Decision Making in Real Estate Developments Based on Building Information Modeling – BIM

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ABSTRACT

This work presents the development of a multicriteria method to evaluate real estate investments based on Building Information Modeling (BIM). Information on possibilities in construction, renovation, expansion, acquisition or rental of buildings is used to enable a decision-making process. The BIM digital models contain building information from planning, execution and as built. The model contains the different representations of top, front view, plants and internal cuts besides the volume. The elements are refined and have the digital representation of data or information of a real estate business project and bring diverse possibilities of analysis. The choice among the available undertakings and the investments to be made is a complex problem that involves relationships between the goals and criteria of each project. The proposed method classifies the undertakings projects using objective criteria based on information automatically obtained from the digital models. It also considers intangible criteria, which are subjective evaluations based on the experience of specialists in the area. This comparative method among project alternatives has proven to be feasible and quite useful, as shown in the case study presented, and it can be further improved by developing a recommender system based on historical data from previous evaluations.

Keywords: Multicriteria Methods; Analytic Hierarchy Process (AHP); Building Information Modeling (BIM).

1. INTRODUCTION

The development of research, methodologies and solutions that integrate different information has the potential to bring improvements in strategic areas such as Civil Engineering. New construction or enhancements to existing projects can be improved with the use of new technologies.

Considering the demand for the use of new spaces and the availability of real estate assets, information management can be very useful in the decision-making process in the area of Architecture, Engineering and Construction (AEC).

New real estate investments involve various activities such as search, acquisition, construction, expansion, renovation or rental of buildings. These usually deal with large capital investment and are influenced on different standards to living and consumer demand. At the same time, investors need to be on the lookout for the best way to make a profit from the construction of these assets. The decision about which projects to carry out must be based on current technological inventions, historical data and activities used along with improvements in Project Management in all phases.

Current Information and Communication Technology (ICT) capabilities allow Computer-Aided Design (CAD) processes to incorporate a variety of informational resources. In addition to the geometric representation of the drawing, these features include the use of the three-dimensional model, the modeling of information with the use of intelligent objects and the database. In this context, in addition to providing tools for the representation of geometric forms based on CAD technology, the process known as Building Information Modeling (BIM), seeks to optimize the design of construction projects.

For Chiavenato (2004) [1], this planning allows for the early determination of the activities to be carried out, objectives to be achieved and helps institutions or companies to organize themselves to achieve the desired goals.

New tools that are based on overall project challenges, such as budgets, deadlines, and product excellence, can help organizations to achieve better results and to approximate the overall expenses proposed in the planning process.

According to the Project Management Institute (PMI)[1], the management of a project is the application of knowledge, skills, and techniques to execute it effectively. Thus, information contained in the BIM models provides and defines a data life cycle, which allows for improvements in the planning, assessing progress and increasing knowledge about real estate undertakings at different times.

The identification of information from various external and internal sources to undertake projects in the AEC area enables the inclusion of data in the digital BIM models representing these projects. Three models were considered to demonstrate the proposed method. These models were structured hierarchically as a multicriteria problem. The analysis ranks the possibilities for the desired solution, based on peer-to-peer comparisons, in a process that sometimes becomes indispensable for decision making.

2. INFORMATION RETRIEVAL IN BUILDING INFORMATION MODELS

The technology known as building information modeling (BIM) came about with the evolution of the graphical applications aimed at the generation of technical drawings (CAD) occurred in the 1990s. This new way of designing, or better, modeling the information of a building, as well as the application of CAD solutions to the AEC industry are widely discussed in papers such as Eastman et al. (2005) [2] and Björk and Laakso (2010) [3]. Some of the main features, recommendations and ways of using the various technologies associated to the BIM technology can be obtained in Eastman et al. (2011) [4] and in Porto *et al*. (2015) [5]. The latter also presents a detail of the characteristics and recommendations for the implementation and better use of this technology. BIM is also widely discussed in works such as those by Jacoski (2003, 2008) [6] [7], Flemming *et al*. (2004) [8], Isikdag and Underwood (2009) [9], Pereira Junior and Baracho (2015) [10] and Laiserin (2019) [11], and can be considered a new industry standard, just as with CAD technology.

BIM technology contains all the information required of a building or a real estate investment in a virtual model. The virtual model can be used to extract information, to automate the undertaking's documents generation, to improve constructive aspects, to analyze conflict, to plan, to schedule, to analyze cost and budget, among others. The life cycle of the BIM process covers the entire useful life of a building or construction, as shown in Fig.1, taken from Cobau (2019) [12].

BIM can be understood as the technology responsible for managing a huge amount of information related to construction and is also a great repository of information. The use of BIM technology brings challenges and opportunities worldwide and is also being established and gaining prominence as a tool for the design and management of Architecture and Engineering (WATSON, 2011; BRYDE *et al*., 2013; PORTO et al., 2015; PEREIRA JUNIOR, BARACHO, 2015) [13] [14] [5] [10].

BIM software runs on graphical platforms and uses various ICT resources to allow the manipulation of digital models of a building or construction. The software uses multidimensional and parametric digital representations, as well as, intrinsically, the paradigms of object-oriented programming (OOP), which is a technology for programming computers in which "objects" are the fundamental elements that represent the entities involved in the system. More details on OOP can be obtained in works such as Gamma *et al*. (1995) [15].

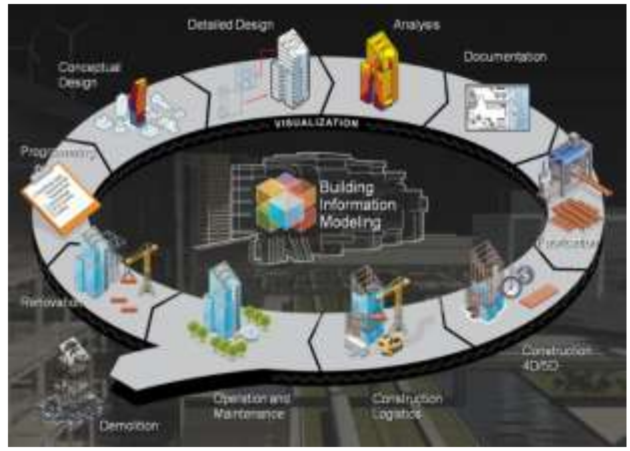

Figure 1 - BIM process
Source: Cobau, 2019 [12]

Many BIM software also offers tools to extend functionality by creating new interfaces within their environments (extension applications known as plug-ins or add-ins), further enhancing BIM capabilities. These extension applications access, through source code, the parametric objects of the BIM models, which represent the building components, also known as family instances, and thereby retrieve useful information in various contexts. Thus, the information contained in the BIM models allows several analyzes and developments, such as the one proposed in this work.

Fig. 2 shows a prototype developed to read data from a BIM model and prepare a global budget of the building based on the costs of each component or family instance.

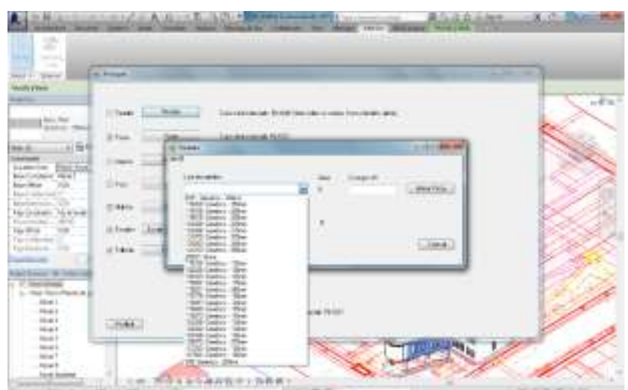

Figure 2 – Add-in that estimates budgets of BIM models
Source: Authors

The elaboration of computational solutions for Engineering problems using BIM technology can be associated with the use of several tools and methodologies. Source code snippets, useful for the development of extension applications for Revit software

[1] Project Management Institute – PMI. <https://www.pmi.org>. Accessed March 3, 2019.

(AUTODESK, 2019) [16], are available on several websites such as Tammik (2019) [17].

3. MULTICRITERIA METHODS AND RECOMMENDER SYSTEMS

For Nutt (2011) [18], in a decision making's process, managers should evaluate available alternatives and choose an option based on specific criteria.

Decision problems can be solved by some methods, including multicriteria methods and recommender systems.

Thokala & Duenas (2012) [19] propose a classification of multi-criteria method approaches into three categories: value measurement models, over-classification models, and goal-based or reference-level models, Figure 3.

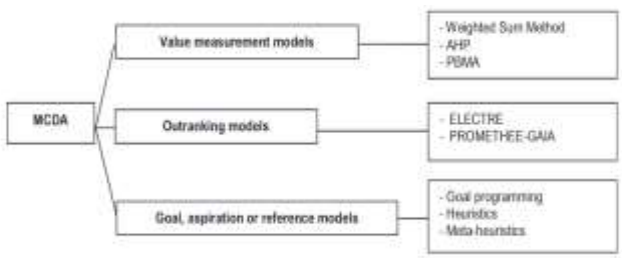

Figure 3 – Classification of multicriteria methods
Source: Thokala & Duenas, 2012, p.1173 [19].

Value measurement models, including the Analytic Hierarchy Process (AHP), are those that allow value functions to be applied to measure one option against another. The degree to which one option is preferred over the others is represented by comparing values, initially for each criterion, and then integrated into a global set (NUTT, 2011) [18].

Some examples of established methods using this approach are: methods based on the multi-attribute utility theory (MAUT); von NEUMANN, MORGENSTERN, 1947 [20]; PEACOCK, 2007 [21] and those based on hierarchical analysis – AHP, DANNER et al., 2017 [22]; SAATY et al., 2001 [23].

Table 1 describes the characteristics of these two multicriteria methods within the value measurement approach mentioned above.

Table 1 – Types of multicriteria methods

Method	Approach	Positive Points	Negative Points	Applications
MAUT	Value Measurement	Consider uncertainties, Incorporate preferences	Needs a lot of inputs, Need to be accurate	Economics, finance, water and energy resource management, agriculture, health
AHP	Value Measurement	Ease of use, Hierarchy adapts to different issues	Interdependence between criteria and alternatives	Resource management, corporate management, public management, strategic planning

Source: Authors

The AHP type is justified in decisions that imply the selection of multiple alternatives and criteria. As a rule, decision makers have mutually exclusive goals and may process information in different ways because of their value judgment and experience. Therefore, multi-criteria methods have emerged to facilitate situations where more than one criterion is evaluated and considered in the decision-making process (Chen, 2006) [24].

Aggarwal (2016) [25] presents widely the recommender systems, explaining that in these systems an analysis based on the previous interaction between users and items is performed. This analysis applies well to web-based e-commerce systems where customer-to-item relationships are represented by transactions.

The recommender systems can use a variety of data sources to infer customer interests if the interests and inclinations of the past are often good predictors of future choices, according to Aggarwal (2016) [25]. A notable exception, also according to the author, is the case of knowledge-based recommender systems, where recommendations are suggested based on user-specified requirements, not on the user's previous history.

Zhang *et al*. (2018) [26] propose knowledge-based recommender system framework for improving BIM-based design efficiency. In that work, the authors also present in detail a prototyped system for interior lighting selection, developed as a Revit plugin and based on the proposed framework.

The decision-making method presented in this paper focuses on the multicriteria aspect, leaving the development of recommender systems for future improvements. Moreover, among the multi-criteria method types, the AHP has been adopted here. The following section explains how this method applies to the problem to be addressed.

4. ANALYTIC HIERARCHY PROCESS (AHP)

The modeling of complex problems in a hierarchical structure involves the relationships between goals and criteria that express the alternatives details. As discussed in Saaty et al. (2001) [23], this hierarchical structure is expressed from the objective for the criteria and alternatives at successive levels.

The multicriteria method has three principles for its application, briefly explained as follows:

The construction of hierarchies: in which the problem is structured at multiple levels and is a fundamental step to understand it;

The definition of priorities: which is based on the ability to perceive the relationships between objects and diverse situations;

The comparison between the criteria pairs: it must also observe the logical consistency, in which the Analytic Hierarchy Process (AHP) allows to evaluate the prioritization model built for its consistency, making use of mathematical concepts such as matrix manipulations.

For the proposed analysis, results from unstructured interviews with AEC specialists is considered. Each individual evaluation of some real estate investment alternatives is compared one to another and between the criteria coming from the BIM models or CAD projects. The definition of priorities among the criteria is then performed among the elements of the hierarchy identified.

The matrices of judgment (always square matrices) are generated, where the number in row *i* and column *j* gives the importance of the criterion *Ci* in relation to the *Cj*. The relative importance among the elements aims to minimize the inconsistency of the elaboration of the matrices of judgment.

The degree of inconsistency reflects the accuracy of the judgments made by the managers and a maximum degree is stipulated. Previous works detail the description and the steps of calculations in a similar use of the method (BONATTI; BARACHO, 2015, 2016) [27], [28].

5. PROPOSED APPROACH

The proposed approach is to develop an extension application that automatically retrieves information from BIM models and feed the criteria to be used by the multicriteria analysis. In this analysis, each BIM model, which refers to an investment project, is then evaluated according to a comparison that should be made by AEC specialists.

Modeling

The Fig. 4 presents a BIM model for the building complex of the old School of Engineering of the Federal University of Minas Gerais (Universidade Federal de Minas Gerais – UFMG). This model was created using the software Revit and represents the old buildings as it is. Then some alternatives of investment projects to continue the life cycle as a viable real estate development and a useful public facility were proposed and analyzed to evaluate possible enhancements.

When the new facilities of the School of Engineering moved to the UFMG campus, located in the Pampulha region of the city of Belo Horizonte in the early 2000s, alternative uses would need to be considered for the old property located in the center of the city. An alternative that emerged then was its donation to another public agency. This new owner would then be responsible for renovating the property to adapt it to its new use.

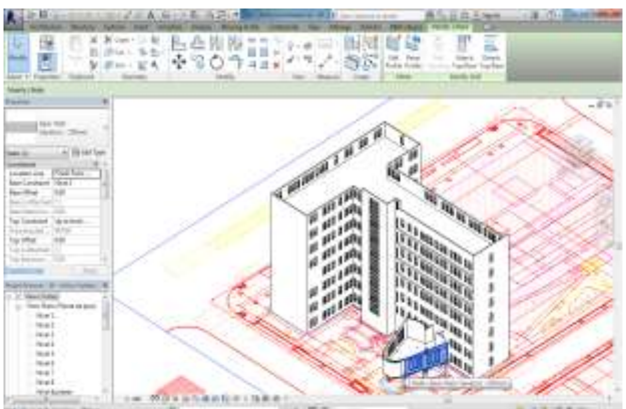

Figure 4 - BIM model of the old School of Engineering of the UFMG
Source: Authors

The Brazilian Labor Court accepted the transfer of the real estate assets and began a plan to carry out the reforms, adaptations, and new construction required. Around 2010 the architectural project for the complex was then idealized and contracted. However, the process of approving the project with the local public agencies was too time-consuming and involved, among several other setbacks, the amendment of the specific legislation surrounding the project to adapt the local vocation to the functioning of the new labor justice forum.

BIM was not adopted, and the project was not completed until the bidding for its construction was carried out, around 2016. In the expectation of finalizing the project at the executive level, and beginning construction soon, public agency was faced with numerous problems of inconsistency and incompatibility in the project. Subsequently, during the execution of the first subcontract, referring to a smaller building, on a plot of land adjacent to the main building, which would be used as an annex and parking lot, so many unforeseen circumstances arose that the construction had to be suspended.

As the construction of the real estate complex has been halted, a deadlock needs to be resolved. As early as 2019, it was hoped to give the property another useful purpose, such as passing it on to another public agency, or else the project could be resumed. But in the case of the resumption of the project some considerations need to be made.

The entire project will need to be redesigned, because under current Brazilian legislation, BIM is already necessary and mandatory for public real estate projects of this size in Brazil. Consequently, decision-making options emerge, which motivated the present analysis of the real estate investment project alternatives.

Methodology

The adopted methodology is in accordance with the objective of making feasible the use of building information modeling in a decision-making process that involves real estate investments. The first step is to identify the elements that make up the structure of the decision problem. Criteria are then defined to make a comparison between the viable project's alternatives.

Data from the BIM models are considered as requirements for the automation of the process and compliance with some of the analysis criteria required by the method. Historical data from previous decisions also can be considered in the methodology proposed as a recommendation system, but this complementary approach was left for future developments.

6. EVALUATION

The information contained in the context of BIM process and models, retrieved from functionalities present in a tool or software, were inputs for the execution and the presented result.

The adopted multicriteria method allowed, using this information, the comparative analysis between the five criteria considered. Three scenarios of projects or investment alternatives were also considered. An evaluation of the results obtained was then performed.

Information Retrieval

The criteria were defined based on the information extracted from the BIM models plus others, based on the considerations of respondents that are experts from the AEC sector.

The evaluation of these criteria and the calculation of consistency allow organizing the results of each of the respondents. For execution of the process, judgment matrices are generated, and the priority of one alternative over another is given at the end.

Definition of Criteria

In a BIM environment, some criteria can be automatically obtained from the models. In addition, subjective criteria were considered, for example, the manager's intention to undertake projects in a certain area or to use certain materials or even if he thinks he has more expertise to execute. Thus, as an example to be applied to the case study presented in this paper, the following criteria were proposed:

C1: Overall cost of the model / project: objective criterion, obtained based on the BIM / CAD information resources;

C2: Level of detail of the model / project: this objective criterion aims to represent compliance with current regulatory standards, depending on the technology adopted, which could also be treated as a simplified code-checking analysis;

C3: Complexity of the model / project: objective criterion that considers variables such as type of materials, geometry, terrain, foundation components and aggressiveness of the environment. It can be obtained internally in the case of use of BIM models or in the specifications, in the case of CAD projects;

C4: Maturity of the organization: this subjective criterion does not have a specified value, because it evaluates aspects such as the organization's expertise in relation to the use of the adopted technology, the number of professionals trained and the existence of appropriate software;

C5: Organizational experience: subjective criterion that considers the organizational interest for the execution of the investment project.

Comparison Between Projects

The information and data used to evaluate the proposed approach were obtained from the three investment project alternatives for the building complex of the old School of Engineering of UFMG, shown in Fig. 4.

A1: existing CAD project for a refurbishment / retrofitting of the existing building complex. The level of detail of the projects is very low. Standard materials have been adopted in the specifications and the modeled geometry is only approximate, but the cost is relatively low;

A2: migration of the existing CAD project for the building complex to BIM technology. The level of detail of the BIM model will be considered medium, since the team needs to be trained and does not have great experience in the new technology. The specification of materials is generic, but the geometries will represent the reality of the project very well, so there should be few changes during execution. However, no cost allocation was made and there is a budget limit;

A3: new design conception using a complete BIM model from scratch. The BIM model will have a high level of detail, with full coverage of construction components. The material specification will reflect exactly what is to be built and the cost allocation will be made for all components. However, the overall cost will be the highest among the project alternatives.

From this scenario, AEC specialists can participate in the evaluation. With a scale of conformity of values (1 - equal, 2 - slightly more important, 3 - more important and 5 - much more important), we arrived at a matrix of correlation between criteria.

This correlation matrix reflects the pairwise comparisons between all the criteria. To illustrate, consider the following question: how important is a criterion, such as cost (C1), relative to another, as the detail level of the model / project (C2)? Thus, the importance (weighting) of the criteria is determined in relation to the objective. The normalization of the correlation matrix between criteria, presented in Table 2, is called global priority, and following the AHP methodological steps, we define the Global Priority Vector (GPV).

Table 2 – Normalization of the correlation between criteria and corresponding GPV

	C1	C2	C3	C4	C5	GPV
C1	0,15	0,32	0,38	0,07	0,08	**0,20**
C2	0,07	0,16	0,38	0,10	0,15	**0,17**
C3	0,05	0,05	0,13	0,41	0,46	**0,22**
C4	0,44	0,32	0,06	0,21	0,15	**0,24**
C5	0,29	0,16	0,04	0,21	0,15	**0,17**

Source: Authors

The importance of the criteria in relation to the alternatives is then defined. Each normalized matrix is then generated, corresponding to the Local Average Priorities (LAP). The LAP vectors can be defined then. Table shows the LAP vector generated for the first criterion, C1, in relation to all the three alternatives, A1, A2 and A3.

Table 3 – Normalization of the correlation between alternatives to criterion C1 and corresponding LAP vector

C1	A1	A2	A3	LAP C1
A1	0,59	0,60	0,56	**0,58**
A2	0,29	0,30	0,33	**0,31**
A3	0,12	0,10	0,11	**0,11**

Source: Authors

The same process for other criteria results in the LAP vector set.

Table 4 – LAP vectors

LAP C1	LAP C2	LAP C3	LAP C4	LAP C5
0,58	0,16	0,25	0,33	0,60
0,31	0,59	0,5	0,33	0,20
0,11	0,25	0,25	0,33	0,20

Source: Authors

The sum of the multiplication of the LAP's by the GPV is the last step of the calculation and generates the result that defines the Global Priority, namely: A1: 0.38; A2: 0.39; A3: 0.23.

The overall priority reflects the importance given to the criteria involved in relation to the project alternatives, expressing in numbers the considerations made, for example, by AEC experts. In the given example, it is then suggested that the alternative A2 is slightly better than alternative A1, and both are considerably more recommended than the third one.

This result means that due to the organization's expertise in real estate investment and the characteristics of the models / projects, the most interesting alternative would be to adapt the CAD project to BIM; The use of the CAD would also be feasible, since the multicriteria analysis considered this alternative well, however, by Brazilian legislation this option can no longer be considered, since in Brazil BIM already has its own standards that require its adoption in some cases and its use and dissemination are increasingly intense.

7. CONCLUSIONS

In the informational context, BIM functions as a basis for the digital representation of data or information of a building, not just a static drawing. The BIM models represent the components of the constructive systems in a dynamic way, being able to interconnect to several other repositories or information systems.

The proposed method presents a way to explore the potential of BIM together with a subjective evaluation, adopting intangible criteria. The analyzes performed verified the operation of the method, but it must be taken into account that computational data were generated to test the method, based on real estate investment alternatives that have BIM models at different levels of detail.

A recommender system engine based on historical data can be plugged into the solution in future work. The implementation of this recommender system can assist the main analysis mechanism in order to allow the ranking of the investment alternatives to consider the historical data form previous decisions.

The paper includes the use of BIM to assist in various stages of the construction process and to assist in decision making. To make feasible the reform and reuse of a public building in Brazil involves many variables and a difficult and long process of decision making. This methodology presents a proposal to obtain more accurate information using BIM and in parallel to consider the expertise of the specialists in the decision-making process.

From this proposal will be carried out the complete modeling of the building of the former School of Engineering of UFMG and the simulation of different scenarios.

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