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Sustainability assessment of social housing by building elements and materials specification

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Abstract

Objective of the Study: The present paper aims to continue the development and application of the MASP-HIS tool for the sustainability analysis of social housing (SH) projects, which was applied to certain elements of this type of building.

Methodology/Approach: The criteria developed for this assessment are based on environmental, sociocultural and economic aspects. Thereby, it is possible to individually evaluate the complete project and the elements specifications of a building. A case study was evaluated.

Originality/Relevance: The work presents a versatile and adaptable tool to different SH projects. It has the potential to systematically assess different aspects of sustainability (environmental, sociocultural and economic). It considers the diversity of materials and construction elements used in the project.

Main Results: Different combinations of the specified materials, components and elements can be analyzed. Structural, roofing and frame elements were developed.

Theoretical/Methodological Contributions: The use of the tool can subsidize and facilitate the specification of SH projects attending sustainability criteria.

Conclusion: Ultimately, it was possible to obtain a global sustainability index for different combinations of an SH project.

Keywords: Sustainability. Social Housing. Project. Tools.

Avaliação da sustentabilidade de habitações de interesse social a partir da especificação de materiais e elementos da edificação

Resumo

Objetivo do estudo: Este trabalho tem como objetivo dar continuidade ao desenvolvimento e aplicação da ferramenta para análise de sustentabilidade de projetos de habitações de interesse social (HIS), denominada MASP-HIS, que foi aplicada em alguns elementos deste tipo de edificação.

Metodologia/abordagem: Os critérios elaborados para essa avaliação têm como base os aspectos ambientais, socioculturais e econômicos, a partir dos quais é possível avaliar o projeto completo e também as especificações dos sistemas de uma habitação isoladamente. A avaliação foi realizada para um estudo de caso.

Originalidade/Relevância: O trabalho apresenta uma ferramenta versátil e adaptável a diferentes projetos de HIS. Ela tem o potencial de avaliar sistemicamente diferentes aspectos de sustentabilidade (ambiental, sociocultural e econômico), levando em conta a diversidade dos materiais e elementos construtivos empregados no projeto.

Principais resultados: Podem ser analisadas diferentes combinações dos materiais, componentes e elementos especificados. Foram desenvolvidos os sistemas de estrutura, cobertura e esquadrias.

Contribuições teóricas/metodológicas: O uso da ferramenta pode subsidiar e facilitar a especificação de projetos de HIS com critérios de sustentabilidade.

Conclusão: Ao final foi possível obter o índice de sustentabilidade global para diversas combinações de um projeto de HIS.

Palavras-chave: Sustentabilidade. HIS. Projetos. Ferramenta.

Evaluación de la sostenibilidad de la vivienda social por meio de la especificación de materiales y elementos de la edificação

Resumen

Objetivo del estudio: El presente documento tiene como objetivo continuar el desarrollo y la aplicación de la herramienta MASP-HIS para el análisis de sostenibilidad de proyectos de vivienda social (SH), que se aplicó a ciertos elementos de este tipo de edificios.

Metodología/Enfoque: Los criterios desarrollados para esta evaluación se basan en aspectos ambientales, socioculturales y económicos. De este modo, es posible evaluar individualmente el proyecto completo y las especificaciones de los elementos de un edificio. Se evaluó un estudio de caso.

Originalidad/Relevancia: El trabajo presenta una herramienta versátil y adaptable a diferentes proyectos de SH. Tiene el potencial de evaluar sistemáticamente diferentes aspectos de la sostenibilidad (ambiental, sociocultural y económica). Considera la diversidad de materiales y elementos de construcción utilizados en el proyecto.

Resultados principales: Se pueden analizar diferentes combinaciones de los materiales, componentes y elementos especificados. Se desarrollaron elementos estructurales, de cubierta y de marco.

Contribuciones teóricas/metodológicas: el uso de la herramienta puede subsidiar y facilitar la especificación de proyectos de SH atendiendo a criterios de sostenibilidad.

Conclusión: Finalmente, fue posible obtener un índice de sostenibilidad global para diferentes combinaciones de un proyecto SH.

Palabras clave: Sostenibilidad. Vivienda social. Proyecto. Herramientas.

Introduction

The study of sustainability is justified when considering the reality that the planet's future generations will suffer the impacts of the continuous exploitation of natural resources. Consequently, several preventive actions are necessary. For instance, the development of guidelines and methodological bases to assess the sustainable performance of housing projects.

The construction sector is considered one of the main culprits of several negative environmental impacts. Social housing (SH) has seen considerable growth in recent years, as a result of funding from federal government programs, such as *Minha Casa, Minha Vida (My House, My Life)* (MCMV), among others (Sposto & Paulsen, 2014).

Although Brazil faces a political and economic crisis - which resulted in a partial decrease of financing for the construction sector - considerable growth is still expected in order to meet the country's housing deficit.

The construction of new SH will result in the consumption of natural resources and the consequent production of negative environmental impacts. Thus, measures to mitigate these impacts are required, attending sustainability criteria.

The life cycle of housing comprises the following stages: planning, design, construction, utilization and demolition. From the sustainability perspective, the planning and design stages are the most impactful. This occurs because, in this initial period, the project's materials and components, the type of employment, the costs (budget) and schedule are defined, which will influence following stages.

During the project design, sustainability considerations - including specifications - can generate a more sustainable SH, since it is at the beginning of such process that more effective results can be achieved, from the perspective of the final product's performance.

Additionally, numerous researches focusing on the system of vertical or horizontal sealing have been conducted, based mainly on energy efficiency in the operational phase. Although further building elements (structures, roofs, frames and others) are of great importance - especially regarding the impacts of material consumption - the energy expended in the extraction and manufacturing phase, type of labor used in these processes, or even in the economy in choosing the system, which is fundamental when referring to social housing.

In this context, the present research proposes the following query: is it possible to facilitate the process of sustainability assessment in social housing projects, focusing on the specification of materials and construction systems, through the utilization of a methodology or tool? Based on this question, this study aimed to apply the Methodology for the Sustainability Assessment of Social Housing Projects (MASP-HIS) for the structural, frames and roofing systems of a project. The results were presented for the environmental, economic and social aspects of different combinations of frames, and certain examples of combinations that can be performed by the MASP-HIS methodology. Possible combinations and the one with the highest project sustainability index were presented.

Sustainability in the Construction and Social Housing sectors

The construction industry is one of the sectors of the economy that produces large-scale goods. It can be considered the leading consumer of natural resources in any country, being responsible for a considerable portion of the nations' Gross Domestic Product (GDP) (Isaia, 2007). It is often identified as one of the main causes of environmental impacts in the world, such as: depletion of natural resources, atmospheric and underground water pollution, land degradation, among others.

Recent researches have verified how companies in the construction sector have faced the process of insertion and transition to a more sustainable model. Macêdo and Martins (2015) assessed the perception of urban sustainability in the context of construction companies in Campina Grande - PB, based on the aspects of quality of life, legitimacy of public policies and flow of resources and waste. The study showed isolated actions, focusing on the dimension of quality of life. Nevertheless, it was observed that the construction sector in the region does not face major obstacles in adopting practices considered to be more sustainable. Teixeira, Zamberlam, Santos and Gomes (2016) investigated how three construction companies in Santa Maria - RS are transitioning into a more sustainable management, based on interviews with the directors. Some of companies' initiatives were verified, which basically varied according to their environmental policies, the importance given by senior management, and the real involvement of employees.

Another theme that has aroused interest in the sector is the proposition of sustainability indicators, as it can be seen in studies: a) international, as presented by Heravi, Fathi, and Faeghi (2015), who identified and investigated sustainability indicators - based on environmental, social and economic criteria - for the construction, operation, maintenance and demolition phases of petrochemical work projects, through questionnaires. Kylili, Fokaides, and Jimenez (2016) proposed indicators based on additional criteria beyond environmental, social and economic, using Key Performance Indicators (KPI) to measure the sustainability of building projects. b) national surveys, in construction projects with sustainability principles (Salgado, Chatelet, & Fernandez, 2012; Kowaltowski, Granja, Moreira , Silva & Pina, 2016).

In Brazil, there is little research with focus on the proposition of sustainability indicators or indexes for the construction industry, mentioned below.

Carvalho (2009) and Carvalho and Sposto (2012) proposed global sustainability indicators for projects and specifications for wall systems (facades and partitions), based on environmental, social and economic criteria for social housing.

Oliveira, Silva and Gomes (2013) proposed environmental and economic performance indicators for the project of concrete structures. However, they did not address criteria related to the social aspects of sustainability and for other construction elements.

Saade et al. (2014) developed an eco-efficient index for the main Brazilian construction materials, such as ceramic blocks, ceramic tiles, sand, gravel, steel, cement etc. They used as indicators: embodied energy, CO_2 emissions, water consumption and emission of volatile organic compounds.

Caldas and Carvalho (2018) proposed a global performance indicator relating environmental issues with thermal and acoustic performance for the main vertical sealing systems employed in Brazil, in order to facilitate the designer's decision-making.

In the environmental and energetic efficiency aspects, several studies have been developed - beginning mainly during the oil crisis of 1970 - many referring to the assessment of material life-cycles, the need for cutting back on energy consumption, and to the impacts generated by greenhouse gas emissions (GGE) in the world and in Brazil. In the social and economic aspects, however, that does not occur at the same rate, which justifies the proposition of research on environmental, social and economic sustainability, focusing on Brazilian SH.

Social housing (SH) is a suitable lodging for population segments with a monthly family income of up to three minimum wages located in urban and rural areas (Brazil, 2015). Its importance lies in the existing housing deficit in the country, including units unsuitable to inhabit as a result of the precariousness of these constructions, as well as those that have suffered structural deterioration and that must be replaced due to the need to increment stock (Fundação João Pinheiro, 2005). Therefore, an increase in this type of construction in Brazilian urban areas is expected. According to statistical data from the João Pinheiro Foundation (2016), the last housing deficit assessed for the country, in 2014, reached a total of approximately six million of homes. Government investment in recent years in social programs, such as the "*Minha Casa, Minha Vida (My house, my life)*" program helped to mitigate this deficit. Nonetheless, it is difficult to believe the country is close to being able to eradicate the number of people without decent housing.

Plessis (2002) characterizes SH in developing countries as:

- Overload or almost total absence of basic infrastructure for urban services, such as water, sewage and electricity networks. This results in the increase of adverse effects on the environment, such as pollution of water resources and soil, making the environment favorable to the development of diseases.

- Irregular occupations, most of which are in areas of environmental protection, or vulnerable from an ecological perspective.
- Low quality of constructions, resulting from the lack of skilled labor and the negligence during the construction stage, as well as a lack of maintenance.

The SH problem is of international scope, and though each country presents specific problems and challenges, they all converge on the goal to produce more sustainable housing projects. In more developed countries this occurs through legislation, guidelines and research related to the sustainability of the production of this kind of construction, as it can be seen in Canada (Mckay & Khare, 2004), Portugal (Tolete, 2003) and Slovakia (Cervenová, 2005). In developing countries, where the demand for SH is higher, there is no denying the importance of caring for sustainability, including China (Chen, 2003), India (Kumar, 2002) and Mexico (Noguchi & Velasco, 2005).

According to Sedrez, Rosa and Sattler (2001), the design of a more sustainable SH must attend criteria related to environmental comfort, the optimization of the use of natural resources and the prioritization of local construction systems and materials. Benett and Sattler (2004) listed a few sustainability indicators for SH:

- Environmental indicators: waste collection, sewage treatment, green public areas and community food production.
- Social indicators: public transport, security, public telephones, health and daycare centers.
- Cultural indicators: learning, proximity to school, entertaining and leisure.

The selection of materials and components to reduce energy consumption and other resources, pollutant emissions such as CO_2, and toxicity must be one of the priorities of SH projects. Nevertheless, issues related to the costs and socio-cultural impacts of these materials and components should not be neglected.

Thus, adequate planning and projects with a systemic view, in which the various aspects of sustainability (environmental, socio-cultural and economic) are considered through an arduous process, which can be facilitated with the use of certain evaluation methodologies. Most of these methodologies refer to environmental assessment, some of which are mentioned below.

The methodology for assessing environmental performance applied to the construction sector that has been widespread in Brazil and internationally is the Life Cycle Assessment (LCA). It consists of measuring inputs (consumption of raw materials, energy)

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and outputs (emissions, waste, effluents, etc.) over the life cycle of a product or process, allowing for the evaluation of its environmental profile (IBICT, 2015). Applied to buildings, it is possible to measure the environmental impacts from the stage of raw material extraction to the destination of waste generated.

Another method of measuring the environmental performance of buildings is the Environmental Certification System, present in several European countries, and other regions, such as the United States, Canada, Australia, Japan, Hong Kong and Brazil (Roméro & Reis, 2012).

According to Wei, Ramalho and Mandin (2015), the most widespread environmental certification systems in the world are: the French Haute Qualité Environnementale (HQE), the English Building Research Establishment Environmental Assessment (BREEAM) and the North American Leadership in Energy and Environmental Design (LEED). All these certification systems have requirements to be fulfilled by the building and many of them are linked to the design stage (Salgado, Chatelet, & Fernandez, 2012). In Brazil, the French HQE methodology was adapted, resulting in the High Environmental Quality - AQUA certification (Buoro, Neto, Gonçalves, & Harris, 2015).

Meeting these requirements and obtaining an environmental certification does not guarantee that the building is sustainable. However, it provides a greater number of possibilities for better environmental performance, when compared to buildings that do not have this concern (Mahdavinejad, Zia, Larki, Ghanavati, & Elmi, 2014).

According to Gabay Meir, Schwartz and Werzberger (2014), most environmental certification systems involve a considerable initial cost, also resulting in greater complexity for their implementation in smaller and simpler projects. Therefore, the application of these certification systems to SH turn out to be economically unfeasible.

Another common feature of these certification systems is the absence of effective criteria related to the sociocultural and economic issues of buildings. Once again, they focus only on environmental issues.

In order to create a sustainability assessment methodology specific to the Brazilian reality - focusing on housing projects - the Casa Azul Sustainability Seal was conceived in 2010. The main differences of this certification in relation to the others is the greater simplicity of application to single family homes, and to a specific category of social practices (Lamberts, Scalco, Fossati, Montes, & Versage, 2015). Grünberg, Medeiros and Tavares (2014) compared LEED, Aqua and Casa Azul Seal certifications to the reality of Brazilian homes and concluded that the latter system is the most appropriate. Nevertheless, there is a lack of criteria related to economic sustainability.

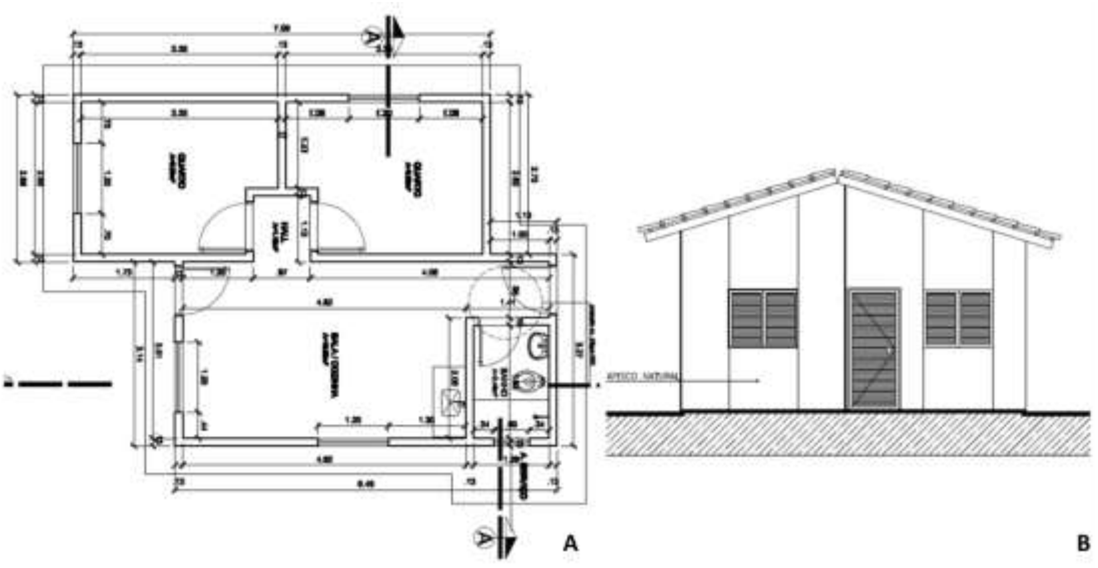
Finally, comparing all methodologies and certification systems that were briefly presented, not one presents specific requirements and criteria for each construction element, such as structures, roofing, frames etc; most are concerned about the sealing (facades, roofing and floors). All while focusing only on issues of energy efficiency, without considering sociocultural and economic issues.

This work aims to apply the MASP-HIS methodology, previously developed by Carvalho (2009) for structural, frames and roof elements. This methodology considers environmental, sociocultural and economic aspects.

Method

A case study was used as the methodology for this research.. According to Gerhardt and Silveira (2009), the case study consists of a more in-depth and detailed assessment of a specific object. In this sense, the MASP-HIS methodology was applied to a specific project - typical of Brazilian social housing - considering the context of the city of Brasília (Figure 1). The MASP-HIS methodology is detailed below.

Figure 1 - Social housing project assessed in the case study. (A) Floor plan. (B) Front facade



Source: Carvalho (2009).

The Methodology for Sustainability Assessment of Social Housing Projects (MASP-HIS)

This methodology was developed by Carvalho (2009), and provides scientific criteria for assessing the environmental, sociocultural and economic sustainability of projects, to support the choice and specification of construction materials and components. MASP-HIS can assist in the assessment during the design phase in buildings life cycle focusing on sustainability, minimizing impact and ensuring quality in the management of the design process through sustainability indexes. It is user-centered, especially for designers (engineers and architects) in the construction sector focused on SH. It can be applied on: (a) complete projects: verification of complete projects, considering aspects of environmental, socio-cultural and economic sustainability based on previously established requirements; (b) housing elements: specification of materials and components of building elements (e.g. structure, walls, roof etc.), considering environmental, socio-cultural and economic criteria.

As previously mentioned, the methodology was applied to the vertical sealing system (Carvalho, 2009; Carvalho & Sposto, 2012), due to its greater participation - among other aspects - in mass and costs of an SH project, as evidenced in the studies by Tavares (2006) and Saade et al. (2014).

Within MASP-HIS, a computing tool was also developed, which performs calculations and logical considerations, according to the consistent and comprehensive sustainability criteria provided.

In order to obtain project sustainability indexes, the MASP-HIS methodology consists of data entry assumptions through the database inserted into the tool. This allows for the verification of whether the projects submitted to the analysis contemplate certain sustainability requirements, such as the use of natural resources, embodied energy and CO_2 emissions when producing and transporting materials and components. The following criteria were adopted for calculating the sustainability index:

- Environmental: embodied energy, CO_2 emissions, recycling potential, toxicity, and abundance.
- Socio-cultural: participation, cultural heritage, material suppliers.
- Economic: life cycle cost.
- Application of the Sustainability Assessment Methodology for Social Housing Projects (MASP-HIS) in structural, frames and roofing elements.

For the comparison between structure, roofing, and frame elements, unitary measurements were used, referring to the m² of built area.

For the assessment of the system related to the structure, reinforced concrete, wood and steel were chosen. The compressive strength (fck) of reinforced concrete was of 20 MPa, 25 MPa or 30 MPa; the wood can be kiln-dried or air-dried. The steel was CA-50, CA-60, for reinforced concrete and for structural steel, laminated or welded profiles were considered. The structural concrete adopted was the wheelset on site using gravel and Portland cement CP II-E-32 (compressive strength of 32 MPa).

For the assessment of the roofing system, the roof structure and the type of tiles were considered. Wood or steel roof structures were studied, given that wood can be either kiln or air-dried. As well as two types of tiles: ceramic and fiber cement.

Finally, for the frame system, doors and windows were considered. For the calculation of the m2 of frame, each of these elements has a different recommended thickness. The depth of 14 cm was assumed for the portal and 7 cm for the counter window frame. The materials considered in the evaluation of this system were steel, wood or aluminum frames. The wood can be kiln or air-dried.

Environmental Aspects

Five subcategories for environmental sustainability were assessed, including: embodied energy (for the extraction, manufacture and transportation of raw materials), embodied CO_2 emissions (for the extraction, manufacture and transportation of raw materials), recycling potential, abundance and toxicity.

Issues related to energy and CO_2 were chosen because these environmental aspects are employed as indicators of environmental sustainability applied to the construction sector in several countries, through the adaptation of the Life Cycle Assessment (LCA) methodology, denominated by Life Cycle Energy Assessment (LCEA) and Life Cycle CO_2 Emission Assessment (LCCO_2A), as verified by Cabeza, Rincón, Vilariño, Pérez and Castell (2014) and Chau, Leung and Ng (2015).

The main characteristics and/or numbers that appear in MASP-HIS are: Embodied CO_2 emissions (in kg of CO_2/kg of materials); Embodied energy (in MJ/kg of materials); and characteristics regarding recycling potential and toxicity (Table 1).

Table 1 - Parameters of Materials for Structural Systems, Roof and Frames

Element	Material	Material	Embodied energy (MJ/kg)	Source	Embodied CO_2 emissions (KgCO2/kg)	Source	Recycling potential	Toxicity
Structure	Concrete	Gravel I	0.01	Saade *et al.* (2014)	0.004	Santoro e Kripka (2016)	Yes	No
		Steel	10.27	Saade *et al.* (2014)	1.55	Saade *et al.* (2014)	Yes	No
		Cement	3.37	Saade *et al.* (2014)	0.51	Saade *et al.* (2014)	Yes	No
		Sand	0.01	Saade *et al.* (2014)	0.004	Santoro e Kripka (2016)	Yes	No
	Steel	Steel	10.27	Saade *et al.* (2014)	1.55	Saade *et al.* (2014)	Yes	No
	Wood	Kiln-dried	9.0	Caldas (2016)	0.32	Caldas (2016)	Yes	No
		Air-dried	0.5	Caldas (2016)	0.04	Caldas (2016)	Yes	No
Roof	Roof structure	Wood (kiln-dried)	9.0	Caldas (2016)	0.32	Caldas (2016)	Yes	No
		Wood (air-dried)	0.50	Caldas (2016)	0.04	Caldas (2016)	Yes	No
	Tiles	Ceramic	1.59	Saade *et al.* (2014)	0.53	Saade *et al.* (2014)	Yes	No
		Fiber Cement	6	Tavares (2006)	2.72	Tavares (2006)	No	Yes
Frames (Windows and Doors)		Steel	10.27	Saade *et al.* (2014)	1.55	Saade *et al.* (2014)	Yes	No
		Wood (kiln-dried)	9.0	Caldas (2016)	0.32	Caldas (2016)	Yes	No
		Wood (air-dried)	0.5	Caldas (2016)	0.04	Caldas (2016)	Yes	No
		Aluminum	98.2	Tavares (2006)	1.8	Bessa (2010)	Yes	No

Source: Authors.

In the end, the results obtained from the sustainability index related to the environmental aspect were averaged. These values were adopted based on researches by

Bessa (2010), Saade et al. (2014), Caldas (2016) and Santoro and Kripka (2016). These studies are inserted in the Brazilian context, with a scope defined as "cradle to the grave" (raw materials extraction, processing, transportation, maintenance and destination of the materials and components).

Sociocultural Aspects

Social aspects were assessed in the form of questions, divided into three criteria: user participation, cultural heritage and material suppliers (Table 2). These aspects were chosen to enable the relation between the building elements and the materials adopted at SH.

Table 2 - Questions considered for the sustainability index related to sociocultural aspects

Questionnaire for Sociocultural Aspects
User Participation
Is there a proposal for the participation, integration, and cohesion of consumers and other interested parties to define the construction processes, materials and components?
Was there any consultation made with consumers regarding the satisfaction of the presented project?
Cultural Heritage
Are there elements which are part of the consumers' effective memory in the projects?
Are local and traditional components specified for the region where the project will be inserted?
Does the project suit the lifestyle of future consumers?
Is the project able to support the process of cultural cohesion (different cultural needs)?
Material Suppliers
Does the company adopt purchase criteria that considers the guarantee of origin, to avoid the acquisition of pirated or defective products?
Does the company demand the purchases to be the absent of products and sources of child labor and forced labor?
In order to hire a supplier - in addition to requiring a fair commercial proposal (with quality, price and deadline) - does the company assess whether it maintains social responsibility practices?
Does the company seek suppliers within small cooperative producers, neighborhood associations and income generating projects?

Source: Authors.

The socio-cultural indexes are calculated with simple mathematical formulas, allowing for quick and easy understanding. They were established by the QS / QT ratio, in which QS is the sum of the answers YES, and QT is the sum of the answers YES and NO, for each of the themes. The user also has the option "Not applicable", which isn't accounted for the indexes calculation.

Economic Aspects

Measuring the economic performance of SH is simpler than measuring the environmental and sociocultural performance. Publications on economic performance are readily available, with well-established standard methods.

The most appropriate method to measure the economic performance of buildings is the Life Cycle Cost (LCC) method, standardized for the construction investment analysis by ASTM E917 (ASTM, 2015).

The LCC assessment is a mathematical-financial method used to arrange and support a decision, and it is usually applied when deciding out of a selection of options. Such analysis considers all cost components, such as initial costs, financing, operation, maintenance, replacement, among others, for each alternative (Oliveira, 2013).

The economic aspects of building systems deal with the materials LCC. In the MASP-HIS methodology, the present value method was considered, as it is the most used in the context of the construction sector. Thus, the total (or global) costs considered in the life cycle of each system are represented in equation (1) presented below:

$$C_T = C_I + C_M + C_D \quad (1)$$

Where CI is the Initial Cost; CM the Cost of Maintenance; and CD the Cost of Demolition / Deconstruction. The initial costs of the materials must be informed by the qualified professional in a specific PROMASP-HIS spreadsheet and reliant on each evaluated system.

Maintenance and demolition / deconstruction costs must be quantified based on the forecast of replacement scenarios for the materials used as the forms of demolition. This information can be found in the technical sheets of materials and components, such as the tables of composition of services of the Brazilian National System of Research of Costs and Indexes of Civil Construction (SINAPI) and / or Table Price Compositions for Budgets (TCPO). All that based on the stipulated project's lifespan by the manufacturers and in specific standards, such as NBR 15575-1 (ABNT, 2013).

Global Sustainability Index

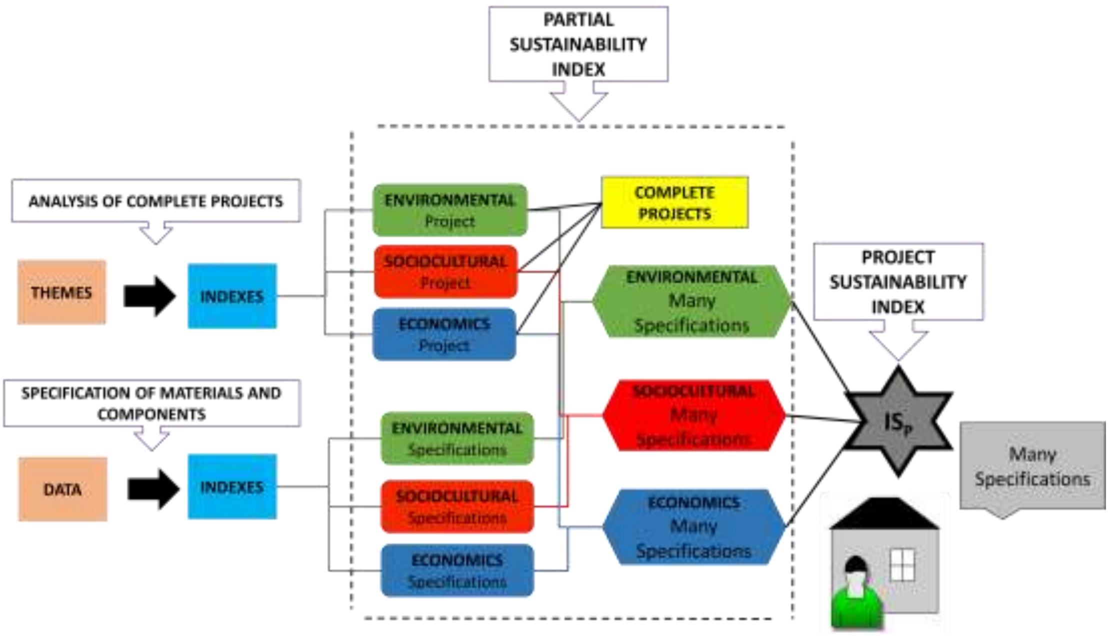
All these indexes are calculated from a simple arithmetic average and multiplied by 100, and always range from 0 to 100. The closer to 100, the more sustainable the building.

At the end, the indexes of the three aspects (environmental, sociocultural and economic) are added. All have the same weight to obtain the final value (grade). The set of indicators enables the establishment of an index which has practical applications.

It must be noted that in the present work, the environmental and economic dimensions are focused on the chosen elements (structure, roof and frames) and the sociocultural issue assess the general aspect of the building site.

In Figure 2, the complete process to obtain the global sustainability index for isolated elements and the whole building is presented.

Figure 2 - Complete process for the construction of the social housing global sustainability index



Source: Carvalho (2009).

The MASP-HIS tool can be split into two stages: (1) specification of materials and components, attending environmental, sociocultural and economic criteria; (2) analysis of the complete project, also based on these criteria. In this work, only the part referring to the specification of materials and components of specific elements (structure, roof and frames) is presented.

Thus, based on the design and specifications of materials and components of the different housing elements, it is possible to reach partial sustainability indexes (environmental, social and economic) and the global sustainability index, both for a specific element and a complete building.

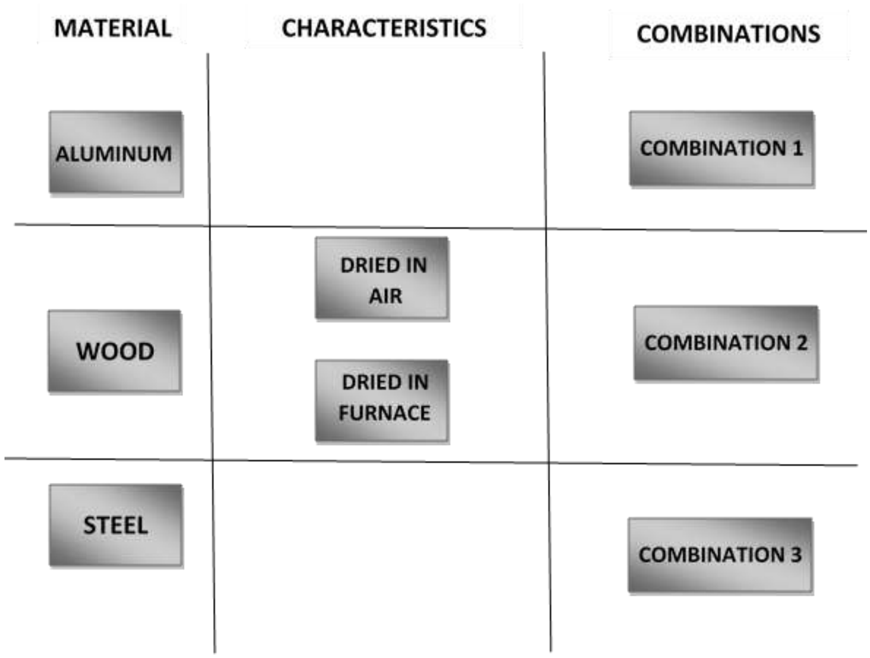
Finally, it should be noted that this tool can be updated, through the adaptation and reviewing of the input data.

Results and Discussion

The tool was configured and expanded so the user can evaluate a construction through the environmental, social and economic aspects of the whole project, and of the structure, frame and roofing elements.

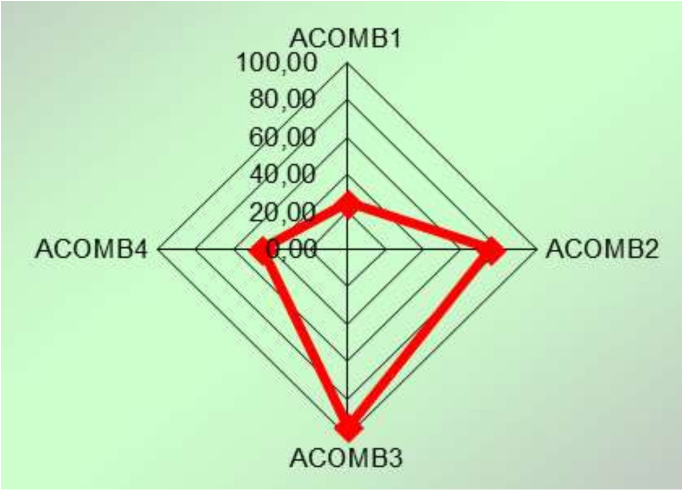
According to the input data, location and other evaluation criteria already mentioned, solutions can be easily visualized by means of graphs and indexes. For instance, Figure 3 shows a scheme of combinations and Figures 4, 5, and 6 show results of the frame element for the environmental, economic and social aspects, respectively. Figure 7 presents the results for the project sustainability index (ISp).

Figure 3 - Example of presentation of the graphical results for frames



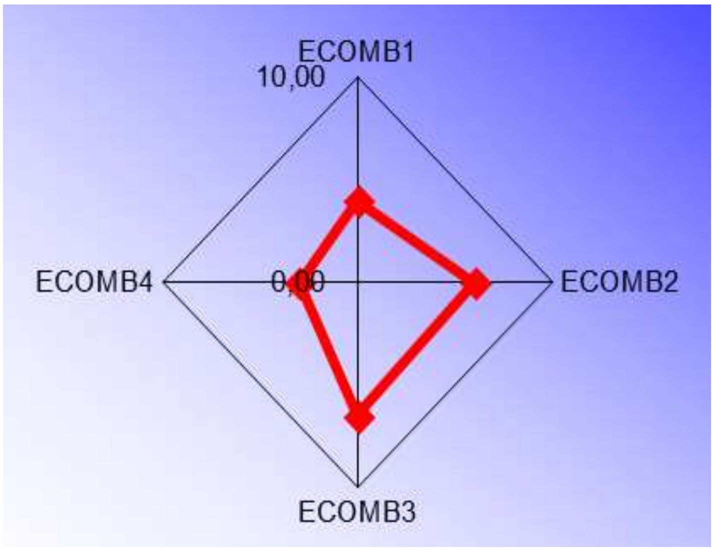
Source: Authors.

Figure 4 - Result for the environmental aspect of the different frame combinations



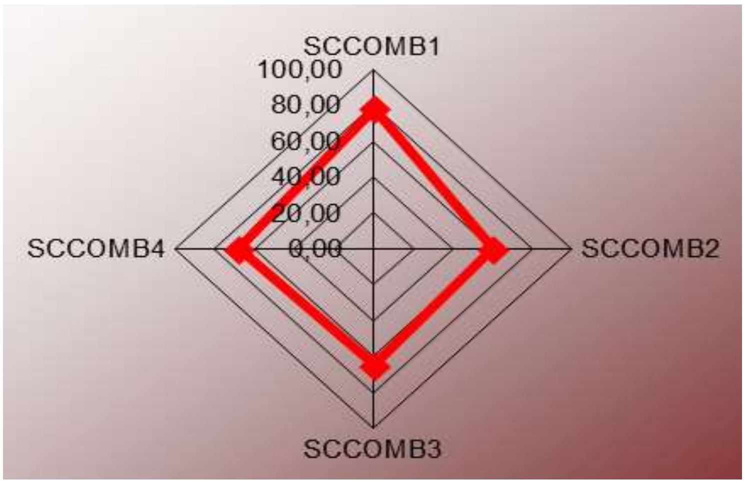
Source: Authors.

Figure 5 - Result for the economic aspect of the different frame combinations



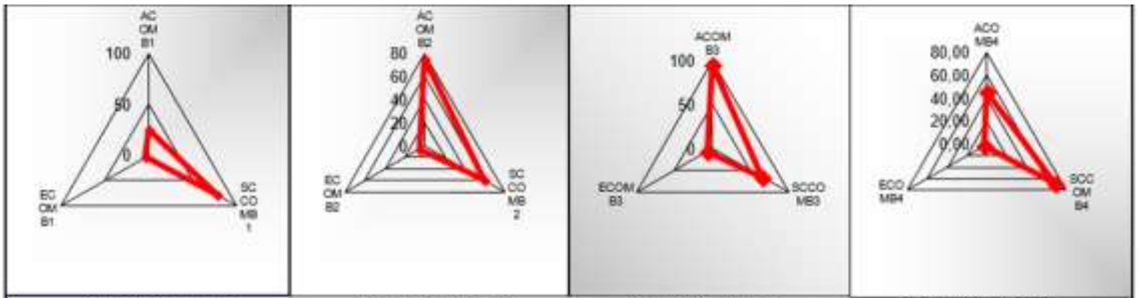
Source: Authors.

Figure 6 - Result for the sociocultural aspect of the different frame combinations



Source: Authors.

Figure 7 - Results for the project's Sustainability Index (ISp)



Combination 1		Combination 2		Combination 3		Combination 4	
A_{COMB1}	25,00	A_{COMB2}	75,00	A_{COMB3}	95,00	A_{COMB4}	45,00
SC_{COMB1}	78,00	SC_{COMB2}	60,00	SC_{COMB3}	65,00	SC_{COMB4}	68,00
E_{COMB1}	4,00	E_{COMB2}	6,00	E_{COMB3}	6,50	E_{COMB4}	3,00
ISp_{COMB1}	35,67	ISp_{COMB2}	47,00	ISp_{COMB3}	55,50	ISp_{COMB4}	38,67

Source: Authors.

As it can be seen, combination 3 (composed of air-dried wood) was the one that presented the best index for the environmental and economic aspect of the frames (windows), whereas combination 1 (of aluminum) presented the worst index. However, it is interesting to note that, in the economic aspect, the difference between the results of different combinations is smaller, given the higher maintenance cost of wooden frames.

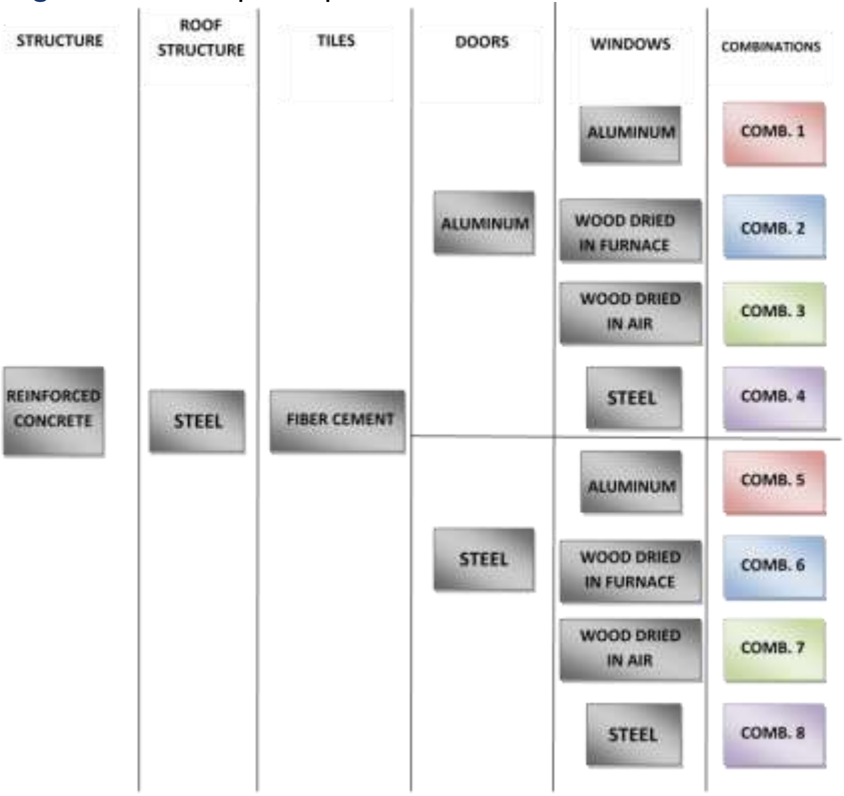
It can be observed that there is a tendency for environmental and economic aspects to converge to similar results, considering that more intensive production processes culminate - in most cases - in higher costs and greater environmental impacts, as it is the case of aluminum production. On the other hand, in the social aspect the results are more balanced amongst the four alternatives, with the aluminum frame being the most advantageous, while the one with air-dried wood being the worst. One of the items that lowered the score of wooden frames was the greater difficulty in obtaining wood in the study region (Brasilia), and - when thinking about consumer lifestyle - greater maintenance demands appear.

Thus, the tool shows the sensitivity of calculating different combinations and demonstrates that a given alternative is unlikely to be the most advantageous in all aspects. This result faces the difficulty of specifying fully sustainable systems. Therefore, it is necessary to select the most efficient alternative that ultimately presents an optimized result on environmental, economic and social aspects. For the situation presented in this case study, the combination 3 was the alternative that obtained the highest index, of 55.50 points, followed by combinations 2, 4 and 1.

The results for the frame element can be obtained for the structure, roofing and the rest of the housing system. It was verified that in total, 1,920 combinations can be made.

Some of the combinations that the tool can generate are shown in the diagram in Figure 8, in a simplified form. The global sustainability index of the project is obtained through combinations of the indexes for each stage, which are acquired through the grouping of each element - obtained through a calculation based on the chosen criteria.

Figure 8 - Example of possible combinations



Source: Authors.

The combination of an air-dried wood structure covered with ceramic tiles, wooden windows and air-dried doors was the one that obtained the highest sustainability index value for the housing project. This was due to the low environmental impact of wood in conjunction with the relatively low costs and sociocultural impacts.

On the other hand, the combination of a steel structure, steel roofing with fiber cement tiles, aluminum windows and doors was the one that obtained the lowest value of sustainability index for the housing project. Aluminum presents high values of embodied energy and CO_2 emissions, as well as being a costly material.

Hereupon, the proposed tool may result in changes to the current scenario, aiding in the improvement of sustainability within the Brazilian civil construction sector, especially in the context of social housing.

It can be considered a useful tool, with potential applications for the designer and which can subsidize the amplification of more sustainable projects and specifications, considering environmental, social and economic aspects throughout the building's life cycle. The results generated by this tool are different from the criteria based purely on initial costs, adopted by most design and construction companies nowadays.

It is worth noting that issues related to the three aspects (social, economic and environmental) of a given material or construction system may change soon, due to the technological development in the construction sector. Materials and systems whose construction process are more conventional, such as reinforced concrete and masonry structures, tend to suffer fewer modifications. However, those that are more industrialized are prone to some efficiency during the process. Thus, the methodology is not static - on the contrary - it has the characteristic of being updated with new data from the materials and systems considered. In fact, data relating to the reality of other countries can also be added.

Conclusions

A tool known as "Sustainability Assessment Methodology for Social Housing Projects (MASP-HIS)" was used to evaluate structural, roofing and frame elements for the design of a social housing (SH) project, attending environmental, sociocultural and economic criteria,

Subsidies were provided for the setup of a database on the use of natural resources, energy consumption and CO_2 emissions, when producing and transporting materials and components for purposes of supporting its specification.

Combinations were established between the various materials and components that form certain structural, roofing and frames elements combinations. Then, it was verified which solution presented the best alternative in terms of sustainability aspects. When different frame combinations were compared, the option with air-dried wood presented the highest project sustainability index, while aluminum presented the lowest.

For the housing project, considering the other building elements (structure and roof), the combination of structure and frames of air-dried wood with ceramic tiles was the one that presented the best sustainability index, while the combination of steel structure, aluminum frames and fiber cement tiles presented the worst index.

Unlike the existing environmental certification systems, the proposed tool may offer different combinations of construction systems usually employed in Brazilian SH, quickly and objectively subsidizing the design stage and the choice of the most sustainable combinations. Thus, in answer to the research query, the MASP-HIS methodology proved to be a tool with great potential to facilitate the assessment - in an objective and quantitative way - of the sustainability of SH projects. It is important to highlight that this tool can also be adapted to the reality of other countries.

For future work, we suggest the insertion of new building elements, such as waterproofing systems, installations, painting etc., as well as other materials and components for innovative construction processes.

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