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An Enterprise Architecture Approach to Digital Transformation in Small and Medium-Sized Construction Companies

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Abstract

This paper addresses the critical issue of digital transformation in the construction industry, a key component of the global economy and an area lagging in adopting Industry 4.0 technologies. Despite the recognized need for digitalization to enhance profitability and performance, small and medium construction enterprises (SMEs) face barriers such as lack of support, standards, awareness, high costs, and significant workflow changes. The research introduces a system-oriented framework based on enterprise architecture and social network analysis graph models to counter these challenges. This framework aids construction SMEs in assessing their current processes and determining the best digital solutions to meet their specific needs. The effectiveness of this framework is demonstrated through a case study in a Colombian construction SME in the oil and gas sector, showing significant improvements in construction planning and design processes through the adoption of digital technologies. This study provides a practical approach for SMEs in the construction sector to navigate their digital transformation journey.

Keywords
Project Management, Network Analysis, PMBOK 7, System Modeling, Enterprise Architecture

1. Introduction

Digital transformation is a worldwide topical issue of significant importance for all companies in all sectors, given that it changes customer relationships, internal processes, and value creation (Zaoui & Souissi 2020) by deeply transforming the business and operation model of the organization using breakthrough technologies (Ilin et al. 2021). These technologies, a feature of the Industry 4.0 concept, are designed to ensure the interaction of people and technologies (Ilin et al. 2021), support the growth and evolution of various fields and industries (Lu 2017), and enhance project performance and management success (Demirkesen & Tezel 2022).

Influenced by the gains that resulted from the revolution mentioned above, and considering that these technological advancements continue to evolve, researchers in construction began investigating the potential of integrating Industry 4.0 into construction, creating the term Construction 4.0. Moreover, motivated by this sector's crucial role in the global economy, governments and regulatory bodies have developed different standards, guidelines, and implementation plans to promote digitalization within the industry and standardize this practice.

Despite these efforts, the AEC industry needs to catch up in the maturity and adoption of digital technologies compared to other sectors (Bosch-Sijtsema et al. 2021). In this regard, small and medium construction enterprises (SMEs) need to move from traditional business models towards new digital models that would facilitate the implementation of modern means of production (Sadeh et al 2023) that can help these companies in terms of profitability and performance (Agarwal et al 2016).

Although digitalization is considered a key to the industry's survival in the market, SMEs have shown a continuous trend of hesitation toward this change (Sadeh et al. 2023). As a result, several researchers have studied the main barriers found by the practitioners during the digitalization process, which has led to this low adoption rate, identified the lack of support and incentives, the lack of standards and codes, the lack of awareness, the high cost and the radical changes in workflow, practice, and procedures as a some of the main barriers impacting the digitalization process.
To satisfy this need and facilitate the implementation of digital technologies in construction SMEs, this research aims to provide a system-oriented framework based on enterprise architecture and graph models that will allow the companies to assess their current processes, understand the relationship between organization components, data, and project information to evaluate the best digital solutions that fulfill company's needs.

This framework was assessed through a case study performed in a construction SME operating in Colombia's oil and gas sector, for which the construction planning and design processes were evaluated and optimized using digital technologies.

2. Background

2.1 Digitalization in the Construction Industry, from Industry 4.0 to Construction 4.0

Digital transformation is a worldwide topic of major importance for companies in all sectors, as it changes customer relationships, internal processes, and value creation (Zaoui & Souissi 2020). It consists of deeply transforming an organization's business and operation model using breakthrough technologies (Ilin et al. 2021) and contributing benefits such as safer operations, improved productivity, higher accuracy, better communication, and more innovation (Sadeh et al. 2023).

The technologies associated with digital transformation are a feature of the concept of Industry 4.0 (Ilin et al. 2021); the German Federal Government gave this term to highlight the fourth industrial revolution, which can be defined as "a new technological age for manufacturing that uses cyber-physical systems and Internet of Things, Data and services to connect production technologies with smart production processes" (Kagerman et al. 2013). Industry 4.0 technologies are designed to ensure the interaction of people and technologies (Ilin et al. 2021), support the growth and evolution of various fields and industries (Lu 2017), and eventually result in enhanced project performance and management success. (Demirkesen & Tezel 2022).

Influenced by the gains that resulted from the revolution mentioned above, researchers in construction began investigating the potential of integrating Industry 4.0 into construction, creating the term Construction 4.0. Which, according to the European Industry Construction Federation (FIEC), is the counterpart of industry 4.0 in the Architecture, Engineering, and construction (AEC) industry, and it refers to the digitalization of the construction industry (García de Soto et al. 2019), representing it is shifting towards increasing digitalization (Winfield 2020).

The main goal of Construction 4.0 is to create a digital construction site that monitors progress throughout the life cycle of a project by using different technologies. (Rastogi 2017). Adopting Construction 4.0 will change the construction process, organization, and project structures to shift the fragmented construction industry into an integrated industry (García de Soto et al. 2019). Consequently, shifting to Construction 4.0 requires changing the thinking approach and the process (Jazzar et al. 2020).

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Under the frame of Construction 4.0, numerous digital technologies are currently being developed, and it becomes challenging for the AEC industry to select what kind of digital technology would be beneficial and what should be prioritized (Bosch-Sijtsema et al. 2021). As a result, several research has been conducted on this topic: Oesterreich & Teuteberg (2016) and Statsenko et al. (2022) presented an state of the art of Construction 4.0 technologies; Demirkesen & Tezel (2022) provided recommendations for implementing digital technologies in order to lead industry practitioners to recognize the main challenges before adoption of technology, and Bosch-Sijtsema et al. (2021), Karmakar & Delhi (2021) and Jazzar et al. (2020) presented a compressive list of the digital technologies in construction.

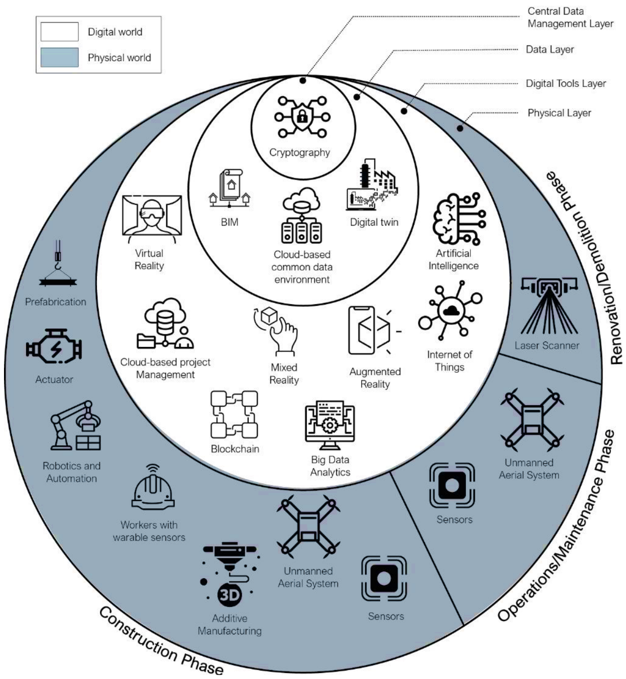

Figure 1. Construction 4.0 and its key components
Adapted from Karmakar & Delhi (2021) and Van Milaan (2022)

Building Information Modeling (BIM), Augmented Reality and Virtual Reality (AR/VR), Digital twins, the Internet of Things (IoT), and Artificial Intelligence (AI) are just some of the technologies under the umbrella of Construction 4.0 listed by the researchers. These technologies can be visualized according to their integration through the construction project lifecycle (Jazzar et al., 2020) and as a four-layered model proposed by Karmakar & Delhi (2021) in Figure 1, consisting of the physical layer, the digital tools layer, the data layer, and the control data management layer.

2.2 BIM as the core of the Construction 4.0

Building Information Modeling (BIM) should be regarded as the backbone of the new way of working, given that different elements (such as various software, drones, construction engines, and building and infrastructure equipment) should ultimately be connected to this model (Kaufmann et al. 2018) making it the central repository for collating digital information about a project (Maskuriy et al. 2019).

The key benefits of BIM include better cost estimation and control (Chan et al. 2019), efficient construction planning and management (Davila Delgado et al. 2019; Oke et al. 2018), improvement in design and project quality, better data management, and conflict resolution (Ghaffarianhoseini et al. 2017), which makes this technology an attractive topic not only to AEC companies but also to the government and public institutions worldwide, who have started to make this technology even more obligatory (Girginkaya Akdag & Maqsood 2020).

In order to standardize this practice, governments and regulatory bodies have developed different standards, guidelines, and implementation plans which can be highlighted: the AIA Digital Practice Documents - Guide,

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instruction and commentary by the American Institute of Architects (AIA, 2013); the level of development specification by the BIM forum (BIMForum, 2020); UNI 11337- 1 by the Italian Entity of Standardization (UNI, 2017); The BS 1192:2007 (BSI, 2007) and PAS 1192-2:2013 (BSI, 2013) by The British Standards Institution; The ISO 19650-1by International Organization for Standardization (ISO, 2018) and the CEN/TC 442 N 483 by the European Committee for Standardization (CEN, 2019).

2.3 Enterprise Architecture as a corporate process view

Given that the ever-evolving landscape of the construction industry is prompting a fundamental shift towards digitization and the adoption of digital technologies, it is possible to state that this digital disruption is transforming how organizations run their business (Wijaya et al. 2022). This mindset shift is pushing construction companies to digitalize their existing processes, which represents an additional challenge given that most processes were designed before current digital tools were available and that not all the processes can be directly digitized (Jazzar et al. 2020). As a result, the re-engineering of existing processes to accommodate this mindset shift and support the 4.0 transformation becomes an important issue to the industry (Arayici et al. 2012; Owen et al. 2011), and the main questions to be answered are how to successfully handle the organizational and process changes within the organization and how to redesign the current business model (Oesterreich & Teuteberg 2016).

To address these challenges and effectively manage the transition to Construction 4.0, researchers have identified that organizations need a comprehensive approach that aligns technology, processes, and organizational objectives and guides the integration of digital technologies into their business processes. As a result, Zaoui & Souissi (2020) and Cai et al. (2022) proposed a three-stage digital transformation model that comprises: evaluation and goal definition, strategy definition, and implementation; Wijaya et al. (2022) proposed to create a guideline such as an architecture design to support this technological transformation, and Atencio et al. (2023) stated that the system-oriented nature of Enterprise Architecture (EA) provides a structured way to represent, analyze, and optimize business processes within an organization.

Considering that the foundation of any successful digital transformation lies in understanding and documenting the existing processes (Mirarchi et al.,2020). Business process mapping, such as BPMN or EA, offers a structured way to visually represent the interconnected activities within an organization (Recker 2012), offering insights into potential areas for technology integration and optimization.

Enterprise Architecture (EA) is a group of principles, methods, and models for designing and analyzing the enterprises' organizational structure, business processes, information systems, and infrastructure (Lankhorst 2013). It was first introduced by Zachman (1987) and nowadays, it is considered as an answer to the problems of alignment of business requirements and IT infrastructure (Levina et al. 2020) given that EA is a management tool that has the advantage of graphically represent the interrelationships between different components of an organization (Atencio et al. 2023).

3. Development method

This study aims to provide SMEs a system-oriented framework that allows the companies to assess their current processes and understand the relationships between organization components, data and project information to evaluate the best digital solutions that fulfil the company’s needs. By concluding this study, it may be possible to incentivize the digitalization of SME s in the construction sector.

The research aim and problem statement above have led to the question: “How can small and medium-sized AEC enterprises effectively integrate Construction 4.0 technologies to enhance operational efficiency and competitiveness?”

This research proposes a framework based on the general process of implementing new digital technologies in a construction company proposed by Jazzar (2020), as presented in Figure 2.

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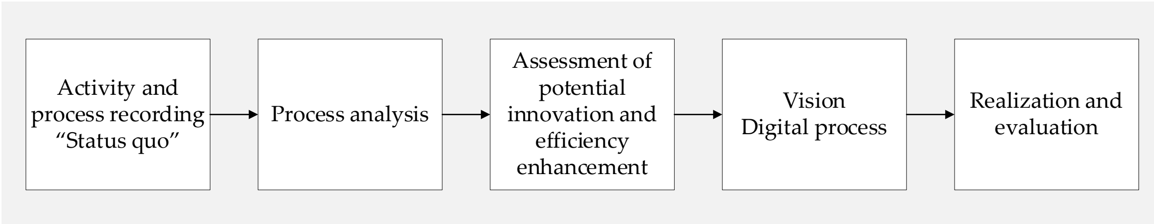

Figure 2. The process to implement Construction 4.0
Adapted from: (Jazzar et al. 2020)

4. Results

4.1 Framework development

The proposed *SMEs' Digitization framework* aims to provide SMEs with a system-oriented framework that allows the companies to assess their current processes and understand the relationships between organization components, data, and project information in order to evaluate the best digital solutions that fulfill the company's needs.
In order to meet the requirements, this research incorporates the two artifacts:

- *Artifact 1: The PMBOK graph model allows one to understand and have a clear vision of the* project management process inside the company and its relationships. This framework proposes to use this artifact as a consultancy tool to evaluate the company's processes according to the PMBOK.
- *Artifact 2: EA integration with PMBOK features allows us to provide a systemic view of the company in order to help to understand workflows between processes and organizational components for* better integration and transition of data and project information, facilitating the re-engineering of processes inside the company.

The resulting framework is presented in Figure 3.

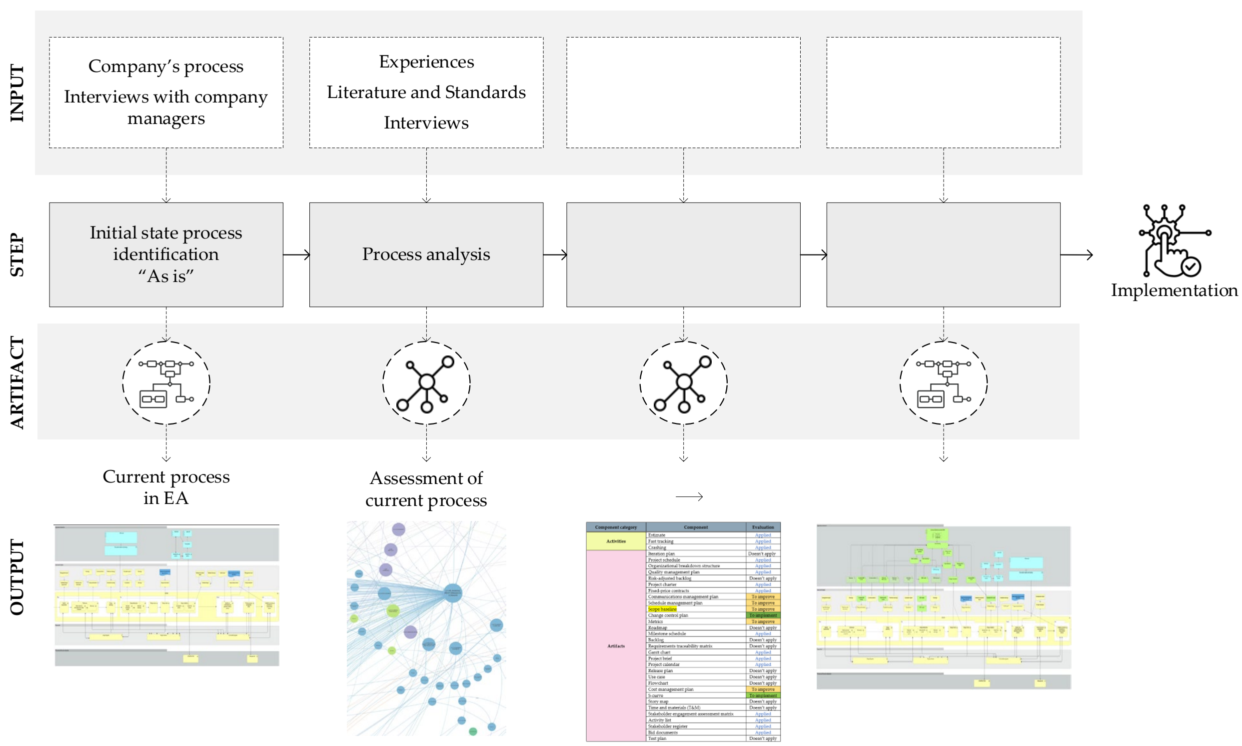

Figure 3. The SMEs' Digitization Framework

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First, during Stage 1, the actual company state and processes are modeled under Enterprise Architecture to have a systemic view of the company and understand the relationships between organization components, data and project information, and the company's capabilities. To facilitate the EA modelling of the company, the framework proposes using the *Artifact 2: EA integration with PMBOK features,* as it provides a clear correspondence between the PMBOK concepts used to model the process and EA elements. Secondly, during Stage 2, the current company's processes are analyzed according to the company's goals. Given that AEC companies represent one of the most representative types of project-based organization, and they are mainly opting for digital technologies to enhance progress monitoring, cost estimation, prediction, planning, and control; during this phase, the project management processes are assessed according to the PMBOK by using the Artifact 1: *PMBOK graph model* in order to identify possible improvements to implement during the next stage.
Third, once the process has been analyzed, and the lists of possible technology and process improvements are identified, it is evaluated which improvements will be applied to satisfy company needs. During this phase, the data table obtained from Artifact 1: PMBOK graph model is evaluated through interviews with the company's managers in order to define the final list of improvements and implementations to the processes that will be applied with the purpose of getting the best results from digital technologies.

Finally, during Stage 4, the improved process is modeled under the EA by using Artifact *2: EA integration with PMBOK features.* This final model will allow us to understand the actual flow between organization components, data, and project information. Moreover, it will allow to identify existing barriers or interferences with software and help identify the structural and capabilities requirements requirement for the digital implementation.

4.2 Case study

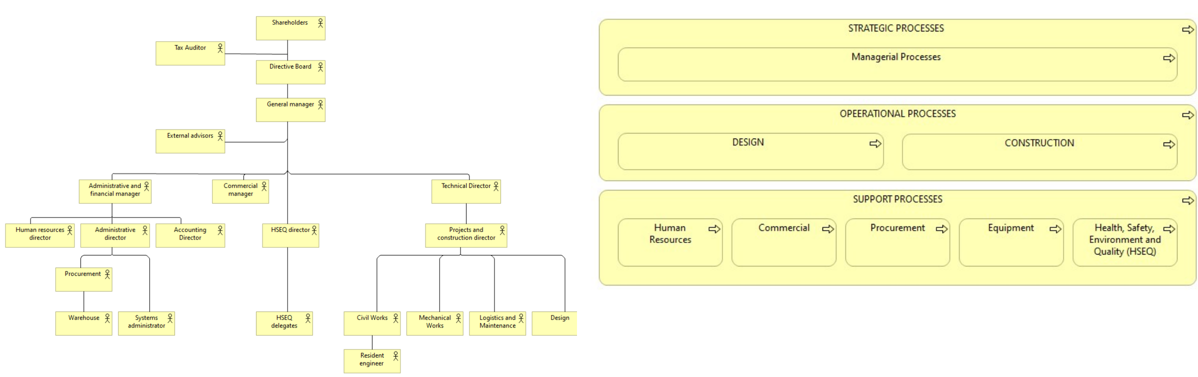
The proposed framework has been applied in a company dedicated to designing and constructing steel and polyethylene networks for the Oil and gas sector in Colombia. Considering the growing strategy of the company and the market requirements, the company will need to start an implementation plan for digital technologies to remain competitive in the market, given that The Government of Colombia presented the BIM national strategy in 2020 (Gobierno de Colombia, 2020), which states that for 2026 all the public construction projects in the country are required to use BIM.

The following case study aims to help the company identify the right technologies that fit their need to implement to start the digitization journey.

Therefore, the four stages presented in Figure 3 have been applied as follows:

Stage 1

With the purpose of representing the As-Is situation of the company, there were performed a set of interviews with company managers who provided valuable information about the company's goals, strategy, and structure. Moreover, given that the company is certified with the ISO9001, ISO45001, and ISO14001, they already had a set of processes structured inside the company; those processes were provided by the company to facilitate the modeling process and were the main input for the process modeling. As a result, a set of EA views were modeled, as presented in the examples displayed in Figure 4.



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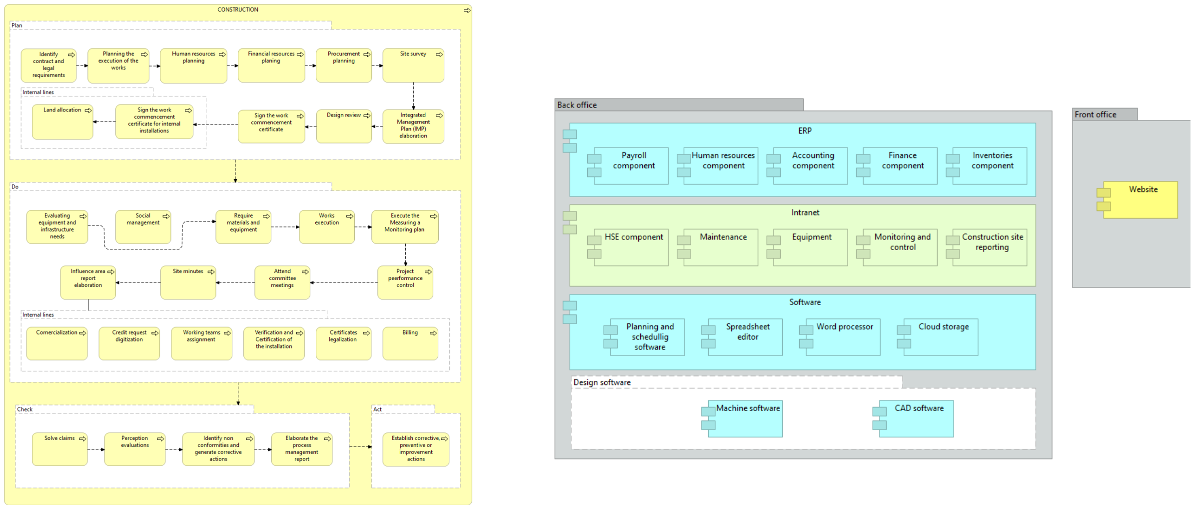
(a) (b)



(c) (d)

Figure 4. Architectural views modeled in the As-Is situation (a) Organizational view; (b) Business process map view (c) Construction process description (d) Applications view

Stage 2

Considering that the company goal is starting the journey into digitization, during this stage, the base process – the planning process - was analyzed according to the PMBOK standard by using Artifact 1: PMBOK graph model in order to identify possible process improvements.

In order to evaluate the process, first, there were extracted from the PMBOK graph model the PM concepts and features related to the planning domain as presented in Figure 5.

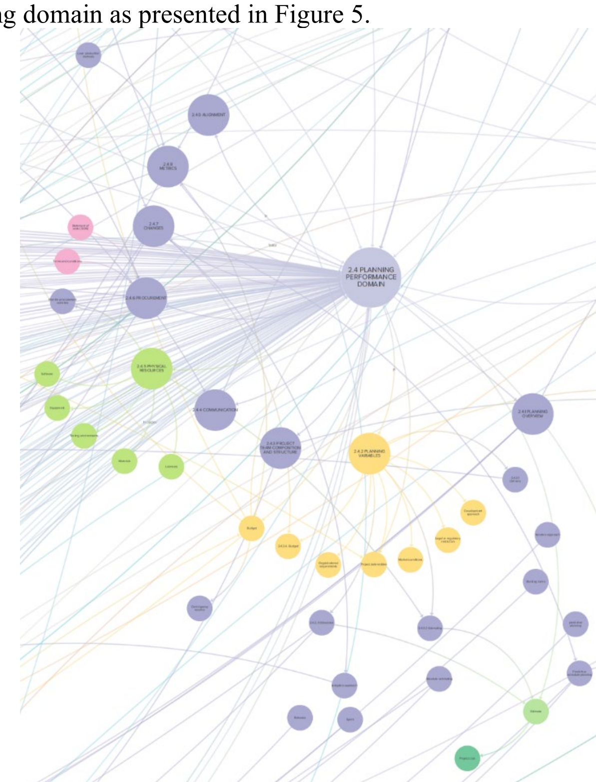


Figure 5. Extraction of planning domain PM components and features

Stage 3
During this stage, the data table obtained before was assessed by the company managers through interviews. To perform the assessment, each component was evaluated as follows:

- **Applied:** Component or feature already applied by the company and represented in the actual process, as presented during the previous stage.
- **To improve:** Component or feature already applied by the company but expected to be improved to allow the implementation of digital technologies or to be improved by the implementation of digital technologies inside the company.
- **To implement:** Component that is not currently implemented inside the company. To be implemented to enhance the process and get the best results from the digital technologies.
- **Doesn't apply**: Component that will not be applied inside the company due to management decisions.

Stage 4
Finally, during Stage 4, the improved process was modeled under the EA by using Artifact 2: EA integration with PMBOK features, integrating the improvements identified during the previous stage and the digital technologies (in this case, BIM) to be implemented inside the company.

After implementing the technologies inside the company's process, it was possible to model the following application view (Figure 6).

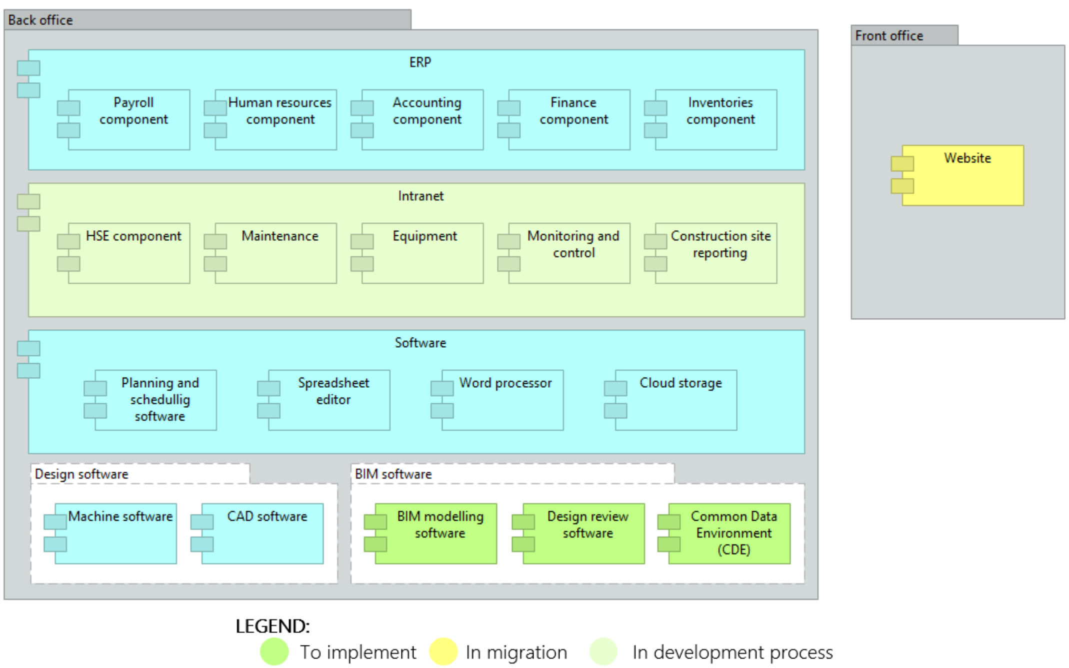


Figure 6. To-be application view

From this application, view is possible to identify that as an initial step to digital transformation, the company will be required to acquire the licenses for a BIM modeling software; a design review software; and a Common data environment.

The process improvements identified in Stage 3 and the above-mentioned applications were integrated into the company's Construction planning process, as shown in Figure 7.

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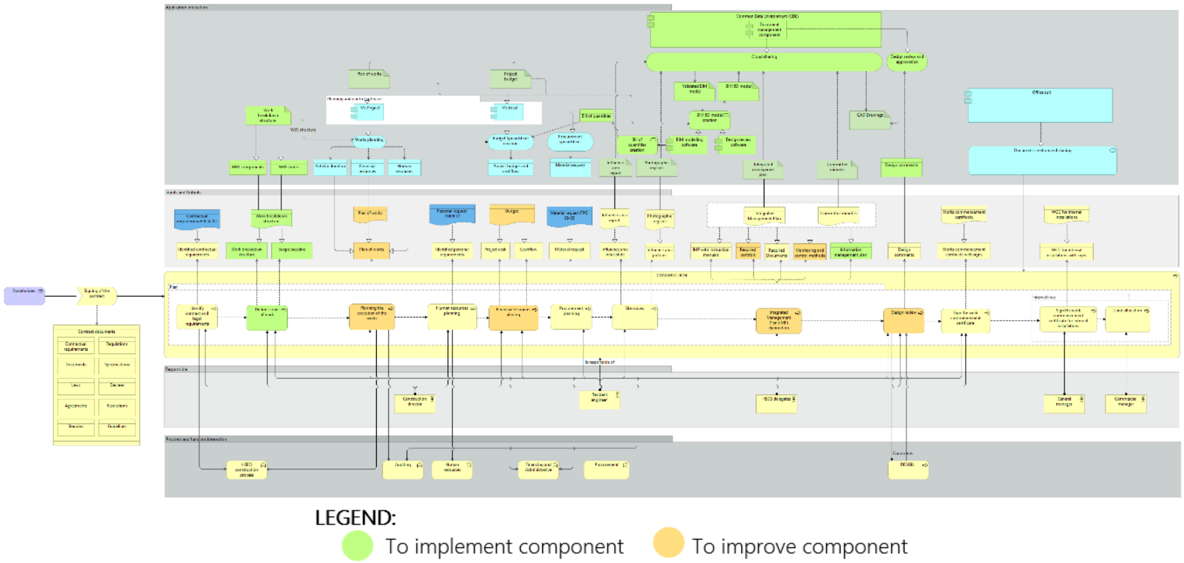

Figure 7. To-be construction planning process view

As a result of the to-be modeling process, it was possible to identify the flow between organization components, data, and project information. Moreover, it allowed the identification of existing barriers or interferences with software, as shown in Figure 8, where it was identified that the machine software that is, the software linked to the equipment used on the drilling, is only able to work with.CAD files. As a result, it was necessary to export the CAD drawings from the BIM model to allow the interaction with the drilling machine.

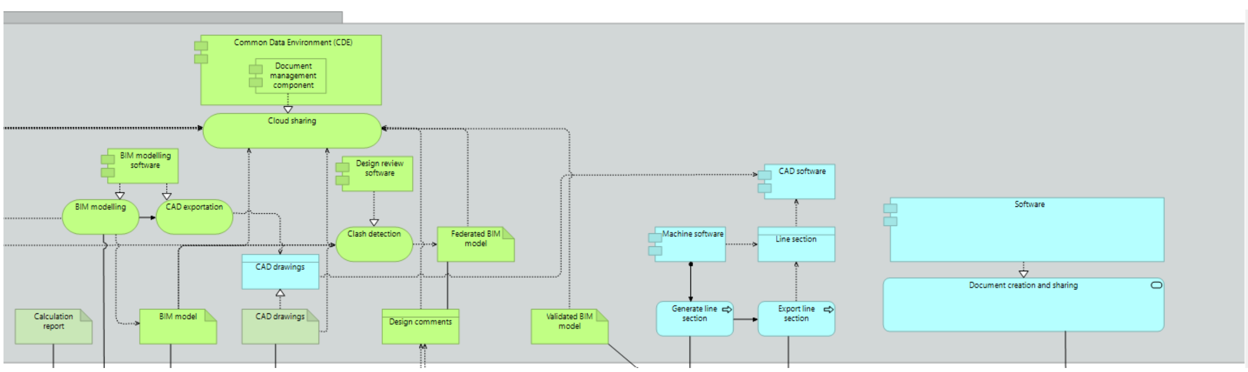

Figure 8. Software interference in the Design Process

Finally, the EA model also allowed us to identify the relations for services required for each software, which allowed us to propose some software available in the market that fulfilled actual company needs, as presented in Figure 9.

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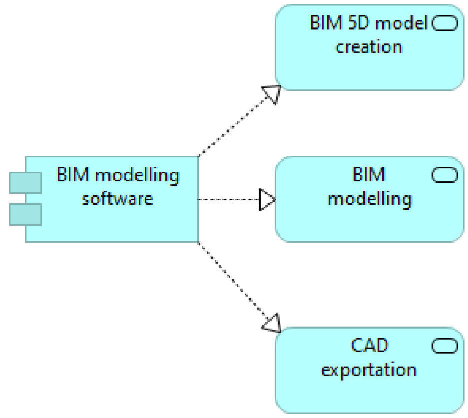

Figure 9. Services required from BIM modeling software

5. Conclusion

This research provided the SMEs with a systems-oriented framework developed in four stages: (i) Initial state process identification "As is," (ii) Process Analysis, (iii) Assessment of process improvements and potential innovations, and (iv) Improved process modeling. The framework was evaluated through a case study performed in a construction SME operating in the Oil and Gas sector in Colombia, from which it was possible to confirm that the SMEs digitization framework allows the AEC companies to assess their current processes and understand the relationships between organization components, data and project information in order to evaluate the best digital solutions to implement in the company.

Given that the framework implements Artifact 1: PMBOK graph model, it allows us to understand and have a clear vision of the project management process inside the company and its relationships. Moreover, since Artifact 2: EA integration with PMBOK features facilitates the representation and re-engineering of processes inside the company, the framework allows to provide of a systemic view of the Construction SME by modeling the company under the enterprise architecture.

From the network analysis performed during the creation of Artifact 1: PMBOK graph model, it was possible to identify that the planning performance domain plays an important role in project management, given that it has 138 connections, demonstrating great influence on the other PM components. As a result, this research suggests paying special attention to the planning processes during the modeling and assessment stages of the framework.

Moreover, the network analysis confirmed that PMBOK7 concepts act as a system since the metric "Connected components" have a value equal to 1, which shows that all concepts make an interconnected block. This fact highlights that project management processes are interconnected, confirming that it is crucial to have a systemic view of the company's process.

Finally, from the creation of Artifact 2: EA integration with PMBOK features was possible to identify that EA modeling languages such as ArchiMate can successfully support the design of an AEC company, given that its elements cover the main concepts from the PMBOK.

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