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Research Article

Tool for the integration of building performance information within the BIM process

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Abstract: Decision-making regarding building performance in all construction project phases is a complex task. This article addresses the challenge of managing building performance information throughout construction project phases. It proposes a tool that assists in verifying the building performance requirements for different stakeholders and supports the integration of this information within the BIM process. The developed tool allows the launch, monitoring, and creation of a database with information about the project, the work, and the stakeholders. A practical study was chosen to test this tool. Its result is particularly meaningful to all stakeholders, as it prioritizes the information and underlying activities for the collaborative project development among the participants. In summary, the information integration related to the requirements to guarantee the building performance, co-related to the construction project development phases, is essential for improving internal processes. It is worth mentioning that managing this information is not a simple process and requires contextual knowledge, leadership, and management and communication skills.

Keywords: Building performance; information integration; tool; project phases; BIM.

1. Introduction

The construction of new buildings must comply with the requirements of current regulations (Alonso et al., 2021). However, the specification of minimum building performance levels is a fundamental value judgment that requires collective decision-making. This is due to the multidisciplinary nature of the AEC sector, which involves interdependencies between variables, and presents many challenges for capturing building performance data and integrating and evaluating it effectively (Hu et al., 2016; Meacham, 2010; Meacham & van Straalen, 2018).

The information necessary for decision-making, which will generally be uncoordinated and isolated, added to the complexity generated by the multidisciplinary nature of the stakeholders, making the information integration a challenge for the civil construction sector (Meacham, 2010; Sanchez et al., 2018). Thus, "information integration in the construction industry should largely be about the degree to which knowledge is shared, transferred or diffused across these research levels" (Rempling et al., 2019).

Making changes in the construction project demand a multidimensional view from the market that integrates different perspectives, as advances in the development of new materials and technological development provide the agents participating in the project with the search for innovation and renewal in the processes (Arriagada, 2019; Göçer et al., 2015; Liu et al., 2019). The variety of materials, products, structural solutions, and architectural styles that designers have to decide on and the sheer volume of information related to buildings are defiant for design teams, making this process increasingly complex in several areas (Göçer et al., 2015). Building Information Modeling (BIM), associated with the integration of information, covers all construction project stages, enabling communication between participants at the appropriate time, helping to understand the project, and reducing common errors (Yan et al., 2014).

In summary, monitoring and verification during all construction project phases are important to ensure the performance and durability of the building since this process involves different stakeholders, such as developers, designers, builders, contractors, residents, etc. In this sense, the objective of this article is to propose a tool that helps in the insertion of the building performance requirements, for different stakeholders, throughout the construction project phases, to support the integration of this information, within the BIM process.

2. Literature review

2.1 The concept of building performance

The concept of performance linked to building dates back to ancient times, as described in a specific article of the code of King Hammurabi, who reigned in Babylon between 1955 and 1913 B. C., which states: "if a builder builds a house for someone and does not construct it properly, and the house which he built fall and kill its owner, then builder shall be put to death" (KING, 2005).

In 1953, the Council for Research and Innovation in Building and Construction (CIB) began to address this issue to stimulate and facilitate international cooperation and the exchange of information between governmental organizations so that everyone could adopt the same conceptual framework. A general trend toward deregulation has emerged in response to the lack of flexibility about prescriptive building regulations and a deficiency of an industry that promotes innovation (Szigeti & Davis, 2005; Tubbs, 2001).

In 1996, to develop, implement, manage and support regulations based on building performance, six countries created a forum in which they could debate building regulatory systems and provide for the exchange of knowledge and experiences (Almeida et al., 2010; Meacham, 2010). This forum, the Inter-Jurisdictional Regulatory Collaboration Committee (IRCC), currently has members from 15 (fifteen) countries – Germany, Australia, Austria, Canada, China, England, Netherlands, Japan, New Zealand, Norway, Scotland, Singapore, Spain, Sweden and the USA. In 2000, the European Union (EU) created the Performance-Based Buildings Thematic Network (PeBBu), which replaced the Eurocode, the older building code (Gülkan & Sözen, 2018).

In Brazil, the Performance concept development began in the 1980s, through the work carried out by the Institute of Technological Research of the University of São Paulo for the National Housing Bank and later for the Federal Savings Bank, called Minimum Performance Criteria. Requirements and criteria for evaluating the performance of single-family single-storey dwellings were systematized, considering structural safety, fire safety, water-tightness, hydrothermal comfort, acoustic comfort and durability (Borges & Sabbatini, 2008; Oliveira & Mitidieri Filho, 2012; Silva et al., 2014). In 2008, the first version of the Brazilian building performance standard was presented to the construction community. Due to the complexity arising from the proposed amendments to the Standard, the deadline to enter into force, initially in 2010, was extended to 2012 and, subsequently, to July 2013.

The standard specifies minimum performance criteria and evaluation methods for each user's need. It also defines the tasks and interventions required for the minimum mandatory service life of buildings, making the task difficult due to the amount of information to be considered, including the awareness of everyone involved in the project (Cotta, 2017; Silva et al., 2014). In summary, the need for knowledge of relevant construction system performance considerations, technical details and cost-effectiveness to establish meaningful standards within the organization (May, 2001).

In this case, Meacham (2016) highlights the challenge implementing building performance regulations that vary significantly in each organization, although they are similar in structure. According to Almeida et al. (2015) to ensure that all performance variables can be met planning, design, construction and maintenance procedures must be managed and executed correctly.

2.2 BIM and information integration

Traditionally, information systems play an essential role in the management of a business, a company or a project, supporting decision-making (Abdirad, 2017; Golzarpoor et al., 2016). BIM is recognized as a fast and virtual environment to simulate and explore various construction project options, whose objective is to improve the project/ work interface facilitating communications between all the stakeholders, and providing a framework for building data-rich product models (Abanda et al., 2017; Golzarpoor et al., 2016; Lu et al., 2013; Zhong et al., 2018).

There are several definitions for BIM, it is important to understand that BIM is not a common three-dimensional (3D) model but a process to improve performance throughout the life cycle of buildings, which should include the adoption and adaptation processes (Abdirad, 2017; Lu et al., 2013). Implementing BIM in construction projects can improve workflows and support the coordination of information during all project phases between different stakeholders. Thus, design and construction errors can be diagnosed and addressed before causing process delays (Franz & Messner, 2019; Wang & Chong, 2015; Zhu & Mostafavi, 2017). As a way of integrating information, BIM goes through all the stages of a construction project, enabling all participants to obtain the necessary information at the right time, helping to understand the project, and reducing common errors (Yan et al., 2014).

It is known that implementing BIM in AEC processes is not an easy task. Therefore, the role played by the project manager is essential to providing the BIM tool integration into the company's processes. The beginning of the migration of activities in Computer Aided Design (CAD) to BIM must be with training and standardization of procedures, and the increase in productivity will occur after the transition period.

3. Methods

Methodologically, the approach used in this study is the Design Science Research (DSR). DSR looks for builds, and evaluates artifacts supported by problem knowledge, to allow the transformation of situations and change their conditions to better or desirable states (Dresh et al., 2015). Artifact is something that is built by man; interface between the internal environment and the external environment of a given system (Dresh et al., 2015). According to Birkhofer & Wäldele (2005), the DSR has the function of generalizing the knowledge used in a specific area for a specific product type or process chain in all product development phases. The research is structured in five stages: the problem identification, the proposition of a solution, the development, the demonstration, and the tool validation. Figure 1 presents the research methodological structure.

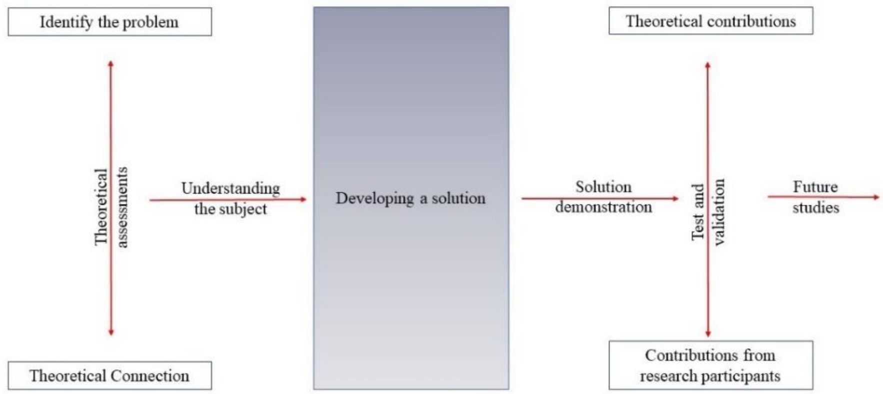

Figure 1. Research design.

In this article, an artifact is a tool that aims to support the integration of building performance information throughout the development of a construction project, which allows the control of information to guarantee the building performance, such as design specifications, simulation results, test results and definition of responsibilities as model parameters. The built tool makes it possible to launch and monitor information with data from the work, the model, and the stakeholders and allows the creation of a database.

3.1 Artifact scope

According to Dresh et al. (2015) and Oyegoke (2011), at this stage, it is necessary to seek as much information as possible, ensuring a complete understanding of its facets, causes, and context through the theory. The tool scope consists of the management of the five forms of evaluation of the building performance according to what is specified by the Brazilian standard for the conceptual design of a residential building: design analysis, computer simulation, tests, on-site verification and analysis of the use, operation and maintenance manual. The design analysis consists of verifying whether the information present in the design is by specific Brazilian performance standard. Computer simulations are performed to determine the behavior of the still in the design phase and can be used to asses structural performance and environmental comfort. The tests are performed to determine the actual behavior of the building, they are established in specific standards and, can be developed in laboratory or field, by sampling or prototyping. As well as on-site verification. Finally, information related to the building performance, such as specifications of construction systems and materials used, must be included in the Use, Operation and Maintenance Manual

3.2 Artifact proposition

Based on the practical problem identified, the second phase aims to define requirements and expectations in correlation with the contextual literature review (Oyegoke, 2011; Oyelere et al., 2017). The proposal present was a plug-in (NBR15575) installed in Autodesk Revit® software (Figure 2). The plug-ins are extension features in addition to the design tool (Negendahl, 2015). The use of the plug-in can be during the three-dimensional modeling of the building for release of design specifications and simulation data. There is also the possibility of releasing the results of tests and verifications carried out in-site during the construction phase to monitor the building performance. When activated, the plug-in will present the program user windows with building performance information to be completed by professionals in the AEC area throughout the construction project phases. In addition to assisting in decision-making, it ensures monitoring and compliance the performance standard requirements.

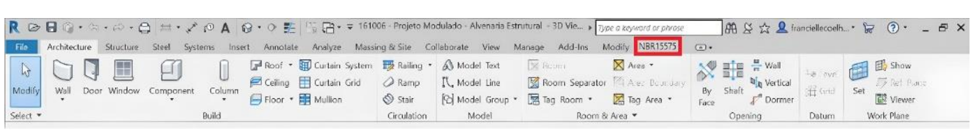

Figure 2. Revit® ribbon with the addition of the NBR 15575 tab.

Figure 3 presents the proposed conceptual framework for managing information related to building performance. The definition of the agent involved and the form for of evaluation each performance criterion are two vital elements for the information integration in the construction project phases. The activities that involve the construction project's success must be managed, visible and made available to all stakeholders in the project, making it possible to ensure the continuous feedback of information related to the building performance at each project stage.

3.3 Tool development

Microsoft Visual Studio 2017 is an Integrated Development Environment (IDE). An IDE is a full-feature program that can be used for many aspects of software development (MICROSOFT, 2017b). Visual C# was the programming language chosen tool development. Visual C# 2017 uses the C# 7.0 language supported by the .NET Compiler Platform, which is a class of libraries, by default, automatically related to Microsoft's C# compiler (MICROSOFT, 2017a, 2017b). These compilers create a detailed model of the application code as they validate the code's syntax and semantics. Through the IDE resources, it is possible to access the model that only compilers can create as they process the application code (MICROSOFT, 2017b). Developers can add functionality to an application by creating and implementing External Commands and External Applications they are made accessible (Oti et al., 2016). Thus, with the use of API's (Application Programming Interface), it is possible to "open black boxes" and allow the tools and end-users to share information that compilers have about the code (MICROSOFT, 2017b).

The Revit Platform API is accessible by languages supported by the Microsoft .NET Framework and .NET Core, such as Visual C# or Visual Basic, allowing access to the platform's design and modeling environment (Oti et al., 2016). The plug-in was developed to visualize the information extracted from the 3D model generated in the Revit® software and impute data referring to the ABNT NBR 15575: 2013 items, transforming them into monitoring reports. In addition to the plug-in, the integration tool had a Database Management System, Firebird, with IBExpert.

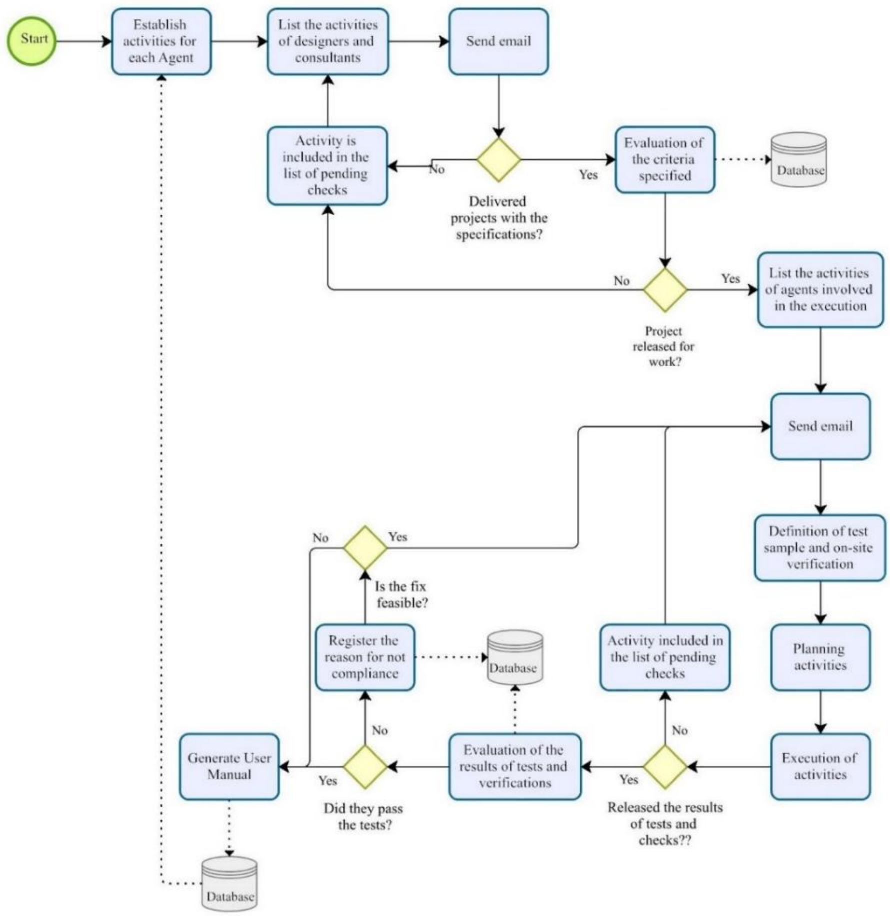

Figure 3. Information flow of the operation of the plug-in.

3.4 Artifact demonstration

At this stage, the objective was to present an initial version of the tool created, as an illustrative case, making it possible to analyze the feasibility of the solution. The developed tool enabled the systematic recording of performance information in the design phases (when planning the specifications, tests, on-site verifications, and necessary simulations), in the construction phase (when performing the tests and on-site verification), and keeping this information stored helping in the elaboration of the user manual (Oyelere et al., 2017). It is worth mentioning that the activities represented in the plug-in must be managed and executed progressively during the project phases. The construction ends with delivery to the customer; however, the maintenance actions must be monitored and passed on to the tool as a way to feed the database with the building performance information and feedback during the entire design process.

3.5 Tool validation

According to Dresh et al. (2015), "it is to ensure that the research carried out can serve as a reference and as a support for the generation of knowledge, both in the practical and theoretical fields". This phase aimed to reflect on the results obtained in the previous phases, as well as the contributions of the professionals participating in the research.

As it is constructive research, it is necessary to evaluate the generated artifact. Based on the model developed, in-depth interviews were carried out with experienced professionals to present and discuss the available content and obtain insights into the relevance and model's potential applicability. It is intended that the results of the validation that the model developed indicates innovative approaches in the sense of correlating the applicability and management of the Performance Standard with the project stages, as well as contributing to the theoretical knowledge, pointing out the practical applicability of the model developed and indicating future research.

4. Results

4.1 Tool presentation

As stated earlier, the Brazilian performance standard has a several requirements and criteria to be monitored. Each criterion is composed of different activities, which vary according to the evaluation method. For each activity, many agents can be involved. Figure 4 shows each plug-in parts, and Table 1 details their functions of each part.

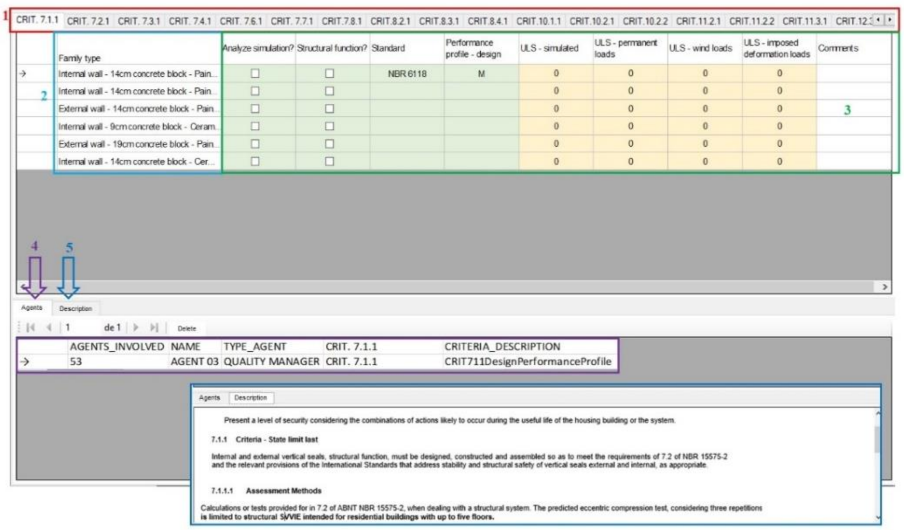

Figure 4. Performance information interface.

Table 1. Menu Functions displayed in the performance information interface.

#	Description
1	These are the criteria of the performance standard. Each tab corresponds to criteria to be verified throughout the process.
2	Family type: are the wall families registered in the model.
3	Criteria activities: each column corresponds to information from the Brazilian performance standard.
4	Agents: after registering all the stakeholders in the process, the project coordinator needs to define the attributions of these participating agents.
5	Standard items: when activated, the section of the standard corresponding to the criterion will appear.

The first step was to register the model, whose numerical code established by the system was number 5 (five). Subsequently, the stakeholders were registered. According to León et al. (2019), it is necessary for the project management team to identify and prioritize, in the form of procedures, the involvement of each of the agents in the project development. In this sense, for each evaluation method included in the standard, their respective stakeholders were registered.

The second-round launches begin with the building information still at the design stage. All criteria have four fundamental pieces of information that still need to be defined in the early design stage: sample definition (test, simulation or on-site verification), list of reference standards, building performance profile (minimum, intermediate or higher), and project service life.

The user must indicate the walls that will be simulated and tested according to the families registered in the model. It is worth noting that the evaluation methods, simulation, tests, and on-site verification are generally carried out by sampling. Such definitions must be carried out in the early design stage together with the designers and consultants of the construction system. Subsequently, in the "Standard" column, the reference standards must be listed and considered throughout the process, in addition to defining the "Building Performance Profile" and the project service life indicated by the designer.

In the case of carrying out tests, in Figure 5 below, the example of suspended loads on vertical fences at a point described in Criterion 7.3. The user indicates the test performance and the results obtained. The rules and restrictions are according to the requirements of the standard. Based on the test results, the "pending test" information changes to "Minimum", "Intermediate" or "Higher". In addition, it is possible to store the test report by clicking on the results column, and the reporting storage screen will appear on the interface. The on-site verifications were programmed with the same routine as the evaluation by testes. Based on the results of the assessments, the "pending test" information may change to a minimum, intermediate or higher.

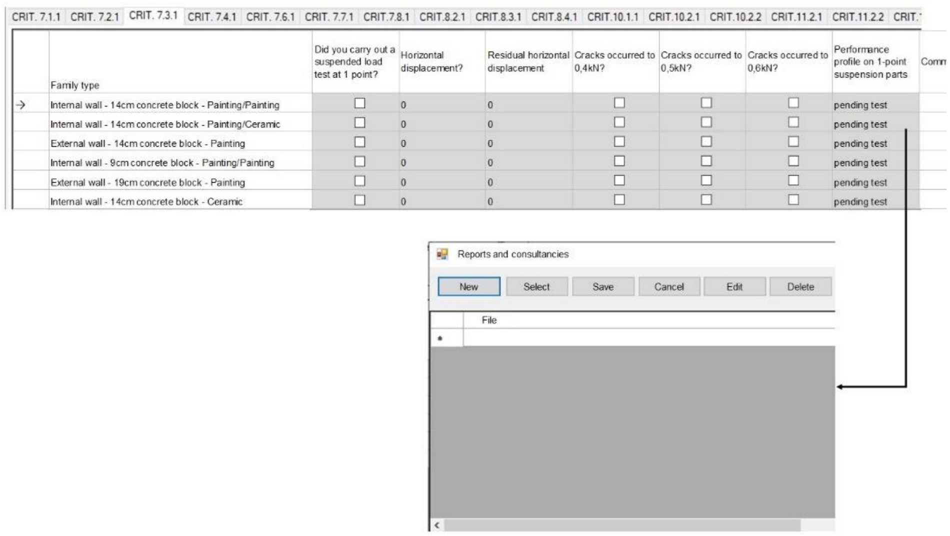

Figure 5. Building performance information screen - evaluation method: test.

Final product information is based on design specifications, material acquisitions, and service execution. With the systematization of this information, there is a space in the plug-in to be launched during the project development and construction of the building. The information entry screen, aiming to facilitate the gathering of information at the end of the project for the preparation of the use, operation, and maintenance manual.

4.2 Tool applicability

It is known that the complexity of integrating information related to the amount of data generated and collected in parallel by specific sectors, even without considering the needs of other stakeholders or the project development phases (Sanchez et al., 2018). The integration of the process can be carried out through electronic "cloud", in which participants will view project information and enter or review each attribute of the building performance. Even if the participant does not have the plug-in installed, it is possible to fill in the necessary information in the template shared by the project coordinator.

In the context of construction projects, all agents are part of this organizational structure. From the earliest possible moment, different types of boundary objects are historically created by the various parties to ensure communication and coordination (Al Ahbabi, 2014; Forman, 2018). Discussion and understanding of information that impacts building performance must happen early in the design process. Project stakeholders must establish a high level of understanding of what they can deliver through collaboration and what functionality is needed for BIM to meet customer requirements (Al Ahbabi, 2014). In this sense, when optimizing and connecting all building performance information integrated into the design process is carried out with the plug-in at all project stages. Due to the amount of information needed to meet the Brazilian performance standard, monitoring them is not a simple process and requires the involvement and knowledge of all agents. In this way, the proposed tool contributes to the increase of the efficiency of the coordination and integration of information, favoring communication between the agents.

4.3 Application and validation

This phase was one of maturing and deepening the concepts. To assess the feasibility, effectiveness and suitability of the tool developed, the author presented it to the professionals interviewed. The research involved four professionals from the civil construction sector, who are part of the staff of construction companies, all with experience in multiple floors residential construction projects. All selected participants had already participated in at least one project that met the requirements of the Brazilian performance standard. Table 2 presents the general characterization of the professionals participating in the research, highlighting training, occupation, and time in the market and the construction company. The evaluation process aims to analyze the tools proposed in the search for their improvement. Therefore, the professionals' participants in this research presented their criticisms for the tool improvement.

Table 2. Characterization of the professionals participating in the research

Agents	Training	Occupation	Training time	Time in the company
AGENT 1	Civil Engineer	Quality manager	10 years	8 years
AGENT 2	Civil Engineer	Construction Engineer	12 years	7 years
AGENT 3	Civil Engineer	Quality manager	6 years	8 years
AGENT 4	Civil Engineer	Project Manager	5 years	7 years

For the integration of building performance information, the level of collaboration necessary depends on the project scale and complexity, both in the management of information between the stakeholders, and throughout the phases of the construction project. Any project involves interaction between different participants, and most activities require a proper understanding of each one's needs (Sinesilassie et al., 2017). This relationship between stakeholders, activities, and information can therefore have a substantial influence on project outcomes (Croitor, 2008; Oppong et al., 2017).

This phase is important because most of these projects consider the possibility of reading and understanding data structures to transfer information to BIM models through BIM (Zanchetta et al., 2017). The integration of information is holistic, as it involves all professionals involved in the project development. From the design phase to maintenance management, each one with their knowledge of the decision-making process will increase the project's constructability, functionality and economy. That is, it will meet all user requirements (Al Ahbabi, 2014).

In general, the plug-in presentation and evaluation processes were carried out in three stages. The first step consisted of inserting the data presented by the company into the NBR15575 plug-in database. The second stage consisted of training the project coordinators, following the script presented in the item "Presentation of the tool". In the third stage, the project coordinators who participated in this research (Agents 1 to 4) evaluate the tool's functioning.

Agent 1 considered the plug-in development very positive, showing concern about the involvement of other agents due to the amount of information that makes up the Brazilian standard for building performance. For this reason, Li et al. (2019) highlight that it is necessary to understand and position the roles of each agent involved in all stages of the development of the enterprise and clarify their rights and responsibilities to analyze its governance structure. The higher the level of involvement between teams, the more consistency there will be in project performance (Din et al., 2011; Gosling et al., 2015).

Agent 2 considered the integration of building performance information with 3D modeling software positive according to him, 100% of the projects carried out in the company are already being developed in this way. The volume of information to be presented to meet the performance standard was cited as a disadvantage. The issue of commitment to the use of the tool among all the stakeholders is worrying.

In a conventional design process, only after the owner and architect have defined that other designers and consultants are involved in the process. Site engineers enter a very late stage in the process, preventing design optimization and building functionality (McDonald & Persram, 2012). In this model, there is almost no exchange between designers; each performs their functions, leading to incompatibilities in the design and then generating changes that demand more human and time resources, prolonging the construction period and increasing costs of investment in construction (Zheng & Chen, 2018). To avoid this, partners must establish a high level of understanding about what they can deliver through collaboration and what functionality is needed for BIM to meet customer requirements (Al Ahbabi, 2014). In the case of the integrated information process, project goals and strategies related to building performance become optimized through a collaborative and interdisciplinary approach. In addition, the owner is more actively involved from the beginning than in the conventional process (McDonald & Persram, 2012).

Agent 3 considered it an excellent tool for planning and controlling the project of the enterprise, especially regarding the definition of responsibilities, monitoring, and applicability of the standard from the design phase. The disadvantage is related to the time required to release the information for each project. It is necessary, however, to build a standardized method for project evaluations, participants, and clients (Hwang et al., 2013). It is essential to ensure a sustainable balance between these elements for the success of construction projects, being fundamental, particularly in the execution of the required duties and the defined goals for the main stakeholders linked to the project (Kabirifar & Mojtahedi, 2019). The adoption of BIM, in this case for the information integration, allows designers to collaborate on the model, and any changes made by a designer can be accessed by others immediately through the cloud (Zheng & Chen, 2018).

Agent 4 considered time optimization and step integration that makes up the building cycle as the main advantage of implementing the plug-in. In addition, he highlighted the possibility of integrating project participants in a more agile way, ensuring a more critical and efficient analysis of the information generated. The importance of the collaborative environment, that is, trust and commitment between partners, so that they affect the relationships between these factors and the success criteria (Eriksson & Westerberg, 2011).

It is worth mentioning that the building characterization process and defining performance requirements depend on a structure for integrating the various stakeholders, including identification, evaluation, communication, and analysis, always focusing on user requirements (May, 2001), since this depends on a well-structured information flow to integrate the various stakeholders, the data, tools, and methods to develop an agreed decision on the building characterization within legal and regulatory standards(Meacham & van Straalen, 2018).

Agent 4 also highlighted the possible difficulties in using the plug-in within the scope of design software knowledge, as it is not yet aware of the tool. The challenges required for designers and builders regarding the integration of building performance analyses in the design and construction process increase (Reeves et al., 2012).

In summary, to ensure that the building performance requirements and each stakeholder in the construction project considered at all project stages, the allowed better information monitoring, making it easier for decision-makers and project managers.

5. Conclusions

The general objective proposed by this work was to establish a tool for information integration for different stakeholders, to involve them in the collaborative effort of continuous improvement of the building performance involving the construction project phases, incorporated into BIM.

Faced with the difficulty in managing the information that is in the Brazilian performance standard, most studies suggest the formation of work teams composed of professionals from different areas of knowledge to achieve the best performance result. The strategy for managing this information was the NBR15575 plug-in creation from the perspective of information and stakeholders in the process in each construction phases.

1. The proposed plug-in supports the management of building performance information in the design and construction process in BIM. The basic structure is based on the evaluation methods provided in Brazilian performance regulations (design analysis, simulations, tests, on-site verification). It has the function of helping the project coordinator together with his team to manage the information that is necessary to meet all the requirements, providing monitoring and formation of a database of this information;

2. This work offers an extension of the BIM scope in the area of information management necessary for monitoring the requirements of the Brazilian performance standard. In this article, we present the operations and results of the proposed

prototype for monitoring the construction project in all its phases, from the beginning in defining the building performance profile, in the launch of simulation results during the development of complementary designs, from the release of the test results and on-site verifications during the building construction to the information on durability and service life. The project coordinator is responsible for defining the responsibilities of each information;

3. The potential for monitoring building performance information based on BIM usages serves an important role in building information management. In this work this potential is the possibility of sharing information even if the project participant does not have the plug-in installed on his computer. Through a template it will be possible to fill in all the requested information, and when this information returns to the project coordinator will automatically be fed to the plug-in. In addition, there is the possibility of creating a database, which can assist in the decision-making process during the elaboration of new projects as a form of continuous feedback of performance results at each project phases. Thus, information integration in BIM has a promising future;

4. The tool allows prioritizing the information and activities the collaborative development of the project. Based on this work, building performance can be more comprehensively assessed and monitored with integrated databases, using the performance assessment methods described in the standard. It is worth mentioning that managing this information is not a simple process and requires contextual knowledge, leadership and management and communication skills.

There is a need for more research to understand how the flow of information can be used as an improvement tool in construction project management, especially in strategic information integration, to guarantee the building's performance in the process.

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