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Proposal of an Artefact in the Design of BIM Systematizing Lean Concepts and Tools through Neural Networks

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Abstract: Research studies related to BIM go beyond the use of models where other tools are applied in synergy. Lean, for example, has been inserted with the perspective of improving processes both qualitatively and quantitatively and goes beyond the technological aspects, covering behavioural and cultural issues. Studies related to the simultaneous applications of Lean and BIM have shown several benefits but also several adversities inside the BIM cycle. Having raised this gap, this work aimed to identify existing adversities in the design phase of BIM through a systematic literature review and enable a method to guide the main causal factors in this stage for companies that work with BIM using artificial neural networks, to build an artefact composed of Lean concepts and tools that promote simple alternatives to be applied in companies. The obtained results indicated that obstacles to the application of Lean and BIM in the design phase are related to technology, cost, management, shortage of professionals, data interoperability and changes to workflow processes. An analysis including standards and guidelines can be useful to understand the company's processes and apply BIM protocols in order to collect particularities and aspects to be implemented.

Keywords: BIM; Lean; neural networks

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1. Introduction

The construction planning process is experiencing a period of transformation where current techniques have proven to be insufficient and communication between interested stakeholders, throughout the life cycle of a project, is fragmented.

Building practices have changed considerably, including digital technologies and tools such as building information modelling (BIM), automation, prefabrication, artificial intelligence, 3D printing, etc., to increase efficiency [1,2].

The inclusion of these technologies is due to important requirements such as the identification of sources of waste and delays at the beginning of the construction phase and the implementation of earlier measures to eliminate these occurrences. Within this context, the application of techniques, tools and systems in companies that aim to integrate processes that minimize costs, reduce times, and increase productivity and performance on a global level, is becoming increasingly necessary in such a competitive market.

Thus, the civil construction industry (CCI) has been trying to implement, partially or entirely, concepts that enable the management of the flow of processes and information, among which Lean and BIM can be highlighted. BIM is a set of tools and information interconnected by a system, and Lean is an association of practices derived from a philosophy in which both aim at an incisive reduction in waste. It is relevant to investigate whether these concepts, practices and tools have proven to be sufficient, both separately and jointly, to reduce losses (costs and time) within the construction system and in particular in the design phase.

These concepts, originating from the automotive industry, have evolved from the initial work by Koskela, who proposed a coherent theory applying these concepts and practices from the Toyota production system to civil construction called Lean construction (LC) [3].

The critical objective of the Lean principles in construction includes establishing a clear set of goals for the delivery process, looking to maximize customer performance at the project level, as well as the concurrent design of products and processes [4,5]. When the Lean principles are applied to construction they take on a new dimension because participants consider the entire project lifecycle when they decide what to build and how to build it [6].

Lean organizational strategic projects allow managers to apply Lean management principles so organizations can align their creative activities into a value stream [7]. Complementing this idea, in [8] the authors highlighted that the main benefit of adopting Lean is the reduction in complexity offered to the organizational leader and decision maker.

Value stream mapping (VSM) was proposed by [9] with a software, and provided an innovative framework to support the design of work in a healthcare system. Within this same perspective, the VSM was applied to an emergency department of a hospital to improve patient waiting times and the level of service provided by professionals. After these studies, a simulation was carried out in two different layouts verifying which project model design was the most effective [10].

Lean management practices of the supply chain (cost reduction, flexibility, waste elimination and inventory minimization) are aligned with competitive priorities (demand management, customer service management, product development and flow management) suggesting a project model [11,12].

According to [13], when organizations are under increasing pressure to address economic, environmental, social and sustainability aspects, the integration of Lean-based practices act as an enabler towards this goal. Therefore, the use of Lean practices and tools are well disseminated in the industry, including civil construction, and produce a managerial function, covering organizations, process flow and management entirely.

Solving local and global challenges related to management practices has become an extremely complicated exercise, since detecting characteristic structural issues, and providing organizational leaders with Lean solutions, is a complex task. Within this context, Lean has been synergistically associated with BIM in order to generate faster, more complete and effective information among all stakeholders throughout the entire construction lifecycle.

In the current situation of the ICC, the established circumstances and existing points of view on these two conceptions have been presented in a collaborative and mutual context. For [14], the combined use of the philosophical principles of Lean production and BIM are efficient mechanisms to deal with the complexity of building projects. It was observed by [15] that the opportunity for making a better project management, increasing production planning and control (PPC), decreasing non-conformities in both processes and design, facilitating greater and more diverse stakeholder interaction [16].

From the perspective of [17], they state that construction management increasingly needs to integrate processes, technologies and people in order to eliminate waste and achieve more efficient results. The synergistic use of modelling and Lean construction principles can bring continuous improvement to the construction industry by improving productivity and minimizing waste [18–20].

Emphasizing the importance of integration between BIM and Lean principles also impacts organizational factors, such as coordination. Coordination time can be considerably reduced, while design and engineering issues can be pre-emptively resolved during the design phase [21], with a design structure promoting collaboration and communication through a BIM–Lean symbiotic process [22].

The studies carried out by [23] aimed to verify the different interactions between LC and BIM, and found improvements in efficiency rates in construction processes due to their similarities and overlapping benefits. From the point of view of [24], it was revealed that the different interactions between Lean construction and BIM reduced the volume of non-value added activities.

Researchers examined the effects of a KanBIM production control system on subcontractor task selections in internal works and the efficiency gains achieved on a project. The information from the BIM model influenced the decisions made by the construction teams when determining the sequence of activities, and positively affected the task selection behaviour of the commercial team leaders, resulting in a better workflow and waste elimination [25,26].

Lean integrated with BIM provided a crucial performance improvement in the sequencing of construction processes in an industrial facility. The implementation of a digital Obeya room (DOR), combined with the application of the plan-do-check-act (PDCA) stages, a compatibility matrix between Lean principles and BIM functionalities guided managers, leaders and decision makers to prioritize the correct, efficient and effective use of human resources, materials and technologies, making better use of resources and reducing work and waste during construction [17,27].

Analysing Lean interactions resulting from BIM processes and their transformations, ref. [28] realized that through the implementation of BIM project management processes at the construction site, Lean principles were achieved and congestions were identified.

A study by [29] combined Lean and Agile inside the BIM environment in a facility project. The results demonstrated that the proposed conceptual approach provided a way to implement and rapidly evaluate facility designs, minimizing the required models to achieve proper functionality.

According to [30], an improved workflow based on BIM and value stream mapping was proposed in order to simplify the process and achieve Lean construction. The results showed that if the proposed workflow was followed, there would be an overall productivity improvement of approximately 36% for the processing time and 38% for the total time. Better process viability and reduced lead times were a result of cultivating improved coordination and collaboration between the different project participants, which increased flexibility and transparency in processes, streamlining and synchronizing the workflow.

The two combined concepts of Lean–BIM, from the initial stages to the integrated process, can lead to an increase in efficiency, including time and financial savings, subsequently reducing the occurrence of future problems [31].

Through the research reported here, it can be seen that the synergistic use of Lean and BIM helps the construction life cycle in all stages. However, along with the demonstrated benefits, the most frequent issues or causal factors within the BIM cycle were highlighted, with emphasis on the design phase. These barriers or obstacles to BIM and Lean application in the construction industry are related to technology, cost, management, shortage of professionals, data interoperability and changes in workflow processes [32].

Machine learning through ANNs has been used to predict future issues, and is associated with several benefits, such as automation, versatile application to different subjects, and the ability to collect big data-banks [33]. In this work, neural networks are presented as another method which has garnered interest, with the objective of creating fast and innovative solutions in multiple disciplines.

In [34], an ANN was used as an useful alternative based on statistical concepts for recognizing patterns, e.g., convolution neural networks (CNN), efficient in the classification and identification of images, resulting in a faster training process and a less complex system [35]. Moreover, the system could learning and execute time series previsions.

ANNs are based on the function of neurons in the human brain and are responsible for processing information, characterized as computational models that have adaptive, learning, recognition and data organization skills [36]. They are related to computational intelligence by improving multivariate and non-linear processes [37,38] that are poorly understood or detailed [39,40] by humans.

Based on these facts, several research studies have been coordinated in an attempt to simulate the behaviour of the brain through the process of learning by experience, with the objective of creating intelligent systems capable of performing tasks such as classification, pattern recognition, and image processing, among others. Subsequently, the artificial neuron was generated, and later a system with several interconnected neurons.

The topology of the neural network is related to the arrangement of neurons in the network, how they are structured, and how the network is linked to the type of learning algorithm used. The network can be classified into: feed-forward, recurrent, competitive, multilayer perceptron, radial base function, and Hopfield networks.

The feed-forward neural network is a type of network structured in layers, the neurons arranged in distinct sets and ordered sequentially. The flow of information is always from the input layer to the output layer. The network information comes from the input layer or neurons (nodes) and is subsequently transmitted to the following layers until the output layer. This network is also known as an acyclic network, because its graphical representation does not include cycles. Moreover, it has some important particularities, among them: the neurons are arranged in layers, with an input layer (signal receivers) and an output one; the middle layers are called hidden layers, each neuron in one layer is connected to all neurons in the next layer; there are no connections between neurons of the same layer [41].

In recurrent networks there is the occurrence of feedback where the output of a neuron is applied as an input to the neuron itself or to other neurons of previous layers. This differs from a feed-forward network by having at least one feedback loop in which a cyclegraph occurs. This may consist of a single layer of neurons with each neuron feeding its output back to the inputs of all other neurons [41].

In competitive networks, according to [42], a competitive learning algorithm is used to solve, for example, a grouping problem. Neurons are divided into two layers: the input and output nodes, known as the "grid". Neurons of the grid are forced to compete with each other, based on the level of similarity between the input pattern and the grid, in which only the winning neuron will be activated at each interaction. The best known network of this class is the Kohonez network, also known as the self-organizing map.

In multilayer perceptron networks, the architecture is fully connected. This means that a neuron in any layer of the network is connected to all neurons (nodes) in the previous layer. The signal through the network progresses in a direct direction, it does not establish connections with lateral neurons (of the same layer) and the flow occurs layer by layer. The main training algorithm is the error feedback algorithm, based on the error correction learning rule that basically consists of two steps: the forward step, called propagation, where values originating from input neurons (source nodes) are applied to the hidden neurons and later their outputs are applied as inputs to neurons in the final layer. The backward step, responsible for adjusting synaptic weights through error calculations performed in the output layer, where the synaptic weights between the previous layers are adjusted according to the error correction rule [41].

Radial base function networks have a neural network design and work as a curve-fitting problem (approximation) in a high-dimensional space. They are classified into patterns whose structures consist of two characteristic layers: the input layer is composed of origin nodes (sensory units) that connect the network to its environment; the second layer, which consists of hidden units, applies a non-linear transformation from the input space to the hidden space (feature). For most applications, the dimensionality of the network's single hidden layer is high. This network is trained in an unsupervised manner using stage 1 of the hybrid learning procedure; the output layer is linear, designed to provide a response to the activation pattern applied to the input layer. This network is trained in a supervised way using stage 2 of the hybrid procedure.

Considering radial base function networks, ref. [43] showed that radial basis function networks can be applied in pattern classification and function approximation tasks.

The Hopfield network is a fully connected network, acting as an associative memory capable of storing patterns. In [44], an associative memory was used to store a set of vectors in such a way that if addressed with an arbitrary vector $\vec{y}$, it could return the closest vector in some predefined series. An associative memory can be interpreted as a pattern classifier, where classes are represented by stored vectors.

With the diverse range of topologies present in the literature, neural networks, in general, are applied in most areas of research.

Considering these facts, the following research questions were collected: Problems and adversities have been identified and are recurrent during the BIM cycle, especially in the design phase; the use of Lean concepts and tools in this phase has been shown to be efficient in identifying these problems.

To answer these questions, the existing adversities during the BIM design stage were first collected through a systematic literature review (SLR). After this, a method for sending the principal causal factors in the design phase to the companies working with BIM was presented. Finally, using an artificial neural network (ANN), an artefact was developed formed using Lean concepts and tools, to put forward Lean alternatives for applications in companies.

Thus, in the next section, the methodology is proposed with the inclusion of neural networks to eliminate approaches to adversities/causal parameters collected from the literature within the BIM project management process, with the objective of seeking Lean solutions to minimize waste.

2. Materials and Methods

The methodology used in this work was based on DSR (design science research), a research method for solving problems. We aimed to build and evaluate artefacts from understanding problems, allowing to transform situations, changing their conditions to better or desirable states, both in academia and within organizations [45,46].

DSR produces knowledge in the form of a prescription to support the solutions of a real problem or project, to build a new artefact [47]. To delineate the process of this research, the method was divided into four distinct phases, as shown in Figure 1.

Phase 1 comprises a systematic literature review (SLR) with the objective of collating primary studies on the subject, substantiating theoretical issues, seeking solutions to research gaps, and objectively identifying and understanding problems. In phase 2, the main causes of the problems were analysed in order to delimit the boundary conditions for proposing a solution to the problem. Phases 3 and 4 aim to apply a tool to the highlighted problems in a systematized way. Finally, in phase 5 shows the performance on a case study in an enterprise which works in design and has 18 years of experience in the market.

2.1. Phase 1—Identification of the Problem

In the systematic literature review (SLR) the databases Web of Science and Scopus were chosen. Both have slightly different advanced search systems; however, the same terms were applied to delimit the subject. In the chosen "STRINGS" for the search, the operators "OR" and "AND" were used in order to relate the search terms Lean, BIM and design, as shown in Figure 2.

With the theme defined, the next step was to determine the search strategy and synthesize the results. Search filters were applied on the cited platforms, characterized by title and with a time interval between 2015 and 2020. The classification of articles was based on the correlation between existing objectives, methods and keywords. The applied technique made it possible to obtain a greater perspective on the topic, as well as identify gaps in which more research is needed [48].

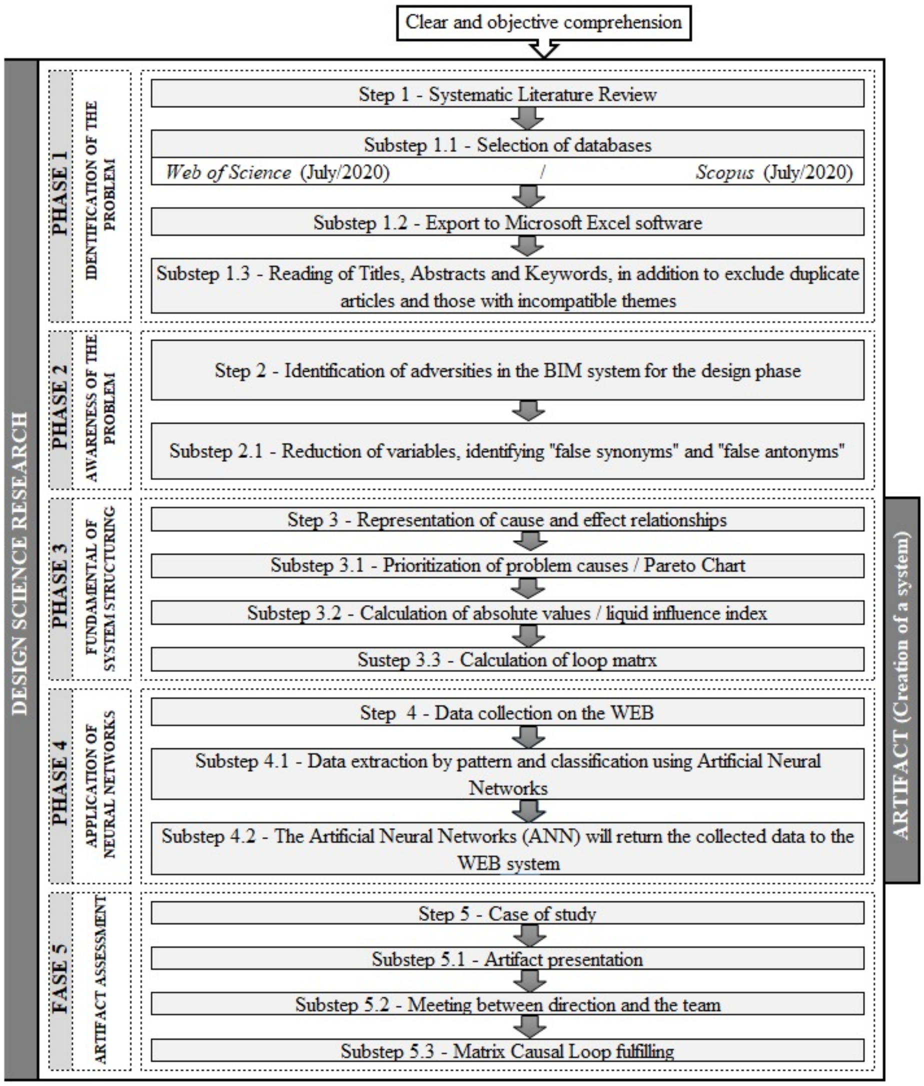


Figure 1. Structural organization of the workflow.

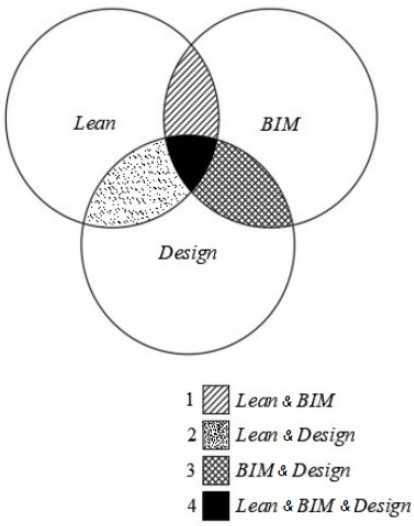


Figure 2. Theoretical framework.

In this way, the specific objectives of the SLR were to recognize relevant points concerning obstacles to designing in BIM based on reading articles and making a cut on the opinions of various authors in relation to the topic. This parameter allowed us to synthesize, according to the literature, the main factors (i.e., adversities, causal parameters, variables) identified within the BIM cycle for the design phase and their relationships with main stakeholders. This was the starting point for phase 2.

2.2. Phase 2—Awareness of the Problem

A total of 44 causal parameters were obtained, among them it was important to ensure that semantically similar terms (false antonyms) were not duplicated. For example, one person might mention speed and another might mention a deadline to finish, which, upon careful inquiry, may be the same phenomenon. Conversely, possible causes which seem to be identical but are fundamentally different (false synonyms) must be recorded in order to identify the unique aspects of each one. For example, customer delay and employee delay are similar causes, but not identical [49].

Transposing this reasoning to the research, it was observed, for example, for false antonyms "very heterogeneous design tools" and "variety of software", and for false synonyms "making wrong decisions". However, this is a recurrent aspect related to different stakeholders, i.e., designers and customers. When applying this method, there was a reduction in the causal parameters from 44 to 29.

2.3. Phase 3—Structuring the System

In this context, the introduction of the causal matrix demands a mathematical representation of the perceived causal relationships, which are structured and developed as a network analysis [50]. Along with this article, basic indicators of a network analysis were used, such as outside degree (outdegree) to highlight the influence of a cause over others, and the inside degree (indegree) for designating the influence factor of a cause related to others [51]. In addition to these indicators, analyses were complemented with matrix operations (multiplication and transposition).

The structuring of the loops matrix was began in a systematic way using the PHP programming language, as shown in Figure 3.

The Pareto chart was used to visualize and classify the processes of companies by order and importance, identifying errors and reducing their costs, risks and problems in the product or service. This means that sometimes the largest number of problems results in little damage, as they are irrelevant or trivial, and the smallest number of accumulated problems can generate greater losses.

It is important to emphasize that the causal parameters are related to the number of times they were collected and cited in the studies for the application of the Pareto chart, as shown in the Appendix A.

At the end of this stage, an analysis of the inter-causal relationships (causal map) was carried out with the generation and analysis of the loop matrix. The causal map is a mathematical representation of the perceived cause and effect relationships between the variables of a problem. For example, the statement "work generates richness, but richness does not generate work" satisfies the basic criteria for a causal map. In this statement there is no loop, since a causal relationship between work and richness is postulated, but there is no actual relationship between richness and work.

For illustrative purposes, a two-by-two matrix based on the last example is shown in Table 1. To express the idea that "work" generates "richness", "1" is placed in the second column of the first line. Since no other causal relationship is perceived, the other cells are filled with "0", resulting in the causal map where the lines describe the causes and the columns describe the effects.

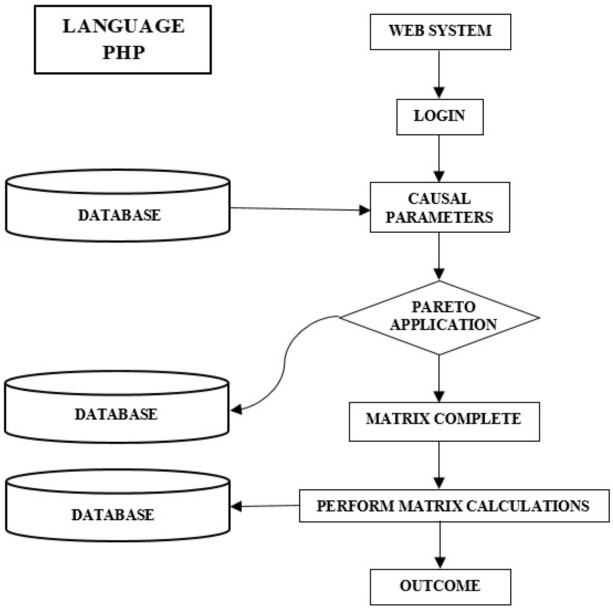


Figure 3. Systematization of the loop matrix.

Table 1. Example of a causal map.

	Work	**Richness**
Work	0	1
Richness	0	0

For this research, the causal loop matrix was completed in compliance with the following specifications: the influence can be positive, in the sense of motivating and aggravating the described cause in the column, indicated by "1"; it can be negative, in the sense of demotivating or reducing the cause described in the column, indicated by "−1"; or it can be neutral, indicated by "0".

The sum of the arranged absolute values in the rows of the causal matrix informs, for each cause, how much it interferes with the other causes, and to what degree the other causes are influenced by the sum of the arranged values in the column. The influence of a cause on the other causes is calculated by the outdegree or output degree networks (Σ row = outdegree). Furthermore, the sum of values in the columns is called the indegree or input degree networks (Σ column = indegree) [51].

Subtracting the input degrees (indegree) of the output degrees (outdegree) obtains the liquid influence index (LII), that is, which variables have the highest influence on the causes described in the matrix, discounting those that are influenced by other variables [52].

In programming, this first part of the system is classified into two steps, the front end (visual) and the back end (hidden part, where calculations occur). The front and back end work together on the project [53], as shown in Figure 4.

For the creation of the system visual platform, HTML, CSS and JavaScript languages were used. In the back end, the first step was to create an information set that can be moved inside the system, such as the causal parameters and their respective weights, the application of the Pareto chart, the articles, etc. To store the information, the MySQL 8.0.21 version database was used,in the SQL programming language, with the PHP version 8.0 programming language to perform the calculations.

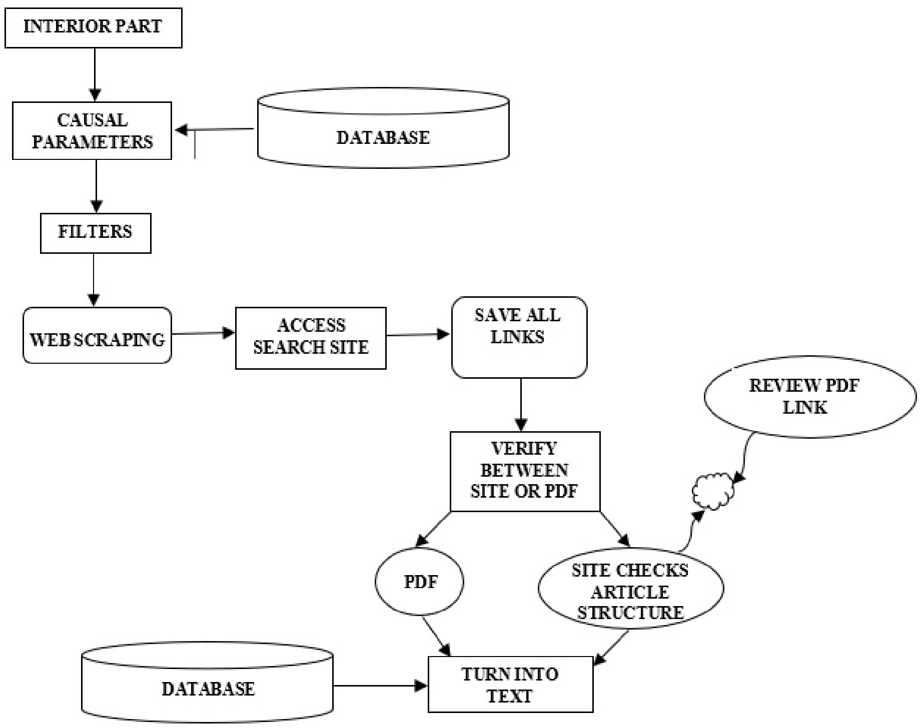


Figure 4. Structure of web system.

To guarantee the agility and safety of the system, the Laravel version 7.4 framework was adopted. A framework is a programming architecture that joins a variety of generic codes to simplify, structure and facilitate the web development process. Laravel is a free, open source PHP framework for web system development. Some prominent Laravel features include its simple and concise syntax, a modular system with a dedicated dependency manager, various ways of access to relational databases and several indispensable utilities to help with the development and maintenance of systems [54].

After calculating the Pareto chart from the transposed matrix, the system stores the causal parameters in order based on the number of loops. After this the system looks for the articles related to each variable in Google Schoolar and related platforms. To look for these articles and save them in our system, the technique known as web scraping was used.

Web scraping is a technique of collecting data from online platform, such as websites, social networks, etc. The data is captured from the scripts generated by the pages and programs, "scraping" the information that will be used in later analyses [55].

In this system, the web scraping searches the database for the variable name in English and the respective filters associated with it. The causal parameter and filter, using web scraping, send this information to the desired site (Google Schoolar, Web of Science, Scopus or IGLC).

These sites return several links related to the published articles, the system examines the structure of the articles, transforms all text information and saves it to the database. If the article is not found, the system checks for any PDF links, transforms the PDF into a text format, and saves it to the database.

The web scraping technique, applied to the collection of articles, used the PHP programming language in conjunction with the cURL library. The cURL library is a command line tool used to obtain or send data, including files, using the URL syntax. Using the LIBCURL library, cURL supports several common network protocols, including HTTP, HTTPS, FTP, FTPS, SCP, SFTP, TFTP, LDAP, DAP, DICT, TELNET, FILE, IMAP, POP3, SMTP and RTSP.

2.4. Phase 4—Application of Neural Networks

All the described steps in phase 3 were systematized and united with the artificial neural network (ANN), as shown in Figure 5.

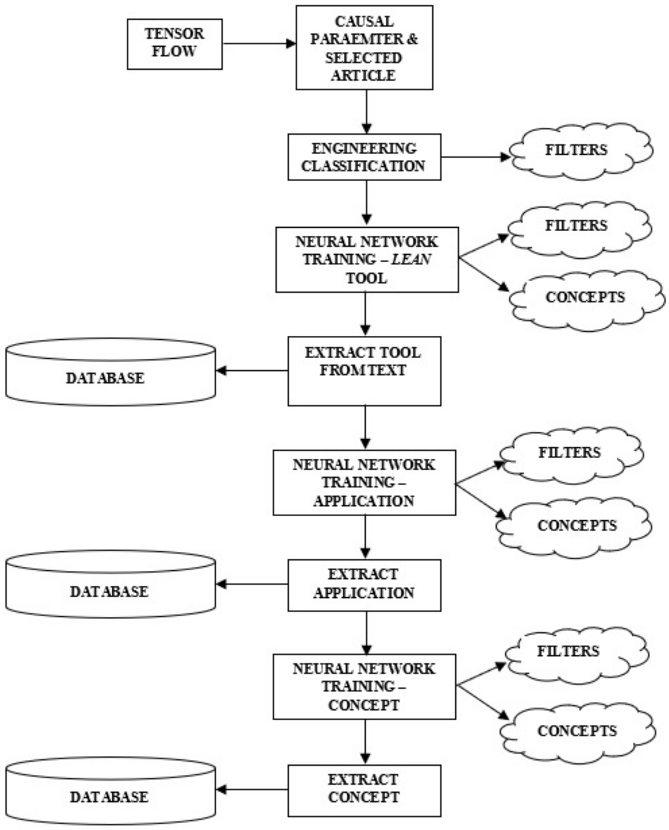


Figure 5. Representation of a neural network within the system.

For the construction of this neural network, the Tensorflow library was used. This is an open source library for machine learning, applicable to a wide variety of tasks. It is a system for creating and training neural networks to detect and decipher analogous (but not equal) patterns and correlations similar to the way humans learn and think. It is used for both search and production on Google [54].

In summary, in this research, the system searches the database for the variable, then the article related to the prediction model for that variable (defined filters), and finally applies the neural network in the article, as illustrated in Figure 6. Using this prediction model, texts are classified into tools, applications and concepts, and the results are stored in the database associated with the variable.

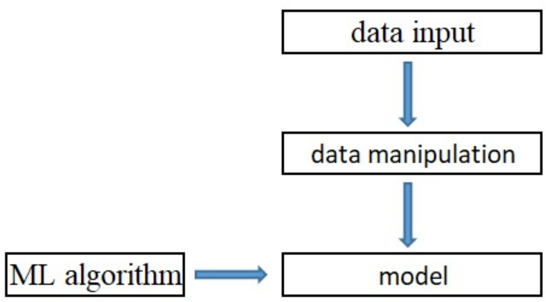


Figure 6. Prediction model.

Note that the model in Figure 7 is composed of a machine learning algorithm "trained" with the data we provided, in this case our created filters. When creating the model, we used the data at the input to obtain the results.

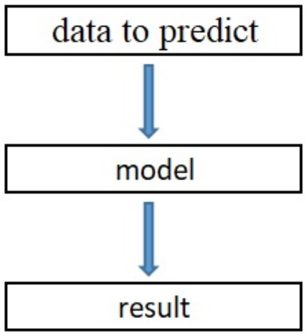


Figure 7. Model prediction process.

The purpose of the model was to build and categorize texts where the article is obtained at the input, and the tools, concepts and applications are obtained at the output. A training set, with all texts and labels (tools, applications and concepts), is categorized. In machine learning this type of task is called supervised learning, where the algorithm is taught about the correction of its errors [55].

After artefact creation, an analytical assessment was carried out, seeking to analyse the internal architecture as well as its interaction with the external environment [47]. The development of the analytical methods for appropriate models takes into account a wide range of external and internal factors, which is a complex problem [56].

2.5. Phase 5—Artefact Assessment

To design the case study, company "A" was chosen, which has worked with BIM design for eight years, consisting of two partner directors, one coordinator with expertise in structural projects and geotechnics, one coordinator with expertise in hydrosanitary and electrical projects, two structural designers, one designer with expertise in hydrosanitary installations, one designer with expertise in electrical installations, and three interns.

Once the company was chosen, the evaluation of the artefact was initially carried out in a meeting to present the tool to the two partner-directors and explain to them which guidelines should be followed when choosing adversities. In a second meeting, the partner-directors met with the entire company team to choose and define which causal parameters were more incisive inside that organization.

Once this step was complete, another meeting was held with all the company's members to explain and guide the causal loop matrix. It was decided, among all the participants, that filling the loop matrix would be carried out with the collaboration of all, without exception.

Finally, with the entire team gathered, the loop matrix was completed highlighting that all members gave their opinions on the relationships established between the causal parameters in that context.

3. Results

In this research, the several benefits that BIM offers were presented in the AEC industry. However, concerning the adversities inside the BIM cycle in the project phase, few studies have been developed to investigate these causal factors and seek solutions to the problem.

The first part of the results underline the opinion of some authors concerning which causal factors most explicit and cited in the literature, with subsequent the presentation of the artefact created as a possible minimization tool of these problems.

Regarding coordination, congestion, such as the lack of simultaneous project updates, and the lack of communication between the different disciplines in the BIM design phase, is a factor that contributes to the divergence problem [57].

It was shown by [58–60] that common problems are incur excessive cost and time, inefficient processes and technological aversion. When classifying these factors, specifically in the project phase, the following barriers were highlighted: requests for changes by customers, redesign, predictability of time, insufficient documentation, rework, changes in activities, inefficiencies in project reviews and discontinuity of them, low productivity, and lack of integration and collaboration between different disciplines. The lack of commitment between stakeholders was highlighted by [61], specifically between high and medium management.

The lack of integration may be related to the lack of systematic strategies for exploring projects or the lack of capable technologies for identifying the problem [27,62].

Following [63], the exploration of projects regarding the lack of comprehensive BIM protocols keeps all stakeholders on the same side. For example, it was observed that the same level of LOD was not maintained in all disciplines, creating a barrier both for the adoption of BIM and for the development and compatibility of projects.

Research by [64] concluded that depending on the scope of the project (residential, industrial, hospital) modelled in BIM, greater or lesser degrees of LOD can be achieved contributing to the imbalance.

The level equalization of project development can be an effective technique for standardizing information related to BIM design. In [65], it is relevant that a structured method obtains an interdisciplinary and common language and understanding among project participants. In the observations shown in [17,66], it is highlighted that the standardization of engineering information makes it possible to promote better collaboration and interdisciplinary communication, since the lack of these factors are incisive in the design.

The lack of communication, interaction and common misunderstandings between stakeholders are recurrent in the AEC industry, particularly in the design stage. These failures often manifest themselves through a number of significant areas, from design representation, understanding and translation to process fragmentation, resulting in delays [67,68].

This prognostic was evidenced in [69] focused on project management issues during the first design process, considering the critical impacts of these issues in subsequent phases. This hypothesis agreed with the conclusions of [70] showing that incorrect decision making by both designers and customers in the design stage inferred a worse performance of product development until the beginning of the construction phase. At this point it is too late to make any significant improvements at low cost.

Interoperability issues between structural engineering tools and software platforms act as a barrier in the collaborative design process [71]. The greatest difficulty in applying BIM models lies in the exchange of data, when designers from different professions use heterogeneous design tools [72].

Deficiencies in interoperability persist between architectural structures and structural designs, regarding the optimization of models. In this scenario, any change in the architecture requires the entire structural model to be redesigned, reanalysed, or reprogrammed [73].

With the disadvantages related to the BIM information system for the design phase, it is clear that a model which promotes greater interactivity between the stakeholders (architect, client, coordination and complementary designers) is ideal. Figure 8 shows this idea.

It is observed that all stakeholders, including those responsible for complementary projects (P1, P2, P3, P4 and Pn) are related to each other and participate simultaneously and gradually in the coordination process as the design stage evolves. A factor that promotes, from a theoretical point of view, greater communication and a better flow of information between agents.

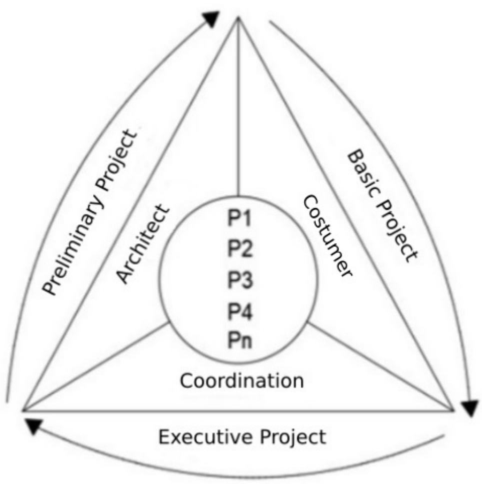


Figure 8. Integration model.

Therefore, only through a true collaborative process is it possible for architects to elaborate their project with few unwanted changes caused by other disciplines, often due to the lack of efficient communication between the design stages [74].

The lack of coherence between project participants is not limited to the aforementioned aspects. Factors such as a deficiency of hardware and software technologies, in addition to the low levels of education and training for new professionals, are important indicators for reducing adversities in all stages of the BIM design phase.

Complementing this idea, ref. [75] claimed that expenses related to the adoption of new technologies (hardware and software) also imply requirements for knowledge of the mechanism and its scope [76], in addition to training the workforce [77] which further increase costs, especially in small companies. However, even with these obstacles, there is a need to understand and develop BIM training mechanisms and models for its diffusion, mainly in small and medium-sized enterprises [78].

Concerning the interoperability of hardware and software, although there have been great improvements in the ability of systems to transparently communicate with another one, studies have shown limitations regarding communication between different platforms, even in the early stages of the project [79]. These limitations, according to [60], may be linked to the variety of software used by stakeholders.

Another relevant aspect, that promotes a more collaborative and innovative communication environment in the design phase, is the training of new professionals with knowledge of the process. However, some studies have demonstrated an emphatic antagonism towards this issue.

In research presented by [80] concerning the design of a BIM curriculum for training professionals in architecture and engineering, they realized, through a systematic review, that the implementation of BIM in university curricula is an important requirement to satisfy the educational demands of the AEC industry.

Along with this idea, ref. [81] concluded that building information modelling is becoming a standard for design and should be incorporated into the education of future engineers and architects. Highly developed countries face a significant problem caused by the lack of specialists who can efficiently operate this technology.

Finalizing this idea, ref. [82] complement the research by reporting that the lack of BIM knowledge is, among architects and contractors, predominantly caused by not being taught in US architecture schools.

However, despite the reported potential benefits of designing in BIM, the challenge remains to develop tools that suppress the highlighted adversities. From this gap, we consider the idea of structuring a method that would help BIM management in the design phase with the systematization of the causal loop matrix and the application of Lean tools aided by neural networks in a case study. Figure 9 represents this idea.

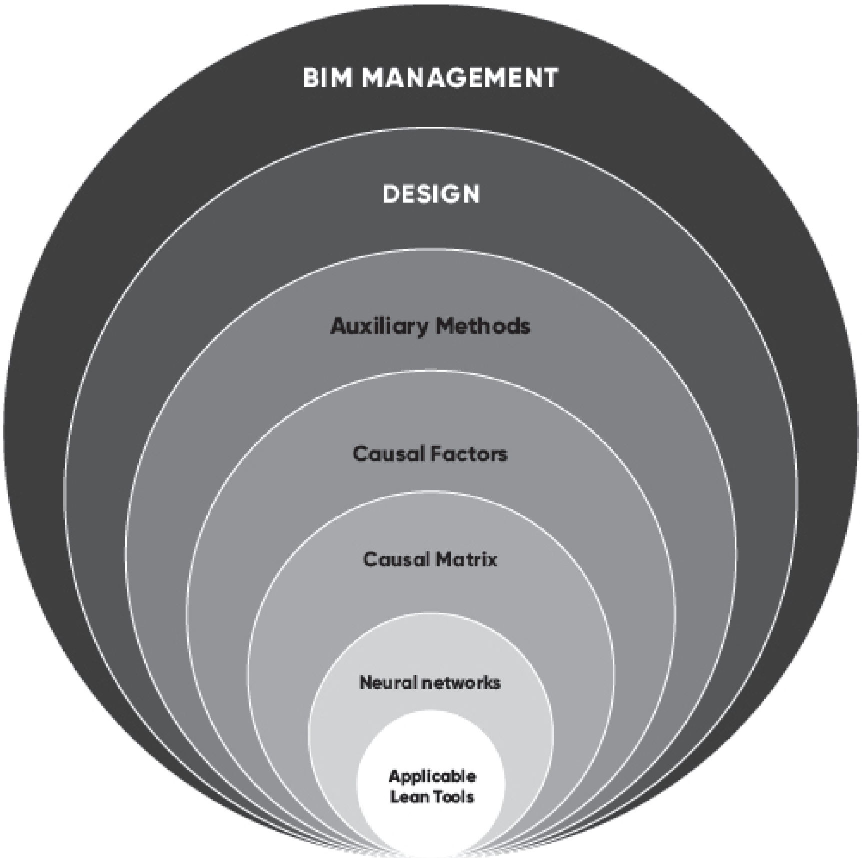


Figure 9. Method structure.

Regarding the case study carried out at the company, among the 29 adversities made available in the system, the team of designers defined 21 of them as the most incisive in their BIM design process, as shown in Figure 10.

Having chosen the causal factors, the results of the causal loop matrix were verified, as shown in Figure 11.

The causal matrix shows that for the variable "desk size" a liquid influence index (LII) is equal to 7, influencing seven other variables and is not influenced by any, with a total of 33 loops. The variable with the second largest LII, LII = 5, was the "lack of optimization of the models", influencing six variables and is influenced by one. Both variables present the highest values for the total indicators of LII and loops. This means that the two causes are the most significant, having the greatest importance inside the system. However, more important than identifying the cause with the highest LII, is determining the variables with the highest loop values that reciprocally influence the systemic movement.

In an antagonistic way, the variables with the lowest liquid influence indexes were analysed. The variable "lack of training of professionals", presented an LII equal to −6, with a total of 13 loops. The variable "lack of implementation of a comprehensive BIM protocol", presented an LII equal to −5 and a total of 23 loops. This number of loops is a considerable value for the system in relation to the other variables. This example characterizes the principle in [83], in which the sum of the parts is more important than the isolated analysis of each one.

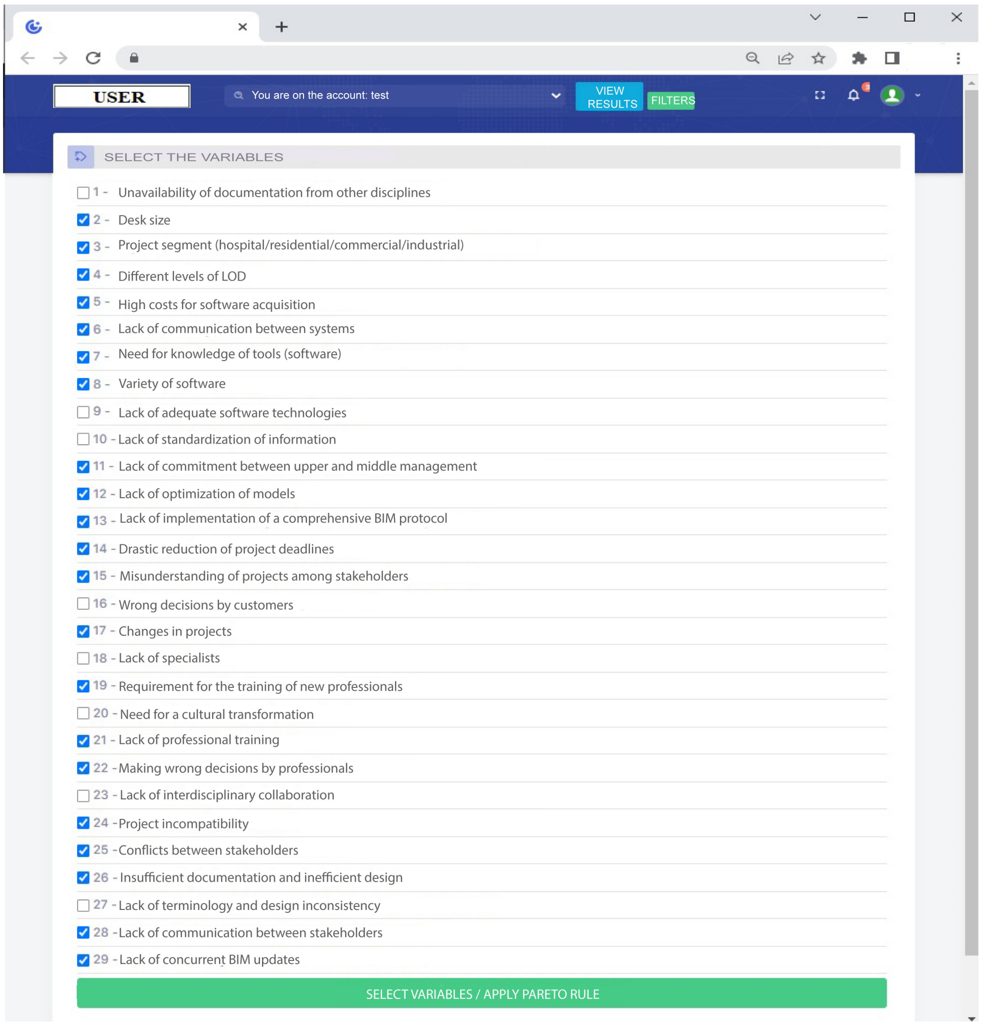
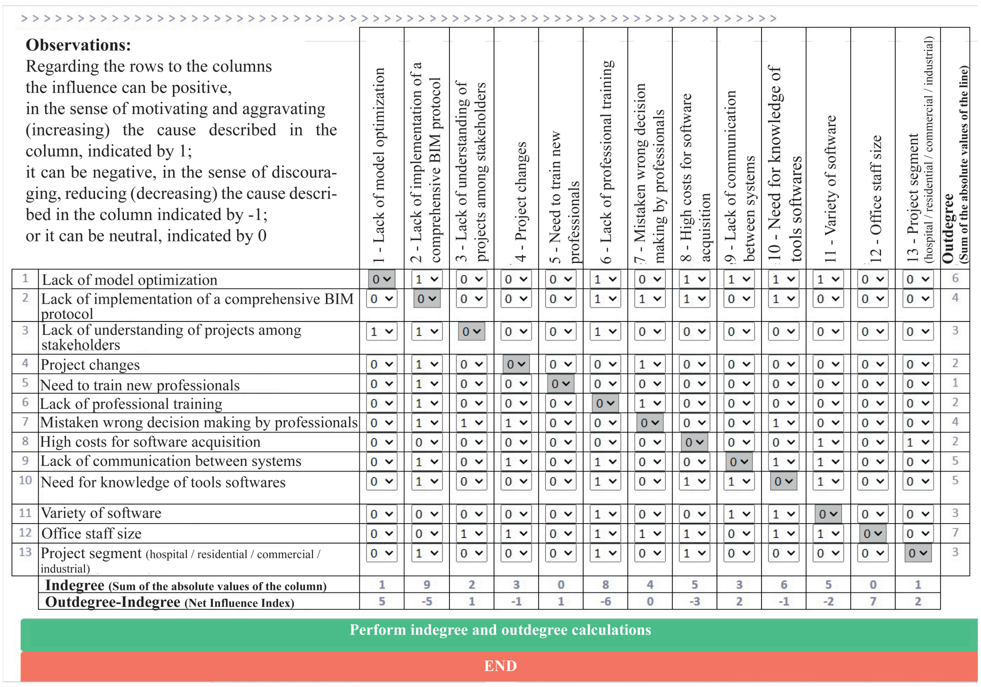


Figure 10. Selection of adversities.



Observations:
Regarding the rows to the columns the influence can be positive, in the sense of motivating and aggravating (increasing) the cause described in the column, indicated by 1; it can be negative, in the sense of discouraging, reducing (decreasing) the cause described in the column indicated by -1; or it can be neutral, indicated by 0

		1 - Lack of model optimization	2 - Lack of implementation of a comprehensive BIM protocol	3 - Lack of understanding of projects among stakeholders	4 - Project changes	5 - Need to train new professionals	6 - Lack of professional training	7 - Mistaken wrong decision making by professionals	8 - High costs for software acquisition	9 - Lack of communication between systems	10 - Need for knowledge of tools softwares	11 - Variety of software	12 - Office staff size	13 - Project segment (hospital / residential / commercial / industrial)	**Outdegree** (Sum of the absolute values of the line)
1	Lack of model optimization	0	1	0	0	0	1	0	1	1	1	1	0	0	6
2	Lack of implementation of a comprehensive BIM protocol	0	0	0	0	0	1	1	1	0	1	0	0	0	4
3	Lack of understanding of projects among stakeholders	1	1	0	0	0	1	0	0	0	0	0	0	0	3
4	Project changes	0	1	0	0	0	0	1	0	0	0	0	0	0	2
5	Need to train new professionals	0	1	0	0	0	0	0	0	0	0	0	0	0	1
6	Lack of professional training	0	1	0	0	0	0	1	0	0	0	0	0	0	2
7	Mistaken wrong decision making by professionals	0	1	1	1	0	0	0	0	0	1	0	0	0	4
8	High costs for software acquisition	0	0	0	0	0	0	0	0	0	0	1	0	1	2
9	Lack of communication between systems	0	1	0	1	0	1	0	0	0	1	1	0	0	5
10	Need for knowledge of tools softwares	0	1	0	0	0	1	0	1	1	0	1	0	0	5
11	Variety of software	0	0	0	0	0	1	0	0	1	1	0	0	0	3
12	Office staff size	0	0	1	1	0	1	1	1	0	1	1	0	0	7
13	Project segment (hospital / residential / commercial / industrial)	0	1	0	0	0	1	0	1	0	0	0	0	0	3
	Indegree (Sum of the absolute values of the column)	1	9	2	3	0	8	4	5	3	6	5	0	1	
	Outdegree-Indegree (Net Influence Index)	5	-5	1	-1	1	-6	0	-3	2	-1	-2	7	2	

Perform indegree and outdegree calculations

END

Figure 11. Causal loop matrix.

Once the most important variables in the system were identified, filters were applied with the help of neural networks, in order to search for Lean tools that would help minimize the losses caused in the selected enterprise, according to the causal factors evidenced by the loop matrix, as show in Figure 12.

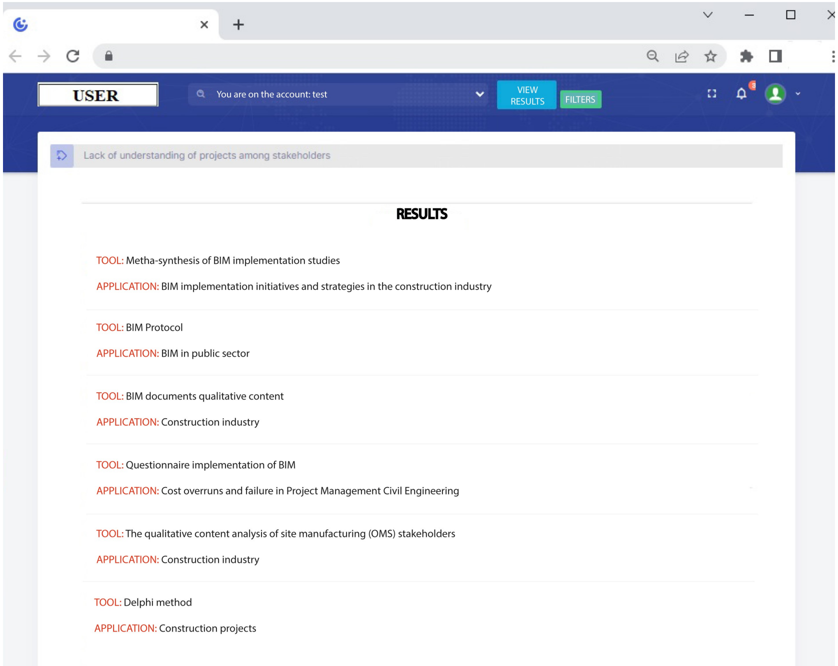


Figure 12. Lean tools.

The Lean tools identified were: metha-synthesis of BIM implementation studies; BIM protocol; BIM qualitative content of documents; questionnaire implementation of BIM; the qualitative content analysis of off-site manufacturing stakeholders (OMS); Delphi method.

The identified Lean tools lead to the conclusion that a study should be carried out, including standards and guidelines to understand the company's management process. After understanding the conditions of this company, a qualitative content analysis of the published BIM protocols, which are very important in Brazil, was recommended in order to identify common particularities and missing aspects to be applied.

At the end of this study, two aspects were considered together with the partner-directors, in relation to the applied method: understanding processes and the time spent. They claimed that the method was easy to understand in a short time frame in relation to the listed benefits that could help in the management process of that company.

4. Discussion

In this study, it was verified that even with the synergistic use of Lean and BIM in the construction cycle, several adversities were evidenced in the design phase. This knowledge gap was identified through a systematic review of the literature, in which a similar proposal or publication was found.

From this gap, a method was structured to help BIM management in the design phase, aiming to improve processes, technologies, professional and the flow of information, targetting the main objective of this research.

The structuring of this method fulfilled two aspects for the creation of artefacts proposed in the DSR. First of all, to obtain a better perspective of the subject as well as identify gaps in which more research is needed. Second, to identify relevant points concerning obstacles of BIM design, based on reading articles and opinions of the authors in relation to this subject. This aspect was a specific objective of RSL.

The proposed method introduces Lean tools to the BIM design process, allowing to generate alternatives that could help small, medium or big corporations to discover and solve their problems, since the proposed complementary tools (causal factors, matrix loop and neural networks) are easy to apply in a very short time.

After carrying out the study in a company using the artefact, Lean principles were identified for possible corrections of the highlighted problems, proving the tools could provide important contributions both in the scientific field and in the civil construction market.

It is understood that there is the possibility of further refinement of the neural network. This can be achieved by establishing parameters that link a limited number of Lean tools, ordered by effectiveness, to minimize the problems highlighted by the causal matrix in BIM design, according to the behaviour of each variable in the research.

In future research, the system can be improved by using a new neural network updating the number of citations and the degree of importance of causal/variable parameters according to their respective appearances in research.

Another aspect would be to carry out a quantitative and qualitative analysis inside an enterprise, establishing a parallel before and after applying the Lean tool indicated by the system, measuring the implications of applying this system.

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Abbreviations

The following abbreviations are used in this manuscript:

BIM	Building Information Modelling
UNB	Universidade de Brasília
UFG	Universidade Federal de Goiás
IFG	Instituto Federal de Educação, Ciência e Tecnologia de Goiás
LC	Lean Construction
CCI	Civil Construction Industry
PPC	Production Planning and Control
AEC	Architecture, Engineering and Civil Construction
LII	Liquid Influence Index
DOR	Digital Obeya Room
PDCA	Plan-Do-Check-Act
DSR	Design Science Research
SLR	Systematic Literature Review
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
FTPS	File Transfer Protocol
FTPS	File Transfer Protocol Secure
SCP	Secure Copy
SFTP	Secure File Transfer Protocol
TFTP	Trivial File Transfer Protocol
LDAP	Lightweight Directory Access Protocol
DAP	Directory Access Protocol
SMTP	Simple Mail Transfer Protocol
RTSP	Real-Time Streaming Protocol

Appendix A

Table A1. Theoretical framework of causal parameters.

Citations	Causal Parameters	Authors
3	Lack of concurrent BIM updates Lack of communication between stakeholders Lack of terminology and design inconsistency Insufficient documentation and inefficient design Project incompatibility Conflicts between stakeholders	[57,63,69]
2	Lack of interdisciplinary collaboration Lack of information standards	[17,65]
8	Making wrong decisions by professionals Lack of professional training Need for a cultural transformation Requirement for the training of new professionals Lack of specialists	[10,70,75,77,78,80–82]
1	Wrong decisions by customers	[70]
1	Misunderstanding of projects among stakeholders	[67]
1	Drastic reduction in project deadlines	[79]
3	Lack of commitment between upper and middle management	[59–61]
7	Lack of adequate software technologies Variety of software Need for knowledge of tools (software) Lack of communication between systems High costs for software acquisition	[17,60,71,72,76,77,79]
6	Different levels of LOD Project segment (hospital/residential/commercial/industrial) Desk size Unavailability of documentation from other disciplines	[17,62–64,66,71]
8	Changes in projects	[59,60,63,66,68,74,77,84]
9	Lack of implementation of a comprehensive BIM protocol Lack of optimization of models	[17,59,60,63,68,73,77,79,84]

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