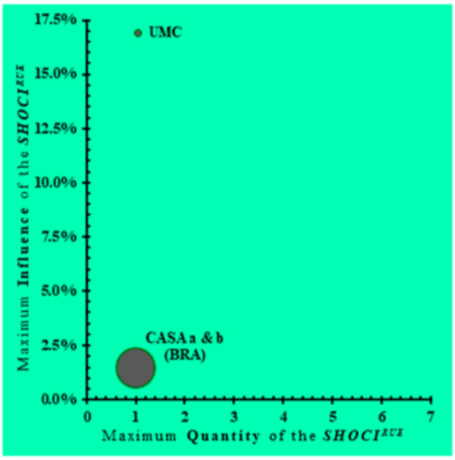


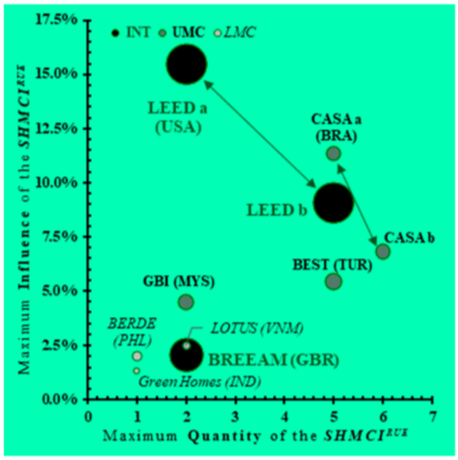
Figure 6. Maximum influence of the SHI^{RUEs} and their distribution according to each NMA.

In Figure 6, ENE, INN, and WST have the lowest percentage of representation among the SHRSs. However, their consideration as NMA allowed for valuable information for the objectives of the study to be obtained: (i) In the case of ENE, several researchers have pointed out that there is a bias toward assigning a high weight to categories that promote energy efficiency in housing [32,33,82,83]. Despite this, in the SHMCI^{RUEs}, only 63% of the systems considered them while emphasizing 100% of the tools developed by a UMC. (ii) Only BREEAM and LEED considered INN with a representativity of more than 10%. Furthermore, except for CASA, no system developed by an MIC contemplated the consideration of INN. (iii) The case of WST was unusual, as it was the second NMA that contained SHOCI^{RUEs}, but concerning the SHMCI^{RUEs}, only three of the eight systems recognized it as NMA, with values lower than 4% in CASA and LOTUS, and 12% in BREEAM.

Concerning the NMA of LCT, it is noteworthy that only CASA recognizes the SHOCI^{RUEs} (Figure 7). Therefore, an analysis of the possible reasons for this situation could be addressed in future research. Moreover, despite the acceptance of this NMA by the different systems, the difficulty of finding correlations between them was evident.



(**a**)



(**b**)

Figure 7. Maximum influence and quantities according to the SHI^{RUEs} identified in the SHRS, according to LCT: (**a**) results according to the SHOCI^{RUEs}, and (**b**) results according to the SHMCI^{RUEs}. The size of the points corresponds to the GNI per capita [81] of the country in which the system was developed.

TRA is another NMA in which all systems consider SHMCI^{RUEs}; however, LEED (a), CASA (a), and Green Homes assess the inclusion, as optional compliance criteria of amenities in the area of LCT [69,70,72]. In this NMA, GBI stood out as the rating system with the highest influence percentage, while CASA (b) showed the lowest rates (Figure 8). Moreover, three indicators were the most studied quantities by the SHRSs. Additionally, a linear behavior was seen in the quantity–influence relation between the systems developed by the MICs.

Referring to the most significant NMAs: MAT could also be regarded as a relevant NMA, given that it was considered in all of the systems, although only by the SHMCI^{RUEs} (Figure 9). In this NMA, both the quantities and the percentages of influence presented in each system differed considerably; however, it was noticeable that LOTUS had a more significant influence and number of indicators, showing values very different from those of the other SHRSs; GBI and BEST also had higher figures, with two indicators each and percentages from 2.27% to 3.00%. Additionally, the results showed a group in which all systems had only one indicator, but the rates of influence varied from 0.39% to 1.50%.

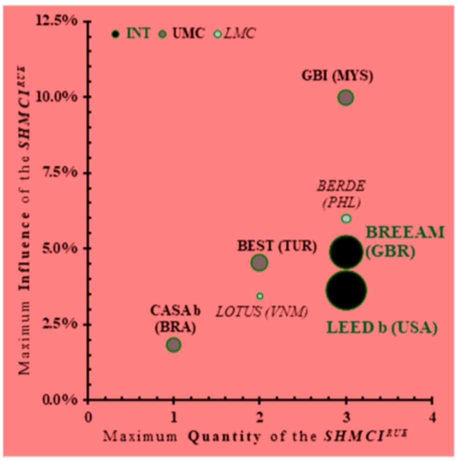
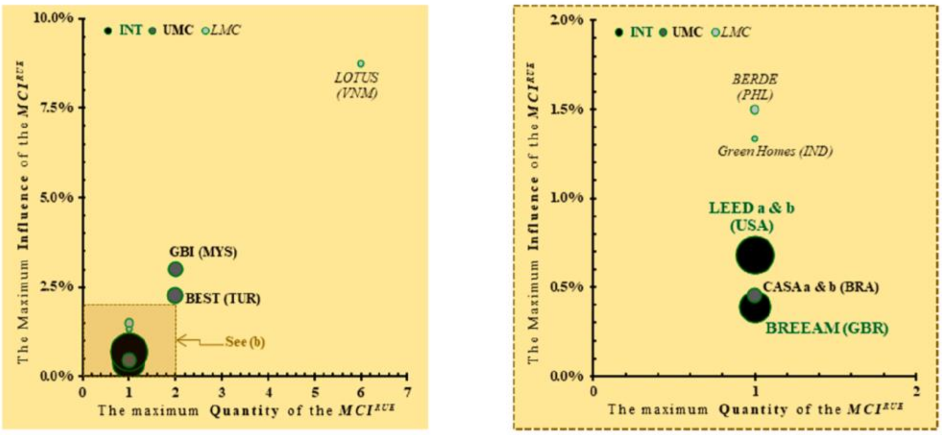


Figure 8. Maximum influence and quantities according to the SHMCI^{RUEs} identified on the SHRS, according to TRA. The size of the points corresponds to the GNI per capita [81] of the country in which the system was developed.



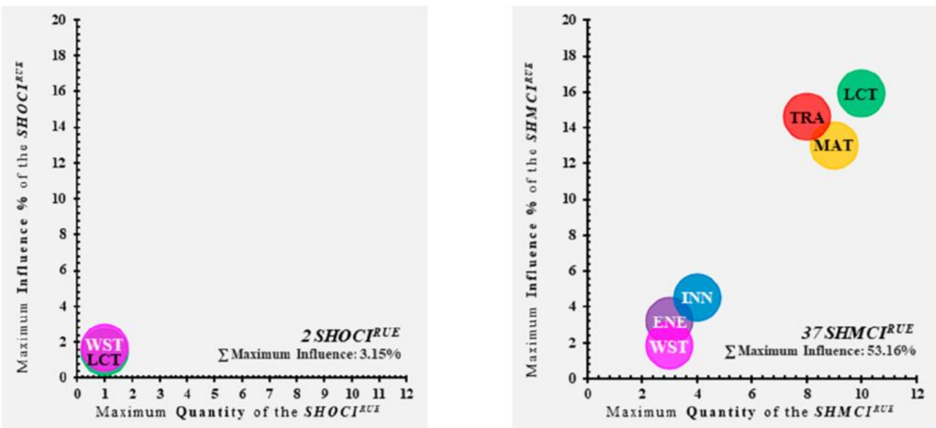
(**a**) (**b**)

Figure 9. Maximum influence and quantities according to the SHMCI^{RUEs} identified on the SHRS, according to MAT: (**a**) results according to the SHMCI^{RUEs}, and (**b**) zoom of the SHMCI^{RUEs}. The size of the points corresponds to the GNI per capita [81] of the country in which the system was developed.

Finally, the fact that LCT and TRA were positioned as the NMAs where most of the SHRSs fit a higher distribution percentage, reaching 70% or more in the BREEAM, LEED (b), GBI, and BERDE rating systems (Figure 6), this could be considered understandable in terms of the urban environment. However, the consideration of ENE, INN, MAT, and WST validated the importance of carrying out detailed comparative analyses of the compliance criteria of the indicators between different rating systems.

3.2. *The SHI^{RUEs} Identified for Sustainable Cities in the Middle-Income Countries*

A total of 39 SHI^{RUEs} were identified to provide the broadest possible range of solutions to the concerns regarding the RUE of the MICs. In these indicators, a maximum influence percentage of 3.15% could be achieved in the case of the SHOCI^{RUEs}, and up to 53.16% in the SHMCI^{RUEs} (Figure 10). Furthermore, if the maximum percentage that could be reached by a system in the multi-criteria evaluation was from 2.67% in Green Homes (Figure 3), the consideration of the SHI^{RUEs} and their maximum influence percentage could result in an increase up to 50.49% in the multi-criteria indicators.



(**a**) (**b**)

Figure 10. Maximum influence and quantities according to the SHI^{RUEs} identified on the NMAs: (**a**) results according to the SHOCI^{RUEs}, and (**b**) results according to the SHMCI^{RUEs}.

The next sections provide an explanation of the 39 SHI^{RUEs} identified concerning the SHOCI^{RUEs} and the SHMCI^{RUEs}.

3.2.1. The SHOCI^{RUEs} Identified for Sustainable Cities in the Middle-Income Countries

As mentioned in previous sections, the identification of the SHOCI^{RUEs} showed the null consideration that most systems had in their schemes, in which it was only possible to identify two indicators (Figure 8a). This nullity opens a new horizon in the academic field that allows for improvement in both the quantity and quality of these indicators. On the other hand, it is also striking that only the NMAs of LCT and WST were considered. In this study, it was only possible to identify two SHOCI^{RUEs}, provided by CASA (Table 4).

Table 4. Description of the SHOCI^{RUEs}.

Indicator	Influence (%)	The Influence Percentage Is Obtained When the Urban Environment:
1. Water Systems	1.47	Has an infrastructure network from which the house can be fed (sewage treatment and water supply network).
2. Waste Management	1.68	Has market agents that act in the reception of waste and waste transporters that comply with the operational requirements established in laws and regulations.

Reference: [70].

At present, increasing pressure exists worldwide for the achievement of the sustainable use of surface water resources [84]. Moreover, in developing countries, water efficiency is considered a critical issue [83]. Since, as Narain and Singh stated [85], in countries such as India, some inhabitants have difficulty accessing water, any SHRS adopted in the MICs should consider the indicator of the "water systems" as an OCI in its evaluation methodology.

On the other hand, the identification of the "waste management" indicator should also be considered by other SHRSs. This is consistent with another study [37], which shows that issues related to waste management require more attention from rating systems; most systems can omit the use of this indicator, as very few consider it to be an aspect of mandatory compliance. Additionally, waste management has a significant impact on the sustainability of a city [86]. Nguyen et al. [46] state that the MICs must seek to achieve coordination among the stakeholders, market agencies, and local communities to enhance the sustainable qualities of the cities, as also indicated by CASA [70].

3.2.2. The SHMCI^{RUEs} Identified for Sustainable Cities in the Middle-Income Countries

This study demonstrated that 31 of the 37 SHMCI^{RUEs} identified were in the range of 0.2% to 1.0% relative to the minimum influence, and 0.2% to 2.0% concerning the maximum influence that each indicator can attain in the labeling of a house (Figure 11). This insignificance in terms of influence can be considered a reflection of the concerns shown by the New Urban Agenda regarding the lack of housing integration in the countries' urban policies [42].

Future research should address the indicators that have a low percentage of influence in order to better understand the implications that the increase in these percentages could have on the sustainability of cities, as well as on the configuration of SFH (Figure 11b).

The description of the indicators is as follows: (i) the "certified neighborhood" indicator, (ii) the SHMCI^{RUEs} that are considered by all SHRSs, (iii) the SHMCI^{RUEs} that are particular to a single system, (iv) the SHMCI^{RUEs} considered by two SHRSs, and (v) the SHMCI^{RUEs} considered by three and five SHRSs.

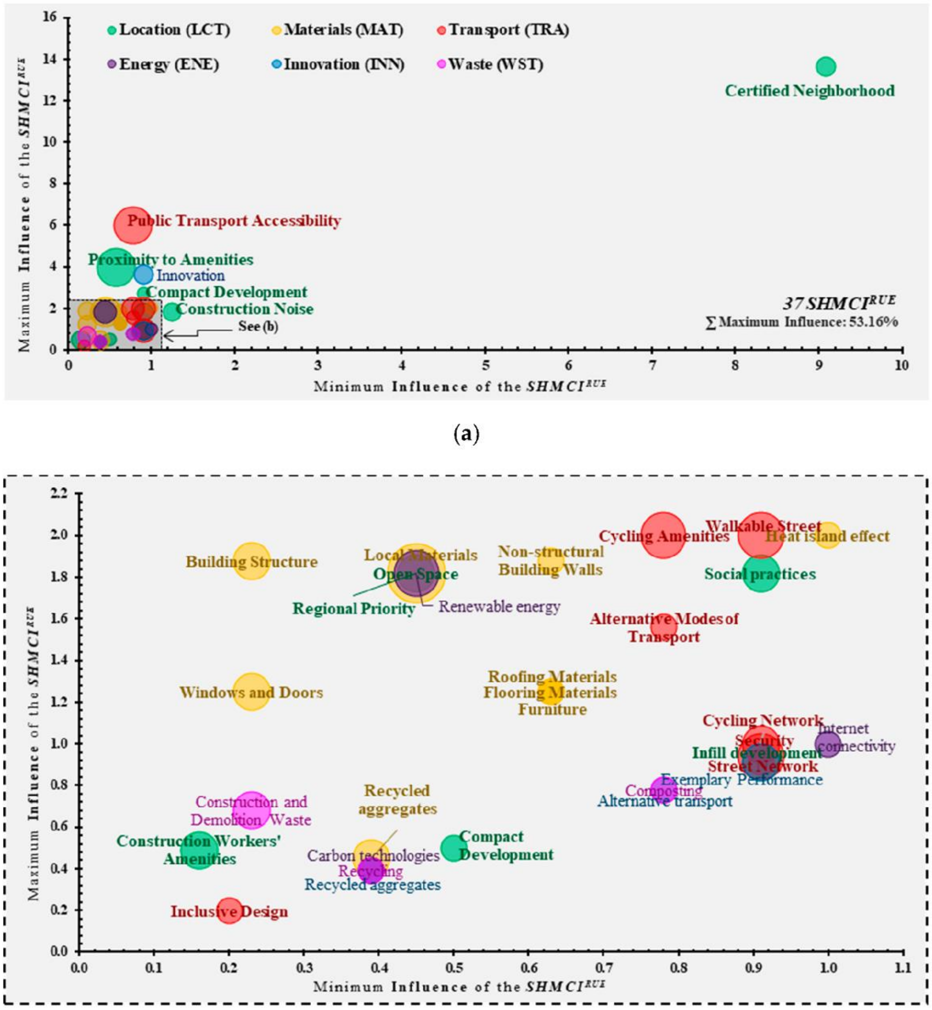


Figure 11. SHMCI^{RUEs} identified: (**a**) full picture of the SHMCI^{RUEs} identified, and (**b**) zoom of the SHMCI^{RUEs}. The size of the points corresponds to the quantity of SHRSs that consider the indicator.

The SHMCI^{RUE}: Certified Neighborhood

Certified neighborhood is the indicator that had the highest influence percentages, and was widely differentiated from the other indicators (Figure 11a). This indicator was only contemplated by LEED and CASA, with CASA being the system that presents the most considerable flexibility in terms of compliance, but at the same time, its influence percentage was 4.55% lower than the percentage that could be obtained in LEED (Table 5).

Table 5. Description of the "certified neighborhood" indicator.

Considered by:	Influence (%)	The Influence Percentage Is Obtained When the Urban Environment:
LEED	13.64	Complies with LEED certification for neighborhood development.
CASA	9.09	Complies with an environmental certification from a recognized certification body, such as AQUA-HQE Districts and Lots, LEED-ND, BREEAM Communities or SITES.

References: [69,70].

It is plausible that a home located in a certified development must comply with the majority of the criteria indicated by the rest of the SHI^{RUEs}. However, several investigations [87,88] point out that neighborhoods that have both certifications (such as the systems responsible for labeling the neighborhoods of the MICs) were not fully engaged with sustainable practices, especially in the case of social and affordable housing.

The SHMCI^{RUEs} Considered by All SHRSs

Only two SHMCI^{RUEs} are considered by all SHRSs: "public transport accessibility" and "proximity to amenities." This indicates that even though the criteria among the systems varied concerning the needs of each country or region, these two indicators had universal applicability among the SHRSs. In these indicators, there were significant differences in the percentile ranges of the influence that each system considered in its evaluation methodology (Figure 11).

Except for LEED, CASA, and Green Homes, the other SHRSs considered that "public transport accessibility" is an indicator that generates better sustainable conditions for housing, because this indicator had more significant influence percentages (Figure 12); in LEED, the rates between both indicators were equivalent, while CASA and Green Homes valued the inclusion of this indicator among the amenities of an SFH. On the other hand, each system's conception of the compliance criteria also varied significantly between the systems (Tables 6 and 7).

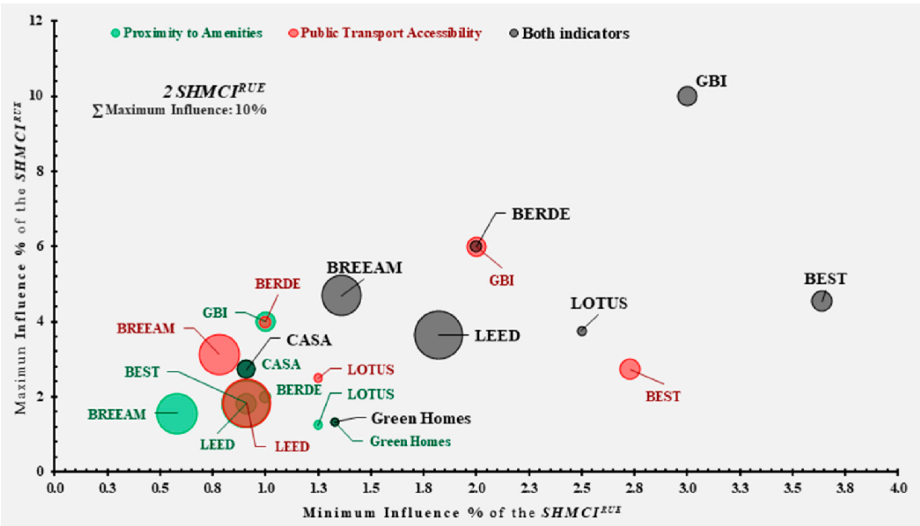


Figure 12. SHMCI^{RUEs} considered by all SHRSs. The size of the points corresponds to the sum of the GNI per capita [81] of the countries in which the systems were developed.

One of the principal hypotheses that motivated this study was that it is necessary to view housing as an essential part in the development of communities [89]. In order to achieve a residential sector that contributes to increasing the livability of cities and to fit this hypothesis in the MICs, one of the main steps is that the process of urban planning and decision-making needs to establish a cross-relation between the availability of their amenities [90] and their public transport [34,91]. All the SHRSs understand the above, given that all consider the proximity of urban amenities and public transport to the house (Table 7). Nevertheless, the definition and compliance criteria of both indicators are extremely different in each of the SHRSs. Future research could focus on the description of which facilities and types of public transport, as well as their quantity, connectivity, and accessibility, are essential for consideration in a sustainable house. Additionally, the analysis of the inclusion of these indicators and their possible implications in obligatory-criteria assessment could be a significant step in assimilating sustainability into the cities of the MICs.

Table 6. Description of the "public transport accessibility" indicator.

Considered by:	Influence (%)	The Influence Percentage Is Obtained When the Urban Environment:
BREEAM	0.78–3.13	Has a public transport accessibility index (AI) for the assessed SFH ≥ 0.5, 1, 2, or 4.
LEED	0.91–1.82	Has a bus or streetcar stop within 400 m walking distance from the SFH or bus rapid transit stops, light or heavy rail stations, or ferry terminals within 800 m walking distance. With a transit service that meets the minimum daily transit service for projects with multiple transit types; weekday trips = 72, 144, or 360; weekend trips = 40, 108, or 216; or minimum daily transit service for projects with commuter rail or ferry service only: weekday trips = 24, 40, or 60.
BEST	2.73	Has a public transportation point within 500 m from the SFH.
GBI	2.00–6.00	Has public transport stop with one route within 500 m from the SFH; and/or has public transport interchange with same mode of transport with more than one route, within 750 m from the SFH; and/or has a public transport interchange with more than one mode of transport (e.g., bus, monorail, train, ferry, etc.), within 1 km from the SFH.
BERDE	1.00–4.00	Has one or two public transport services: existing or currently planned funded commuter rail or light rail within 500 m walking distance; a bus stop for at least two public, campus, or private bus lines within 500 m walking distance; stop for at least two Asian utility vehicle (AUV) or public utility vehicle (PUV) routes within 250 m walking distance; shuttle service provided for the users from the SFH to any public transportation stops or stations; and/or has one or two appropriate transport amenities, which may include: covered walkways connecting the building entrances to transport waiting areas, covered waiting areas for public utility vehicle (PUV), terminals for PUVs and Asian utility vehicles (AUVs), and stations for public transportation routes accessible to the users of the project.
LOTUS	1.25–2.50	Has a mass transit services within 400 or 800 m from the SFH.

References: [66–69,71,73].

Table 7. Description of the "proximity to amenities" indicator.

Considered by:	Influence (%)	The Influence Percentage Is Obtained When the Urban Environment:
BREEAM	0.58–1.56	Provides at least four amenities in a proximity of 500 m from the SFH; and/or provides at least seven amenities in a proximity of 1000 m to the SFH.
LEED	0.91–1.82	Has 4–7, 8–11, or more than 12 uses within an 800 m walking distance from the building entrance.
BEST	0.91–1.82	Has at least four or eight facilities within a 500 m walking distance.
CASA	0.91–2.73	Has 4, 7, or 11 basic community resources within 500 m; and/or has 7, 11, or 14 basic community resources within 1 km; and/or has transport services with at least 30, 60, or 125 trips per day of the week within 1 km from the SFH.
GBI	1.00–4.00	Has three or six amenities within 750 m from the SFH; and/or has another three or six different amenities within 750 m from the SFH.
BERDE	1.00–2.00	Has 5–9 or 10 key establishments, within a 250-meter radius from the SFH.
Green Homes	1.33	Has at least five basic house-hold amenities within a walking distance of 1 km from the SFH.
LOTUS	1.25	Has at least five different types of basic services within a 0.5 km radius from the SFH.

References: [66–73].

Exclusive $SHMCI^{RUEs}$ between the SHRSs

Among the indicators found, 16 of the 37 $SHMCI^{RUEs}$ were exclusive to LEED, BREEAM, GBI, or LOTUS (Figure 13), where BREEAM had higher quantities and LOTUS had the highest percentage of influence (8.75%). Moreover, "compact development" was the indicator that had the highest influence ranges; however, its consideration among MICs should be carefully considered. Hodson et al. [92] show different points of view within the scientific field for the consideration of this indicator.

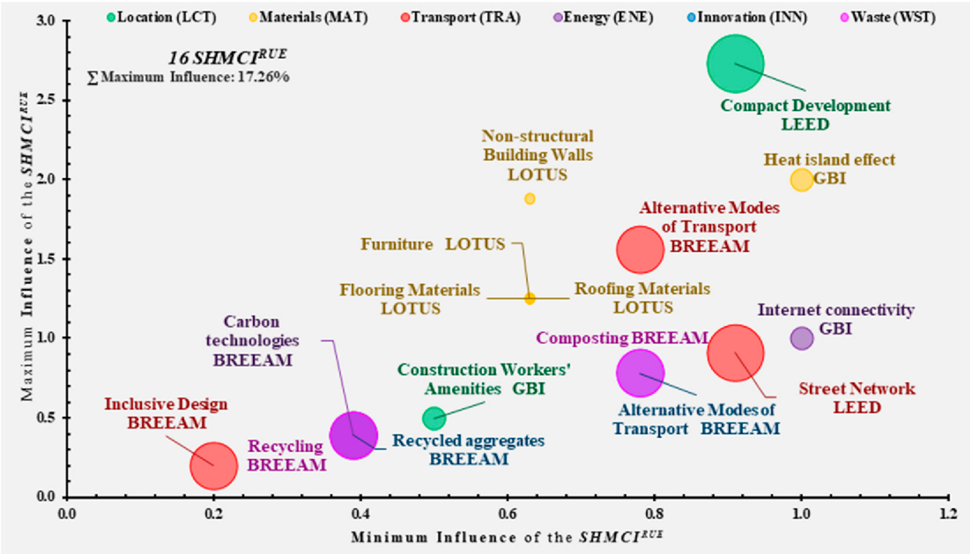


Figure 13. Exclusive SHMCI^{RUEs} identified. The size of the points corresponds to the sum of the GNI per capita [81] of the countries in which the systems were developed.

Table 8 shows the description of every SHIMCI^{RUE}. Similarly, in the case of indicators 3 and 14, it is notable that they have the same name, but were considered separately, because BREEAM performs this same differentiation based on the rigor established between their compliance criteria [67]. Finally, any of these indicators could be accepted as innovation criteria in any system that uses this category, such as LEED and CASA [69,70].

Table 8. Description of the exclusive SHMCI^{RUEs} between the SHRSs.

Indicator	NMA: Influence (%)	The Influence Percentage Is Obtained When the Urban Environment:
1. Carbon Technologies	ENE: 0.39	Has the infrastructure to provide low- or zero-carbon energy sources for the SFH.
2. Internet Connectivity	ENE: 1.00	Has infrastructure with access to internet service.
3. Alternative Modes of Transport	INN: 0.78	Has two of the following options or alternative modes of transport: communal car-club, electric recharging stations, or cycle storage spaces.
4. Recycled Aggregates	INN: 0.39	Has the infrastructure for transporting recycled or secondary aggregate, with a distance lower than 30 km by road transport to the housing unit.
5. Compact Development	LCT: 0.91–2.73	Has a DU/hectare of buildable land ≥ 17, 30, or 50.
6. Construction Workers' Amenities	LCT: 0.50	Has accommodation for construction workers and has adequate health and hygiene facilities for workers.
7. Heat Island Effect	MAT: 1.00–2.00	Provides any combination of the following strategies for 50% or 75% of the site hardscape (including sidewalks, courtyards, plazas, and parking lots): shade (within 5 years of occupancy), and/or paving materials with a solar reflectance index (SRI) of at least 29, and/or an open grid pavement system.
8. Non-Structural Building Walls	MAT: 0.63–1.88	Has infrastructure to extract, harvest, and manufacture 40%, 60%, or 80% of the non-structural walls of the SFH.

Table 8. *Cont.*

Indicator	NMA: Influence (%)	The Influence Percentage Is Obtained When the Urban Environment:
9. Flooring Materials	MAT: 0.63–1.25	Has infrastructure to extract, harvest, and manufacture 40% or 80% of flooring materials of the SFH.
10. Roofing Materials	MAT: 0.63–1.25	Has infrastructure to extract, harvest and manufacture 40% or 80% of roofing materials of the SFH.
11. Furniture	MAT: 0.63–1.25	Has infrastructure to extract, harvest, and manufacture 25% or 50% of all furniture items of the SFH.
12. Inclusive Design	TRA: 0.20	Has communal or shared parking with spaces with a width of 3300 mm and maintains the distance from the public parking space to the dwelling entrance of ??? as a minimum, and is level or gently sloping.
13. Street Network	TRA: 0.91	Has high intersection density, defined as an area whose existing streets and sidewalks create at least 90 intersections per square kilometer.
14. Alternative Modes of Transport	TRA: 0.78–1.56	Has a communal-car club, where the members share the use of a locally based fleet of vehicles, and/or provides electric recharging stations for the SFH occupants (Table 35 in [67]).
15. Composting	WST: 0.78	Has an accessible local communal or community composting service, run by either a local authority or a private organization; or has a management plan, which is in place to ensure food or green waste is appropriately removed and delivered to an alternative composting facility; or has a local authority, private organization, or green/kitchen waste collection system.
16. Recycling	WST: 0.39	Has an established recyclable waste collection scheme.

References: [67,69,71,73].

The SHMCI^{RUE} Considered by Two SHRSs

A total of 35% of the indicators were obtained from the relationship between two SHRSs (Figure 14). Of these indicators, only three come from systems developed in an MIC, of which, the "construction noise" indicator, considered by BEST and LOTUS, can be counterproductive regarding increased social responsibility in the houses, because the fulfillment of this would mean that the house is located at a large distance from any public amenity.

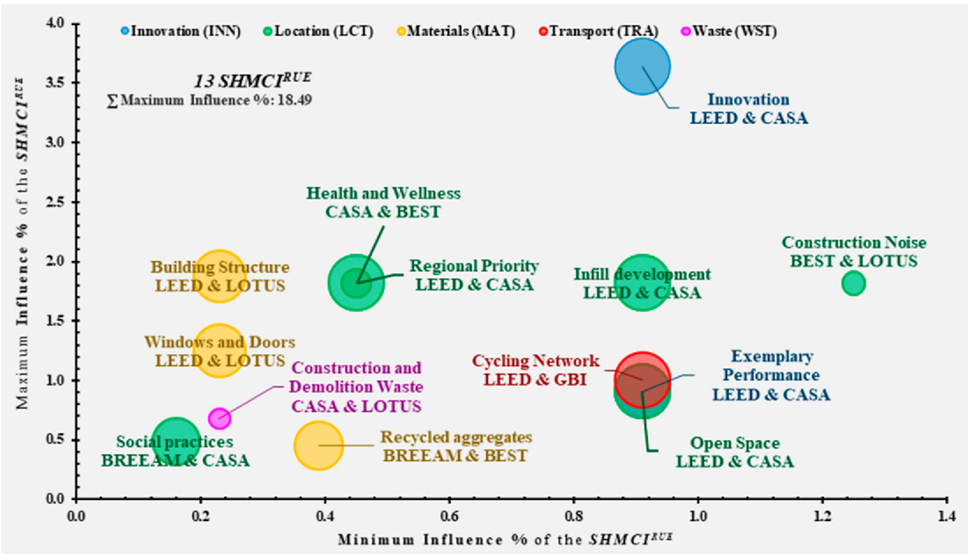


Figure 14. SHMCI^{RUEs} considered by two SHRSs. The size of the points corresponds to the sum of the GNI per capita [81] of the countries in which the systems were developed.

Table 9 shows that, for the majority of the time, the systems that were more rigorous in terms of the compliance criteria corresponded to those that were developed in the country with the highest income level. The description of each indicator, as well as the established relationships, are provided in the Appendix A.

Table 9. SHMCI^{RUEs} considered by two SHRSs.

Indicator	Considered by: Influence (%)	Variations	Most Rigorous
1. Innovation	LEED: 0.91, CASA: 0.91–3.64	1	LEED and CASA
2. Exemplary Performance	LEED: 0.91, CASA: 0.91	1	LEED and CASA
3. Social Practices	BREEAM: 0.16–0.49, CASA: 0.16–0.45	2	BREEAM
4. Infill Development	LEED: 1.82, CASA: 0.91–1.82	2	LEED
5. Open Space	LEED: 0.91, CASA: 0.91	2	LEED
6. Regional Priority	LEED: 0.91–1.82, CASA: 0.45	2	LEED
7. Construction Noise	BEST: 1.82, LOTUS: 1.25	2	LOTUS
8. Health and Wellness	CASA: 0.45, BEST: 1.82	2	BEST
9. Recycled Aggregates	BREEAM: 0.39, BEST: 0.45	2	BEST
10. Building Structure	LEED: 0.23–0.68, LOTUS: 0.63–1.88	2	LOTUS
11. Windows and Doors	LEED: 0.23–0.68, LOTUS: 0.63–1.25	2	LOTUS
12. Cycling Network	LEED: 0.91, GBI: 1.00–2.00	2	LEED
13. Construction and Demolition Waste	CASA: 0.23–0.68, LOTUS: 0.50	2	CASA

References: [67–70,73].

The SHMCI^{RUEs} Considered by Three and Five SHRSs

According to Dall'O' et al. [93], "The major causes of environmental impacts in urban areas can be linked to local traffic patterns." Additionally, although recent studies [94,95] have demonstrated the importance of developing an environment that favors pedestrian mobility in the RUE, only BEST, CASA, and GBI establish this criterion as an important issue (Figure 15). However, their relative characteristics for consideration only deal with specific cases of determined routes followed by users, and so walkability is not considered in the general environs of the SFH.

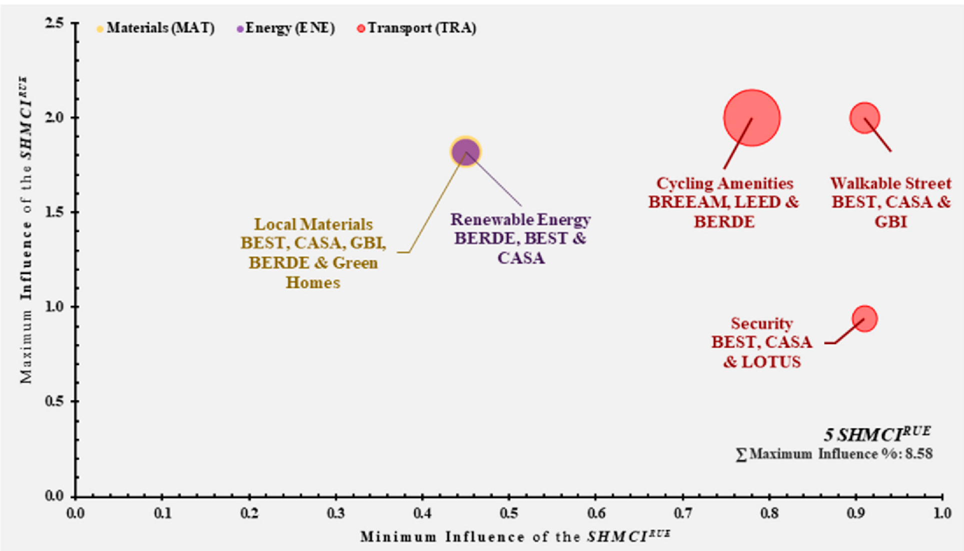


Figure 15. SHMCI^{RUEs} considered by three and five SHRSs. The size of the points corresponds to the sum of the GNI per capita [81] of the countries in which the systems were developed.

Among the SHRSs, CASA has the most standardized indicators in the industry of global construction, given that it possesses most of the indicators that have relations between two or more systems (Tables 9 and 10). On the other hand, the indicators "local materials," "renewable energy," and "security," are only considered by systems developed in MICs; therefore, a more in-depth study in terms of these would be interesting in order to understand the implications they could have on the systems developed by an HIC. The description of each indicator, as well as the established relationships, are provided in the appendices.

Table 10. SHMCI^{RUEs} considered by three and five SHRSs.

Indicator	Considered by: Influence (%)	Variations	Most Rigorous	Least Rigorous
1. Renewable Energy	BEST: 0.45–1.36, CASA: 0.45–1.82, BERDE: 1.00	2	BEST and CASA	BERDE
2. Local Materials	BEST: 0.91–1.82, CASA: 0.45%, GBI: 0.50–1.00, BERDE: 0.50–1.50, Green Homes: 0.67–1.33	5	BEST	Green Homes
3. Cycling Amenities	BREEAM: 0.78–1.56, LEED: 0.91, BERDE: 1.00–2.00	2	BERDE	BREEAM
4. Security	BEST: 0.91-1.82, CASA: 0.91–1.82, LOTUS: 0.94	2	BEST	CASA
5. Walkable Street	BEST: 0.91, CASA: 0.91–1.82, GBI: 1.00–2.00	2	LEED	CASA

References: [66–73].

4. Conclusions

This paper has provided 39 indicators (SHI^{RUEs}) for assimilating sustainability into the cities of MICs by means of the RUE recognized by the SHRSs. The study provides an image of the current situation regarding how the SHRSs consider the influence of the RUE surrounding the SFH to determine the final label of a dwelling considered as sustainable, as well as the similarities and differences between the systems analyzed (BREEAM, LEED, BEST, CASA, GBI, BERDE, Green Homes, and LOTUS).

The main findings of this work have shown that the percentages of maximum influence obtained in the multi-criteria assessment and the lack of consideration of SHOCI^{RUEs} in seven of the eight systems make certified sustainable housing possible; in which the urban environment does not meet the requirements to contribute to the sustainable development of the cities. This implies a bleak perspective for the objectives decided upon by the different countries in the new urban agenda, and also justifies the proposals of UN-Habitat III, which refers to the urgent need for different bodies (in the public and private sector) to collaborate to establish guidelines that will clarify the qualities necessary for a RUE to be considered sustainable.

The results indicate that deciding on a possible global homologation or standardization of the RUE's inherent qualities in SFH is complex and will only be realized in the long-term. Although each system has its own conception of how the urban environment impacts the labeling of housing and its maximum influence on the score, carrying out the NCP allowed the identified indicators to be clustered into six new macro-areas: LCT, TRA, and MAT being the most important, with ENE, INN, and WST making up the rest.

The relationships among the SHRSs developed by a country with a specific income level shows that those developed in a HIC (LEED and BREEAM) had a higher number of requirements than those systems developed by an MIC and, in general, were more rigorous in terms of their compliance criteria. Consequently, this had a more significant effect on improving the urban environment. However, the rating systems developed by an MIC, such as CASA, GBI, and LOTUS, also have exclusive indicators, which could be applied in the systems developed by a HIC.

On the other hand, this study also shows the lack of interest on the part of the academic sector in analyzing the SHRSs that are developed by the UMC and LMC countries. However, the methods developed show that, although several studies state that BREEAM and LEED were the most widely recognized by the construction industry and academic sector, it was also essential to consider other

SHRSs in the comparative analyses conducted to provide results in the MICs in order to acquire results that better match the specific features of these countries.

The use of the SHI^{RUEs} identified can also have significant repercussions on the policies of the MICs because many of these countries base their urban guidelines on what is established by the rating systems. Therefore, it is expected that the identification of the two SHOCI^{RUEs} and the 37 SHMCI^{RUEs} could provide a variety of real and proven instruments, which will enable sustainable urban habitats to be obtained through the construction or evaluation of the SFH.

One of the main limitations of this work is that the view of the current situation of the RUE characteristics by the SHRSs cannot be considered complete, as a study of the scores obtained by real cases is missing. Moreover, some concerns were raised regarding the identified SHI^{RUEs} during the discussion of the results, indicating the need for further investigation. Finally, the NCP carried out in this study has shown that there are criteria among the indicators that can be included in a different NMA as an exclusive indicator. Therefore, a more in-depth analysis of each criterion (or possibly a segregation of each) could lead to a more dynamic and effective understanding of the RUE, as well as the value that each SHRS gives to the requirements of each indicator.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

ENE	Energy
HIC	High-Income Country
INN	Innovation
LCT	Location
LMC	Lower-Middle-Income Country
MAT	Materials
MCI	Multi-Criteria Indicators
MIC	Middle-Income Country
NCP	Normalization Criteria Process
NMA	New Macro Area
OCI	Obligatory-Criteria Indicator
RUE	Residential Urban Environment
SFH	Single-Family Housing
SHI^{RUE}	SFH Indicator that focuses on the RUE
SHMCI^{RUE}	SFH Multi-Criteria Indicator that focuses on the RUE
SHOCI^{RUE}	SFH Obligatory-Criteria Indicator that focuses on the RUE
SHRS	Single-Family Housing Rating System
TRA	Transport
UMC	Upper-Middle-Income Country
WST	Waste

Appendix A

Figure A1. Relationships among the SHI^{RUEs} according to energy (ENE), innovation (INN), and waste (WST).

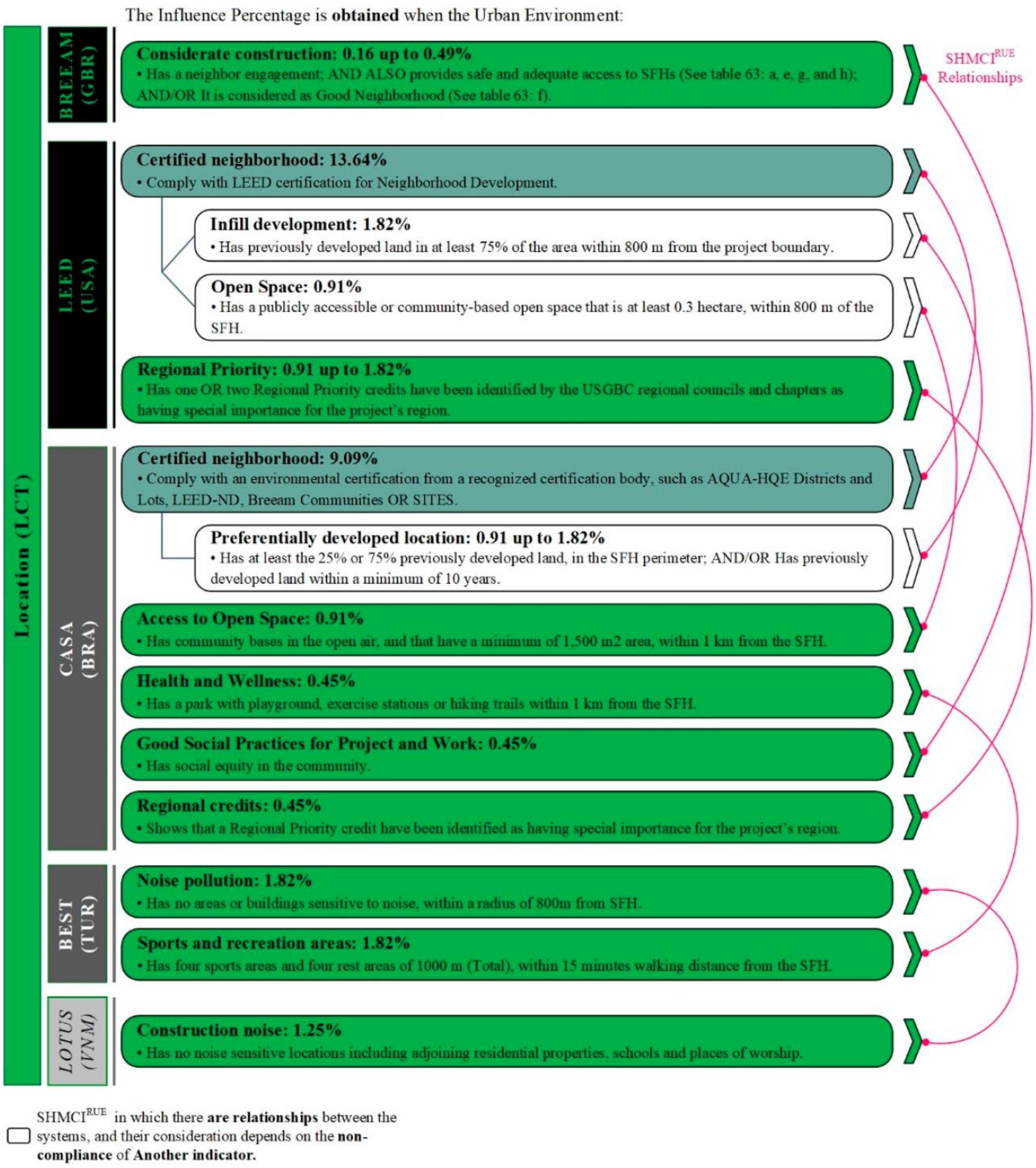

Figure A2. Relationships among the SHI^{RUEs} according to location (LCT).

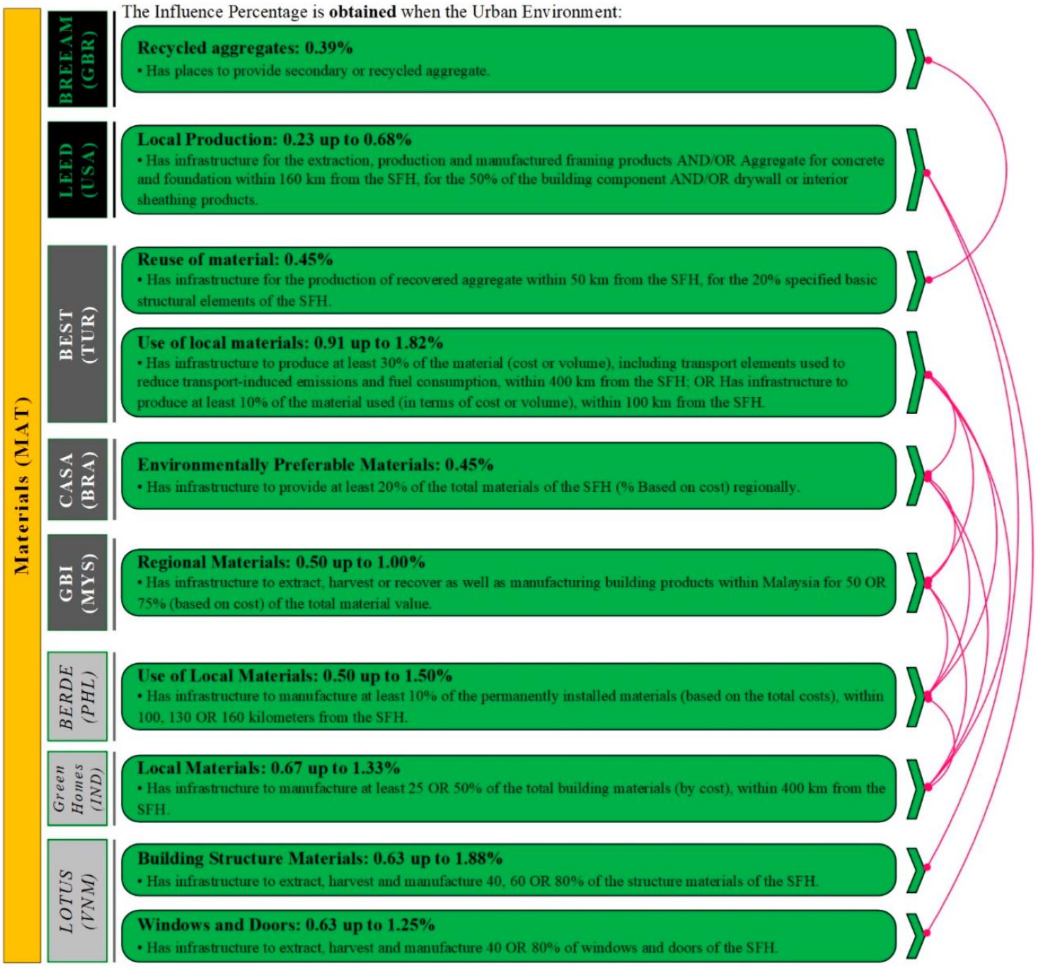

Figure A3. Relationships among the SHI^{RUEs} according to materials (MAT).

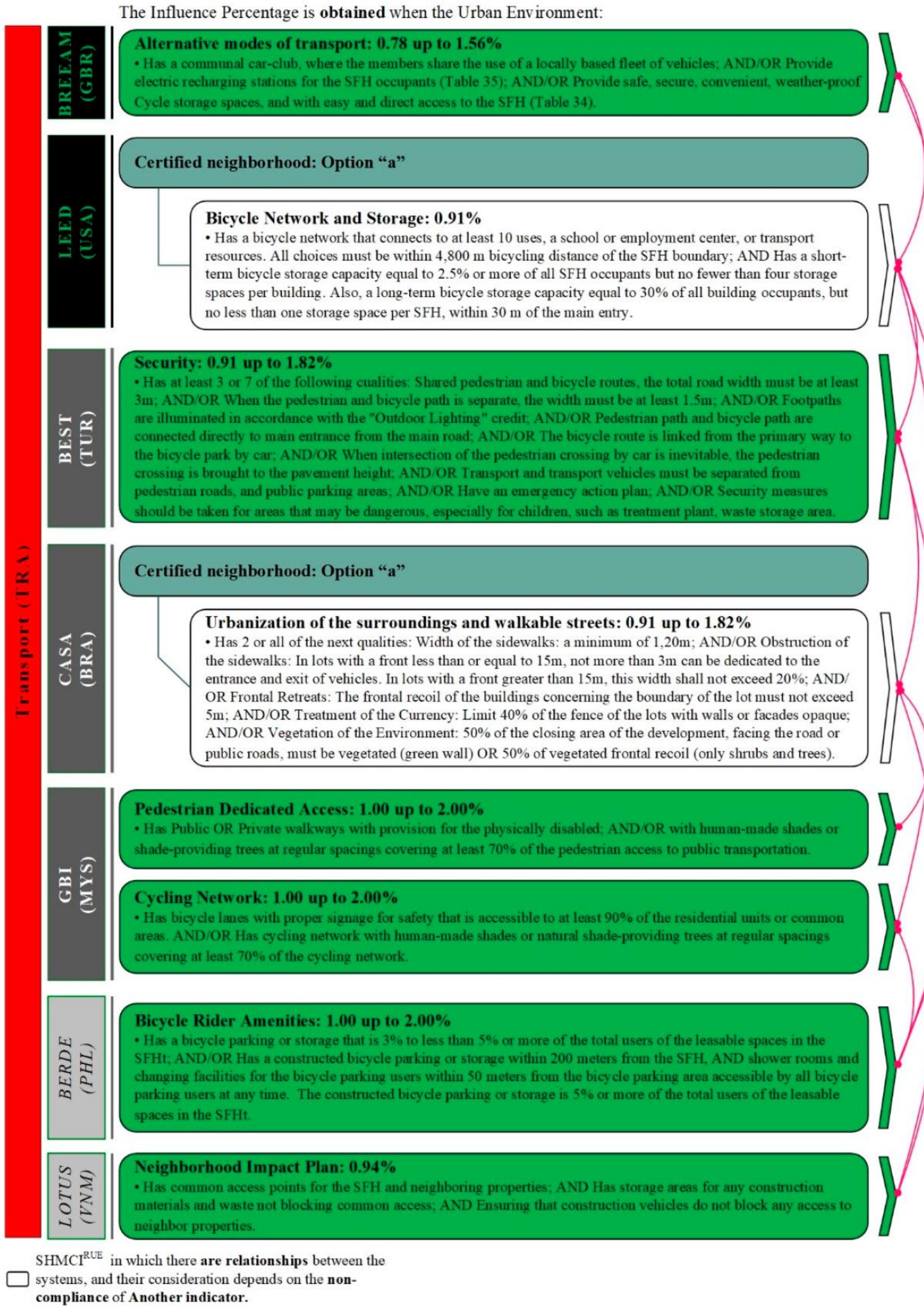

Figure A4. Relationships among the SHI^{RUEs} according to the Transport (TRA).

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CAPÍTULO V

CONCLUSIONES E INVESTIGACIÓN FUTURA

"Yo creo que todavía no es demasiado tarde para construer una utopia que nos permita compartir la tierra" ***—Gabriel García Márquez—***

Capítulo V

Conclusiones e investigación futura.

El objetivo principal de esta tesis fue el de obtener una aproximación que permita esclarecer el cuestionamiento sobre si el uso de los SESV coadyuva a la obtención de ciudades sostenibles, y al mismo tiempo, se buscó auxiliar en la consecución de una evaluación más robusta de la sostenibilidad de la vivienda, así como en el logro de una comprensión más amplia de los problemas conocidos en los sistemas actuales de evaluación.

Si bien, los resultados obtenidos sugieren que el uso de los SESV efectivamente contribuye a incrementar el nivel de sostenibilidad de las ciudades, también exhiben que los sistemas de evaluación poseen un sesgo significativo en lo referente a la ponderación que se asigna a los indicadores que buscan la obtención de una eficiencia energética en la vivienda, omitiendo diversas cualidades que pueden contribuir al desarrollo de ciudades sostenibles con la misma repercusión de la obtención de eficiencia energética, o incluso con un impacto superior.

En el presente capítulo, se muestran las conclusiones globales de los artículos expuestos en los capítulos II, III y IV, así como también las líneas de investigación futuras que pueden derivarse a partir del conocimiento generado. En forma transversal, se generaron diversos productos científicos, los cuales, a pesar de no formar parte de este compendio, han contribuido también a la obtención del conocimiento expuesto en el presente documento.

5.1. Conclusiones.

De acuerdo con los artículos expuestos en este documento, los SESV, al igual que se ha especificados por diversos estudios, pueden ser considerados como mecanismos que contribuyen en la mitigación de las emisiones de GEI y en la disminución de las demandas de los recursos necesarios para el funcionamiento de las viviendas. Sin embargo, si la visión del concepto de sostenibilidad en la vivienda, se expande hacia una escala de mayor alcance, en la que se pretenda contribuir en la obtención de ciudades sostenibles, se demuestra que aún existen brechas y vacíos en las metodologías de los SESV con mayor uso y difusión en la industria de la construcción, los cuales deben de ser abordados en los próximos años con la finalidad de asegurar que su uso en el sector residencial, contribuye verdaderamente en la obtención de ciudades sostenibles.

Por otra parte, los resultados expuestos en los artículos que constituyen esta tesis, respaldan lo señalado en 2015 por Abdellatif et al. [1], "vivir espacios y puntos de encuentro para las comunidades debe formar parte de la función de un edificio, así como garantizar un confort en la vivienda." Por lo que se considera que las características urbanas en las que se sitúa una determinada vivienda, deben de ser cualidades intrínsecas a la visión de cualquier involucrado en la configuración de los sistemas que evalúan el concepto de sostenibilidad en la vivienda.

En el artículo "The Passivhaus Standard in the Mediterranean Climate: Evaluation, Comparison and Profitability." [2] Los resultados señalaron que una casa adosada, que cumple con las características convencionales de construcción en el clima mediterráneo del ámbito español; requiere un aumento del presupuesto final de solo el 8.65% para obtener la certificación Passivhaus. Sin embargo, con un aumento de costos del 14,65%, las emisiones de CO_2 pueden reducirse hasta en un 63% y la demanda de energía primaria puede reducirse en un 66%.

Del mismo modo, el estudio también muestra que el uso del estándar Passivhaus es rentable, ya que las propuestas de diseño para el cumplimiento del estándar presentaron una rentabilidad entre el noveno y duodécimo año. Sin embargo, entre los resultados obtenidos, se encontró que los indicadores utilizados en el cálculo se enfocan en las características exclusivas del edificio, sin considerar la escala urbana; por lo que, su contribución en el incremento de la calidad del espacio público de la ciudad es mínimo, o incluso se puede considerar inexistente.

Lo señalado en el párrafo anterior, sugiere que el uso del estándar se complemente con otro mecanismo de evaluación que si tenga como objetivo el de acrecentar las cualidades del entorno urbano en el que se sitúa una determinada vivienda, con el fin de que la vivienda pueda ser considerada como sostenible, en un sentido más holístico e integrador, y por consiguiente, contribuya a la obtención de ciudades sostenibles de una forma más significativa, de lo que representa el estado actual de su metodología.

Diversos estudios [3-5] señalan la importancia de considerar el entorno urbano en el que se sitúan las viviendas entre los SESV. Los estudios han demostrado que las viviendas sin un entorno urbano que no pueden satisfacer las necesidades básicas de los habitantes, emitirán más GEI, independientemente de que la vivienda tenga cuente con algún etiquetado o certificación ambiental. En México, el programa de financiación para soluciones habitacionales, puede considerarse como un SESV que prioriza las características del entorno urbano, sobre las características propias de los edificios, debido a la metodología con la que se definen los subsidios otorgados por el gobierno. En este programa, se enfocó el segundo artículo que constituye el presente compendio: "Sustainable social housing: The comparison of the Mexican funding program for housing solutions and building sustainability rating systems." [6] Entre los principales resultados obtenidos, se encontró que priorizar las características relacionadas con el entorno urbano en la ponderación de los indicadores, puede representar un nuevo paradigma para evaluar la vivienda social. Siendo esto fundamental en el caso de los países de ingresos medios, donde existe una necesidad prioritaria de mejorar el hábitat urbano de los desarrollos que poseen esta tipología de vivienda [7-12].

En el análisis específico de la relación entre vivienda y su entorno urbano, el tercer artículo "Housing Indicators for Sustainable Cities in Middle-Income Countries through the Residential Urban Environment Recognized Using Single-Family Housing Rating Systems." [13] Da a conocer que, si bien entre la mayoría de los SESV —que poseen un enfoque cualitativo— se consideran indicadores que toman en cuenta las características externas a las viviendas, sólo el transporte público y los servicios urbanos son considerados con aplicación internacional, al ser contemplados por todos los sistemas analizados. Sin embargo, ninguno de éstos sistemas, ni de los analizados en los artículos de los capítulos II y III, considera que estas características deben de constituir a las cualidades de sostenibilidad intrínsecas en las viviendas, ya que en ningún modelo de evaluación los toma en cuenta entre sus indicadores de cumplimiento con carácter obligatorio. Asimismo, cualidades como accesibilidad, seguridad, transporte no motorizado, diseño del paisaje urbano, entre otras, pasan prácticamente desapercibidas por la mayoría de los SESV.

En otro orden de ideas, la falta de interés en el sector académico hacia los SESV elaborados por los países en desarrollo ha quedado manifiesta en los procesos de selección de los artículos realizados. El déficit que se presenta en el número de artículos elaborados en los que se analizan dichos sistemas es preocupante, debido a que su estudio, y su comparación con los estándares más utilizados por la industria de la construcción en el ámbito internacional, son dos acciones que permitirán que exista una mejora continua en la calidad de sus indicadores, y, por consecuencia, en la calidad de las viviendas que se construyan mediante los modelos establecidos en éstos sistemas. Por ejemplo, en el caso particular del capítulo III: a pesar de que la metodología establecida por el programa de subsidios Mexicano se puede considerar como un modelo a seguir por los demás países con características similares a México, la comparativa realizada con los demás SESV, permitió identificar las deficiencias que presenta el paradigma mexicano de vivienda social en cuanto los criterios utilizados en sus indicadores, los cuales se encuentran muy por debajo de los criterios establecidos por los SESV con mayor difusión en el ámbito internacional.

La importancia de los artículos publicados también radica en que cada uno de éstos presenta indicadores que pueden ser considerados por la plétora existente de sistemas de evaluación, con la finalidad de poder establecer características o áreas de interés comunes, ya que existen enormes diferencias entre los distintos sistemas evaluados, incluso, entre los que consideran áreas de evaluación similares; la ponderación o los criterios de cumplimiento implícitos en cada uno de los indicadores suelen diferir en demasía entre los distintos sistemas.

El presente documento permite obtener una comprensión más amplia de la relación inherente entre la vivienda y la ciudad, y expone la necesidad de considerar esta relación en los modelos metodológicos de los SESV, con la finalidad de conseguir una evaluación más holística, que permita calcular la sostenibilidad de las viviendas en un concepto más robusto de como se considera en la actualidad. Por otra parte, las metodologías empleadas en cada uno de los artículos, son extrapolables a otros entornos, de manera que pueden servir como guía para aumentar las competencias en esta área del conocimiento.

Finalmente, con el entendido de que las ciudades representan oportunidades para enriquecer tanto la ecología como la ciencia del cambio global [14], y se consideran lugares críticos para crear futuros más sostenibles [15]. Es que este compendio pretende facilitar los hallazgos que promueven la sostenibilidad urbana a través de la construcción y evaluación del parque de viviendas nuevos y existentes, que faciliten la cristalización del convencimiento de que la vivienda puede significar la vía hacia la obtención de ciudades sostenibles. Los resultados expuestos, procuran ser de utilidad para el sector de la construcción, así como también para los organismos encargados del desarrollo y gestión de las ciudades, y de los mismos sistemas de evaluación. Asimismo, se pretende que funjan como base para el establecimiento de nuevas teorías o paradigmas en la epistemología de diseño o evaluación de la vivienda.

5.2. Investigación futura.

Durante la elaboración de la pesquisa, y en paralelo a la consecución del objetivo general, se identificaron algunas brechas y vacíos existentes entre los sistemas analizados, así como diversos hallazgos que permiten exponer las bases referentes a nuevas líneas de investigación.

En el capítulo II, los resultados que aseguran que la utilización del estándar en climas húmedos o cálidos es factible —los cuales se presentan en sintonía de otras investigaciones—, sugieren que el análisis realizado en el estándar Passivhaus, y la falta de indicadores relativos a la evaluación del entorno urbano en el que se ubican las viviendas, podría significar una aportación novedosa, mediante la elaboración de una propuesta que incorpore la evaluación de las cualidades del entorno urbano que rodea a una determinada vivienda. Dicha propuesta, podría sustentarse en la metodología correspondiente al análisis de ciclo de vida (ACV).

El capítulo III, señala que la investigación futura podría centrarse en el análisis de un estudio más significativo de SESV desarrollados por países de ingresos medios, lo que permitiría obtener mejores argumentos para sacar conclusiones relevantes sobre las diferencias en la conceptualización de la definición de sostenibilidad que tienen los diferentes países. Del mismo modo, sería interesante analizar entre un universo de sistemas más extenso, y con una variedad más significativa de contextos diferentes: todos aquellos indicadores considerados como obligatorios, con la finalidad de establecer en un futuro criterios internacionales, que facilite la estandarización de los mismos.

Por otra parte, y, enfatizando el contexto de los casos de estudio (México). Se sugiere que las próximas líneas de investigación profundicen en las áreas relacionadas con materiales, energía, confort interior y gestión de la construcción y el edificio, con la finalidad de incrementar el abanico de opciones relativas al sector residencial del contexto mexicano.

En el capítulo IV, se señaló que los 39 indicadores que consideran las cualidades del entorno urbano en las viviendas unifamiliares se identificaron basándose en el análisis exclusivo de las metodologías de cada uno de los SESV evaluados, por lo que falta un estudio en casos reales, que permita corroborar la identificación y relevancia de cada uno de los indicadores. Asimismo, el proceso de normalización de criterios llevado a cabo en este estudio ha demostrado que existen criterios entre los indicadores que pueden incluirse en un área o clasificación distinta a la que se incluyó en el presente estudio, pero considerándose como indicador exclusivo. Por lo tanto, un análisis más profundo de cada criterio —o posiblemente la segregación de cada uno— podría conducir a una comprensión más dinámica y efectiva del entorno urbano residencial característico de las viviendas unifamiliares, así como de las ponderaciones que cada SESV otorga a los requisitos de cada indicador.

El estudio realizado en el capítulo IV, también se puede extrapolar a otras tipologías de vivienda, y se puede realizar considerando una gama más amplia de sistemas de evaluación, con la finalidad de establecer conclusiones más generales que abarquen el parque habitacional total existente, por lo que bien puede considerarse como una nueva línea de investigación.

Entre las líneas de investigación señaladas, y que se están abordando en la actualidad como producto de lo realizado a lo largo del doctorado, se encuentra la propuesta de un cambio en la epistemología del diseño de la vivienda social de los países clasificados como países de ingresos medios; esta propuesta se fundamenta en configurar la vivienda priorizando las cualidades existentes en el entorno urbano del que se sitúa, para posteriormente atender las cuestiones que tienen que ver con la estructura del edificio y las características del terreno de uso exclusivo por los habitantes de estas. Se prevé que la publicación resultante de esta línea se realice el próximo año.

5.3. Productos transversales a este compendio.

Paralelo a la realización de los artículos expuestos en este compendio, la investigación desarrollada en el transcurso del doctorado generó otros productos académicos, los cuales se detallan a continuación.

5.3.1. Artículos publicados.

- Gómez-Soberón, J.M., Saldaña-Márquez, H., Gámez-García, D.C., Gómez-Soberón, M.C., Arredondo-Rea, S.P., Corral-Higuera, R. 2016. "A Comparative Study of Indoor Pavements Waste Generation During Construction through Simulation Tool." ***International Journal of Sustainable Energy Development***. 5 (1): 243–251. doi:10.20533/ijsed.2046.3707.2016.0032.
- Gámez-García, D.C., Saldaña-Márquez, H., Gómez-Soberón, J. M., Corral-Higuera, R. 2017. "Estudio de factibilidad y caracterización de áridos para hormigón estructural." ***Ingeniería y Desarrollo***. 35 (2): 283–304. http://dx.doi.org/10.14482/inde.35.2.10162.
- Gámez-García, D.C., Gómez-Soberón, J.M., Corral-Higuera, R., Saldaña-Márquez, H., Gómez-Soberón, M.C., Arredondo-Rea, S.P., Gámez-García, D.C. 2018. "A Cradle to Handover Life Cycle Assessment of External Walls: Choice of Materials and Prognosis of Elements." ***Sustainability***. 10: 2748. doi:10.3390/su10082748.
- Gámez-García, D.C., Saldaña-Márquez, H., Gómez-Soberón, J. M., Corral-Higuera, R., Arredondo-Rea, S. P. 2019. "Life Cycle Assessment of residential streets from the perspective of favoring the human scale and reducing motorized traffic flow. From cradle to handover approach." ***Sustainable Cities and Society***. 44: 332–342. doi:10.1016/j.scs.2018.10.018.
- Gámez-García, D.C., Saldaña-Márquez, H., Gómez-Soberón, J.M., Arredondo-Rea, S. P., Gómez-Soberón, M. C., Corral-Higuera, R. 2019. "Environmental Challenges in the Residential Sector: Life Cycle Assessment of Mexican Social Housing." ***Energies***. 12: 2837. doi:10.3390/en12142837.

5.3.2. Presentaciones en congresos internacionales y workshop.

- 2do Congreso internacional de Ciencias de la Ingeniería, en Los Mochis, México. Noviembre, 2015.
- World Congress on Sustainable Technologies, en Londres, Reino Unido. Diciembre, 2016.
- 14th International Conference on Urban Health, en Coimbra, Portugal. Septiembre 2017.
- 1st Workshop esLCA. Life cycle management in the sectors of construction and energy, en Madrid, España. Junio, 2016.

5.3.3. *Otros indicadores colaterales de investigación.*

- Revisión de Artículos (17): Journal of Cleaner Production (Indexada en JCR; Q1). Actualmente el doctorando posee el estaus de "Outstanding reviewer", por parte de la revista.
- Integrante del Grupo Interdisciplinar de Ciencia y Tecnología en Edificación (GICITED), desde 2015.

5.4. Referencias.

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ANEXOS

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A Cradle to Handover Life Cycle Assessment of External Walls: Choice of Materials and Prognosis of Elements

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Abstract: This research focuses on a comparison of 20 external wall systems that are conventionally used in Spanish residential buildings, from a perspective based on the product and construction process stages of the life cycle assessment. The primary objective is to provide data that allow knowing the environmental behavior of walls built with materials and practices conventionally. This type of analysis will enable promoting the creation of regulations that encourage the use of combinations of materials that generate the most environmentally suitable result, and in turn, contribute to the strengthening of the embodied stages study of buildings and their elements. The results indicate that the greatest impact arises in the product stage (90.9%), followed by the transport stage (8.9%) and the construction process stage (<1%). Strategies (such as the use of large-format pieces and the controlled increase in thickness of the thermal insulation) can contribute to reducing the environmental impact; on the contrary, practices such as the use of small-format pieces and laminated plasterboard can increase the environmental burden. The prediction of the environmental behavior (simulation equation) allows these possible impacts to be studied in a fast and simplified way.

Keywords: LCA; cradle to handover; external wall; construction materials; building components; envelope

1. Introduction

The construction industry is responsible for the unsustainable use of natural resources, and is an important source of air, soil, and water pollution [1]. Published data indicate that this sector uses between 30–40% of primary energy worldwide [2], with these figures including the energy required by the buildings [3–5]. The costs of the primary energy consumed by buildings for some countries are 23% in Spain, 39% in the United Kingdom, 47% in Switzerland, 50% in Botswana, 40% in Europe, 25% in Japan, 28% in China, and 42% in Brazil [6]. Most of this energy consumption is due to heating, ventilation, and air conditioning throughout the building's operating life [7–9]. Studies have shown that most of the environmental impacts occur in this phase, representing approximately 80-90% of the total impacts generated in the useful life of the building [8,10–17].

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Life Cycle Assessment of residential streets from the perspective of favoring the human scale and reducing motorized traffic flow. From cradle to handover approach

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ABSTRACT

Currently, few studies have compared the variations in environmental impact throughout the different stages of the life cycle of urban construction elements; and of these, only a minority approach it from the perspective of favoring mobility on a human scale and reducing the space allocated to motorized traffic flow.

This study, by means of quantitative data, shows the environmental implications associated with prioritizing the non-motorized mobility of a city's inhabitants during the design process of an urban construction element, the residential street (referring to the stages of the product and the construction process: the "cradle to handover" approach). An emerging methodology in urban themes was used in order to obtain the environmental analysis: Life Cycle Assessment (LCA).

The results show that the increase in the human scale and the favoring of non-motorized mobility generate a lower environmental impact (considering the same uses of materials for the different zones of analysis). Additionally, it was possible to establish the influence that the specific use of materials employed in the construction of the streets may have, as well as the importance that an LCA acquires in the design of the urban environment.

1. Introduction

The street is one of the principal elements that define the configuration of the urban environment: "Streets lie at the heart of communities, shape human health and environmental quality, and serve as the foundation of urban economies. In many cities, streets make up more than 80% of all public space, and collectively have the potential to foster business activity" (GDCI & NACTO, 2016). Several researchers (Gilderbloom, Riggs, & Meares, 2015; Haider et al., 2018; Kwan & Hashim, 2016; Lindelöw, Svensson, Sternudd, & Johansson, 2014) show the advantages that can accrue from an environment in which the human scale is prioritized during the design process of urban planning.

In recent years, aspects related to the analysis of streets, which favor a pedestrian environment over motorized traffic flow, have been studied and developed. Nevertheless, the majority of studies carried out focus exclusively on the usage stage, neglecting to use integral environmental data from the complete life cycle (Mendoza, Oliver-Solà, Gabarrell, Rieradevall, & Josa, 2012). If used, this data would allow the environmental load produced in the various stages of the life cycle of a specific street to be known from the design process.

Some of the studies which justify the consideration of environmental criteria (Araújo, Oliveira, & Silva, 2014; Loijos, Santero, & Ochsendorf, 2013; Mendoza, Oliver-Solà, Gabarrell, Rieradevall et al., 2012; Noshadravan, Wildnauer, Gregory, & Kirchain, 2013; Oliver-Solà, Josa, Rieradevall, & Gabarrell, 2009) focus on comparisons and the exclusive implications involved in choosing the materials for a specific section of the street (usually sidewalks or travel lanes). However, from the perspective of favoring the human scale and reducing the space allocated to motorized traffic, no evidence has been found about the figures or proportions that show the possible environmental impact of the stages incorporated in the streets.

Therefore, the aim of this work is, using quantitative data, to show the environmental ramifications when priority is given to the inhabitants of a city during the design process of a street (referring to

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Environmental Challenges in the Residential Sector: Life Cycle Assessment of Mexican Social Housing

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Abstract: Social Housing (SH) in Mexico has a potentially important role in reducing both the emission of greenhouse gases and the use of non-renewable resources, two of the main challenges facing not only Mexico but the planet as a whole. This work assesses the environmental impact generated by the embodied stages of a typical SH throughout its life cycle (cradle to grave), by means of a Life Cycle Assessment (LCA). Two types of envelope and interior walls and three types of windows are compared. It was found that SH emits 309 kg CO_2 eq/m^2 and consumes 3911 MJ eq/m^2 in the product stages (A1 to A3) and construction process (A4 to A5); the most important stages are those referring to the products, namely, A1 to A3, B4 (replacement) and B2 (maintenance). Additionally, benefits were found in the use of lightweight and thermal materials, such as concrete blocks lightened with pumice or windows made of PVC or wood. Although the use of LCA is incipient in the housing and construction sector in Mexico, this work shows how its application is not only feasible but recommended as it may become a basic tool in the search for sustainability.

Keywords: life cycle assessment; social housing; embodied stages; embodied energy; embodied greenhouse gases; residential sector; Latin America and the Caribbean

1. Introduction

The population of Latin America and the Caribbean (LAC) represents 8.55% of the world population [1], of which 75% is concentrated in countries with emerging economies (32% Brazil, 20% Mexico, and 22% for Colombia, Argentina, Peru and, Chile together) [1,2]. The high metabolic rates of this region have obliged governments to design and introduce new approaches to separate their economic growth from the use of resources and, consequently, their environmental impact [3].

Although the LAC countries have twice the population of the United States (U.S.), they produce a lower global warming effect. This is similar to the case of the Asian giants, where India emits just 24% of the Greenhouse Gases (GHG) produced by China, despite each being home to 18% of the world's population. Regarding energy consumption, the USA, the European Union (EU), and China consume 4.15, 1.89, and 1.26 times more than the world per capita average respectively, while India and LAC consume 3.88 and 1.47 times less (Table 1). This indicates that the environmental impact indices generated by each country (and region) are discordant with the number of people living in them.

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A Comparative Study of Indoor Pavements Waste Generation During Construction through Simulation Tool

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Abstract

The construction sector affects the environment through CO_2 emissions generated by the use of massive quantities of materials, energy, and wastes during the construction and demolition processes. Moreover, current technology offers a wide variety of materials, products, and systems that could be used for a similar solution; however, the decision to select one or other element lies with the price and then by regulatory requirements and availability (ignoring the issue of sustainability). In a building, the pavements are one of the elements with major representativeness and with more possibilities of alternative variables in their materials; accordingly, this research exposes three different types of pavements with similar prices, comparable functions, and normative compliance, but providing a new sustainable perspective: The construction and demolition waste (C&DW) analysis. The results show the differences between the waste generated from each type of pavement, stressing that the application of sustainable management criteria can be significant for sustainable buildings construction. This research shows a new criterion applicable to the construction sector that could improve the selection (with equal requirements) of one type of pavement into a more environmentally friendly pavement; allowing the achievement of profits for builders.

1. Introduction

Currently, one of the biggest challenges facing the planet is caused by waste generation and their accumulation in landfills, being the C&DW the most representative [1]. In a building, different construction phases arise including the execution of pavements; which are considered as the elements with the larger horizontal surface, being one of the main causes of C&DW [2].

In this research, the waste generated (considering construction and eventual demolition) by three types of usual interior pavements in Spain are analysed, compared and quantified through simulation. The main purpose of this research is to establish and identify which type of pavement generates more wastes and what relationship maintained between them in order to find an effective solution during the materials selection process for the execution construction of new and existing buildings three types of pavements were applied in the same case study (multi-family housing located in Barcelona, with a pavement total area of 2,341.00 m²); The constructive application was equivalent and with comparable feasibility of use; the selected pavements were: Indoor terrazzo tile (P1), ceramic rustic tile (P2) and Spanish granite tile (P3); The Net Waste Tools software (NWT) was used (with the data of the selected pavements) as a simulation tool, this allowed us to obtain reports for each type of pavement, finally, these reports were standardized to make comparisons.

Results indicate that, although the analysed indoor pavements could be used (solving the technical requirements, regulations, construction difficulty and similar prices), their estimated waste generation is not the same for all of them, enabling us to highlight that this type of analysis can perceive differences which have passed unnoticed by the construction sector so far, with an additional contribution that could be seen as a new approach that promotes sustainability, environmental care and financial savings for the construction sector.

2. Body of knowledge

It is expected that the world population growth will double before the middle of this century, and as a binding cause of this, it is also predicted that this trend will be further accentuated in urban and bordering areas. Taking into account the increasing limitations of building areas in large cities, the building sector seems to be obliged to define new solutions to this problem [3]. Among them, the validation of constructive systems to achieve sustainable housing could contribute in this regard.

Of all the different elements in a building construction, the interior pavements have a high proportion and representation in a work -by a number of materials they use and for horizontal surface of their service-, and nevertheless they have not yet been linked to optimization criteria for comparable sustainable ratification -notwithstanding the existing of a wide variety of similar systems and constructive solutions-; although it has been accepted that the use of more complex systems (diversity of materials and in wet-laying construction) may be less sustainable than those using less variety of materials (with an implementation in-situ simpler). In Spain,

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Estudio de factibilidad y caracterización de áridos para hormigón estructural

Feasibility study and characterization of aggregates for structural concrete

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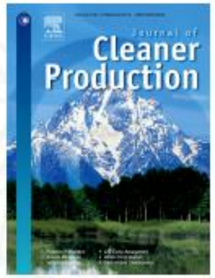

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