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A CONSTRUCTION INFORMATION SYSTEM AS A LEAN INFORMATION MANAGEMENT ENABLER – CASE STUDY

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ABSTRACT

Information Management Systems, or just Information Systems (IS), are important platforms to manage processes with a large volume of information exchange, guaranteeing the appropriate flow of accurate information. In the Architecture, Engineering and Construction (AEC) industry, the use of information systems is still modest in contrast with the volume of data produced in the industry. However, with the advance of the digital transformation of Construction 4.0, this information gains even greater prominence and can be considered the most valuable asset during construction phases such as Pre-design, Design, and Procurement. Lean Information management is the application of lean thinking to information management, where the information can be considered a value and able to flow, removing waste, pull, and being in the process of continuous improvement. This paper presents an analysis of an Information Management System, ProNIC, intensively used and endorsed in Portuguese public construction contracts. Originally conceived to add value to the end-user (customer), the Portuguese Government, ProNIC is now being assessed as an enabler of lean processes in the management of construction information.

KEYWORDS

Information systems, lean construction, digitization, process, enabling lean

INTRODUCTION

Information is a critical resource for the efficiency of today's businesses, and their management systems are essential for the performance of organizations that depend on knowledge. Information management can be defined as the activities that involve the creation, presentation, organization, maintenance, visualization, reuse, sharing, communication, and disposal of information. Information can be considered as value, due to the way it is processed and flows to the end user through the exchange, sharing and collaboration procedures. (Hicks, 2007).

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Lean information management (LIM) is a concept that links two well-established fields in the literature: Lean thinking and information management. The objective is to improve the flow of information by eliminating or reducing waste and non-value-added activities (Teixeira et al., 2019). Therefore, Information Management Systems, or just Information Systems (IS), are the key to treating information with proper value, managing it, and getting it flowing, with due relevance and at due time.

In AEC industry, data waste or inefficient flow can potentially causes loss of important information, rework due to missing or outdated information, delays due to waiting for information, and unnecessary processing of information, among other wastes (Ré & Teixeira, 2018; Tribelsky & Sacks, 2011). There are a large number of different IS that process business information, such as financial, payroll, customer relationship management (CRM), product data management (PDM), and inventory management systems (Hicks, 2007), However, a range of technical information is neglected by the more spread systems, such as design information, which requires specific treatment (Ahankoob et al., 2020).

ProNIC (Portuguese acronym for Construction Information Standardization Protocol) is a construction information system that manages specific information from the construction process (Sousa et al., 2012). The origin of ProNIC comes from the Portuguese Government awareness that there was a lack of standardization on construction projects at the bill of quantities level, as well as flaws at the specifications level supporting the design stage documents (Mêda, Calvetti, Ribeiro, et al., 2021) . Therefore, ProNIC was conceived from the perspective of client improvement, specifically the Portuguese Government. From this evaluation, it is possible to envision that ProNIC can act as a Lean Information Management enabler, even though it was not originally designed in this context.

The analysis of construction information from a lean perspective is necessary to recognize the function fulfilled by the IS themselves under managed information. Analyzing the performance of these systems under a lean vision will enable continuous improvement of the processes involved.

BACKGROUND INFORMATION

LEAN INFORMATION MANAGEMENT

Lean Manufacturing was developed from Toyota Production System (TPS) to increase the competitiveness of the automotive company (Womack & Jones, 1997).

Taiichi Ohno, a Toyota engineer and executive, started the TPS application, by identifying seven types of waste found in any process, and Womack & Jones (1997) added the eighth waste: **Transportation**; **Inventory**; **Motion**; **Waiting**; **Overprocessing**; **Overproduction**; **Defects**; **Underutilization of people**. To prevent, reduce, or eliminate the above-mentioned waste, five Lean principles have been defined, which are (Hicks, 2007; Womack & Jones, 1997): **Specify Value**; **Identify the Value Stream**; **Flow**; **Pull;** and **Pursue Perfection**.

These principles can also be applied to information flows. Ensuring that useful information is produced promptly and made available only to the right people at the right time is the goal of information management. However, waste in the context of information management is less clear and is generally not as visible (Hicks, 2007).

The waste in the context of information management is related to the downtime or additional activities that are a consequence of not providing the stakeholder with the necessary information with immediate access, in a simple, accurate and updated way. Like lean thinking in the manufacturing context, lean in information management is about identifying and enabling improvements in the flow of information, eliminating, or reducing waste in the various aspects of information management. The objective, as in manufacturing industries, is that these improvements are reflected in efficiency, productivity, overall process and product quality, also

by allocating specialized human effort where value is added to the final product (Hicks, 2007). The waste associated with the information flow may include the effort necessary to overcome difficulties in retrieving or accessing information, or in activities that require the confirmation and the correction of inaccurate information. The principles that LIM considers are:

- the information should only be created if it is useful to decision-makers (add value).
- the information should only be sent to those who need them.
- the information should be quickly processed, preferably in real-time, avoiding waiting on the part of the users; and
- the information should be provided by sources without duplication of data.

So even though the concepts have originated in the field of production processes, it is possible to apply Lean principles to information flow processes. The following are examples of how Lean waste can be understood for information flow (Ré & Teixeira, 2018):

1. **Transportation**: consists of the unnecessary movement of information between various sources, manifesting itself, for example, in the re-insertion of information, due to incompatibility of systems or resistance in the use of IS.
2. **Inventory**: supplying more information than is necessary for decision-making at a given moment. In practice, it may also refer, for example, to information that although it exists, is not in the right place, conditioning the execution of certain activities due to lack of information.
3. **Motion**: consists of unnecessary steps to collect information that is not easily accessible.
4. **Waiting**: refers to the time it takes to obtain information, reflected in the time that a task or process cannot be carried out due to lack of information.
5. **Overprocessing**: related to the lack of information and the activities required to fill that lack, which may include the creation of new information or the identification of additional information.
6. **Overproduction**: all the effort devoted to identifying valuable information due to the high volume of existing information, much of it worthless.
7. **Defects**: consists of inaccurate, wrong, outdated, or incomplete information.
8. **Underutilization of people**: consists of the incorrect use of an organization's human resources, due to inadequacies in the processes or in the information itself.

ProNIC

ProNIC – Protocolo para a Normalização da Informação Técnica na Construção (Portuguese Construction Information Standardization Protocol) – is a computer platform initially developed in 2005 – 2008 to promote the standardization of technical contents for the construction of buildings and road works, supported by the Portuguese Government. It quickly grew in scope and functionality, allowing collaborative work, delivering high-quality Bill of Quantities (BoQ) from standardized, comprehensive work break-down structures (WBS), and possessing an organized document repository that could aggregate information throughout the construction process, including managing the monthly measurement reports of the construction phase, as well as producing a variety of indicators and metrics (Mêda, et al., 2021). It was also compliant with the newly launched CCP – Código dos Contratos Públicos (Public Procurement Code), and has been heavily used by Parque Escolar, EPE – a public company overseeing a very large, ongoing, high-school renovation campaign in Portugal (Mêda & Sousa, 2016).

ProNIC perform document collection, storage, management, and sharing functionalities that work exactly like a **Common Data Environment (CDE)**, even before this concept became widespread due to its use for BIM projects (Mêda, et al., 2021). A CDE is a central space for

collecting, managing, evaluating, and sharing information. All stakeholders can obtain information and store their data concerning the project in a single environment. The CDE also allows the creation of models for coordination, partial models, databases, and documents for specific phases of the construction process. In addition, the CDE leads to a higher rate of information reuse, simplifies the aggregation of information models, and simultaneously serves as a central archive for documentation (Preidel et al., 2016).

Figure 1 summarizes the processes supported by ProNIC. For the project phases indicated, the listed stakeholders undertake the corresponding activities in the system, promoting the standardization of information throughout the process.

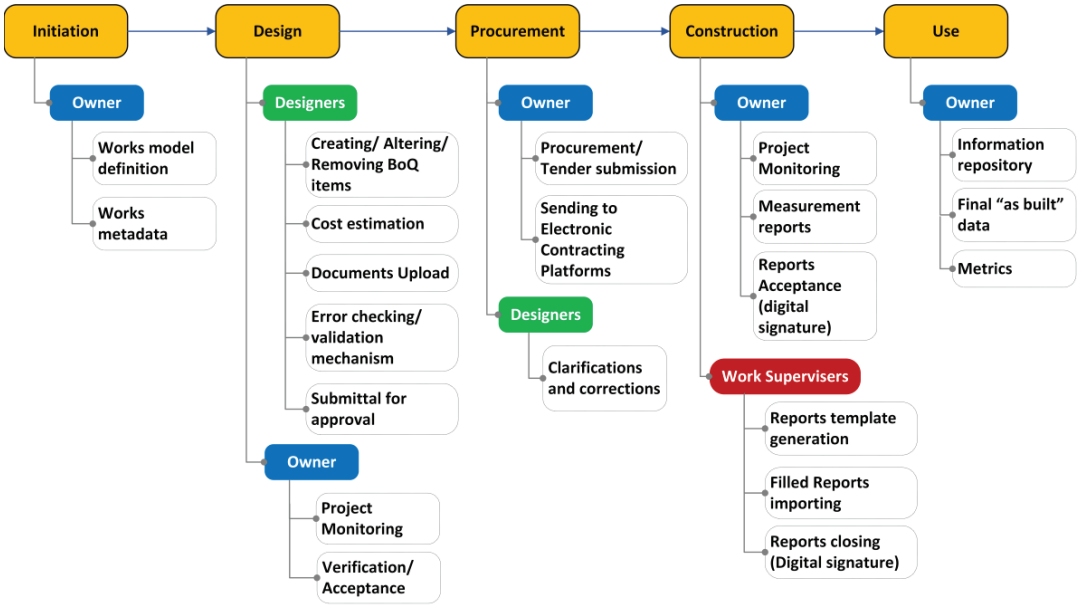

Figure 1: ProNIC Process Overview

Within the scope of the REV@CONSTRUCTION Mobilizer Program (https://revconstruction.pt/), aiming at accelerating the adoption of Construction 4.0 in Portugal, ProNIC is currently being updated: its IT platform is being redesigned and its technical contents are being revised, in order to prepare ProNIC for a new phase within Construction 4.0. New functionalities, such as integration and interoperability with BIM models, a cost database, new classifications tables related to the construction process, and BIM object libraries are being planned for future implementation (Mêda et al., 2016). This evolution is also being designed under a lean perspective to deliver continuous improvement not only in the System itself but also in the processes related to it.

METHODOLOGY AND RESEARCH QUESTIONS

This study grounds a critical analysis of construction project processes performed by different agents considering the support or not of information management platforms. The findings and intuitions are evaluated by facing the basic principles of lean and Lean Information Management. ProNIC is used as the case study to observe improvements in the processes, as shown in Figure 1: ProNIC Process Overviewin terms of information flow, work overload reduction, and suppression of activities not adding value.

The research is motivated to provide answers to the following questions: Can a construction Information System be a tool promoting Lean Information Management? What Lean thinking improvements has ProNIC implemented? How can the processes performed by ProNIC be further improved based on Lean Information Management?

FINDINGS

COMMON DATA ENVIRONMENT

The Common Data Environment feature plays a central role in the operation of ProNIC as an information manager. The research conducted found that, as a CDE, ProNIC follows Lean thinking in the aspects shown in Table 1.

Table 1: Lean Wastes and Benefits of ProNIC as a CDE

Lean Wastes	ProNIC Benefits
Transportation	A single "information container" where all files must be, eliminates the need for the same information to be addressed to all stakeholders.
Inventory	Organizing the files in a predefined directory structure makes it possible for a file to be available only in the right place, in the right version, avoiding being available in multiple versions and multiple locations.
Motion	According to the information above, simply organizing the files eliminates steps such as contacting the responsible parties to request information or confirming that the available version is the current one, for example.
Waiting	All current information is available to all necessary stakeholders at the time it is loaded into the system.
Overprocessing	Using the directory structure you can check the currently available version, and if in doubt you can avoid the trouble of checking and evaluating what is available, for example.
Overproduction	No effort is devoted to searching for valuable information among the vast amount of existing information, much of which is not important.
Defects	Only the current information is available. This is sufficient to ensure that no outdated versions can be used, preventing defects in subsequent processes.
Underutilization of people	The efforts expended for all information organization are usually skilled professionals' time spent on activities with low or no added value.

Therefore, the CDE provides gains in the entire ProNIC process under the Lean perspective. Schimanski et al., (2021) conclude that there was greater confidence in the reliability of the information used in a project when using a CDE workflow, including regarding the conjunction of Lean Construction techniques.

OWNER

The Portuguese government was the one that initially demanded to use ProNIC. Therefore, its functionalities were designed to improve the flow of information related to this specific client. However, only with the in-depth use of Parque Escolar, EPE, the Owner's current scope was defined, with all the phases and activities performed shown in Figure 2.

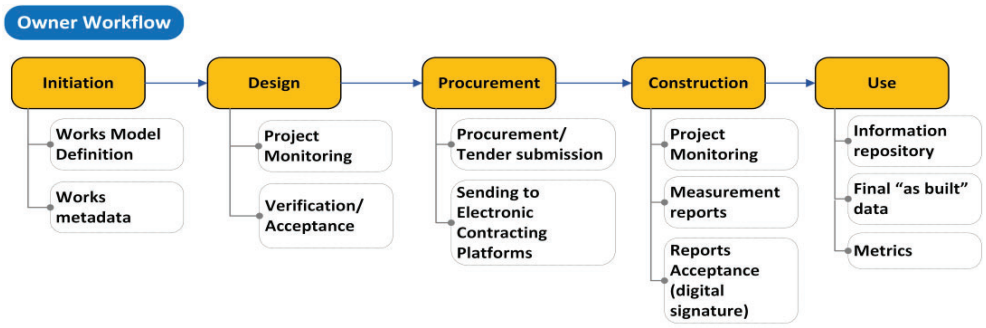

Figure 2: ProNIC Owner´s Workflow

The most relevant flows benefited were:

Works Model Definition/ Works metadata: The Owner defines the Work Model, with information such as Construction Type, Intervention Type, Construction Units, etc. This information is available to the project team at any time from the beginning of the process, avoiding delays in defining information, overproduction of elements with wrong data, and especially minimizing defects in the compatibility of disciplines.

Project Monitoring: In agreement with the CDE definitions, the necessary information for monitoring is always available in its current version, avoiding waiting, searching for information, confirmation of versions, and updates.

Verification/ Acceptance: The confirmation of the reception of the projects, properly formatted to meet the legal requirements, guarantees that the process will only move forward with all the necessary information, avoiding the production of elements not needed at the moment, eliminating the need to search for these projects, move them, store them in intermediate directories, reducing the work of the specialized team with non-technical functions.

Procurement/Tender submission/ Sending to Electronic Contracting Platforms: Like the reception and fulfillment of legal requirements, the tender submission and sending to the contracting platforms benefits from the organization of pre-determined files facilitating the management of the information needed for submission.

Construction Management: The automatic emission of the measurement reports for those involved in the process (Contractor, Supervision, and Owner) avoids divergence in the information, simultaneous verification, and promotes compliance with legal limits regarding modifications of the contract and other legal requirements.

In terms of Lean Wastes, Table 2 shows a summary of the benefits of ProNIC to the Owner.

Table 2: Lean Wastes and Benefits of ProNIC to the Owner

Lean Wastes	ProNIC Benefits
Transportation	Taking advantage of ProNIC's CDE role, the information needed for legal purposes is organized in its respective directories as soon as the appropriate versions for these uses are available, with no need for movement between directories.
Inventory	Once again, the CDE role allows the elimination of intermediate directories to organize files for submission to platforms, provisioning, validation, and other legal provisions.
Motion	The ease of access to information by the owner, with directories organized for the proper uses, avoids unnecessary steps for collecting the correct information.
Waiting	The request for information is one of the primary causes of waiting. Immediate access to all current information by the owner eliminates this wait.
Overprocessing	The predefined structure of the documentation directs the need to create files with only the information needed for the procedure at hand.
Overproduction	There is no need to search for information needed for procedures.
Defects	The owner can monitor the entire process, have access to intermediate versions, control demands, and pull production enabling a correct flow of information, without defects, outdatedness, or incompleteness.
Underutilization of people	The team allocated by the owner for process monitoring oversees technical and management checks, releasing them from the role of mere file organization.

In conclusion, the owner mainly benefits from ProNIC's CDE functionality to achieve a better flow of information. It is worth noting also that the workload at the end of the processes for preparing files and information for tender no longer exists with the automation provided by ProNIC.

Work Supervisors

The role of the work supervisors in the execution of Portuguese public contracts is linked to the owner, and consequently, the activities performed regarding measurement reports are related to the owner's project monitoring activities. Therefore, the analysis made above for the owner, concerning construction management, can be equally replicated for the supervisors.

Design Team

Since a traditional AEC design project contains two major groups of documents, Drawings, which provide a complete visual representation of the final product, and Specifications which are essential for the proper understanding and execution of the Drawings by providing technical specifications, Bill of Quantities (BoQ), material and equipment lists, detailed measurements, and construction/functional descriptions, ProNIC assists in the management of both (Ribeiro et al., 2022).

For the drawings, ProNIC's CDE feature promotes the benefits previously discussed in the specific section of this paper. For specifications, ProNIC stands out in its role with the design team for the creation of the Standardized Bill of Quantities. Although these two facets of the same design project are interdependent by nature, they tend to have incompatibilities due to the segmentation into numerous design disciplines involved, the types of documents created, and the separate production of these documents (Ribeiro et al., 2022). Digitization, on its own, can facilitate how the different elements of design information are related, however, for it to be effective it requires standardized and interoperable information structures (Mêda et al., 2022).

Therefore, ProNIC's role in producing the design specifications begins by providing a Work Breakdown Structure - Construction Works (WBS-CW) with the appropriate parameters that differentiate the items and that influence the activities' price. This serves as the basis for the creation of the Standardized BoQ. At the end of the process, the validation work has partially been done during the process by performing error checking, and the consolidation between all project disciplines, which tends to be time-consuming and error-prone, is automatically performed by ProNIC.

It is for this reason that ProNIC came to have immense importance in the designers' work, even though it is summarized in the overview presented in Figure 3.

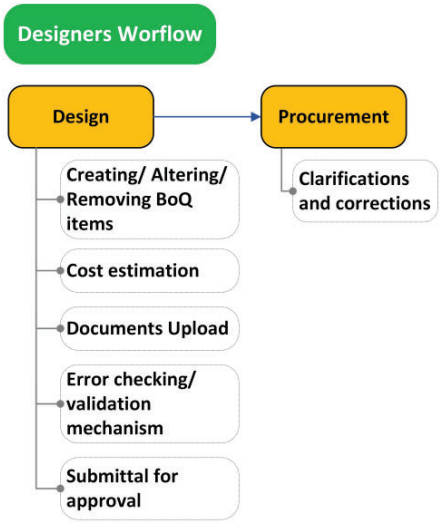

Figure 3: ProNIC Designers overview

However, despite the summary presented, the interaction between ProNIC and the design teams is more intense and can be best represented by the flowchart in Figure 4.

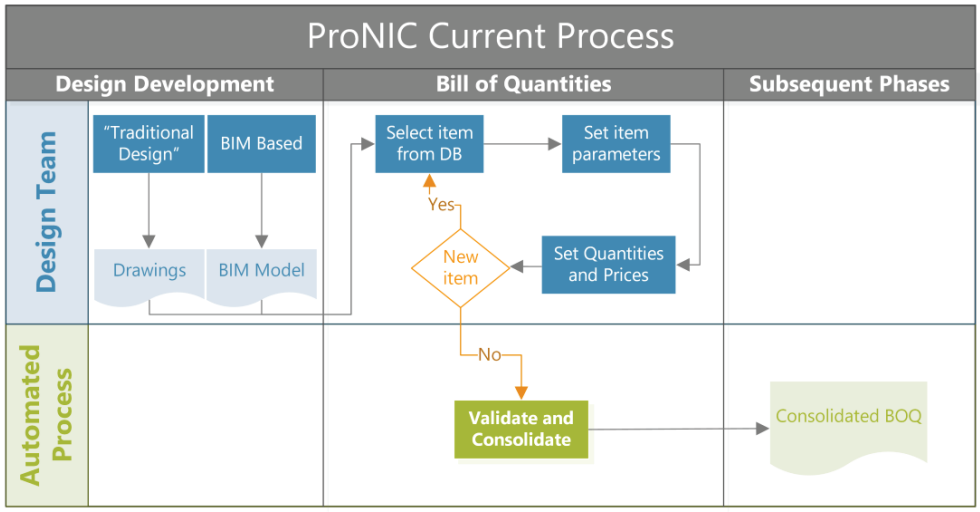

Figure 4: ProNIC designer changes process

Thus, standard BoQ creation in the current ProNIC process is independent of the chosen design method, whether "traditional" or BIM. The design team does most of the work, while ProNIC combines the BoQs from each design discipline to create the consolidated BoQ. The flow of creating a BoQ item is therefore repeated for the totality of items. The predefined WBS-CW items and parameters assist the design team in using complete, correct, and up-to-date design information, and error checking, in addition to the digital signatures and document uploads present at the end of the process. Cost estimating and quantification are also inputs to be filled by the design team.

Therefore, the flow between the design team and ProNIC proves to be one of the most intense, frequent, and repetitive in this process. It is in this perspective that it is possible to verify the advantages achieved in this flow from a lean information management approach:

Creating/ Altering/ Removing BoQ items: This is the main interaction flow between ProNIC and the design team. Therefore, the action takes place from obtaining the Works definition, set by the owner, to the validation and consolidation of the BoQ from all project disciplines, to allow the creation of the Standardized BoQ.

However, the largest share in the significance of information exchanged between ProNIC and the design team is due to the use of WBS-CW, which directs designers to standard information, with items, parameters, options for filling in the parameters, measurement units, all standardized and technically aligned, avoiding erroneous, incomplete, duplicated, or missing information.

Cost estimation: With BoQ standardization, ProNIC allows the project team to have a cost database for comparison at the item level. This comparison is not direct and demands coordination by the team, however, the information is available for use.

Documents Upload: The CDE function along with automatic validation, and error checking, allows the design team to be aware of which documents should be uploaded at the appropriate stages of the process, enables validation by the owner and other stakeholders involved in this process, and that the available versions are always the current ones.

Error checking/ validation mechanism: Occurs simultaneously with the creation of the BoQ, indicating existing items, and creating the consolidated Bill of Quantities.

Submittal for approval: Design team document's final validation. Only from this submission, the information can be considered able to be used in the following process.

The benefits of ProNIC to the Designers regarding Lean Wastes are shown in Table 3.

Table 3: Lean Wastes and Benefits of ProNIC to the Design Team

Lean Wastes	ProNIC Benefits
Transportation	A major gain in face of the number of people involved in this phase of the process inputting information in a unique document. Avoids constant requests and exchange of different versions of the information.
Inventory	Uses the CDE function to organize data to avoid multiple directories and files with the same information.
Motion	Again, due to the CDE function, it eliminates all the need to search for information in different places and with different actors in the process.
Waiting	Automatic error checking at the moment the item is created in the BoQ, without the need to request information. It allows the creation of immediate partial versions of the BoQ, allowing the checking of the process' progress. Submission and immediate availability at the end of the work.
Overprocessing	The creation of intermediate BoQs is a necessity for the proper monitoring of the process, but it demands almost an identical amount of work as the definitive one. This process automation is already an immense gain of information overprocessing for the design team.
Overproduction	CDE allows avoiding the production of unnecessary information at the moment and the immediate identification of current information.
Defects	The biggest gain and the goal of using the system. The standardized information, from previous phases prescribed by the owner to the consolidation with error checking at various moments, allows the creation of construction documentation to be a process with a much-reduced error occurrence.
Underutilization of people	The design team stays fully focused on value-adding activities, especially in the consolidation phase, which tends to be a high-volume phase.

In conclusion, once again the CDE feature plays an important role in this interaction. But this time the emphasis is entirely on the creation of the design specification documents, specifically, the Standardized BoQ.

The creation of a single, standardized document, under intense activity at various times by several distinct participants, and the need for monitoring, required special attention and led to the development of a very robust module allowing only a single flow of information, avoiding overproduction in the consolidation phase, allowing automatic and immediate error checking, directing to assertive information in the WBS-CW items, and minimizing intermediate files.

PROPOSED UPDATES FOR PRONIC

ProNIC is undergoing an update of its technical contents and IT platform, including integration and interoperability improvements – key concepts of Construction 4.0.

The implementation of new interoperability mechanisms should foresee that BoQ information is available throughout the life cycle of the project, so that existing data structures in a 3D model should be interpretable by ProNIC and associated with WBS-CW items/parameters, and a BoQ created in ProNIC can be a structured data source, usable to support, for example, a Digital Building Logbook (DBL) (Mêda, Calvetti, Hjelseth, et al., 2021; Ribeiro et al., 2022).

In future ProNIC, when the design is BIM-based, the intent is to reduce the design team's work within ProNIC to validations and reviews of the information interpreted by the system. As presented in Figure 5, the system will obtain information directly from the model, filling out some of the parameters and item quantities, and suggesting narrowed down lists of other items and parameters for review by the designers. Remaining and additional items or parameters, which may not exist in the modeled elements, need to be defined by the designers as well.

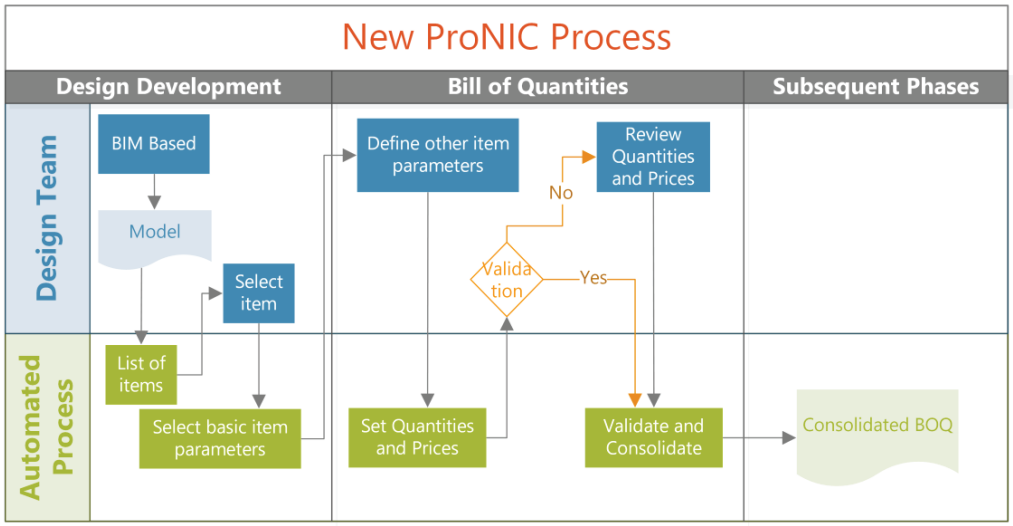

Figure 5: New ProNIC process

Another ProNIC process that can be improved by adopting Lean is the usage of its technical content management module, where the WBS-CW items and technical specifications of construction works are created and maintained by specialist content administrators, for later use by designers. This module allows recent changes in construction technologies and standards to be reflected throughout ProNIC.

To prevent the Underutilization of people, ProNIC should add new mechanisms to simplify repetitive operational tasks such as the updating of references to standards: when standards are replaced with newer versions, the specialist should focus on whether ProNIC's content is still conformant, and not on manually editing potentially hundreds of text fragments. The automated replacement of references to standards also embodies the Lean principle of continuous improvement/pursue perfection and minimizes defects by preventing outdated references.

Lastly, a suggested system-wide improvement is the adoption of a Kanban-like (Arbulu et al., 2007) interface for management of tasks by each ProNIC user, according to their role, and an associated push notification messaging system. In combination with the CDE, this ought to minimize the Wait, Inventory and Motion wastes, by providing streamlined workflows with just the right amount of information at just the right time, ready to be actioned upon.

CONCLUSIONS

The analysis performed in this paper showed that a Construction Information System can ensure a better flow of information, approaching Lean Information Management, by balancing information production, reducing the workload in the construction document production phase, minimizing defects, and eliminating information waste in the design phase. ProNIC brought tangible improvements to traditional workflows by implementing these Lean concepts, despite not being originally conceived under a Lean perspective. ProNIC's key LIM features are:

- Increased reliability throughout the construction process due to standardization of information, error checking, process monitoring, and information available always in its latest version in the CDE.
- Reduction of work overloads due to process automation.
- Each specialized team can focus on activities that add value.

Processes in ProNIC can be further improved by communicating directly with BIM models, reducing complex, error prone activities to mostly verifications and validations. Leveraging Lean principles, proposals for updates related to other operational tasks were also made.

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