INFORMATION SYSTEMS FOR CONSTRUCTION 4.0: CLASSIFICATION OF CONTENTS FOR INTEGRATION AND INTEROPERABILITY – CASE STUDY

Y. Ribeiro[1,2], J. Teixeira[1,2], P. Mêda[1,2*], J. Moreira[1,2], R. Sousa[1,2], and H. Sousa[2]
[1] Instituto da Construção
Campus da FEUP, Rua Dr. Roberto Frias, s/n, Ed. G, 4200-465 Porto, PORTUGAL
[2] CONSTRUCT-Gequaltec, Faculty of Engineering, University of Porto
Campus da FEUP, Rua Dr. Roberto Frias, s/n, Ed. G, 4200-465 Porto, PORTUGAL
[*]pmeda@fe.up.pt

Abstract

ProNIC is a pioneering platform for standardization and management of construction information in Portugal that is currently being updated. Integration between BIM models and the generation of the Bill of Quantities (BoQ) is challenging (construction objects' view vs. construction works' view), and proper structuring of information is essential to support it. In this paper, the analysis and classification of the parameters of the items in a Work Breakdown Structure – Construction Works (WBS-CW) is performed to support that integration. The results show parameter classes with distinct interoperability potential, and suitable strategies towards the integration goal are provided.

Introduction

A traditional design project in the Architecture, Engineering, Construction (AEC) sector contains two large groups of documents: Drawings, which must provide a complete visual representation of the final product, and Specifications, that are essential for the proper understanding and execution of the Drawings. There may also be other documents, such as calculations, detailed measurements, cost estimates, work schedules, resources, labor, and specific analysis of each design discipline.

The Drawings are composed of different types of visualizations, including maps, topography, cross sections, 3D representations, detailed sections, renderings, and technical schematics. The Specifications provide technical specifications, Bill of Quantities (BoQ), bills of materials and equipment, detailed measurements, and descriptions of construction/function.

These two facets of the same design project are by nature interdependent, but there tend to be incompatibilities, resulting from segmentation in numerous design disciplines involved, and of the documents being created, and sometimes delivered, separately. This fragmented landscape of AEC actors and the heterogeneous adoption of IT are commonly reported as obstacles to achieving information interoperability within the construction industry (Laakso and Kiviniemi, 2012). Digitization, among other benefits, can facilitate the way the different elements of design information relate. However, to be effective, it requires standardized and interoperable information structures (Mêda Magalhães *et al.*, 2022).

The adoption of Building Information Modelling (BIM) practices in Portugal is still low (Venâncio, 2015) and is often focused on the materialization of the 3D geometric model, since, regardless of the level of detail, the Drawings are the starting point in most designs, and one of the essential documents to handover, regardless of the type of contract established. However, written Specifications provide a specification and quantification of the materials and resources required, as well as definitions and specifications for the technological processes to be employed in construction. Oversimplifying or forcefully speeding up its creation can lead to errors or omissions that translate into increased risk of not meeting the construction project goals.

The BoQ is a structuring element of the Specifications for the definition of the construction works contract (Legislação Portuguesa, 2008) because it interconnects all the design information, systematizes the works and their quantities, and supports the cost estimate. It is also used for the scheduling of the work at the level of the sequencing of the activities, contributing to the definition of deadlines. Ensuring that the BoQ agrees with the BIM model is challenging because these two sources of information are organized differently: construction objects' view vs. construction works' view.

In this paper, a case study is presented, based on the ongoing update of the ProNIC platform – Protocolo para a Normalização da Informação Técnica na Construção (Protocol for the Standardization of Technical Information in Construction), a part of the Mobilizer Project REV@CONSTRUCTION (ProNIC, 2021).

The focus is on the structuring of information that can lead to improved interoperability in the context of Information Systems for Construction 4.0, by analysis and classification of parameters of Work Breakdown Structure – Construction Works (WBS-CW) items.

The paper is structured as follows: first, a brief history of ProNIC, some of its features, and the context for its ongoing update are introduced, including the generation of the BoQ from the WBS-CW, as well as its items and parameters. Next, the methodology details the analysis performed. Finally, the results are graphically presented, and conclusions are drawn.

Preliminary Information

History of ProNIC

In the AEC sector, multiple organizations collaborate intensively on one-of-a-kind projects in temporary groupings, thus it is vital to have compatible tools and assets within projects (Laakso and Kiviniemi, 2012). According to ECTP, (2019), 95% of its 3.3 million companies have less than 20 employees, resulting today in the lack of an integrated vision.

ProNIC – Protocolo para a Normalização da Informação Técnica na Construção (Protocol for the Standardization of Technical Information in Construction) (Monteiro, Mêda and Poças Martins, 2014) – is a platform for standardizing technical content for construction of buildings and road works, and for the systematization and integration of information during the construction process. Highlights of its functionalities include the generation of BoQ with standardized items, generation of "general" technical conditions, generation of cost estimates, and aggregation of information elements (Drawings and/or Specifications), internal or external.

The initial development of ProNIC took place between 2005 and 2008. The objective was that the information separated into each project phase would become incremental and iterative. Standardized technical contents were implemented, including a WBS. From 2009 to 2015 a contract with Parque Escolar, EPE, a public company responsible for the renovation of high schools in Portugal – expanded the integrated management of works and projects. Its document repository was indeed, a Common Data Environment (CDE) (Mêda, Sousa and Ferreira, 2016).

ProNIC is undergoing a major update both in terms of technical content and at the level of the IT platform, within the Mobilizer Project REV@CONSTRUCTION, which aims to accelerate the implementation of the principles of Construction 4.0 in Portugal. Although ProNIC was born long before this project, its legacy (Mêda *et al.*, 2021) enhances the implementation of Construction 4.0.

The next step, Construction 5.0, requires a further effort to integrate innovative and proven materials, technologies (so-called KET - Key Enabling Technologies), and components, and their integration supported by enhanced data/knowledge management and IT (ECTP, 2019). This requires more information and greater effort to manage it, as well as to ensure its consistency, even when dispersed in elements with different origins and forms.

Since the BoQ is paramount for the design stage and the key element on which ProNIC is structured upon, it is essential to understand the nature of the information present in the parameterization of each item to determine what other elements of information may relate to it.

BoQ generation in ProNIC

Data sharing between project stakeholders faces several interoperability problems (Vieira, 2020) that cannot be overcome by mere digitalization without standardization. The adoption of a CICS (Construction Information Classification System) is a way to achieve this standardization, as a CICS must ultimately provide the properties of each object. These properties are vital in the various decision-making stages during the construction process, since they are what defines the object itself (Pina *et al.*, 2020).

For BoQ generation in ProNIC, in addition to the selection of the item from the WBS-CW, it is necessary to provide characterization information of materials, elements, works, or other information that the designer considers relevant. The fields that receive this information, preset or not, are designated parameters of the item, and complete the text, forming a standardized but unique item, properly characterizing the specific conditions of that design.

The analysis performed in this research was carried out at the level of the parameters of the items in ProNIC's WBS-CW for Buildings. The following is an example of a standardized item text in ProNIC:

"Execution of GROUND FLOOR in normal "grey" reinforced concrete with $1 thickness, including supply, placement, compaction and curing of concrete $3, $4, $5, $6, $7 $8 $2 $21 $22 $23 $30 $31; transport, assembly, disassembly, release agent oil and cleaning of formwork; supply, placement, loading and unloading, waste and splices and assembly of certified armature elements of steel $9, and all work, including construction and retraction joints, joint sealing, load transfer elements, materials and execution according to the design project."

The parameters are encoded as "$number" until they are edited by the designer. There is no special meaning in the assigned encoding and may even vary for the same parameters in different items.

By setting the parameters, the same item can take the following form:

*"Execution of GROUND FLOOR in normal "grey" reinforced concrete with **<u>0,20 m</u>** thickness, including supply, placement, compaction and curing of concrete **<u>C35/45</u>**, **<u>XA1</u>**, **<u>Cl 0.20</u>**, **<u>S3</u>**, **<u>Dmax 12 mm</u>** **<u>with incorporation of hydrofugue</u>**, **<u>application of surface hardener of corundum aggregates</u>**, **<u>in anthracite color</u>**, **<u>resist. abrasion (BOHME) A6</u>**, **<u>at a dosage of 4 [kg/m2]</u>**, **<u>polyethylene film 0.20 mm thick</u>**; transport, assembly, disassembly, release agent oil and cleaning of formwork; supply, placement, loading and unloading, waste and splices and assembly of certified armature elements of steel **<u>A400 NR-SD</u>**, and all work, including construction and retraction joints, joint sealing, load transfer elements, materials and execution according to the design project."*

Therefore, each $number represents a parameter with a specific characteristic that effectively defines the item.

Parameters can also have "names" that are a way for the user to identify which information is associated with that parameter. This name had not been assigned in some cases because it was clear when viewing the available preset options for that parameter.

Methodology

Analysis of Parameters

The same parameter can appear several times in the WBS-CW; for example, the parameters that characterize the concrete material will appear whenever the concrete material exists in the item. The distribution of the number of times in which the same parameters appear in the WBS-CW illustrates well a part of the logic of the construction of the WBS-CW, as exemplified in Figure 1, referring to the partition of Foundations and Structures.

Just 13% of the distinct parameters already represent 80% of the accumulated occurrences of the parameters in the items (green shading), and 40% of the distinct parameters already represent almost all (95%) of the occurrences (yellow shaded). Analysis of the remaining partitions of the WBS-CW revealed similar distributions of parameters (although sometimes with a heavier tail).

In other words, even if only a few parameters could be made interoperable, it could have a potentially large impact. This was a motivating factor to further analyze the parameters and consider other kinds of classification.

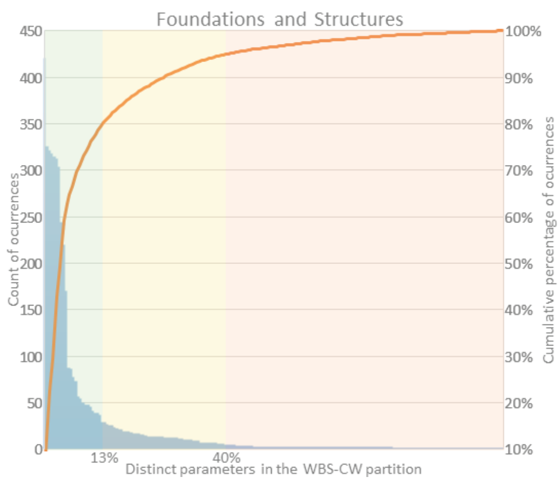

Figure 1: Histogram and cumulative distribution of parameters by the number of times that they appear in the WBS-CW.

Classification and New Encoding of Parameters

During the update of ProNIC, several fields associated with the parameters are being reviewed, including the encoding of "$number", so that it will be a single code per parameter, independent of the item, allowing a regularization of its name and a reduction of the volume of information, and thus improving the performance, interoperability, and usability of the platform.

To improve the interoperability between other construction information structures and ProNIC items, it is necessary to classify their parameters to understand their impact/contribution to the item, due to its essence (e.g., Material), and type of information (e.g., Geometry). This classification is paramount to analyze the potential for relationships with other standards of classification and representation of construction information, such as IFC (Laakso and Kiviniemi, 2012) and Data Templates (ISO, 2020).

The three initial letters of the new code result from the classification of the parameter:

- towards what it regards:
  - Material
  - Element
  - Work
  - Other
  - Additional information
- to which it attributes:
  - Property
  - Geometry
  - Condition
  - Localization
  - Identification
  - Other
  - N/A
- complement to the previous information:
  - (miscellaneous values)

The classes chosen for the first two classification facets were based on the type of relationships and tables listed in ISO 12006-2 (ISO, 2015) when applied to the BoQ, which is a list of construction works, carried out using construction materials, resulting in construction elements. This standard was already used in the definition of the technological architecture of ProNIC. For the correct execution of these works, different information is required, the nature of which allows different possibilities of interoperability with other parts of the design.

The third letter of the encoding is complementary and dependent on the combination of the first two. It allows increasing the detail of these classification facets, for example, if a parameter refers to the geometry of a finished element, or only to the geometry of a part or fraction of the element.

Applying the proposed classification to the parameters of the previously presented item, Table 1 is obtained, where the digits and the final letter are only to avoid repetitions of codes in the system.

Table 1: Example of new encoding of WBS-CW item parameters

Orig. Code	Original name	New Code	Revised name
$1	Specify the thickness of the floor concrete slab [m]	EGX005E	Thickness
$2	---	TCO015E	Surface hardener
$3	Compressive strength	MPI003E	Compressive strength

$4	Environmental exposure class	MPI001E	Environmental exposure class
$5	Chlorides	MPI007E	Chlorides
$6	Consistency	MPI002E	Consistency
$7	Aggregate Dmax [mm]	MGP001E	Aggregate Dmax
$8	---	TCO001E	Additives and Adjuvants
$9	Types of steel	MID001E	Types of steel
$20	Type of hardener	MIN007E	Type of hardener
$21	Specify color	MPV001E	Specify color
$22	Abrasion Resistance Specification (BOHME)	MPI013E	Abrasion Resistance Specification (BOHME)
$23	Dosage [kg/m2]	MCO003E	Dosage
$30	Desolidarization element	EIN004E	Desolidarization element
$31	Additional features	XXX001E	Additional features

Due to the creation of specific fields for the unit of measurement and complementary text, and the need for standardization between articles, some parameter names have also been updated. In summary, the classification performed is reflected in the first two letters of the encoding, as illustrated in Table 2, and displays fundamental information for the characterization of the technical content of ProNIC. From the analysis of these codes, it was possible to quantitatively attest to the diversity of the nature of the information necessary for the creation of a BoQ in ProNIC.

Table 2: Example classification of WBS-CW item parameters

New Code	Refers to	Assigns
EGX005E	Element	Geometry
TCO015E	Work	Condition/conditioning
MPI003E	Material	Property
XXX001E	Additional information	N/A

Information of a different nature should be stored in different data structures (Calvetti *et al.*, 2020). For example, geometric characteristics of elements or material properties are easily interconnected to IFC classes of geometry and their properties. Information relating to construction works can also be associated with the IFC format using the *IfcTask* class and the *IfcRelAssignsToProcess* relationship, or, alternatively, can be stored in an independent data structure (for example, in JSON, XML, or SQL format), which can be related to the model, schedule and cost estimate, per the buildingSMART strategy (buildingSMART, 2020). Maintaining this independent data structure, but in such way that it is relatable to that of the 3D model, is compatible with the notion of *information container* provided for in ISO 19650 (ISO, 2018).

Therefore, the initial analysis performed consists in the identification, quantification and distribution of parameters regarding (Refers to) Materials, Elements, Works, Other, Additional information and how they are distributed as each (Assigns) Property, Geometry, Condition or Conditioning, Other, N/A, so that one can evaluate the impact of parameters that do not have direct adequate connection to the standard data models.

Additionally, a different classification based on the ISO 19208:2016 standard (ISO, 2016) was applied to the items in the WBS-CW. It employs a construction subsystem approach that is quite different from the previously described ad hoc partitioning scheme.

Finally, these results were combined with the lessons learned from ProNIC's legacy (Mêda *et al.*, 2021) to formulate an updated design process to guide further ProNIC developments. To this effect, Figure 2 shows the current process, followed by a brief description.

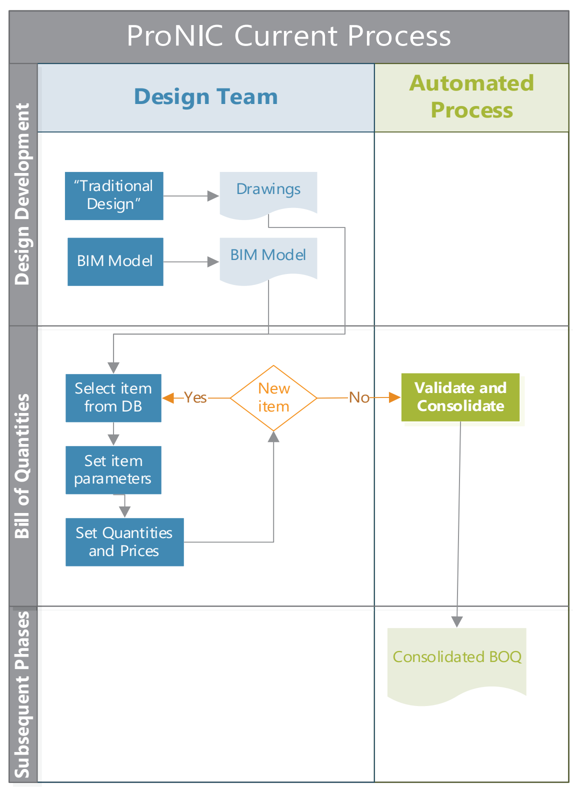

Figure 2: Current design process in ProNIC.

The creation of the standardized BoQ in the current ProNIC process is independent of which design approach is used: "traditional" or BIM. The work is performed mostly by the design team, and ProNIC acts by consolidating the BoQ of each design discipline automatically, creating the Consolidated BoQ. Meanwhile, ProNIC assists with the standardization of the BoQs with WBS-CW items and their predefined parameters, as well as assisting the project team in general with error checking, digital signatures, and document uploading. Cost estimation and quantities are also input by the design team.

Results

The ProNIC WBS-CW was partitioned to aggregate similar or strongly related chapters (the first level of the WBS-CW). Preliminary results were presented in Ribeiro et al., (2022) for some of those partitions. Summarizing those findings: the Works had considerable relevance, mainly for the partition of "Construction Site and Preliminary Works"; Materials (12%) and Elements (18%) had a 1relatively low relevance for the partition of "Construction Site and Preliminary Works"; Additional information and Others were highly relevant in both "Construction Site and Preliminary Works" and "Exteriors and Fixed and Mobile Equipment" partitions (totaling 39% and 44%, respectively).

The analysis has since been extended to the whole WBS-CW and the global distribution of the first-level classification ("Refers to") of parameters of items is now presented in Figure 3.

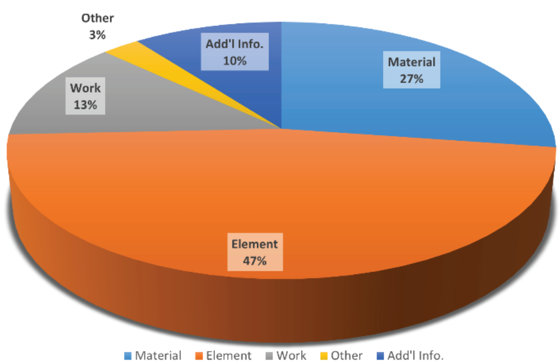

Figure 3: Global distribution of the first-level classification of parameters of items in ProNIC's WBS-CW for Buildings.

As expected, the overall distribution is more well-rounded (roughly half for Elements, a quarter for Materials, and a quarter for the remainder, including Works). The class Additional Information represents parameters that enable the designer to enter freeform information for Elements, Materials, or Works. The Others class is for parameters that do not fit any of the others.

A current BIM model should provide, at least, geometric information about construction elements, and possibly some information about their materials. Progressively, and regardless of the container of information (IFC or Data Templates or others), other properties of these construction elements and materials are expected to become available for interoperability. Thus, there is a real potential to link the data of up to ¾ of the parameters in the WBS-CW, while about ¼ of them is unlikely to be interoperable with "traditional" BIM models supported by a construction objects' view.

The analysis for the second-level classification, presented in Figure 4, was performed by observing the link between it and the initial classification. The main insights are:

- The Elements class has several attributions, with roughly equal weight for Identification, and Properties, and to a lower extent, Geometric.
- The Materials class focuses its attributions on Identification, and to a lower extent, Properties.
- The Works class highly emphasizes the attributions of Conditions/Constraints.
- The Additional Information class nearly always binds to N/A, because, by definition, it is not possible to predict exactly what the designer intends to refer to or complement.

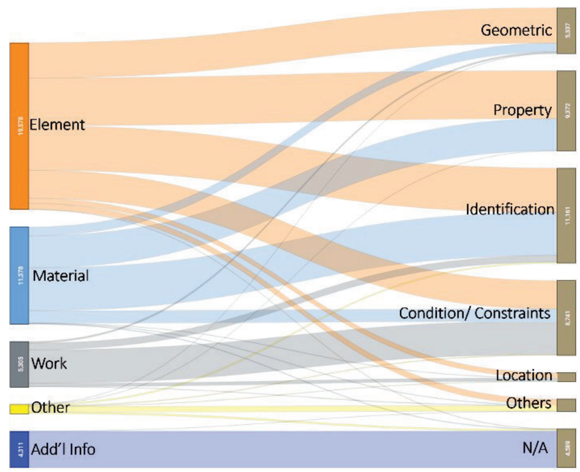

Figure 4: Relationships between the first two levels of parameter classification as a Sankey diagram.

A second classification, based on the subsystem designations from ISO 19208:2016 (ISO, 2016), was also performed on the whole WBS-CW, in order to categorize the items' parameters using a standardized structure.

The results are shown in Figures 5 through 10, and depict the distribution of the same first-level classification of the parameters code in the different building subsystems.

The different information needs of construction works belonging to different subsystems are clearly visible, for example, over 60% of the parameters of items in Services concern Elements, while the Elements category accounts for only 10% of parameters of items in the External Envelope subsystem.

There is also some variability regarding the Additional Information category, stemming from the different levels of imposed legal and standardization requirements (typically strict for Services or Structure subsystems) enabling thorough parametrization, or leaving more room for designers to express their creativity.

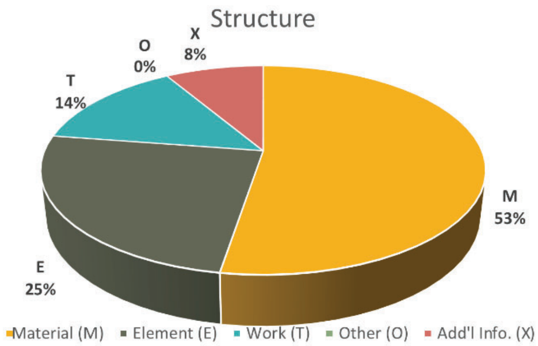

Figure 5: Distribution of parameters of items in the Structure subsystem.

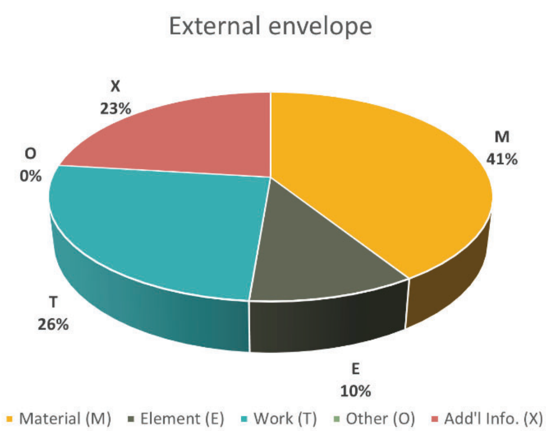

Figure 6: Distribution of parameters of items in the External envelope subsystem.

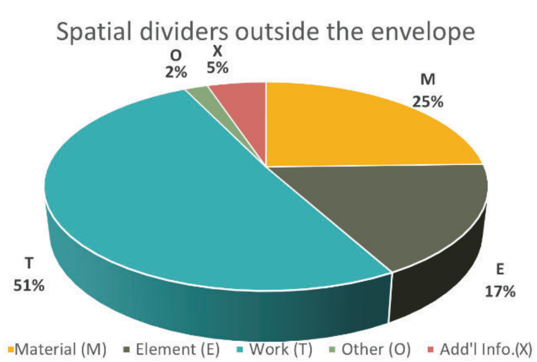

Figure 7: Distribution of parameters of items in the Spatial dividers outside the envelope.

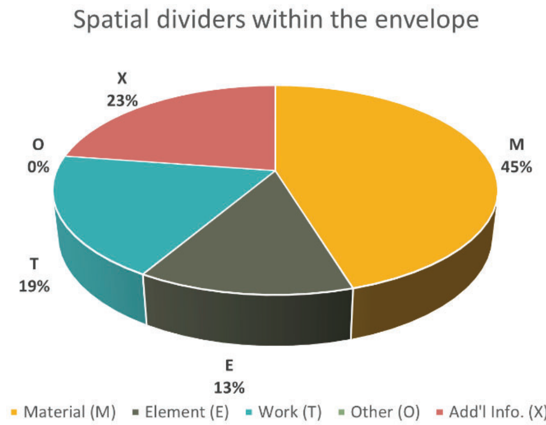

Figure 8: Distribution of parameters of items in the Spatial dividers within the envelope subsystem.

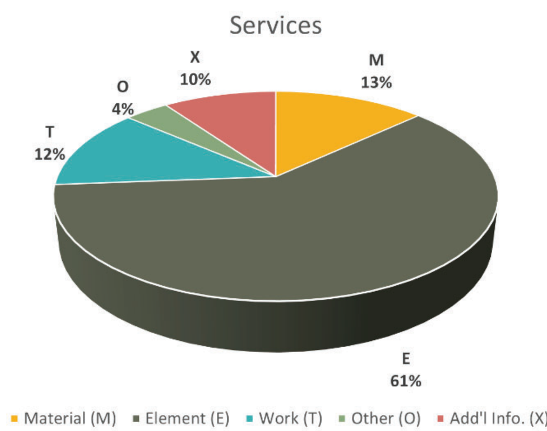

Figure 9: Distribution of parameters of items in the Services subsystem.

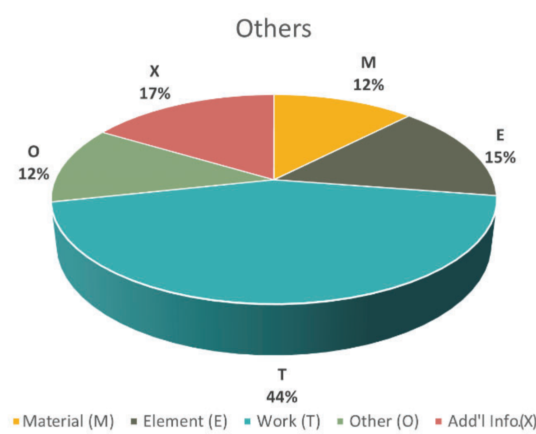

Figure 10: Distribution of parameters of items in the Others subsystem.

Conclusions

The analysis revealed that there is a moderate yet relevant amount of information necessary for the creation of a BoQ that does not fit either in the Elements or Materials classes, and this is hardly found in the 3D models usually produced. In addition, the creation of a BoQ depends closely on information that may not have direct matching on platforms other than ProNIC, especially those that do not use the Works view. This is particularly relevant for some categories of items, such as, “Construction Site and Preliminary Works” or “Spatial dividers outside the envelope”, each observed using different classifications.

On the other hand, many parameters relating to Elements and Materials could conceivably be found on sufficiently detailed BIM models, and some are already widely available, such as those providing Geometry attributions.

This suggests the use of different, yet tightly coupled interoperability mechanisms that would improve the workflow of designers when using ProNIC:

- Accessing existing BIM model information and deriving a partial BoQ from it, mostly with Geometry for Elements and Identification for Materials;
- Taking advantage of ProNIC’s existing functionalities to allow the designer to efficiently introduce the parameters related to Works and Additional Information in the BoQ, as usual, and then make them externally available in a structured, interoperable way via the normalized WBS-CW, for example, for integration with a Digital Building Logbook (DBL).

These implementations of interoperability mechanisms should provide for BoQ information to be available throughout the construction work lifecycle, so the existing data structures in a 3D model should be interpretable by ProNIC and associated with items/parameters in the BoQ, and a BoQ created in ProNIC should be able to be a data source for other information systems, not necessarily those based around 3D models.

A proposed design process, improved from the original shown in Figure 2, is shown in Figure 11, and explained below.

In ProNIC's new version, when the design is BIM-based, the intent is to reduce the design team's work to validations and reviews of the information interpreted directly by the system. Then, it is possible to envision an automatic interpretation of model data that directs ProNIC to a reduced list of items and parameters of those items. As presented in this work, some parameters are unlikely to exist in the modeled elements and are required to be defined by the design team.

In conclusion, the presented work of classifying and analyzing the parameters of ProNIC’s WBS-CW items contributed to the development of new interoperability strategies for future versions of ProNIC towards ensuring that all the necessary information will be present and consistent among the different construction project’s documents.

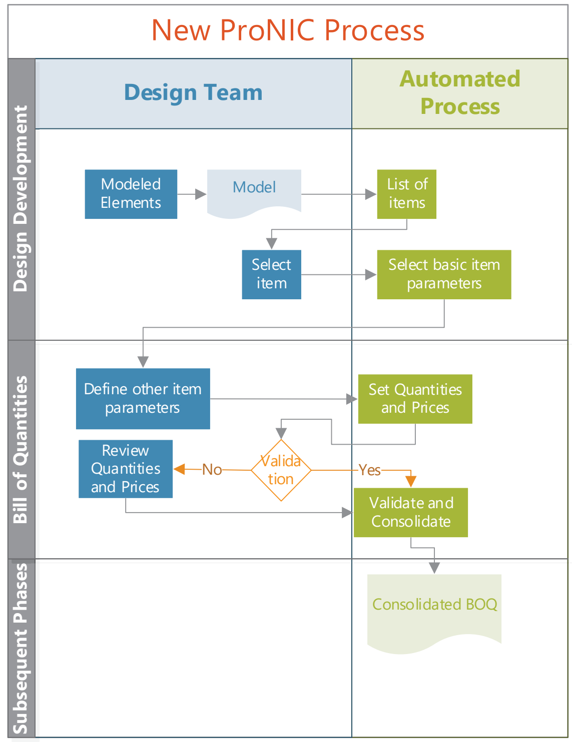

Figure 11: Proposed new design process in ProNIC.

Acknowledgments

This work was financially supported by:

· Mobilizer Project “REV@CONSTRUCTION - Digital Construction Revolution”, POCI-01-0247-FEDER-046123, funded by Fundo Europeu de Desenvolvimento Regional (FEDER), through Programa Operacional Competitividade e Internacionalização (COMPETE 2020), a part of the Portugal 2020 strategy.

· Base Funding - UIDB/04708/2020 of the CONSTRUCT - Instituto de I&D em Estruturas e Construções - funded by national funds through the FCT/MCTES (PIDDAC).

References

buildingSMART (2020) ‘Technical Roadmap buildingSMART: Getting ready for the future’. Available at: https://www.buildingsmart.org/standards/technical-roadmap/.

Calvetti, D. *et al.* (2020) ‘BIM WD: A Dimensão dos Trabalhadores Integrada nos Modelos de Informação’, in *3º Congresso Português de ‘Building Information Modelling’. 3º Congresso Português de ‘Building Information Modelling’*, Porto, Portugal: FEUP, pp. 131–140. Available at: https://doi.org/10.24840/978-972-752-272-9_0131-0140.

ECTP (2019) *European Construction, built environment and energy efficient building Technology Platform, Strategic Research & Innovation Agenda 2021-2027*. Available at:

http://www.ectp.org/fileadmin/user_upload/documents/ECTP/Miscellaneous_doc/ECTP_SRIA_FINAL_20-11-2019.pdf.

International Standards Organization (2015) 'ISO 12006-2:2015 Building construction — Organization of information about construction works — Part 2: Framework for classification'.

International Standards Organization (2016) 'ISO 19208:2016 Framework for specifying performance in buildings'.

International Standards Organization (2018) 'ISO 19650-1:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles'.

International Standards Organization (2020) 'ISO 23387:2020 Building information modelling (BIM) — Data templates for construction objects used in the life cycle of built assets — Concepts and principles'.

Laakso, M. and Kiviniemi, A. (2012) 'The IFC Standard - A Review Of History, Development, And Standardization', *ITcon*, 17, pp. 134–161.

Legislação Portuguesa (2008) *Código dos Contratos Públicos - CCP, Decreto-Lei n.º 18/2008*. Available at: https://data.dre.pt/eli/dec-lei/18/2008/p/cons/20221107/pt/html.

Mêda Magalhães, P. *et al.* (2022) 'A process-based framework for digital building logbooks', in. *2022 European Conference on Computing in Construction*. Available at: https://doi.org/10.35490/EC3.2022.183.

Mêda, P. *et al.* (2021) 'Legacy practices supporting BIM adoption in Portugal – Reflexions from a large Use Case', in E. Hjelseth, S. F. Sujan, and R. Scherer (eds) *eWork and eBusiness in Architecture, Engineering and Construction: ECPPM 2022. 14th European Conference on Product & Process Modelling (ECPPM 2022)*, Trondheim, Norway: CRC Press.

Mêda, P., Sousa, H. and Ferreira, F. (2016) 'Economic Relevance of Building Elements—Studies, New Framework, Evolutions and Support for Refurbishment Operations', in *Sustainable Construction*. Singapore: Springer Singapore (Building Pathology and Rehabilitation), pp. 93–128. Available at: https://doi.org/10.1007/978-981-10-0651-7.

Monteiro, A., Mêda, P. and Poças Martins, J. (2014) 'Framework for the coordinated application of two different integrated project delivery platforms', *Automation in Construction*, 38, pp. 87–99. Available at: https://doi.org/10.1016/j.autcon.2013.11.003.

Pina, R. *et al.* (2020) 'Informação da Construção em Usos BIM – Estudo de Caso', in *3º Congresso Português de 'Building Information Modelling'. 3º Congresso Português de 'Building Information Modelling'*, Porto, Portugal: FEUP, pp. 749–760. Available at: https://doi.org/10.24840/978-972-752-272-9_0749-0760.

ProNIC, C. (2021) 'Projeto Mobilizador Digital Construction Revolution REV@CONSTRUCTION, Entregável 3.1 Interfaces: Identificação e caracterização de necessidades/oportunidades de Integração/interoperabilidade'. Available at: www.revconstruction.pt.

Ribeiro, Y. *et al.* (2022) 'Sistemas de informação para a Construção 4.0: Conteúdos, integração e interoperabilidade – Estudo de caso', in *Atas do Congresso Construção 2022*. *Construção 2022*, Guimarães, Portugal: Universidade do Minho, Departamento de Engenharia Civil, pp. 326–335. Available at: https://civil.uminho.pt/construcao2022/files/Livros_Atas.zip.

Venâncio, M.J.L. (2015) *Avaliação da implementação de BIM – Building Information Modeling em Portugal*. Faculdade de Engenharia da Universidade do Porto.

Vieira, L. (2020) *Coordinated specification and quantity take-off through digital modelling*. Universidade do Minho. Available at: http://hdl.handle.net/1822/73292.