FRAMEWORK FOR AUTOMATED EVALUATION IN THE DESIGN PROCESS OF HEALTHCARE BUILDINGS

Leonardo Jorge[1], Davi Araújo[2], Gustavo Monteiro[3], Daniel Cardoso[4], Mariana Lima[5]

[1] Universidade Federal do Ceará, Fortaleza, Brazil
leolmjl@arquitetura.ufc.br; daviqaraujo@alu.ufc.br; gustavomonteiro@alu.ufc.br; danielcardoso@ufc.br; mariana@daud.ufc.br.

Abstract. The healthcare building design process involves complex decision-making, considering both normative restrictions and other essential program qualities. To address this challenge, a BIM framework is proposed, providing multi-criteria evaluations for architects at various design stages. The framework uses semantic modules to measure the BIM model and compare results with reference goals, including restrictive norms. Employing Design Science Research, existing evaluation modules were integrated. The current implementation includes normative checks, indoor environmental quality, and spatial syntax indicators analysis. The contribution lies in offering a tool that optimizes the healthcare building design process by providing visual feedback for the users, who are designers and regulatory bodies.

Keywords: Analysis, BIM, Healthcare, Computational Design, Decision Support System.

1 Introduction

The design activity can be understood as the cycle of generating options and evaluating them to verify if they are satisfactory with the objectives and constraints (Mitchell, 1990). For healthcare buildings, the evaluation is conditioned to the stakeholders' objectives and also to normative factors. These cycles of analysis and evaluation improve the quality of the project, ensuring that the demands and needs of stakeholders and clients are met and design solutions comply with guidelines and legal requirements (Junior, Tzortzopoulos, Baldauf, Pedo, Kagioglou, Formoso, Humphreys, 2021). Starting from the question of how to optimize decision making in healthcare building design, the paper hypothesizes that an automated computer system may be the way.

In complex buildings such as hospitals, configuration problems can lead to inefficient circulations, costly maintenance, economic dysfunction and operational problems that can affect safety (Nourian, 2016). The author proposes that addressing this challenge requires approaches that focus on explicitly expressing building configurations through integrated design and analysis, using layouts with architectural elements that are systemic, generic and intuitive at the same time.

To analyze the configurational structure of complex buildings, Nourian (2016) brings a path through Space Syntax. In this approach, the topology of the environments is described by using graphs, and their qualities are measured by indicators. This approach is the first path adopted by the work to evaluate health buildings.

Another set of qualities that determine the proper functioning of healthcare buildings is Indoor Environmental Quality, or IEQ. The literature presents four categories of IEQ: visual comfort, thermal comfort, visual comfort and indoor air quality (IAQ) (Shen, Zhang, Li, Qu, Zhao, Kong, Jia, 2023). A building is designed and constructed to be used, operated and inhabited by people, and for this reason, the needs of the occupants must be considered as a fundamental requirement for their comfort. Thus, it is imperative that both planners and managers of the built environment are concerned with maintaining a more satisfactory IEQ in buildings (Nimlyat, Kandar, 2015). Thus, incorporating indicators that measure IEQ into the analysis and evaluation cycles proves to be of great value to the design cycle.

A third set of evaluations addressed in the paper is Code Check. The automation of normative checking is already widely discussed in the literature, and it is known that it can offer a faster, more efficient and reliable process (Junior, Tzortzopoulos, Baldauf, Pedo, Kagioglou, Formoso, Humphreys, 2021). These authors also point out that automating evaluation in health projects is a way that can mitigate some problems: addressing the complexity of the systems and subsystems of these buildings, dealing with the large volume of program information, and also addressing possible conflicts between stakeholder objectives and standards.

Using these three themes the work develops a computational tool that provides real-time feedback to the user. Next, the computational framework that allows linking the design activity in BIM platform to the measurement and evaluation of indicators will be explained. Then, the indicators that were implemented in the tool are presented, showing their calculation, their computerization and their evaluation criteria. And lastly, the interface proposed in the system is presented, in which the user will receive the information and make the decision in the design.

2 Methodological Procedures

The work was developed applying the Design Science Research methodology, according to the version proposed by Nourian (2016). The steps employed are: conceptual problem formulation, design and development, implementation, verification and validation. The current work will point out the current results of the design and development stages of the framework, and the implementation. For the conceptual problem, the importance of evaluating indicators of the three themes mentioned was presented in the introduction.

2.1 Methods

The proposed methodology seeks to serve as an approach to deal with the challenge of decision making in the design process. The design activity involves the generation of several options, followed by the evaluation of these solutions in order to determine which one meets the stated objectives in the design context (Mitchell, 1990).

Based on this flow, the framework was developed based on the performance analysis process proposed by Thomas Maver (1971) in his seminal work "PACE" (computer aided building appraisal): representation, measurement, evaluation and modification. From this reference, the flow is divided into three steps: modeling, measurement and evaluation (see figure 1). In the modeling step, design-related information is entered into the computer. In the measurement step, these entered data are interpreted and indicators are calculated. Finally, in the evaluation step, the measured indicators are compared with reference values to determine whether they meet the established acceptance criteria.

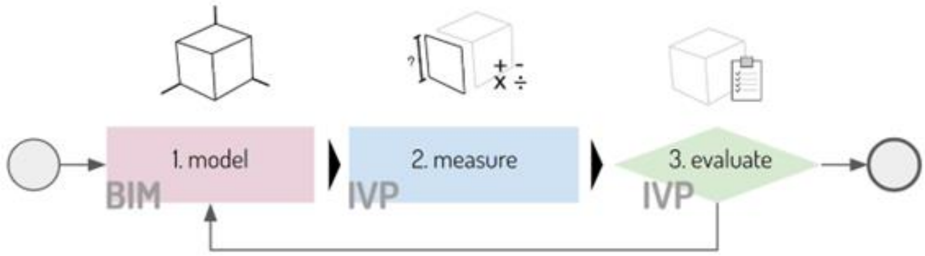

Figure 1. Conceptual methodology flowchart. Source: Author, 2023.

The main representation tool used is the BIM interface, which serves as an integration between the building design process and the evaluation process. The choice of BIM allows the designer to create the building in the architectural design platform and integrate his workflow with the VPI (visual programming interface), responsible for the Building Performance Analysis (BPA) (Jin, 2019).

Through the integration between BIM modeling and the BPA interfaces, it is possible to automatically and accurately enter the data for the analysis. The computationally represented building becomes the primary source of geometric input data for the BPA, in addition to providing various information that the BIM model is capable of storing, such as materiality and cost.

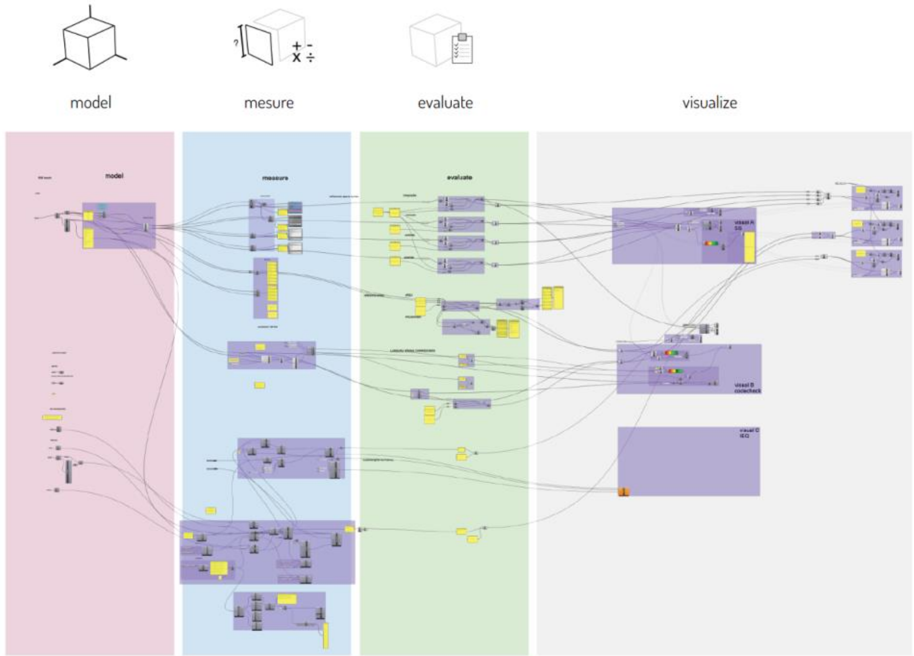

Figure 2. Algorithm with method flowchart scheme. Source: Author, 2023.

In the modeling stage, the designer must first determine the level of detail (LOD) that will be used to model, in order to know which elements must be represented to perform the measurements. The framework can be applied from the initial phases of the design to the detailing, but for this, the modeling must be adequate to the current stage of the project.

After the representation of the building in a computational environment, the next step of the computational flow is measurement. In this stage, variables and indicators are calculated based on the data entered in the modeling stage in order to obtain values from the model. Radford (2003) defines performance indicators as quantifiable measures that represent specific requirements. The set of indicators varies according to the context, adapting to what is valued for a quantitative analysis in different situations. Different architectural typologies, regional contexts, legislations and stakeholders' interests are examples of environment characteristics that determine which indicators are relevant for the context of the analysis. The output of the measurement step is a list of indicator results, obtained from the data entered in the modeling step.

The proposed computational framework uses the interoperability provided by the live link between BIM (Building Information Modeling) and VPI (visual programing interface), allowing real-time information exchange between these two interfaces. In this way, the design representation interface (BIM) and the BPA interface (VPI) provide simultaneous feedback to the user (Lima da Silva, 2018). The designer makes changes to the model and the system shows the impact of these changes on the values of the selected indicators. The design decision-making process becomes based on quantitative measurements, increasing the accuracy of decisions in the complexity of the project. The information needed for indicator calculations varies at each stage of the design, which is why indicators are systematized by LOD. The early stages of the project use more generalist indicators, while the executive detailing stages require more precise and granular indicator calculations.

The proposed tool aims to optimize design decisions by providing informational support to the designer. For this purpose, the values resulting from the measurement of the indicators are not sufficient to determine whether or not the project has achieved the qualities defined in the scope. It is necessary to carry out an evaluation step, in which the measured values are compared with references. It is necessary to establish which ranges of values are considered satisfactory for the initial design requirements and which values are unacceptable for the feasibility of the project. These benchmarks should be based on established knowledge, often obtained from literature describing the indicator in question. Through comparison with the reference values, the framework performs a conclusive analysis for the user.

Prior to appraisal, it is not possible to state whether the design is within the minimum quality parameters, i.e. whether the generated option is feasible. Furthermore, the evaluation allows to understand where the design option is in the range of possibilities, if it is optimized and approaches the objectives set for the indicators, or if it performs poorly. Based on the feedback provided by the evaluation, the designer can make changes and evaluate their impacts.

This evaluation step is crucial to guide the decision-making process, as it provides clear information about the performance of the design against the established requirements. In this manner, the designer can make more informed decisions and make necessary adjustments to improve the design and achieve the desired objectives.

2.2 Development

From the framework presented, indicators belonging to the three different themes were systematized. These indicators were implemented in the Grasshopper VPI using BIM model data as inputs. Table 1 shows at the first level the different thematic axes addressed: Space Syntax, IEQ and Code Check. In the last level the implemented indicators can be observed.

Table 1. Indicator list.

Theme	Field	Indicator
Special configuration	Space syntax	Integration Entropy Control Choice
IEQ	Thermal environment	Energy consumption for comfort
IEQ	Visual environment	Natural Lighting Energy consumption for comfort
Norms and Codes	Healthcare building code	Minimum program Minimum area
Norms and Codes	Accessibility code	Minimum corridor width
Norms and Codes	City construction code	Minimum inscribed circle

Source: Author, 2023

Four indicators were implemented in the Space Syntax theme: integration, entropy, control and choice (Nourian, 2016). Integration is a measure of centrality that indicates the degree to which a space is likely to be considered private or shared. Entropy, in turn, describes the difficulty of reaching other spaces from a specific space. In other terms, the higher the entropy, the more difficult it is to access other spaces from that space in question. Control represents the strength of the connection of a graph vertex with the others in a superior way. Choice reveals the frequency with which a node appears on the shortest paths with other nodes. The measurement was implemented using the Space Syntax plugin for Grasshopper developed by Nourian (2016), which calculates the indicators from a spatial configuration graph. To assess whether the measured indicators are satisfactory, a reference base was developed, capable of pointing out for each environment what the expected value of each indicator is. The measured values are compared with the reference values for each environment, and the deviation is measured. In this way, topological characteristics of the program of the environments are described numerically, and with this the system is able to perform a configurational analysis of the design. To build the benchmark, several exemplars were modeled, and the values of the indicators for each environment were measured, in order to build a data set, from which the average of the measured values formed the reference values. The work has not yet validated the proposed reference benchmark, and it is intended to do so by collecting post-occupancy data from the buildings, and comparing the users' perception with the values measured by the indicators.

Two indicators related to visual comfort and thermal comfort were implemented in the IEQ theme: natural lighting and energy consumption for comfort. In a large literature review, Shen, Zhang, Li, Qu, Zhao, Kong, Jia, (2023) found that natural light and views can help patients relax, reduce stress and depression, shorten hospital stays and improve satisfaction. For employees, they can reduce errors, stress, absenteeism and fatigue, and improve performance, attitude and job satisfaction. In order to verify thermal comfort, it was decided to approach it by measuring the energy consumption that mechanical comfort systems would perform (which was also done to measure energy consumption for visual/light comfort). For the implementation, plugins for Grasshopper from the Ladybug/Honeybee package were used. For illuminance, the reference base used was current normative guidelines, which describe the light level of each functional environment (SOMASUS). For energy consumption, post-occupancy data were collected from health architecture exemplars and an expected average per m2 was established (this reference has not yet been validated). It is important to emphasize that the objective of the energy consumption indicator considered is always to minimize, seeking a sustainable environment.

In the Codecheck theme, four indicators were implemented from the regulations: health projects in Brazil, RDC 50 (2002); accessibility regulation (NBR 9050, ABNT 2015); and municipal building code. The minimum area of each environment, the minimum program, the minimum inscribed circle of each environment, and the minimum width of corridors are implemented in the system. The minimum area assesses whether the environment meets the minimum geometric criteria of area, as well as the inscribed circle and the width of corridors. The minimum program verifies that the project contains all the environments necessary to perform the desired functional activity, and that the adjacencies between them respect those described in the standard. The implementation of the measurement was done through parametric modeling in Grasshopper, and the evaluation was done by comparing the measured values with the maximum and minimum parameters of the norm.

3 Application/Case

The result of the research was the computational system that implemented the framework, capable of providing feedback to the user for optimization of design decisions. The implemented indicators are represented in visuals that update in real time, based on the modifications generated by the user in the BIM model. The visuals use a color code that represents the evaluation, and does so by representing the deviation of the measured values from the reference value. The interface presents a dashboard, in which each theme has a visual, and there is also a summary visual, where it is possible to quickly visualize all the indicators (see figure 3). The user can interact with the interface to select which indicators they want to see, how they want to configure the color coding, and to filter certain rooms.

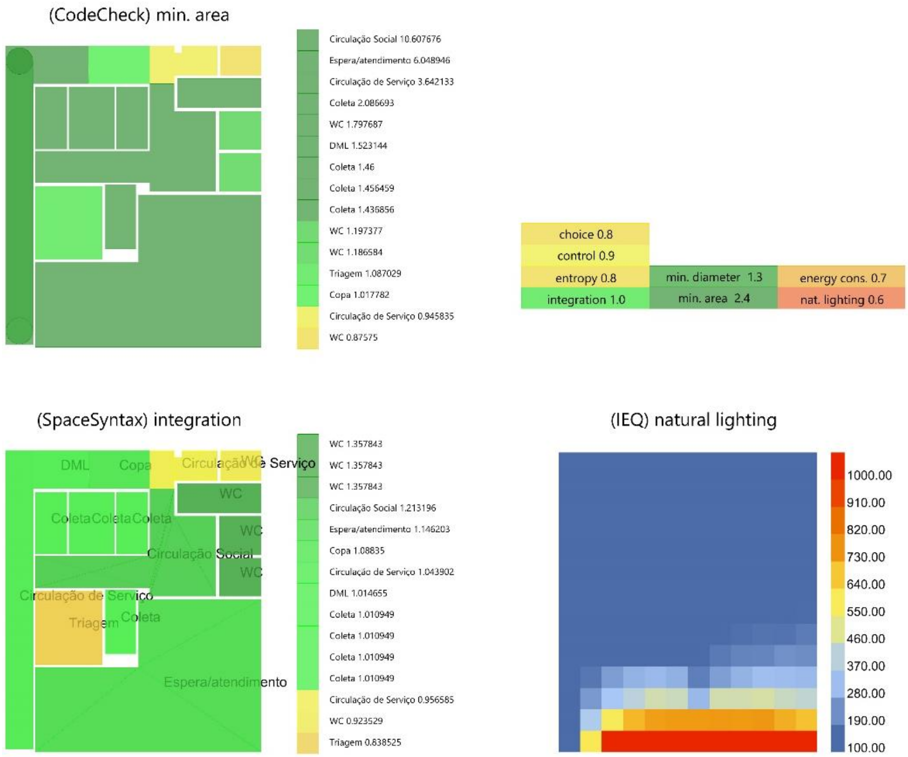

Figure 3. Interface dashboard with feedback of indicators. Source: Author, 2023.

The computational implementation of the visuals takes place in Grasshopper, using the geometric information from BIM and the values from the indicator assessment to create the representations.

The computational system's dynamic visuals not only provide real-time feedback but also empower architects to gain valuable insights into their design choices. By visualizing the indicators' performance through an intuitive color code representation, the architects can quickly identify areas that require attention and optimization. Moreover, the system's interactive nature allows users to experiment with different design options, assess their impact on various indicators, and fine-tune the building's configuration accordingly. This iterative design process fosters creativity and evidence-based decision-making, ultimately leading to improved healthcare building designs that align with both regulatory requirements and essential program qualities. The user-friendly interface and data-driven approach make the computational system a powerful tool in streamlining the design process, enhancing efficiency, and ensuring that healthcare buildings are not only compliant but also optimized for superior performance and user satisfaction.

The validation of the system has not yet been carried out until the publication of this work, but it is planned to do so in two ways: the first is to implement the system in an existing building, collect data regarding post-occupancy indicators and compare them with those simulated by the system. For objective indicators, such as area or lighting, data will be collected through measuring instruments. For subjective indicators of space syntax, forms will be made with the occupants for analysis. The second form of validation will be the UI, where several users will use it and at the end forms will be made to verify its usability, and point out whether it actually assists in decision making in design.

4 Conclusion and discussion

The activity of design analysis with real-time feedback has great potential for healthcare architecture projects. However, as a tool to mitigate the problem of design decision making, it carries with it the difficulty of multi-criteria decision making. Measuring multiple indicators and comparing them to reference benchmark numbers may make it easier to make explicit what weighting is given to different aspects of architecture in design decisions, but it certainly does not bring a ready answer to the designer. From the difficulty of defining the numerical objectives of the indicators, as well as the hierarchy of priority that should be given to each objective, the proposed framework advances in design problems without solving them completely. The nature of health building projects reduces to some extent the degree of subjectivity of decision making, since the great functional need, the degree of regulatory restriction in addition to the high cost and complexity direct decisions to objective criteria. Thus, determining the design objectives for the stakeholders of the typology always starts from a high set of priority technical aspects and constraints. But nevertheless, considering subjective quality aspects, such as aesthetics, can add humanization to users, who are sometimes vulnerable.

4.1 Practical implications

Decision Support: Implementing a BIM-based framework that automates assessments and provides real-time feedback can significantly help architects make informed decisions during the various stages of healthcare building design. By considering multiple criteria simultaneously, the tool can help optimize the design process and ensure that the project meets regulatory requirements and other essential qualities.

Iterative Design and Optimization: The real-time feedback and visualization provided by the framework allows designers to explore different design options and assess their impact on various indicators. This iterative design process stimulates creativity, resulting in better design solutions and supporting evidence-based decision-making.

References

Agência Nacional de Vigilância Sanitária. (2002). RDC 50: Regulamento técnico para planejamento, programação, elaboração e avaliação de projetos físicos de estabelecimentos assistenciais de saúde. Retrieved January 12, 2023, from https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2002/rdc0050_21_02_2002.html

Bennetts, H., Radford, A., & Williamson, T. (2003). Understanding Sustainable Architecture (0 ed). Taylor & Francis. https://doi.org/10.4324/9780203217290

Jin, R., Zhong, B., Ma, L., Hashemi, A., & Ding, L. (2019). Integrating BIM with building performance analysis in project life-cycle. Automation in Construction, 106, 102861. https://doi.org/10.1016/j.autcon.2019.102861

Lima da Silva, J., Quadrado Mussi, A., Leal da Silva, T., & Zardo, P. (2018). Designers of the XXI century: BIM software programming and the development of new competencies. Blucher Design Proceedings, 538–545. https://doi.org/10.5151/sigradi2018-1444

Maver, T. W. (1971). Pace 1: Computer aided building appraisal. Architects Journal, July 1971, 207-214.

Mitchell, W. J. (1998). The logic of architecture: Design, computation and cognition (6. print). MIT Press.

Nimlyat, P. S., & Kandar, M. Z. (2015). Appraisal of indoor environmental quality (IEQ) in healthcare facilities: A literature review. Sustainable Cities and Society, 17, 61–68. https://doi.org/10.1016/j.scs.2015.04.002

Nourian, P. (2016). Space syntax for healthcare buildings: Configurational analysis of complex designs. Environment and Planning B: Urban Analytics and City Science, 43(6), 1105-1124.

Shen, X., Zhang, L., Li, J., Qu, Z., Zhao, Y., Kong, W., & Jia, S. (2023). Impact of natural light and views on indoor environmental quality in healthcare buildings. Building and Environment, 214, 108895.

Soliman-Junior, J., Tzortzopoulos, P., Baldauf, J. P., Pedo, B., Kagioglou, M., Formoso, C. T., & Humphreys, J. (2021). Automated compliance checking in healthcare building design. Automation in Construction, 129, 103822. https://doi.org/10.1016/j.autcon.2021.103822

Associação Brasileira de Normas Técnicas (ABNT). (2015). NBR 9050: Acessibilidade a edificações, mobiliário, espaços e equipamentos urbanos. Retrieved January 12, 2023, from https://www.abntcatalogo.com.br/norma.aspx?ID=18804