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IMPROVING PREMANUFACTURING PHASES IN OFF-SITE CONSTRUCTION THROUGH A DIGITALIZATION APPROACH

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ABSTRACT

The integration of digitalization and building information modelling (BIM) has been lauded as a cornerstone to improve processes and enhance communication across the construction industry. Nevertheless, the implementation of digitalization approaches has suffered due to the lack of methods and processes uncertainties, particularly in the case of off-site construction (OSC) companies where its premanufacturing phases (design, planning, and procurement) differ significantly from traditional construction. This research presents a case study of a digitalization-based workflow to reduce the duration and increase accuracy of premanufacturing phases. To that end, a digitalization plan is developed using value stream maps, supported by Monte Carlo simulation, to identify the waste of current practices and propose suitable improvement measures. Afterwards, a digitalization-based workflow is developed and implemented to exchange data between BIM models and other systems. After one year and a half of implementation, the proposed workflow reduced the duration of tasks in 92.31% while providing an average of 12.24% more accurate bill of materials compared to the previous approach. As such, the contribution of this study is twofold: first, a lean-based method to implement digitalization in OSC companies considering its particularities and inherited process uncertainties; and second, an improved process for OSC premanufacturing phases.

KEYWORDS

Off-site construction, digitization, BIM, simulation, value stream.

INTRODUCTION

Off-site construction (OSC) is characterized by its fast approach in construction where building components are manufactured in a shop floor meanwhile civil and foundation works are performed onsite. Although known for its performance onsite, Barkokebas et al. (2019) attributes the success of OSC to its integrated project delivery approach where premanufacturing (e.g., design, planning and procurement) phases are performed by the OSC contractor to design, procure materials, and develop shop drawings for production and final installation onsite. By adopting this approach, the OSC contractor transfers a significant risk from the client to themselves as they become responsible for all activities from the provision of engineering services up to the partial or full execution of the project.

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To that end, OSC requires expedited procurement processes to account for variances in product and short lead times thus demanding digitized processes to aid in transparent coordination and accurate pricing (Oti-Sarpong, 2019). Additionally, Zheng et al. (2021) suggest the use of digitalization strategies to exchange data between stakeholders and automate processes to streamline premanufacturing phases given the complexity and risks involved in this approach. In this context, building information modelling (BIM) appears as an emerging trend of digitalization as it provides a representation of the intended project while exchanging accurate data (Wen et al., 2021). Indeed, Singh (2019) argues that, despite lagging behind other sectors, digitalization efforts are revamped in the construction industry due to the increased level of maturity in areas such as BIM, analytics and industrialization. Therefore, the development of BIM-based methods is a cornerstone for the advancement of digitalization strategies in OSC given its complexity and intrinsic integration in design and procurement phases.

The objective of this paper is to propose a case study involving the digitization of premanufacturing phases in the largest OSC wood-frame contractor in Brazil. By identifying wastes in current practices, this paper proposes a digitized workflow assisted by a BIM-centric add-on to automate customized quantity takeoffs as means to exchange data to streamline premanufacturing phases and assist in the accurate pricing considering different types of projects. To that end, the following hypothesis is tested: *a BIM-lean digitalization of premanufacturing phases will lead to lower development times and more accurate estimates of OSC projects*. To test this hypothesis, this paper provides methods for the digitalization of premanufacturing phases in OSC companies through a case study that can be later adapted and applied by other researchers and practitioners.

LITERATURE REVIEW

BIM has been heavily studied in the context of OSC in different areas such as constructability, exchange of data, and automation of design and procurement processes. Gbadamosi et al. (2019) propose a BIM-based system to evaluate optimal solutions for the design of elements and materials considering different factors such as the ease of assembly of handling parts, production rate, and waste in OSC projects. Additionally, Rausch et al. (2019) apply Monte Carlo simulation for tolerance analysis in the manufacturing of steel frame module while indicating if rework is required or not. To bridge the gap between design and manufacturing teams, An et al. (2020) propose the use of an ontology to establish a formal link between BIM models and knowledge from manufacturing experts to detect what operations can or need to be performed to manufacture wall panels.

Despite relevant BIM efforts and digitalization, Mukkavaara et al. (2018) argue information is segregated between different stakeholders in OSC projects and requires manual operations to ensure an information flow between systems. Additionally, they point out the importance of automation of contributory activities such as the development of bill of materials (BOM) from BIM models as a key feature for more interactive and digitized processes in OSC. With that in mind, Hussamadin et al. (2020) propose a conceptual model for the conversion of BOM extracted from BIM models to assist different stakeholders from off-site and onsite operations.

To address the issue of manual interpretations from estimators to perform takeoffs, Tang et al. (2022) propose rule-based algorithms to automatically detect takeoffs specific to OSC manufacturing operations. Besides comprehensive applications involving the automation of takeoffs in OSC, there is a lack of studies considering different types of project whereas the addressed papers refer to single case studies only. Despite significant studies to digitize OSC premanufacturing phases applying BIM, Oti-Sarpong (2019) points out the scepticism of practitioners to adopt these approaches due to a natural resistance to innovation from the industry and its inherited uncertainties. Schimanski et al. (2019) voice similar concerns pointing out the need for structured approaches to implement and maintain digitalization approaches in OSC. They also suggest lean thinking as a guiding principle for the implementation of digitalization approaches through the combination of construction-related data generated through premanufacturing phases of OSC projects and BIM models. Moreover, more implementations are needed to assist practitioners and propose methods to digitize OSC premanufacturing phases considering a holistic approach between different stakeholders and the exchange of data between them. To that end, Barkokebas et al. (2021) developed a framework for addressing the impact of digitalization in OSC by adopting a BIM-lean approach. Within the proposed framework, BIM models are used to improve processes and exchange data between teams (e.g., architectural, structural, etc.) while lean-based metrics are applied to evaluate the impact of digitalization in OSC premanufacturing phases.

RESEARCH METHODS

This study applies a case study approach to demonstrate the implementation of a digitalization-based workflow and test the proposed hypothesis. For this purpose, the unit of analysis to test the proposed hypothesis is a comparison between the development times and accuracy of the affected tasks before and after the implementation of the proposed workflow. A case study approach is applied due to its capacity to describe and offer insights on the object of interest (i.e., the effect of digitalization in OSC) (Yin, 2013). Figure 1 shows the research steps followed in this study where the first three steps are achieved by applying a framework developed by Barkokebas et al. (2021) to acquire a digitalization plan containing improvement measures in the case company based on the inherited uncertainties of its premanufacturing tasks. This framework applies value stream mapping (VSM), leveraged by Monte Carlo simulation, to identify waste in the current workflow while suggesting digitalization-based improvement measures that are applicable to the case company. Monte Carlo simulation is applied in this framework to quantify the inherited uncertainties of tasks identified during the development of VSM maps. During the development of VSM maps, durations are often provided by company experts in ranges (e.g., worst-case scenario, best-case scenario, and normal duration) instead of fixed durations to better understand the variability of their tasks.

Indeed, the applied framework asserts the duration of tasks as triangular distributions based on scenarios (pessimistic, realistic, and optimistic durations) provided by experts at the case company. Moreover, tasks are categorized in the VSM as value-added (i.e., productive), contributory (i.e., task necessary to perform the work that do not add value), and waste (i.e., non-contributory work) according to Pérez and Costa (2018). At the end of the framework's implementation, a digitalization plan is provided containing different improvement measures tailored to the context of the case company. Based on the digitalization plan, the case company decides which measure to implement whereas a digitalization-based workflow is designed and implemented. Different interactions between authors and company experts are performed during the implementation of the improvement measure so feedback is incorporated, and better results are achieved during evaluation. After implementation, the proposed workflow is evaluated by comparing the waste and other metrics identified during the development of VSM maps. After the comparison step, the hypothesis is addressed and the results of the proposed workflow are published. In total, the mapping process (i.e., first step of the digitalization plan) was developed in one month followed by another two months of implementation of the approved improvement measure. Finally, a comparison of results between the previously mapped and modified processes is presented after one a half year of its implementation.

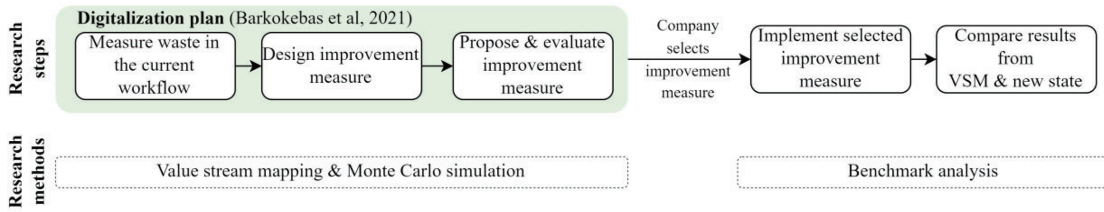

Figure 1: Research steps and methods according to DSR

CASE STUDY

As previously mentioned, the case study involves the work developed with the largest wood frame OSC company in Brazil specialized in the residential sector. The case company must adapt drawings provided by the client often designed to be built in masonry onsite (Brazil's most common construction method) to wood frame panels (walls, floors and roofs). Wall and floor panels will be manufactured on a semi-automated shop floor and later installed onsite while the roof is built onsite. Five premanufacturing teams are identified in the company: (1) project management office (PMO), responsible for estimating, preparing commercial proposals, and bidding for new projects; (2) architecture, responsible for preparing all architectural drawings and documentation for manufacturing and construction; (3) the design for manufacturing and assembly (DFMA) team, responsible for elaborating drawings and plans for the manufacturing and assembly of the manufactured panels; (4) plumbing, responsible for all plumbing drawings and documentation; and (5) electrical, who is responsible for all electrical drawings and documentation. All teams must upload its drawings, models and other documentation (BOM, estimates, schedules, etc.) in an enterprise resource planning (ERP) system. The following section will show the results of the digitalization plan according to the framework developed by Barkokebas et. al. (2021). Afterward, the results of the implementation of the proposed digitalization plan, the digitalization-based workflow, is presented followed by a discussion of similar studies.

RESULTS & DISCUSSION

DIGITALIZATION PLAN

Measure waste in the current workflow

Initially, the overall workflow is mapped to identify the exchange of information between teams on each project. This process is performed through semi-structured interviews performed online with each team's manager followed by other meetings to validate the information provided previously. Figure 2 shows the overall workflow and exchange of information between different teams followed by the main software used at the time. PMO receives the drawings in computer aided design (CAD) format from clients where manual takeoffs are performed to estimate the project's cost and the commercial proposal is delivered for bidding. Changes in the initial design by the client are common, thus the takeoffs must be updated so the commercial proposal reflects the latest project version, and the case company is competitive during the bid. A BIM model is not developed at this point due to the significant effort to develop the model where takeoffs are the only information needed. Moreover, the PMO argues that the significant effort is not justified since the project is still in the bidding stage whereas the case company still does not know if it will win the bid or not. Hence, quantity takeoffs are performed on AutoCAD and manually transposed to MS Excel for cost estimation.

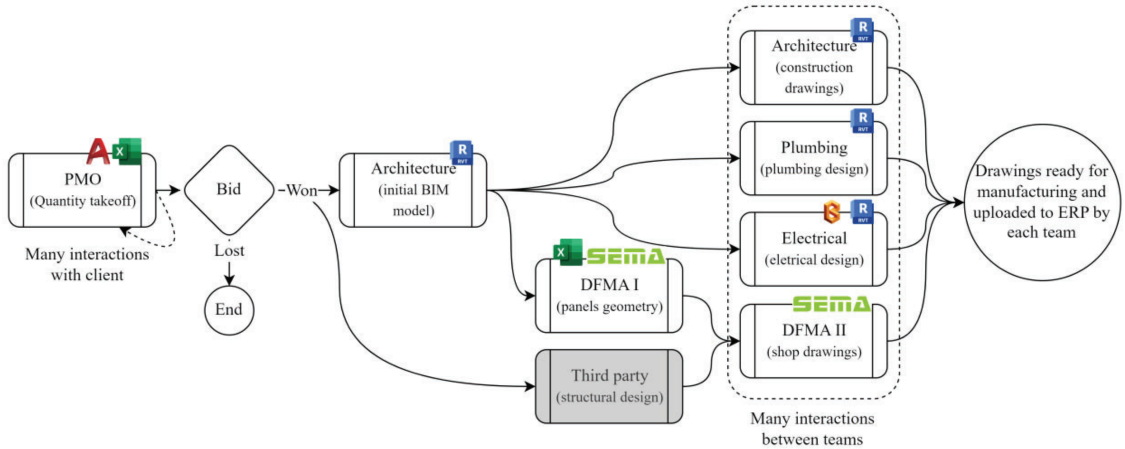

Figure 2: Overall workflow between teams

If the bid is won, the latest version of the project is sent to a third-party structural consultant and the architectural team starts developing the initial BIM model so the remaining teams (electrical, plumbing and DFMA) can start their work using BIM authoring software. At this point, Autodesk Revit is used as the main BIM authoring software by most teams. The initial BIM model includes all panels (floors, walls, and roofs) with its openings, thus delimitating the spaces and overall geometry of building elements in the project. Architectural and construction specifications are defined by the architectural team during the design process whereas decisions are made and coordinated with the remaining teams. The electrical and plumbing teams develop the drawings and specifications of their respective disciplines using Autodesk Revit whereas the electrical team also utilizes a specialized software (AltoQi Builder) to perform calculations. Meanwhile, the DFMA team is responsible for adjusting building elements according to the case company's manufacturing and construction methods. At the beginning of the project (i.e., DFMA I in Figure 2), the DFMA team defines the exact geometry of panels according to previous projects. After structural design is finished by a third-part consultant, the DFMA team revises the geometry of panels and generates shop drawings for manufacturing in the shop floor leveraged by semi-automated machines (i.e., DFMA II in Figure 2). Hence, the DFMA team utilizes SEMA, a specialized software in wood construction, to generate the shop drawings and computerized numerical control (CNC) codes to be use in the semi-automated machines. Due to different software used, data between the DFMA and electrical teams is exchanged using industry foundation class (IFC) format. Since the remaining teams use the same software (Autodesk Revit), data between them is exchanged through native files.

Some of the identified challenges are the loss of data and productivity when using heavy IFC models (DFMA and electrical teams) and the lack of documented design solutions and material consumptions used in previous projects (PMO and DFMA teams). All teams, except for PMO, also pointed out the extensive time required to develop the project documentation while maintaining all information updated during project revisions. Nevertheless, the most common challenges, identified by all teams, are associated with the exchange of data related to takeoffs where schedules created automatically in Revit and other software need to be transposed to spreadsheets or ERP following manual procedures. Indeed, every team needs to perform quantity takeoffs and provide schedules such as BOM to account for the cost of each discipline. Specialized software used by the DFMA and electrical teams provide automated BOM for each discipline. However, automated schedules developed by the remaining teams using Autodesk Revit needs to be transposed and modified manually in Excel to include all materials required without the need of extra modelling in the BIM model. Furthermore, teams indicate that takeoffs are often outdated after several project revisions due to the error-prone and extensive time spent on revising updated takeoffs due to changes in the models. After all teams are finished, this information is uploaded by each team to the case company's ERP system so material can be ordered and the project is scheduled for manufacturing by other departments.

The architectural team was selected for the application of the proposed framework and to evaluate whether it would benefit from a digitalization-based workflow. This team was selected because it provides the base BIM model to the remaining teams and is responsible to determine the actual quantities related to the architectural discipline. Hence, a VSM is developed to map current waste in the architectural team considering the inherited uncertainty of design processes applying a Monte Carlo simulation using Simphony.NET software.

Table 1 shows the tasks identified during interviews with the architectural team manager to develop the VSM supported by the Monte Carlo simulation. Tasks are performed in the order described in the table and are categorized as per value-added, contributory work or waste according to lean philosophy (Pérez & Costa, 2018). The initial three tasks in Table 1 correspond to the first process from the architectural team (i.e., initial BIM model) in Figure 2 whereas the remaining tasks in the table correspond to the second process (i.e., construction drawings) demonstrated in the same figure. As previously mentioned, task durations are given by experts in the form of scenarios (pessimistic, realistic, and optimistic) which, in turn, are modelled as triangular or uniform distributions depending on how the information is gathered by experts. Table 1 shows only one task categorized as waste which entails developing the initial BIM model from the latest CAD drawings while the most impactful contributory work is related to the takeoff and exchange of data process once this design phase is finished. Therefore, the observations made during the interview process with all premanufacturing teams confirms the significant effort in exchanging data as supported by the data displayed in Table 1 where the takeoff and exchange of data task amounts over 30% of the total average duration. The results of simulation are presented in the Propose & Evaluate section together with the proposed scenarios.

Table 1: Input for simulation model

Task description	Task type	Duration (days)		
		P	R	O
Develop initial BIM model	WT	2	1	0,5
Determine location of electric outlets	VA	1		0,5
Send initial BIM model to other disciplines	VA		0	
Review project scope	CW	0,3		0,2
Architectural detailing	VA	3–4	2	1
Roof detailing	VA		1,5	
Construction detailing	VA	5	4	3
Waterproofing detailing	VA	2	1	0,5
Develop views for federated model	CW		0,5	
Quantity takeoff and exchange of data	CW	4,5	4	3

Note(s): VA: Value-added, CW: Contributory work, WT: Waste, P: Pessimistic scenario, R: Realistic scenario, O: Optimistic scenario.

Design

In light of what was mapped and considering the current waste in the architectural team, two improvement measures are suggested by the authors: (1) the development of an add-on to generate BIM elements (walls, floors, and openings) from the latest CAD drawings approved during bid by the client , and (2) the development of a workflow to automate the exchange of data between BIM models and other systems (e.g., ERP) leveraged by an add-on and coupled with the adaptation of currently used MS Excel formulas to increase the speed and accuracy of takeoffs during the design process.

The first suggested measure (i.e., add-on in Autodesk Revit to generate BIM models from CAD files) aims to minimize the only task categorized as waste while ensuring the remaining teams start working as soon as possible. The nature of this task also involves time-consuming and repetitive work without requiring specialized expertise thus becoming an ideal candidate for automation. Moreover, the proposed add-on is also applicable to PMO during the cost estimation phase where a BIM model can provide accurate data without the expense of extensive development time. The second suggested measure aims to automate the takeoff process exchange of data between the BIM model and other systems in the case company. This data is used to provide information related to the quantity of materials, cost and production schedules required during the procurement and manufacturing phases which are uploaded to the ERP system. The development of an add-on for Autodesk Revit is suggested to generate CSV files containing the required data for the entire project that will be uploaded in the existing MS Excel spreadsheets used by the case company. The main difference between the current process and the proposed workflow involves the automated exchange of data from the entire project whereas manually updating information from BIM-based schedules results in mistakes and extensive time to make sure all information is updated and correct. Furthermore, this workflow is also applicable to other teams using Autodesk Revit (Plumbing and Electrical) in case the proposed workflow is accepted by the architectural team. It is important to note that both improvement measures are developed based on previous studies and the experience of authors in similar OSC companies. Therefore, other suggestions may be applicable depending on different experiences if other participants were involved.

Propose & Evaluate

This section provides an evaluation of the impact that the proposed suggestions will have in case they are implemented. To do so, the duration of affected tasks by the improvement measures are adjusted in the validated Monte Carlo simulation to predict changes in the average project duration. The modified tasks durations are estimated according to the author's

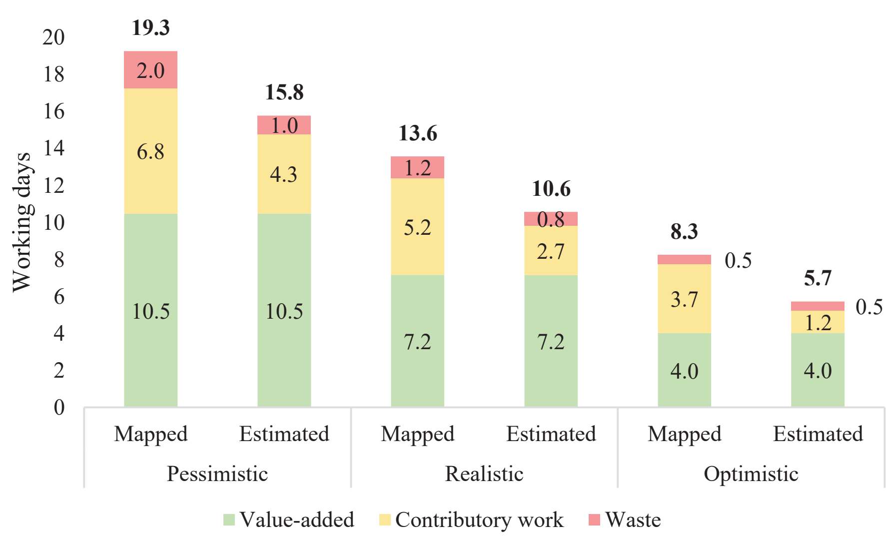

Figure 3: Comparison between the mapped and estimated durations according to different scenarios and task types

experience and in discussion with the case company's experts. The first and second suggested measures will reduce the duration of each task significantly. In the case of the proposed add-on to generate BIM models from the latest CAD drawings (i.e., first suggested measure), authors estimate the task "Develop initial BIM model" will take between half to one working day (e.g., pessimistic and optimistic scenarios, respectively) in case this measure is implemented. Moreover, on the second suggested measure, authors propose an add-on to automate the takeoff and exchange of data process between Autodesk Revit and Excel to reduce the task "Quantity takeoff and exchange of data" between half to two working days (e.g., pessimistic to optimistic scenarios, respectively) considering the size of projects and team's productivity. Hence, the validated Monte Carlo simulation is updated with uniform distributions (i.e., 0,5 to 1 working days in the case of the first modified task) according to what was estimated by authors and compared to the mapped state of durations. Figure 3 shows a comparison between the mapped durations and estimated durations according to what was gathered with the architectural team and author's experience, respectively. Also, the figure shows the total average project duration (in bold) while highlighting the contribution of each task type according to different scenarios. According to Figure 3, the total project's duration can be reduced 23,84% on average in case both measures are implemented. After this assessment, the digitalization plan was completed, and the case company experts could decide to implement the proposed measures or not.

PROPOSED DIGITALIZATION-BASED WORKFLOW

Implementation of selected improvement measures

Based on the digitalization plan developed in the previous subsection, the architectural team decided to not move forward with the first suggested improvement measure and prototype the workflow leveraged by an add-on to automate the exchange of data between BIM models and other systems (i.e., second improvement measure). Therefore, an add-on to automate exchange of data between Autodesk Revit and Excel was developed since these software are currently used by the architectural team. Moreover, the developed addon is applicable to other design teams using Autodesk Revit to design their models while using Excel to import data to the ERP system. Since the ERP system requires specific access to develop applications in it, importing data via Excel was suggested as this is a common default feature in most ERP systems. Hence, in case it is approved by the architectural team, the proposed workflow is applicable for all design teams with the exception of PMO and DFMA. Figure 4 shows changes suggested in the architectural team according to the proposed workflow and leveraged by the developed add-on. The add-on, named BTO provides an automated connection between data embedded in the BIM model and takeoffs required by the design team using Excel as an interface. Once the required takeoffs are entered in an Excel spreadsheet, the spreadsheet is uploaded to BTO which collects the data from Autodesk Revit and returns it in a structured format in Excel. The takeoffs are then processed through formulas in Excel to account for material waste, and labor or materials that are not modelled directly in the BIM model (e.g., ceramic tile placed up to a certain height in wet areas are calculated from the wall length at a specified height).

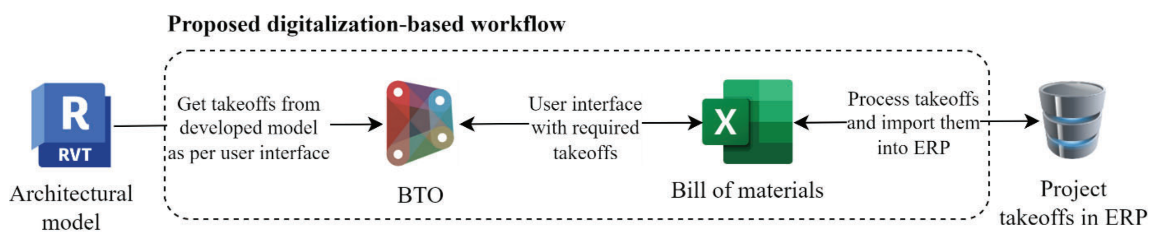

Figure 4: Changes in the current workflow

Comparison between mapped and proposed workflows

To address the hypothesis, this section shows a comparison of results between the previously mapped workflow and actual results gathered through interviews and data provided by the architectural team after implementation. Table 2 shows a comparison between the previously mapped and current durations and coefficients of variation, calculated using the program evaluation and review technique (PERT), in the affected task by the proposed workflow. The actual durations for quantity takeoff were gathered during interviews with the architectural team's manager after one year and a half of implementing the proposed workflow and add-on. Following the same procedure when developing the VSM maps, the actual durations of the affected task were gathered considering the inherited uncertainties (i.e., pessimistic (P), realistic (R), and optimistic (O) scenarios) of design processes as determined by Barkokebas et al., (2021). Table 2 shows that the proposed automated process, leveraged by the addon BTO, reduced the task in 92.31% % where the actual task duration varies between 0,2 to 0,5 working days. This result exceeded the expectation from authors where they forecasted 0,5 to 2 working days in the Propose & Evaluate section of this paper. This discrepancy is explainable with two reasons: (1) authors wanted to be conservative in their forecast while developing the digitalization plan, and (2) company experts modified formulas in their bill of materials so takeoffs could be performed more easily. Nevertheless, this result is aligned with previous studies comparing the application of BIM versus traditional approaches where takeoffs are consistently reduced by 70% of duration (Bečvarovská & Matějka, 2014; Wahab & Wang, 2022). The coefficient of variation increased significantly in the proposed workflow compared with the previously mapped workflow. Nevertheless, the manager of the architectural team indicated that, even when accounting for a more variable process, the duration in the takeoff process is greatly reduced by the proposed digitalization workflow.

Table 2: Task duration comparison between the mapped and proposed workflow

Task description	**Scenarios**			**Expected duration (days)**	**Coefficient of variation**
	P	R	O		
Takeoff and exchange of data (mapped)	4,50	3,80	3,00	3,90	6,38%
Takeoff and exchange of data (proposed)	0,50	0,30	0,20	0,34	14,43%
Difference between takeoff processes				**-92.31%**	**111,71%**

To assess the effect of the proposed workflow in the accuracy of estimates, the architectural team gathered data from three projects and compared their takeoffs performed by BTO with the BOM developed manually by the PMO team during the bidding phase. Table 3 shows the deviation between the manual and automated takeoffs on the main items surveyed by the architectural team. Deviations as significant as 80,3% confirm the high potential for error of manual takeoffs in the construction industry. Furthermore, an average 12,24% deviation between manual and automated takeoffs are observed between the three projects thus indicating that the automated takeoffs are significantly more accurate than the manual approach. Once again, this result is aligned with previous studies such as Pratoom & Tangwiboonpanich (2016) that indicate a deviation of 17,76% in the quantity of items considering manual and BIM-based takeoff practices. The results of improvements in both metrics established to test the proposed hypothesis (tasks durations and takeoff accuracy) are aligned with findings in previous literature as described in this section. Therefore, based on the results provided, the architectural team accepted the proposed workflow and decided to implement it in the entire team.

Table 3: Takeoff deviation between manual and digitalized processes

Material	Unit	Deviation from original takeoff (%)		
		Project 1	Project 2	Project 3
Ceramic tile	m^2	5,19%	12,44%	12,22%
Cementitious board	m^2	9,12%	16,78%	16,02%
Gypcrete	m^3	-15,15%	20,00%	7,03%
Ceiling	m^2	6,75%	7,21%	22,89%
Plaster board	m^2	8,71%	16,16%	4,04%
Water proofing	kg	-0,31%	61,82%	13,86%
Batt insulation	m^2	5,09%	45,39%	8,95%
Windows	un	0,00%	0,00%	0,00%
Painting	m^2	80,30%	6,76%	11,16%
Doors	un	0,00%	0,00%	0,00%
Roofing	m^2	9,10%	14,79%	7,75%
Exterior finishes	m^2	9,35%	7,45%	9,83%
	Average	**9,85%**	**17,40%**	**9,48%**

CONCLUSION

Despite relevant studies in the area, digitalization strategies and the use of BIM are still not fully implemented in OSC due to its inherited uncertainties and specific aspects compared to traditional construction. Aligned to that, the present study provides a practical implementation of a digitalization-based workflow in an OSC company aiming to reduce the current waste in its premanufacturing phases. Through the application of a framework developed by Barkokebas et al. (2021), the authors developed a digitalization plan supported by VSM maps and Monte Carlo simulations to identify current waste and propose improvement measures considering its potential impact to the case company. The digitalization plan identified two improvement measures to automate the generation of BIM models and the exchange of data between BIM models and other information systems, respectively. By selecting and implementing the second improvement measure, an add-on (i.e., BTO) was developed to automate the takeoff and exchange of data process and rendered a reduction of 92,31% in duration while providing more accurate BOM when compared to the previously mapped workflow. The achieved results performed better than expected in comparison to the estimated reduction presented in the digitalization plan. Yet, results were validated by the case company experts throughout interviews and based on the implemented digitalization-based workflow after one year and a half of its implementation. Given the positive results, the proposed workflow is incorporated in the case company. Despite its results, this study still presents limitations regarding the case study approach, as it becomes biased to the specific context of the case company and ultimately, cannot be generalized. Therefore, more case studies are needed to increase the number of methods to digitalize premanufacturing phases in OSC. Nevertheless, the hypothesis of this study is approved within this context since the case study demonstrates that the implementation of a BIM-lean digitalization approach results in lower development times and more accurate estimates when working with OSC companies. Finally, this study contributes with a lean-based method to implement digitalization practices in OSC companies considering its particular context and inherited process uncertainties to improve processes in OSC premanufacturing phases.

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