Pino Álvarez, T., Barkokebas, B., Prieto, A., Bastos, D. (2024). Artificial intelligence-based BIM and ERP integration for industrialized construction. In Herrera, RF, Salazar, LA, (Editors), *Proceedings of the IX Ibero-American Congress of Construction Management and Technology* (IX ELAGEC2024).

ARTIFICIAL INTELLIGENCE-BASED BIM AND ERP INTEGRATION FOR INDUSTRIALIZED CONSTRUCTION

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ABSTRACT

Industrialized construction (IC) has experienced significant growth in the development of innovative construction methods in response to the demands of the construction industry. In this context, building information modeling (BIM) integrates and manages information throughout prefabrication phases (design, bid, and procurement) within an IC project. However, manual tasks such as data transfer between BIM models and enterprise resource planning (ERP) systems are susceptible to delays and errors due to the large flow of information executed between the involved parties. In this context, this article proposes the implementation of new automated workflows using artificial intelligence (AI) to assign codes of construction materials contained in ERP databases with their respective elements in the BIM model. The implications of this research suggest that integrating AI to automate design processes within IC projects could improve project performance in the construction industry, enhancing the efficiency and accuracy of the related processes. Using a case study approach, the results show that 81.57% of the elements were successfully identified by the proposed workflow leading to a 63.47% reduction in the time compared to the manual assignment approach. Despite classifying a considerable percentage of the elements, it was identified that the implemented workflow depends on manual-dependent tasks during the design phase, such as modeling methodologies. This research contributes by providing new methods to improve IC projects using artificial intelligence to integrate different information and its systems. It creates modern workflows compared to traditional methods that generally require extensive manual intervention and management of large amounts of information.

KEYWORDS

Industrialized Construction; Natural Language Processing; Artificial Intelligence; Building information modeling; Lean construction; ERP.

INTRODUCTION

The construction industry has experienced significant transformations through the integration of new building methods and technological advancements in recent years. Despite these innovations, the industry`s productivity has only grown 1% annually over the past two decades, compared to 2.8% for the global economy (McKinsey Global Institute, 2017), which represents a continuous challenge for this sector. In this context, the industrialized construction (IC) approach offers innovative solutions to create these productivity improvements, as it can generate significant enhancements in the performance of project activities focused on production systems (McKinsey Global Institute, 2017). IC involves the off-site manufacture of building components using standardized, modular processes, similar to those used in serial production (Ministry of Housing and Urban Development (Minvu), 2023). Additionally, industrialized construction integrates components throughout the design, execution, and assembly phases, focusing on accelerating the process through assembly and finishing activities (Minvu, 2023). This execution method seeks to improve performance in various stages of the project, aiming to increase productivity and sustainability, reduce waste, optimize costs, and decrease time (National Institute of Standardization [INN], 2023).

In this context, building information modeling (BIM) is implemented within the IC context to develop projects to facilitate the digital coordination and management of information during the project's lifecycle, connecting relevant data during its development, especially during prefabrication phases (design, procurement, and bidding). This approach includes the necessary information provided by the geometry and the information related to its components to support processes associated with each project (Eastman et al., 2011), allowing users to access information efficiently and maintain a smooth workflow among all participants (PlanBIM, 2019).

However, information between BIM models and other information systems, such as enterprise resource planning (ERP), is usually exchanged manually, resulting in high execution times in the design process and a large amount of information prone to errors, leading to additional costs, which calls for a standardized structure for the implementation of BIM and its information management (Manssori et al., 2023). Indeed, Oyarhosseinm (2021) mentions that the dispersion of large amounts of information and the lack of management practices to monitor data makes the implementation of BIM difficult and does not harness the full potential of BIM in the construction industry. Consequently, it is necessary to reduce user intervention to optimize the design workflow of IC projects, aiming to improve the efficiency of each associated process during the prefabrication phases (Barkokebas et al., 2021).

To identify patterns and manage large amounts of information in databases, a novel approach is proposed that uses artificial intelligence algorithms to search and classify elements in the BIM model, simplifying data access and manipulation. In this context, Natural Language Processing (NLP) is a branch of artificial intelligence that allows computers to understand human language by analyzing the grammar, structure, and lexicon of the language (Eisenstein, 2018). Rule-based NLP focuses on a language component (lexicon and grammar) and a strategic processing and generation component based on an operation algorithm (Shaalan, 2010). These techniques enable computers to translate human language into information that can later be analyzed (Sun et al., 2017).

Therefore, this article proposes and analyses the impact of AI-based workflows in IC premanufacturing phases, considering the application of rule-based NLP algorithms in BIM models to automatically connect their information with ERP systems. The objective of the proposed workflow is to minimize user intervention and propose an automated method to reduce time in assigning ERP system codes to elements contained in BIM models during prefabrication phases. In this context, a rule-based NLP algorithm is developed to effectively identify elements based on the information available in their parameters, where the properties are stored in the BIM model. Through an information management approach, it is also expected that the user will reduce the error rate in the assignment process, which could contribute to developing more accurate information models with fewer error rates. Based on the afore-mentioned, new NLP-based automated workflow models are expected to be proposed that can be applied to other areas of the construction industry. Additionally, an approach to new improvement opportunities and research areas is expected regarding the integration of methodologies based on technological advancements related to artificial intelligence to contribute to the existing literature on its implementation and guide future research.

This document provides a comprehensive literature review concerning this research's methods and information technologies. Within this framework, the methodology and the case study based on the scope of this research are introduced to establish the structure of the measure, design, and implementation processes in this research. Finally, the results and their discussion are presented, followed by conclusions from implementing the proposed solution.

LITERATURE REVIEW

The construction industry has previously studied the impact of BIM models and methodologies based on digitalization, standardization, and process automation. Zheng et al. (2021) analyzed the impact of BIM-based digitalization on engineering, procurement, and construction (EPC) projects to reduce project costs and time, where new BIM methodologies improved performance during the research. Additionally, Barkokebas et al. (2023) developed and implemented a workflow to connect project-related information (material specifications, list of materials, etc.) from BIM models to cost-based while observing a significant reduction in processing times while experiencing higher accuracy in the information being transferred

Regarding the automation of BIM processes, Mengtian et al. (2020) developed an automatic interpretation system for digital blueprints to develop a BIM facade model, achieving automation of a large portion of the plan components and avoiding manual data input from views. Similarly, Sheikhkhoshkar et al. (2019) analyzed 4D projects by applying a combination of different methods based on BIM models, automated spreadsheets, and programming routines to offer an automated process to find patterns for concrete pouring, resulting in cost-effective and more accurate methodologies related to these types of issues.

On the other hand, based on data processing, algorithms, and artificial intelligence, Senouci (2008) proposes an optimization algorithm for scheduling linear construction projects, aiming to minimize times and costs related to project durations, resulting in a model that allows to identify the optimal option for resource allocation in activities during planning. Particularly, Namcheol and Ghang (2019) used NLP methods based on search parameters and a support vector machine (SVM) to identify BIM projects through specific classification criteria, achieving a real approach to detecting BIM projects and reducing manual intervention related to the research. In a similar way, Lee et al. (2019) used NLP to identify relevant contract clauses for risk management in documents, obtaining high accuracy rates compared to manual review methodologies and also allowing the development of a preventive model for studying such deliverables.

Upon reviewing the existing literature, it becomes evident that while significant research has been conducted on the application of BIM in IC, the integration of BIM models and other information systems has been largely overlooked in recent years. Furthermore, despite the growing use of NLP in many construction-related processes, its application within IC projects remains notably limited. Regardless of significant research in BIM and the application of NLP in construction, three research gaps are identified: (1) the lack of BIM-based workflows to improve the efficiency during the development of IC projects, (2) little use of NLP-based workflows to identify language patterns in IC, and (3) a lack of approaches combining BIM and NLP to improve processes in IC. Hence, this research presents a workflow to automatically assign codes of construction materials contained in ERP systems by applying NLP algorithms to identify patterns in language extracted from BIM models and ERP systems, considering gaps previously acknowledged in the existing literature.

METHODS

This study employs a case study approach to evaluate, design, and determine the effectiveness of the proposed solution. The research methods are based on the framework developed by Barkokebas et al. (2021) to create specific digitalization plans for industrialized construction. In this context, Figure 1 shows the stages and methods of the research to improve prefabrication phases through automation methods.

In the first stage, referred to as the measure stage, the current workflow will be identified and mapped through interactions between developers and professionals from the design department. This includes identifying the problem and possible solutions, collecting relevant data, and determining the current workflow of the case study. To identify the actual durations of the workflow, information will be collected from the professionals who participated in the case study, along with a review of the literature on similar case studies to validate this information. This review will integrate recent methodologies in design, planning, and management, including Lean principles based on recent IC research. The measurement process will also include evaluating the performance of the current workflow, particularly the code assignment processes, and identifying any waste in the workflow. This approach allows to determine the duration of the code assignment process and measure the workflow's waste.

In the design stage, the categories regarding the scope of the research will be identified. Additionally, the necessary information to recognize elements in the BIM model (such as diameters, area, type, and material) within the project parameters will be selected based on the case study. Subsequently, design patterns in the BIM model and the code assignment process from the ERP database will be detected to determine the structure of the information for the development of search algorithms.

The classification algorithms based on NLP will be developed within a dynamo extension in Revit software. Dynamo will be employed through its visual programming language and Python tools, where algorithms are integrated to automate the information assignment process. This NLP-based approach focused on grammatical structure and word types relevant to the case study, which algorithms are expected to identify for automated assignment. From the automated identification process, a workflow focused on the use of each algorithm separately will be proposed, aiming to evaluate the performance of both routines in the subsequent stage.

Finally, the proposed workflow and the measurement of the assignment process based on the developed algorithms will be evaluated to identify the execution times and accuracy of the routine. This validation stage will focus on testing the algorithms through the proposed workflow, in order to identify any areas for improvement. Particularly, the estimated time for code assignment and the automated workflow will be mapped, in addition to determining the accuracy of the results obtained from the proposed algorithms. Furthermore, a comparison will be made using the execution times of the real workflow and the proposed workflow to recognize and validate the improvement in the workflow and the algorithm that presents the best performance in element detection. Finally, opportunities for improvement in code assignment and execution time will be identified.

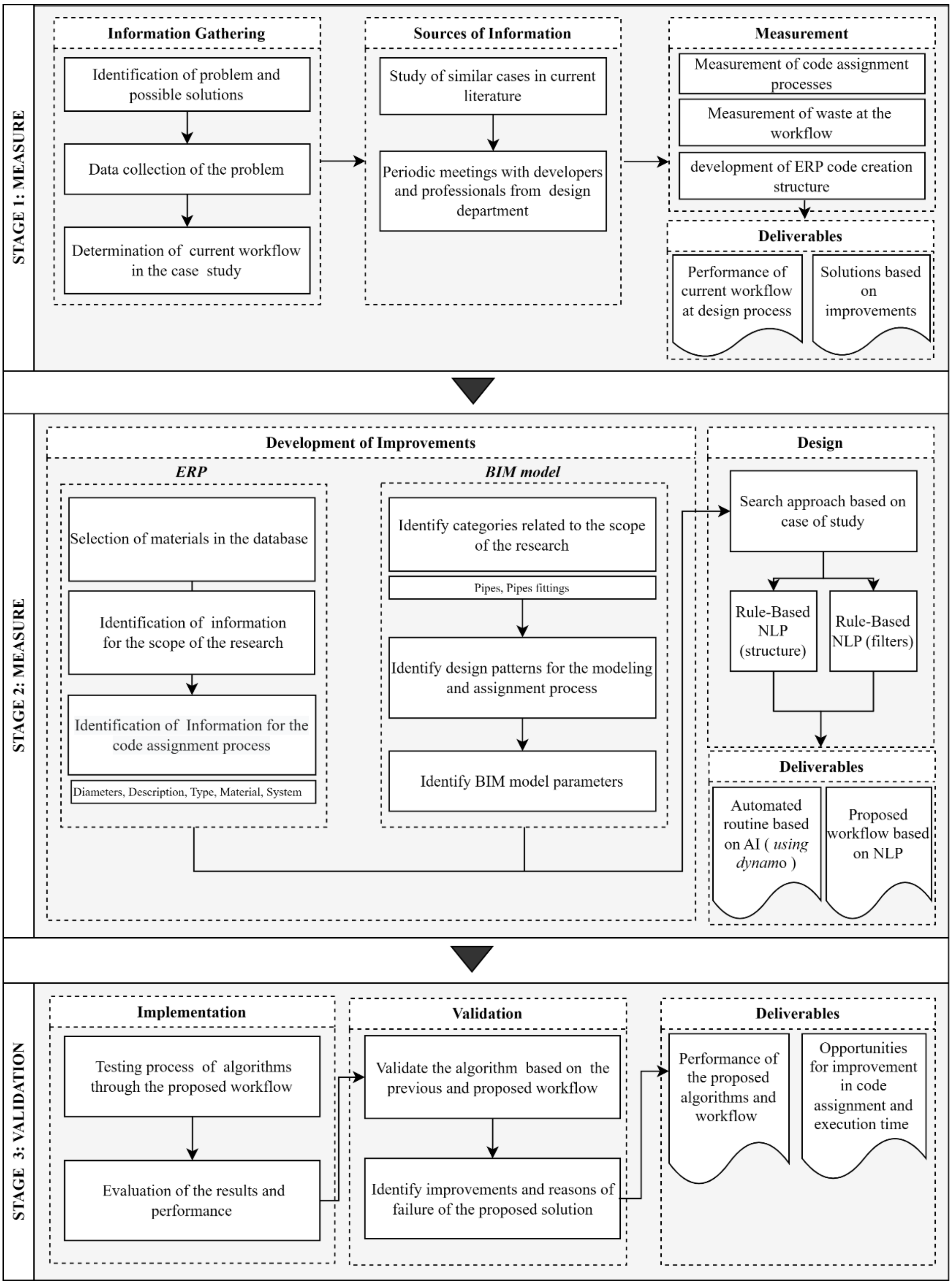

Figure 1. Research steps for the proposed research

CASE STUDY

This study will be developed and executed in the design department of one of the largest IC companies in Brazil. In this context, a model of an industrialized bathroom project developed in Autodesk Revit and a spreadsheet with material and product information extracted from the ERP database are available. For the purposes of this research, the workflow will focus on the elements corresponding to piping, pipes, pipe fittings, and their accessories. To improve efficiency in the prefabrication phases and in the assignment process, an automated information assignment to BIM elements is proposed using a case study approach using rule-based NLP algorithms. Figure 2 presents the representative case study model for piping systems.

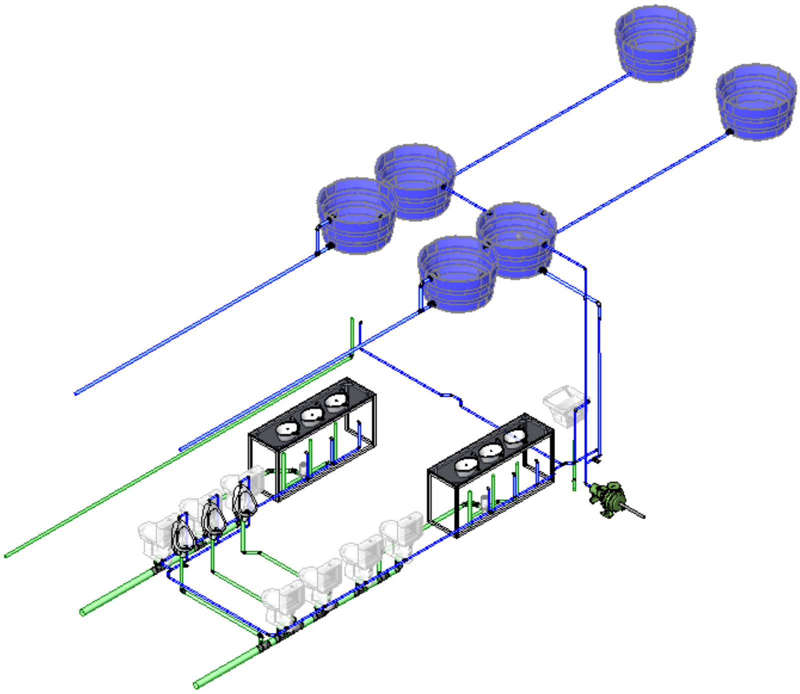

Figure 2. Sample of BIM model used in the proposed research

The current study is limited in its application to the design of sanitary installations within the BIM model and ERP system. However, this system was chosen due to its inclusion of diverse element types, each requiring specific information for accurate identification. Although these limitations may affect the generalizability of the proposed workflow, it is anticipated that by applying these algorithms to generalized construction systems, the required information could be adjusted to meet search requirements based on previously collected data.

RESULTS AND DISCUSSION

This section is based on the methodology developed by Barkokebas et al. (2021) and presented as follows: (1) the measure stage identifies current processes in the case study, (2) the design stage shows the development of the proposed workflow based on results from previous stage and literature review, while (3) the propose and evaluate stage demonstrates the early implementation results.

MEASURE

The mapping and durations of each task performed by the design team are extracted from a previously validated time study performed in the same design team performed by Barkokebas et al. (2021) and demonstrated in Table 1. In this previous study, Barkokebas et al. (2021) evaluated tasks performed by the design team considering a lean perspective (i.e., whether the tasks add value to the overall process or not) and the inherited uncertainty of design tasks. Considering the lean perspective, tasks are identified as value-added, necessary waste, and pure waste, where the latter two types are to be reduced. Considering the inherited uncertainty of design tasks, the duration of the tasks is determined by three possible scenarios: optimistic (O), pessimistic (P), and realistic (R). During the present study, interviews with participants in the design team were performed to confirm design practices and durations demonstrated in Table 1 are still valid for the present study. Based on interviews and results in Table 1, the proposed workflow will focus on reducing tasks 1 and 2, considered necessary work, which amounts between 9% to 30% of the total duration spent per project depending on each scenario.

Table 1. Mapped tasks according to its durations and types (adapted from Barkokebas et al. (2021)

ID	Task	P	R	O	Type
1	Special items and quantity take off	8	4	2	NW
2	Special items to ERP	7	7	7	NW
3	Electrical design	1.3	1.3	1.3	VA
4	Plumbing design	1	1	1	VA
5	Electrical design rework	2.5	2.5	2.5	PW
6	Plumbing design rework	2	2	2	VA
7	Opening and partition design	2	5	9	NW
8	Revised quantity take off	10	20	40	NW
9	Registry to ERP system	20	20	40	NW
	TOTAL	**53.8**	**62.8**	**104.8**	

VA: Value-added, NW: Necessary waste, PW: Pure waste, P: Pessimistic scenario, R: Realistic scenario, O: Optimistic scenario

Figure 3 presents the current workflow executed during the premanufacturing phases regarding code assignment according to the information provided by the design department of the studied company. After the project is awarded, the design department, in addition to being responsible for design for manufacturing and assembly during pre-manufacturing stages, must perform code assignments (i.e., assign each material designed in the BIM model to be procured and purchased by other departments) and quantity take-offs for each of the materials and labor based on the codes that identify each material existing in the ERP (assembly codes). Currently, the company manually assigns each ERP code to each respective element in the BIM model based on the description in both systems (BIM and ERP) including new materials in the database (i.e., special cases). Special cases in this research are referred to new materials proposed in the BIM model that still do not exist in the ERP system. The process consists of searching for elements with specific characteristics based on their description in the ERP database and matching them with the information contained in the BIM model. Based on the performed interviews with the design team, this practice leads to mistakes in quantity and assignment of wrong materials for the production line such as plumbing connections of different types (sewage and water supply) and different diameters. Finally, the model is delivered with this information required for fabrication in the production line.

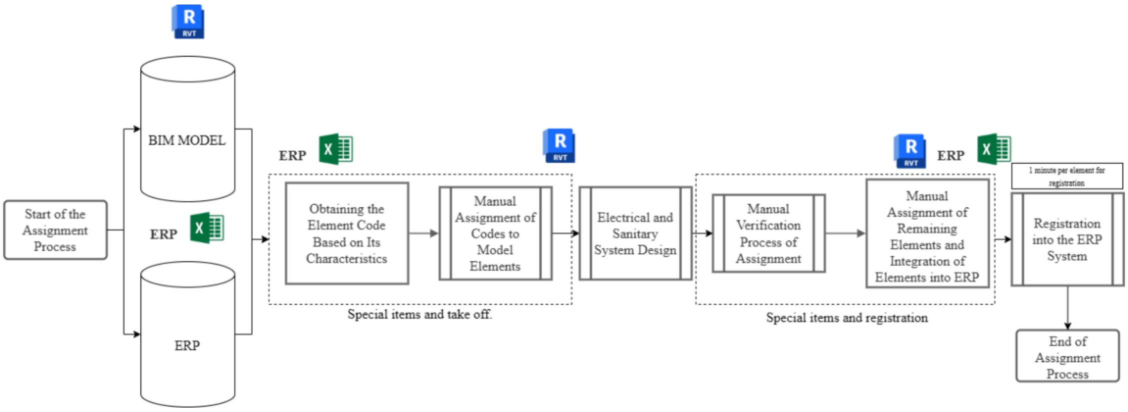

Figure 3. Current mapped workflow

DESIGN

Based on results from the previous stage, an NLP-based workflow is proposed to assign codes of construction materials automatically between the ERP system and BIM models. An NLP-based workflow is proposed due to the significant volume of materials found in the ERP system (more than 4 thousand) coupled with the dynamic environment of design practices found in the design team in which new construction materials are needed to be registered in the ERP system after each project. The research team decided to develop the proposed workflow specific to the plumbing discipline (sewage, rain, and water supply) due to its high number of pieces and connections. To assign ERP codes to each element of the BIM model, the necessary information was matched with data found in the parameters of the elements contained in the BIM model, corresponding to the properties of the elements in the information model. In this context, parameters contain the information of the materials designed in the BIM elements and will allow information collection through the proposed developed algorithms. This information enables algorithms to compare both codes and obtain a matching percentage based on comparative metrics and NLP rules. Table 2 presents the parameters used to identify the initial characteristics in the model and the grammatical component that determines the information.

Table 2. Information available according to parameters found in BIM models

BIM model parameter	Information available
Family	Element family name, additional information
Type	Element type name, additional information
Materials	Materials (PVC, copper, aluminum, etc.)
Dimensions	Diameters
System	Associated System (hot water, cold water, sanitary, etc.)

According to the mapped workflow, modeling practices, and available information in the ERP system, Figure 4 shows the proposed workflow where NLP algorithms will be applied to automatically assign codes from the ERP system to elements in the BIM model based on its descriptions and characteristics. This workflow is implemented by developing plugins using Autodesk Dynamo in combination with the existing BIM models developed by the company's design team and data from the ERP system contained in comma-separated-values (CSV) files.

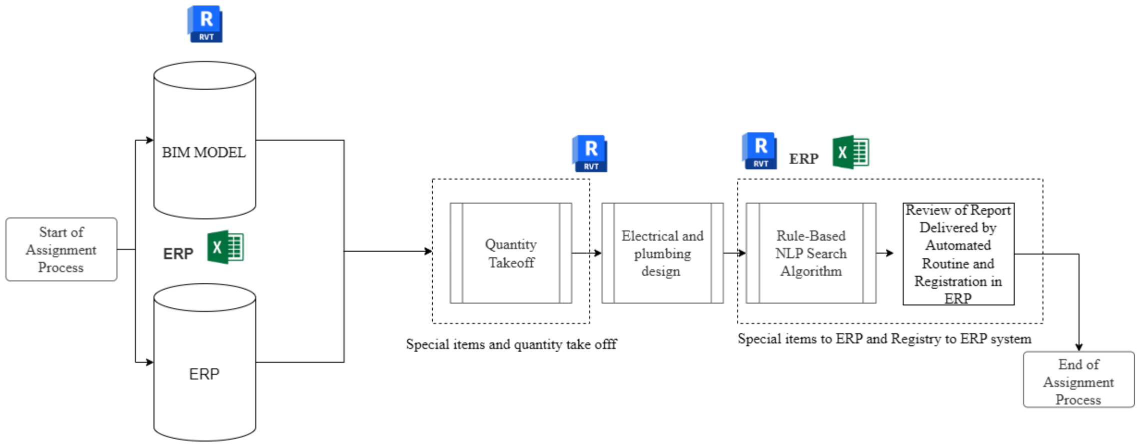

Figure 4. Proposed Workflow for Case Study.

For the development of the proposed workflow, two approaches are tested: (1) NLP-based approach using text matching particularly based on the general structure of the available information, and (2) NLP-based approach using filters on the available information for the general case study. Figure 5 shows the applied logic in both approaches.

Regarding the first approach, comparative metrics are developed based on the general structure detected in the description of the materials found in the database regarding both the structure and the type of information. In this sense, a methodology based only on the preliminary content of the predefined coding in the previous section is developed. The second approach applies two filters to further increase the accuracy of the first approach. Firstly, the type of connection of each element (e.g., plumbing elbow, union, etc.) is identified. Then it is classified according to the element's radius (radius of connections and pipes). Suppose no match is found in terms of the diameter. In that case, the algorithm is reprocessed to verify if there is another element of the same type in the database and determine if the elements were correctly detected. The algorithm stores all elements that can potentially be the correct code and filters based on a predetermined percentage of the match for each of them, considering the content and the type of text of the element. Finally, the algorithm saves the element with the highest percentage of match and assigns the code to the element in a parameter type. It is also reported in a spreadsheet to verify the correct assignment.

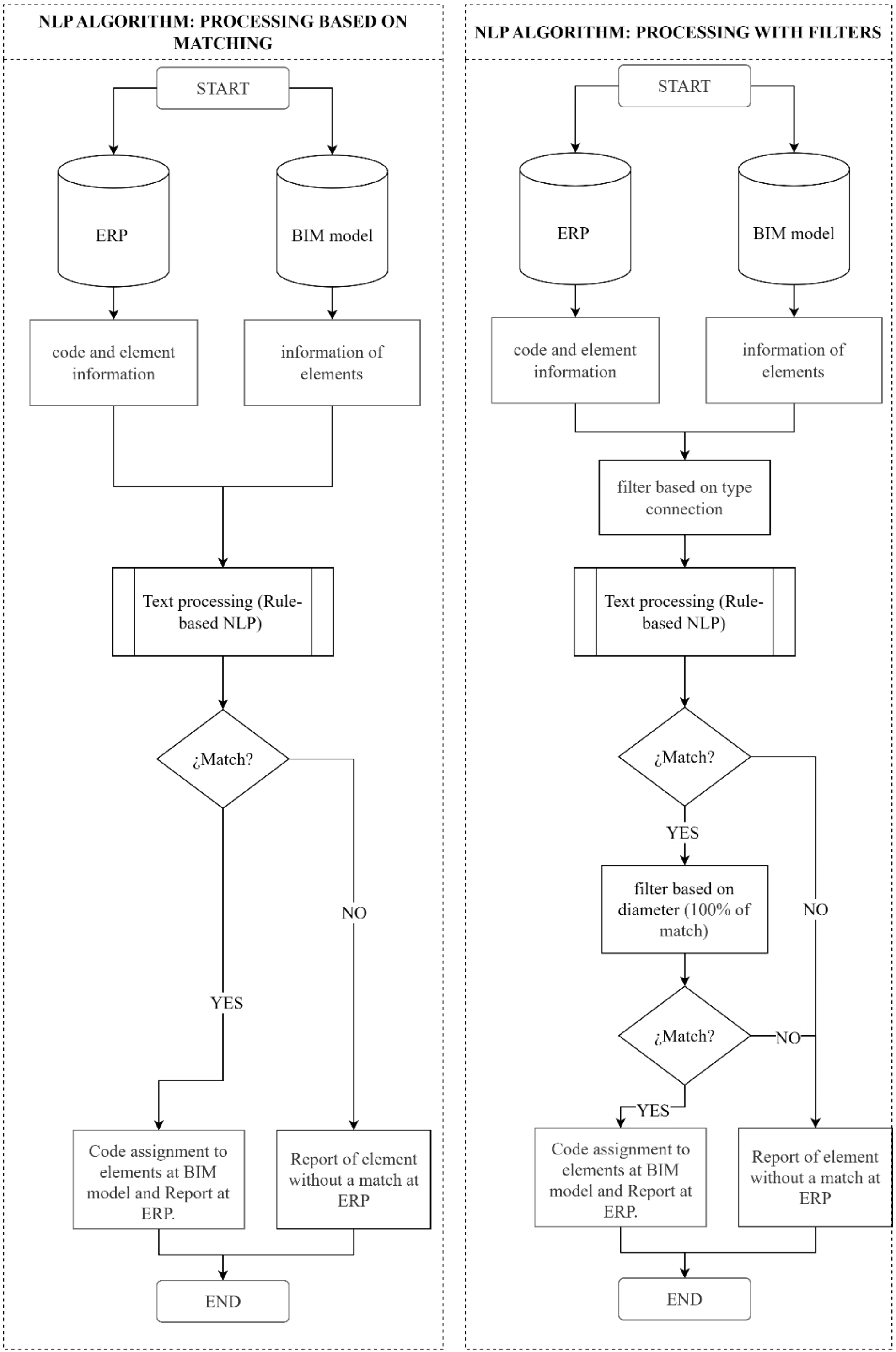

Figure 5. Proposed NLP-based approaches implemented in the proposed workflow

PROPOSE AND EVALUATE

Based on the proposed approaches, tables 3 and 4 present the results of the classification and assignment processes carried out by the proposed automated routines. From the above, it can be observed that approach 2 is considerably more effective than approach 1. Additionally, it is noted that a large portion of the accessories regarding approach 1 were not correctly identified by the search algorithm based solely on the matching criteria of the coding pattern within the database.

On the other hand, it can be observed that approach 2, a total of 80.78%, was correctly detected and assigned, where 57.25% was correctly assigned according to the matching algorithm, and 23.52% did not have an ERP code in the provided data. In this context, it was found that the execution time between activities compared to the values previously presented is reduced by 63.47% based on the estimated duration of the manually performed activity, considering only the elements in the previously mentioned target category. Furthermore, regarding the target time, it can be identified that based on the values obtained from approach 2, it is possible to reduce the estimated execution time by 35.8%, equivalent to a fraction of the 47 target hours. However, it was observed that despite developing approach 2 specialized in identifying text strings for pipe and plumbing connection elements, a significant portion of the sample was not adequately assigned to a code, resulting in an 18.04% error in code assignment and user verification.

Among the sources of error associated with code assignment are the sensitivity of the routine to design and drawing methodologies derived from each element's parameters, as well as how the user develops the model and ERP coding. It was observed that the absence of standardized modeling and coding practices significantly affects the assignment process, as there is dispersion in the methods of structuring the proposed coding in the ERP system. In fact, elements showed a high error rate when they have specific characteristics, such as unique types of products, leading to a particular and specific situation in the BIM model. In this sense, a technical limitation of the code associated with this variable was identified, as well as a potential source of error based on the modeling methodology of other potential case studies.

These advancements highlight the importance of a unified framework for managing BIM information, as non-standardized methods could lead to significant errors in element identification (Massori et al., 2022). Additionally, as Barkokebas et al. (2023) noted, results may differ depending on the digitalized methods implemented to meet each company's needs. Therefore, to enhance the effectiveness of the study methods applied in this research, increasing the information associated with the elements that the algorithm can detect is essential. It is also necessary to consider a standardized information management method related to the data from the model and its design.

Table 3. Estimated time reduction based on Approach 2

	Correctly detected *	Without an ERP code	Correctly assignment	No assigned	Routine Executed time	Estimated time Reduction **	Objective Reduction Time
Amount	206	60	146	46	15	14	-
Percentage	80.78%	23.52%	57.25%	18.39%		63.47%	35.54%

*The element that exists or does not exist in the ERP database and matches 90% with the algorithm routine is considered "correctly detected." If it does not exist, it is verified that its best match is not assigned in the model.

** Considering 230 minutes of manual code assignment and only a reduction in time for elements in the "correctly assigned" category that are automatically assigned in the model. (146 minutes less, considering 1 minute per element).

Table 4. Summary of results obtained from both NLP-based approaches according to types of elements in BIM models

	Total, correctly identified (%)	Type of element correctly identified (%)	elements with code in ERP correctly identified (%)	elements identified without code in ERP (%)	elements incorrectly assigned and not identified (%)
Approach 1	30.98	51	9.01	21.960	68.62
Plumbing accessories	18	46.5	18.4	0.0	81.60
Pipes and plumbing	43.4	70.0	2.000	43.41	100.0
Approach 2	80.78	98.3	57.26	23.5	18.04
Plumbing accessories	69.84	93.8	66.67	3.18	30.16
Pipes and plumbing	94.57	99.0	48.06	46.51	6.20

CONCLUSIONS

This research presented the potential for significant practical improvements in the construction industry by utilizing AI to automate design processes and achieve greater accuracy and performance during project lifecycles. Particularly, the implementation of an automated routine based on NLP has effectively identified a large portion of the codes for elements from the BIM model and in the ERP while also reducing the duration of activities through the implementation of new automated workflows. However, even though access to automated methodologies could be effectively implemented, there are still limitations in the early implementation of the NLP routine in ERP databases. This is because such workflows still depend on more complex search patterns and algorithms that allow for the internalization and standardization of design methodologies for various types of products and projects. In this sense, it is necessary to develop more specific search algorithms based on NLP to correctly classify the cases that could not be assigned in this case study.

To effectively integrate the automated methods and proposed workflows, professionals should adopt a gradual implementation process, beginning with standardizing their BIM design methodologies. This approach should include validating the results and progressively expanding the implementation as confidence in the system's accuracy and reliability grows. It is hoped that this document will provide an approach to more efficient assignment methodologies based on the development of automated workflows related to using artificial intelligence in the construction industry.

REFERENCES

Barkokebas, B., Ost, F., Mourgues, C. y Saruhashi, L. (2023). Improving premanufacturing phases in off-site construction through a digitalization approach. Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31), 812–823. https://doi.org/10.24928/2023/0240

Barkokebas, B., Khalife, S., Al-Hussein, M., & Hamzeh, F. (2021). A BIM-lean framework for digitalization of pre-manufacturing phases in offsite construction. Engineering, Construction and Architectural Management, 28(8), 2155-2175 https://doi.org/10.1108/ECAM-11-2020-0986

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. En *Wiley eBooks*. http://ci.nii.ac.jp/ncid/BA87578739

Instituto Nacional de Normalización (2023). Construcción industrializada y prefabricada - Términos y definiciones (NCh3744:2023).

Lee J., J. Yi, & J. Yi (2019). Development of Automatic-Extraction Model of Poisonous Clauses in International Construction Contracts Using Rule-Based NLP. Journal of Computing in Civil Engineering

Mansoori, S., Harkonen, J. & Haapasalo, H. (2022) Productization and product structure enabling BIM implementation in construction. Engineering, Construction and Architectural Management,30(5),2155-2184. https://doi.org/10.1108/ECAM-09-2021-0848

McKinsey Global Institute (2017). Reinventing construction: A route to higher productivity. McKinsey & Company. https://www.mckinsey.com/~/media/mckinsey/business%20functions/operations/our%20insights/reinventing%20construction%20through%20a%20productivity%20revolution/mgi-reinventing-construction-a-route-to-higher-productivity-full-report.pdf

Namcheol Jung, G. L. (2019). Automated classification of building information modeling (BIM) case studies by BIM use based on natural language processing (NLP) and unsupervised learning.

Oyarhossein, Mohammad, A. & Hamid, S. y Khiali, V. (2021). Identifying Barriers of Implementing BIM in Construction. https://www.researchgate.net/publication/353325138_Identifying_Barriers_of_Implementing_BIM_in_Construction

Planbim (2019). Estándar BIM para proyectos públicos. Intercambio de información entre solicitante y proveedores. Santiago, Chile. https://planbim.cl/wp-content/uploads/2019/06/Estandar-BIM_altaresolucion_V1.1.pdf

Resolución 6577 de 2008 [Ministerio de Vivienda y Urbanismo]. Condiciones y mecanismos de aprobación de proyectos de viviendas industrializadas tipo y fija el procedimiento para revisión de proyectos que incorporen el uso de viviendas industrializadas tipo, desarrollados en el marco de los programas habitacionales fondo solidario elección de vivienda ds n°49 (v. y u.) de 2011, y de habitabilidad rural ds n°10 (v. y u.), de 2015. 17 de enero de 2023.

Senouci, A., & Al-Derham, H. (2008). Genetic algorithm-based multi-objective model for scheduling of linear construction projects. Advances in Engineering Software, 39(12), 1023–1028. https://doi.org/10.1016/j.advengsoft.2007.08.002

Shaalan, K. (2010). Rule-based Approach in Arabic Natural Language Processing. The International Journal on Information and Communication Technologies (IJICT),3 (11),11-19. https://www.researchgate.net/publication/206005947_Rule-based_Approach_in_Arabic_Natural_Language_Processing

Sheikhkhoshkar, M., Rahimian, F. P., Kaveh, M. H., Hosseini, M. R., & Edwards, D. J. (2019). Automated planning of concrete joint layouts with 4D-BIM. Automation in Construction, 107, 102943. https://doi.org/10.1016/j.autcon.2019.102943

Yin M., Tang L., Zhou T., Wen Y. & Xu. R., Deng, W. (2020). Automatic layer classification method-based elevation recognition in architectural drawings for reconstruction of 3D BIM models. Automation in Construction, 113. https://doi.org/10.1016/j.autcon.2020.103082