BIM COST ESTIMATION GUIDELINES FOR BRAZILIAN PUBLIC SECTOR INFRASTRUCTURE

DIRETRIZES PARA ORÇAMENTAÇÃO DE OBRAS PÚBLICAS BRASILEIRAS UTILIZANDO BIM

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Abstract

The cost estimation of public sector projects in Brazil must observe the prevailing legislative framework to reduce the likelihood of under-and-over pricing of construction works and potential corruption. Therefore, initial estimates for projects must be prepared using the National System of Costs and Civil Construction Indices (SINAPI). This is a labor-intensive process, and the result estimates produced may be inaccurate. Therefore, it becomes difficult to determine if the under-or-over pricing of works has arisen during the tendering process. The problem is approached with new guidelines for improving the accuracy of estimates that utilizes SINAPI methodology with Building Information Modelling cost estimation. The research method used was Design Science Research (DSR) developing: problem diagnosis, solution proposition, implementation, and evaluation of contributions. The proposed guidelines were tested in two projects: a multi-family residential building and a Reference Center for Social Assistance (CRAS) using a BIM authoring platform. It has been demonstrated that text parameters can be used to identify material specifications, the geometry of elements, and specify substrates, improving the process to generate an estimate following 'SINAPI factors' tree' elemental costs. The guidelines comply with prevailing Brazilian legislation and can improve the process and accuracy of the pre-tender estimate.

Keywords: Building Information Modelling. BIM. Cost Estimation. Public Building Construction. Brazil.

Resumo

A estimativa de custos de obras públicas no Brasil deve estar de acordo com a legislação vigente para reduzir a probabilidade de subfaturamento ou superfaturamento e potencial corrupção. O orçamento inicial dos projetos deve ser preparado usando o Sistema Nacional de Custos e Índices da Construção Civil (SINAPI). Este processo consome muito tempo e, ainda, as estimativas podem ser imprecisas, tornando-se difícil determinar se o preço das obras está abaixo ou acima do valor real durante o processo de licitação. Para resolver esse problema, são apresentadas diretrizes para melhorar a precisão das estimativas, contemplando o SINAPI e utilizando modelagem da informação da construção (do inglês, BIM). A estrutura proposta foi testada em dois projetos: um edifício residencial multifamiliar e um Centro de Referência de Assistência Social (CRAS) usando uma plataforma de autoria BIM. Foi demonstrado que os parâmetros de texto podem ser usados para identificar especificações de materiais, geometria dos elementos e especificar substratos, o que pode melhorar o processo para gerar uma estimativa de acordo com os custos dos elementos da "árvore fatores do SINAPI". As diretrizes propostas estão em conformidade com a legislação brasileira e são capazes de melhorar o processo e a precisão das estimativas pré-licitação.

Palavras-chave: *Modelagem da informação na construção. BIM. Estimativa de custo. Obra pública. Brasil.*

Introduction

Brazil is one of the largest economies in the world and is a developing nation. It is significantly investing in its economic (e.g., roads and rail) and social (e.g., schools and hospitals) infrastructure to sustain its well-being and prosperity. The public sector's primary procurement model in Brazil to deliver its infrastructure asset is the traditional Design-Bid-Build (DBB). The public sector is responsible for preparing a complete set of designs (e.g., architectural and engineering) and the pre-tender estimate, conducting an auction to contract an asset and supervising the winning company. Designers and cost estimators must observe complex legislation, especially in cost engineering (BRAZIL, 2013).

The pre-tender estimate must follow a detailed Work Breakdown Structure (WBS). The unitary costs for elements and services must be obtained based on cost compositions, limited to the National System of Costs and Civil Construction Indices (SINAPI) (BRAZIL, 2013), maintained by *Caixa Econômica Federal* (CEF), which is the largest public bank in Brazil and responsible for providing housing financing. SINAPI has recently restructured using a methodology called the 'factor tree' (CEF, 2020). While the 'factor tree' results in more accurate cost compositions, this new methodology increases the number of compositions and the complexity of the estimation process (FELISBERTO, 2017).

Brazilian law also classifies a designs' level of development into basic and executive, requiring elaborating the basic design before an auction is undertaken. A considerable amount of information and technical specifications is required to produce a basic design before an auction, without necessarily requiring detailed engineering to have been completed within a building information model (from now on model). In this case, descriptions in Specification Sheets may be sufficient. In the case of the model, a Level of Development (LOD) of 300 or 350 is generally sufficient to carry out a basic design (SOLIHIN; EASTMAN, 2015). The LOD represents the degree of information presented by the model's elements (BIMFORUM, 2019) and denotes the level of maturity and development of a model.

Like many governments worldwide, the Brazilian public sector has found it challenging to deliver its projects within budget, on time, and to desired quality standards. Inconsistencies in the pre-tender estimate have been found to cause a project's inability to deliver its pre-determined objectives (SANTOS, 2015). For this reason, the Federal Court of Accounts (TCU), which controls the use of federal resources, has openly recognized the advantages of Building Information Modelling (BIM) in the estimating process (TCU, 2014).

Given this reality, the following research question arises: Is it possible to develop accurate pre-tender estimates that fulfil the requirements of the Brazilian laws regarding public engineering projects using a model with LOD 300? Therefore, this article aims to present guidelines for assessing a detailed pre-tender estimate for public infrastructure projects, observing SINAPI's new 'factor tree' methodology based on basic engineering designs using BIM with the design elements modelled at LOD 300.

Fundamentals

Cost estimation of public infrastructure projects

Estimating handbooks, manuals, and automated databases form the usual basis for producing cost estimates. Diaz *et al*. (2018) analyzed the accuracy of RSMeans, which is an automated database that is widely used by the United States (US) construction market and utilizes two different data formats: (1) Uniformat (UF); and (2)

MasterFormat (MF). So, they concluded that, while the MF provides better precision regarding the definition of the work scope, it still contains many limitations, such as lack of specific building materials and activities that significantly affect estimates' accuracy. Similarly, Lu, Hasan and Hasan (2017) explored UF and MF's accuracy for a garage building. They did not present any conclusion about how to improve the estimating accuracy when using BIM.

There is a complex legal framework for estimating and contracting parties for public sector projects in Brazil, which places significant emphasis on the development of a reference estimate (BRAZIL, 2013). A pre-tender estimate that is inaccurate due to omissions from underestimated quantities or incorrect prices may result in opportunistic bids being received from contractors (SIGNOR *et al.,* 2020). Moreover, the ability to detect collusive tendering, which has plagued Brazil, is stymied (SIGNOR *et al.,* 2017). If a party is contracted based on the established pre-tender estimate, then there is a potential for claims for additional monies to be made. Conversely, if overestimated quantitative or unit costs exist, then overpricing can occur (TCU, 2014; SIGNOR *et al.,* 2016).

The estimation of public projects in Brazil funded by the General Budget of the Union must be undertaken following the prevailing legislative framework to reduce the likelihood of under-and-over pricing of construction works to mitigate potential corruption. Estimates for projects must therefore be prepared using the SINAPI, which is maintained by CEF. The SINAPI's cost breakdown structure is different from that proposed in Uniformat and MasterFormat bases.

SINAPI produces a monthly series of costs and indices, labor salaries, materials, machinery and equipment, and services for basic sanitation, infrastructure, and housing sectors. SINAPI statistics are fundamental in the programming of investments, especially for the public sector (CEF, 2020).

SINAPI has developed a 'factor tree' that can break down the costs for elements into individual items (e.g., equipment and materials) to improve preparing a pre-tender estimate. For example, a 'factor tree' for a masonry wall is presented in Figure 1. Here the 'factor's tree' for a group of masonry walls built with hollow clay blocks is presented. The highlighted path refers to a non-structural wall constructed with 9cm thick clay hollow blocks, with a net area greater or equal to 6m², with the presence of openings and mortar prepared manually (CEF, 2017).

An estimator needs to select a 'factor's tree' path that best fits the estimated project. Figure 2 illustrates the use of the previous 'factor's tree' to estimate a series of non-structural walls in a house. In this instance, the pre-tender estimate will comprise four different types of walls with varying quantities and unit costs, even though the same material is specified (e.g., 9cm clay hollow block layered with manually mixed mortar). Notably, the SINAPI elemental costs for items takes into consideration their net areas and volumes.

Figure 1 - 'Factor's tree' composition 87520 for non-structural masonry
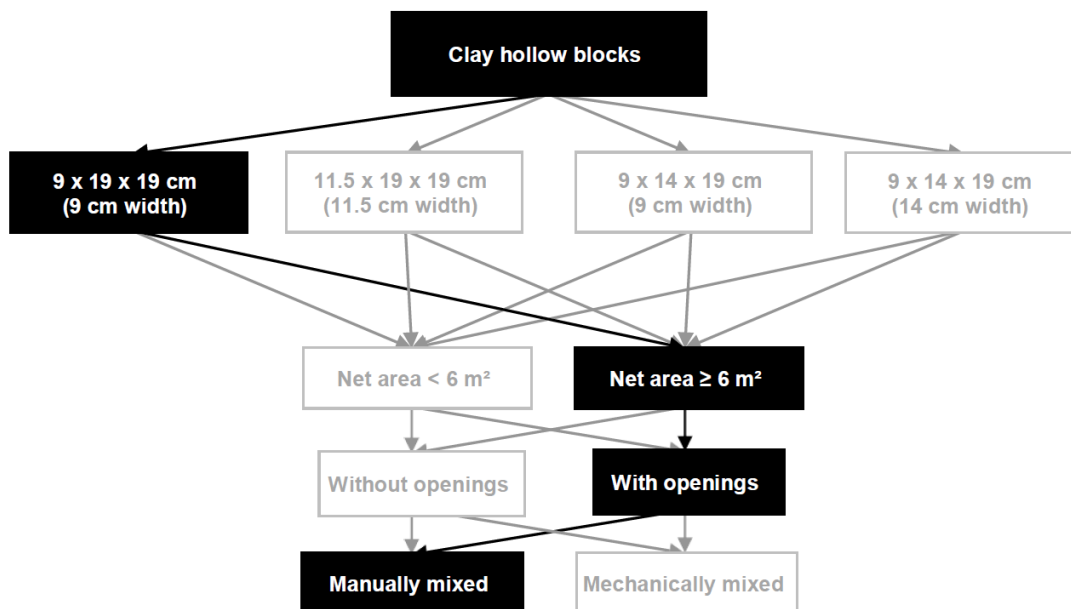
Source: Adapted from CEF (2017).

Figure 2 - Single-family housing project with various types of walls
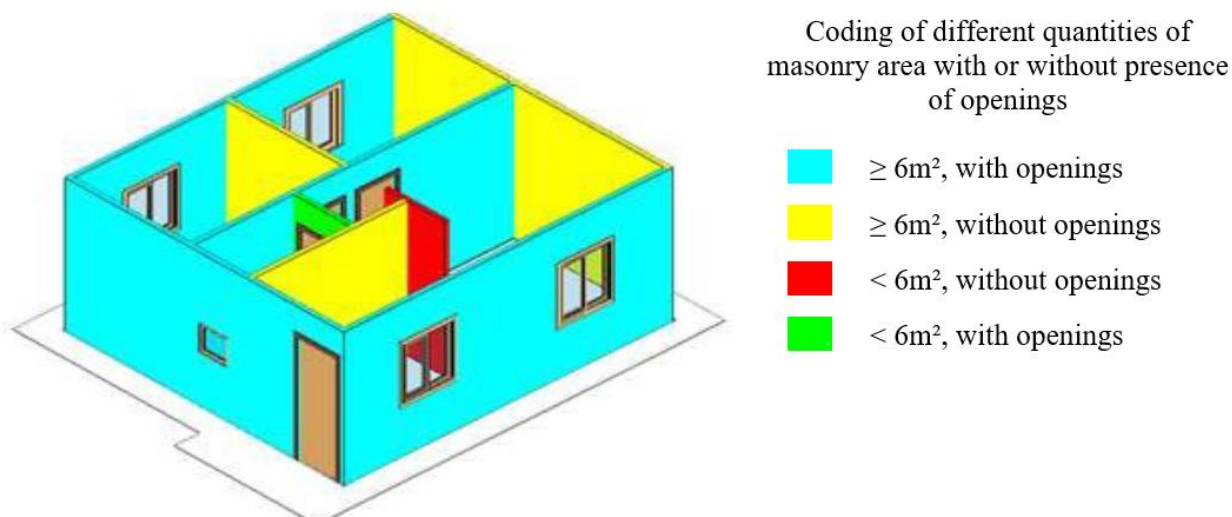
Source: Adapted from CEF (2020).

BIM cost estimation

The Brazilian Federal Government published, in 2020, the Decree 10306 (BRAZIL, 2020) establishing the use of BIM in the direct or indirect execution of engineering projects and services carried out by the agencies and entities of the federal public administration. Thus, auctions must meet regulations for the combined use of SINAPI and BIM.

As previously highlighted, it has been widely acknowledged that BIM can positively contribute to improving the estimating process by the automatic determination of material quantities (MONTEIRO; MARTINS, 2013). An estimate's accuracy, however, is linked to the LOD of objects within a model. Some temporary works, such as formwork, may not be automatically quantified, as they tend not to be modeled as an object within a BIM environment (NEIVA NETO; RUSCHEL, 2015). Irrespectively, if the item is unable to be modelled as an object, it can be added manually to the estimate (MATOS, 2016). A detailed review of benefits and barriers of BIM cost estimation can be found in the

extant literature, e.g., Monteiro and Martins (2013), Stanley and Thurnell (2014), and Smith et al. (2016). For example, Fenato *et al.* (2018) advocate that BIM cost estimation can effectively develop classes of specific objects for modelling operations. However, as this study deals with cost estimation aimed at auctioning and the contractor is unknown, as the operations vary according to each contractor's internal process, it is not possible to reach this level of detail. Therefore, this study proposes using a low level of detail, advocating that a pre-tender estimate using elements modelled up to LOD 300 meets the precision required by public infrastructure auctions.

Integrating SINAPI with BIM

Integrating the SINAPI database to a model has been trailed by several authors (e.g., MENDES et al., 2013; SAKAMORI, 2015; FERRARI, 2016). Mendes *et al.* (2013) aligned components that had been modelled with those contained in the SINAPI database and then exported the quantities of each family contained in Autodesk® Revit® into a Microsoft® Excel® spreadsheet that was linked using a macro to SINAPI's elemental costs. Building upon the works mentioned above, Sakamori (2015) demonstrated the potential of BIM cost estimation by extracting the model quantities and linking these quantities to the unit costs of SINAPI. This work enabled Carvalho and Pinto (2015), in part, to produce a pre-tender estimate using family templates that had been created in Revit® that had been linked to SINAPI's cost database. Difficulties were encountered as there were many combinations of materials and unit costs for elements to choose from, rendering the estimating process cumbersome. For example, 53 different wall types (e.g., masonry, plaster, paint, or tiles) for a 38m² house are contained in SINAPI's database. To address this problem, such authors developed a plugin that enables the estimator to search and choose the desired component following the appropriate composition. However, limitations prevail as it depends on the use of templates created from families Revit®.

Required LOD for cost estimation

Each element of a design can be classified into five levels, according to its degree of modelling, with more information and precision expected at the highest levels. Figure 3 shows an example of the LOD classification proposed by BIMForum (2019) for an internal wall (Masonry) element. This research proposes to obtain a detailed pre-tender estimate using designs with elements modelled up to LOD 300.

Figure 3 - Classification of the internal wall (Masonry) element
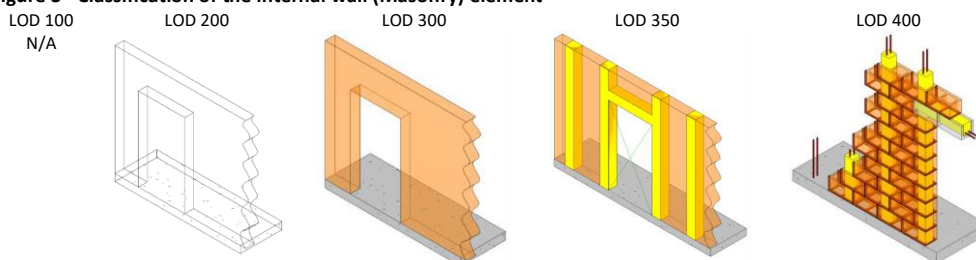
Source: BIMForum (2019).

Methodology

Traditional academic research methods tend to focus on the existing reality trying to explain the existence of phenomena in a given environment. However, since the present research focuses on creating a new reality through a change in current work practices, it is necessary to have an adequate methodology to evaluate this new reality (JOHANNESSON; PERJONSM, 2012). When comparing traditional methods: case study,

action research, and Design Science Research (DSR), Lacerda *et al.* (2013), show that the type of knowledge involved in the first two focuses on "understanding how things are or behave." In the case of DSR, the focus is on "indicating how things should be," which is coherent with the knowledge generated in the present research.

Additionally, when analyzing the problem presented here, there are two aspects to be solved. The first is 'practical' (i.e., it aims to give more accuracy to the pre-tender estimate). The second is the 'knowledge problem,' whereby knowledge is modified (i.e., changed in the way of estimating using a new paradigm, BIM). For Wieringa (2009), when these two aspects are present in a research problem, DSR is, precisely, a method that aims to account for these two types of issues. According to Rodrigues (2018), in DSR, a practical problem is responsible for guiding the research. As a result, other practical problems and questions about knowledge will emerge. Aken (2005) adds that DSR is a research strategy oriented towards elaborating a solution focused on the development of knowledge that professionals can use in practical contexts. Considering the nature of the problem to be addressed in this study and extant literature, DSR is the most appropriate method for conducting this research.

Kehily *et al.* (2015) suggests a process of four steps common in several academic studies for the DSR method that can be implemented when developing and evaluating a BIM artifact: 1) problem diagnosis; 2) propose and develop a solution concept; 3) implement the solution and evaluate the process in action; 4) identify and evaluate contributions to knowledge. Figure 4 presents the flowchart of the present research, based on Kehily *et al.* (2015).

Figure 4 - Research steps
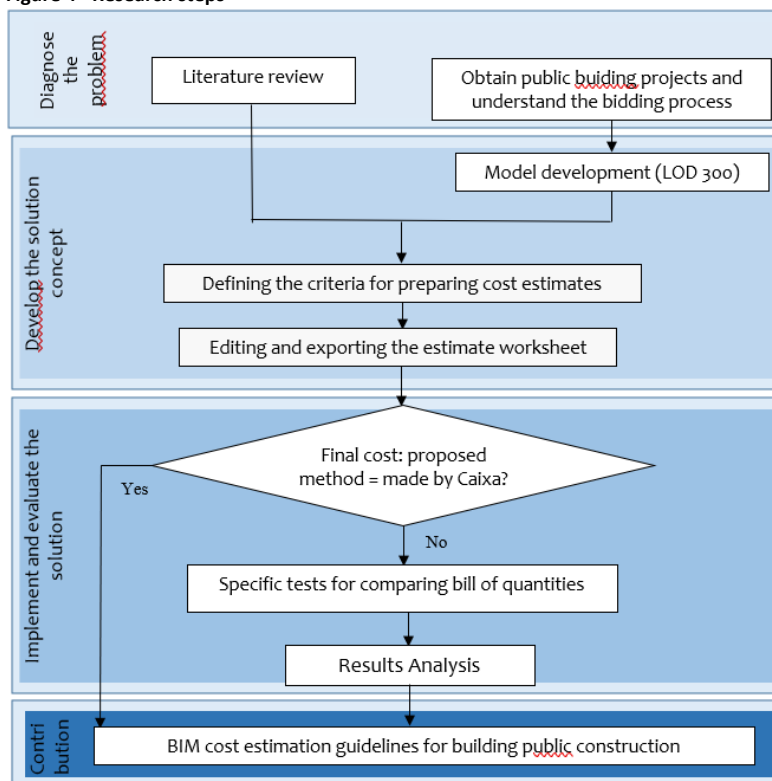
Source: the authors.

In the "problem diagnosis" stage, a literature review of the cost estimating of public projects with BIM was carried out. Two public projects' cost estimates assessed by CEF through BIM modelling at a level higher than LOD 300 were also chosen from CEF's

catalog and analyzed. The specific details of the selected designs are presented in Table 1 and Figure 5 and they represent a recurrent built Brazilian Multi-family residential building and a Reference Center for Social Assistance (CRAS). Figure 6 presents cases of CRAS under construction and completed.

Table 1 - Characteristics of the tested models

Project	Multi-family residential building Code 9672 - R4-2B-49C	Reference Center for Social Assistance (CRAS) Code 10619
Area	1,519.03m²	165.30m²
Construction	Structure in RC and non-structural walls in clay hollow block masonry	Structure in RC and non-structural walls in clay hollow block masonry
LOD	Architecture and structure to LOD 300	Architecture and structure to LOD 300

Source: the authors.

Figure 5 - Architectural and structural models: (above) Multi-family residential building and (bellow) Reference Center for Social Assistance (CRAS), in the left the architectural model and to the right corresponding structural model
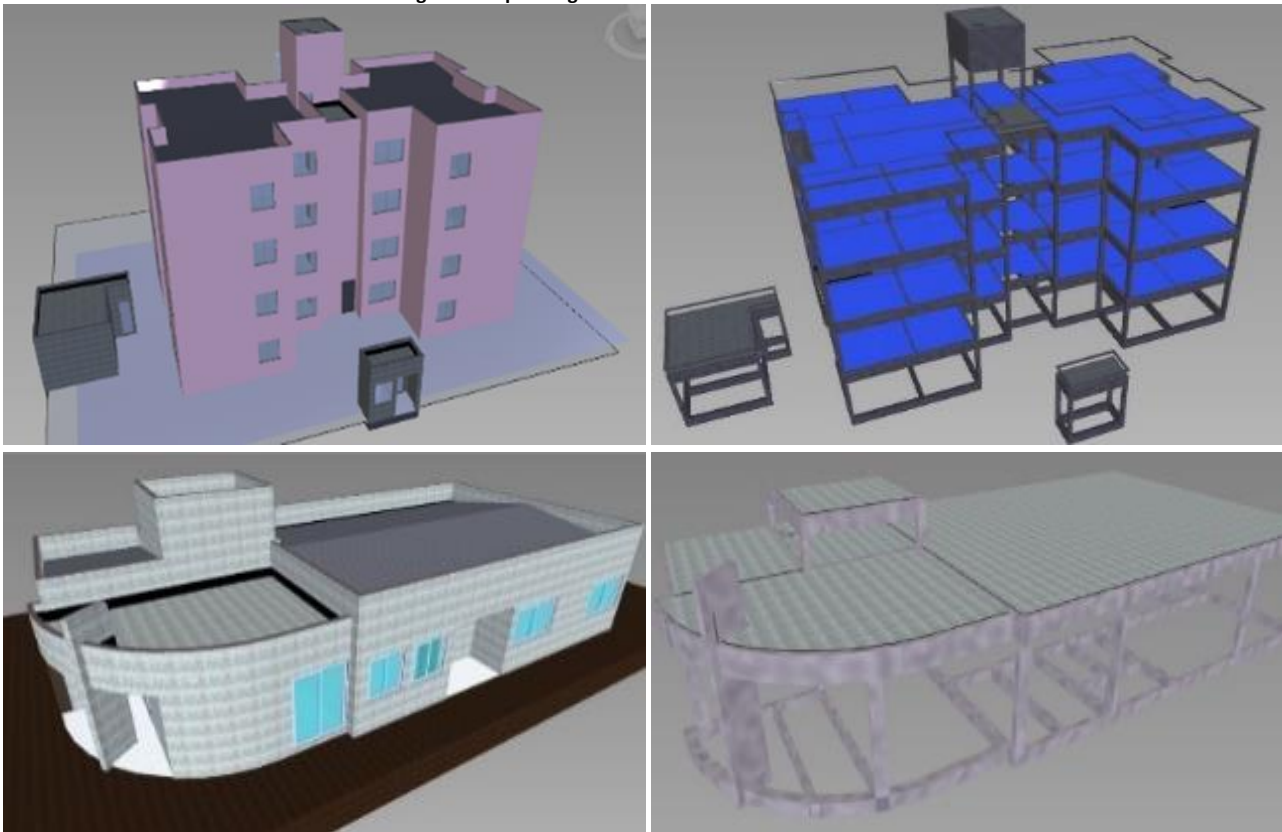
Source: the authors.

Figure 6 - Reference CRAS: CRAS under construction in Riachão das Neves, Bahia (left) and CRAS completed in Adrianópolis, Paraná (right)

Source: the authors.

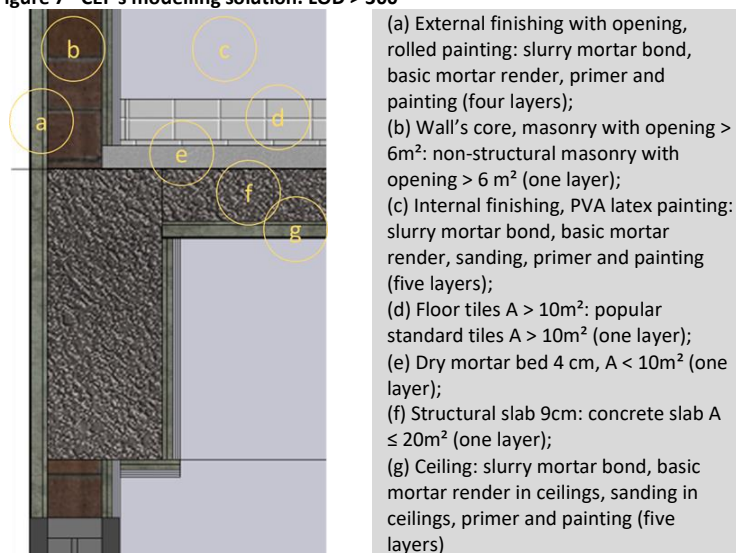The proposed solution was centred on Navisworks® resources. Therefore, in the "solution concept development" stage, it was necessary to propose bills of quantities consistency and accuracy checks for BIM models imported into Navisworks®. Criteria and formulas were defined for extracting services and their quantities through Navisworks® based only on elements representative of the two models in Revit® (Figures 5 and 6), simulating a LOD lower than that modelled by CEF. The cost estimate spreadsheets were generated, edited, exported, and the SINAPI's unit costs linked via Excel® outside the BIM model. The criteria for obtaining the two projects' quantities (a residential building and a center for social assistance) were defined.

Finally, in the "implementation and evaluation of the solution" stage, the final cost obtained by the proposed new structure was compared with that of CEF. When discrepancies occurred between both cases, an analysis was made to identify the causes. All decisions and analyses made in these steps were monitored and recorded to be part of the proposed guidelines. The contributions of this work were then listed and organized.

Solution concept

The residential model developed by CEF contained a considerable amount of detail. For example, to simplify the modelling process, every wall of the residential building was modelled by gathering different layers to represent their core and inner and outer faces (i.e., core, external plaster, international plaster, and internal painting). Within SINAPI's database, productivity levels have been established for different materials and, therefore, various wall compositions. For example, different types of wall exist for those with a masonry core such as (1) with or without opening and an area smaller or greater than six m²; (2) two types of external finishes (with or without openings); and three different internal finishes (e.g., acrylic paint, latex paint and tiles with an area smaller than five m²). Specific elements also were created to represent two types of ceiling and nine flooring categories, with each of these elements having a particular productivity level assigned to them. Figure 7 presents CEF's modelling solution, with a description of the elements and layers of associated materials following SINAPI's 'factor's tree.'

Figure 7 - CEF's modelling solution. LOD > 300

(a) External finishing with opening, rolled painting: slurry mortar bond, basic mortar render, primer and painting (four layers);
(b) Wall's core, masonry with opening > 6m²: non-structural masonry with opening > 6 m² (one layer);
(c) Internal finishing, PVA latex painting: slurry mortar bond, basic mortar render, sanding, primer and painting (five layers);
(d) Floor tiles A > 10m²: popular standard tiles A > 10m² (one layer);
(e) Dry mortar bed 4 cm, A < 10m² (one layer);
(f) Structural slab 9cm: concrete slab A ≤ 20m² (one layer);
(g) Ceiling: slurry mortar bond, basic mortar render in ceilings, sanding in ceilings, primer and painting (five layers)

Source: the authors.

Bill of quantities' consistency and accuracy

Both tested models' analytical pre-tender estimates are available on CEF's website (www.caixa.gov.br/poder-publico/apoio-poder-publico/sinapi/Paginas/default.aspx). Both were imported into Navisworks®. All quantification of architectural and structural elements was re-estimated to check their consistency and precision against CEF's Revit® version. Notably, the models did not contain the mechanical, electrical, and plumbing details. Several elements, however, needed to be modelled, such as the concrete in the columns and beams, while others were added following pre-determined models by using equations. For example: underfloor = ceramic floor area + (perimeter x depth of wall covering). For the reinforcement steel, CEF adopted a fixed ratio to the concrete's quantity (for both the residential building and the CRAS). The entire estimating process was performed in Navisworks®, formulas were created, and filters were applied based on imported from Revit®. Figure 8 illustrates the formula adopted to quantify the CRAS formwork for the concrete columns.

Figure 8 – Formula created to quantify the columns' formwork

Status	WBS/...	Name	Description							
	4.1	92414	FORMWORK FOR THE CONCRETE COLUMNS [...]...							

S...	WBS	Object	V...C...	Length	Width	Height	Area	Volume	PrimaryQuantity	
	4.1.2	COLUMN 15 x 30		3,050	0,150	0,300	1,418	0,137	=(Length-0,4)*(2*Width+2*Height)	m² ∨
	4.1.3	COLUMN 15 x 30		3,050	0,150	0,300	1,418	0,137		2,385 m²

Source: the authors.

Criteria for Preparing the Estimates

If a 5m x 3m wall is modelled in Revit®, its 'Area' parameter will be 15 m². When the Revit® file is imported into Navisworks®, the parameter is imported along with its source value. As Navisworks® does not recalculate quantities, it is expected that they will be the same for both tools – except for manually entered data or that obtained from user-created formulas. Therefore, it would be incorrect to reconsider the elements in Navisworks® that have been modelled by CEF in Revit®. If a wall was modelled by CEF and classified as Masonry < 6m², this information was disregarded. Similarly, elements such as walls and floors were reduced to single elements. As a result, this reduces the number of elements in the modelling process and enables detailed estimate at LOD 300. The improvement made to the estimating process is as follows:

- Residential building: The CEF model was initially imported without any adjustment into Navisworks®, and the pre-tender estimate was generated. As flooring was modelled as a single element in Revit®, it is impossible to apply filters in Navisworks®. Therefore, the floor and ceiling elements were estimated using the 'Environment' family, which provides the necessary area and perimeter; and

- CRAS: Before importing the CEF model, a single parameter assigned for walls with or without opening was created in Revit® to allow the application of filters in Navisworks®. The floor and ceiling had been modelled by rooms, which enabled an estimate of these items to be made.

Editing the Estimation Worksheet and Exporting

The Navisworks® quantities assessment was made using the 'QuantificationWorkbook' module (Figure 9), with the assistance of software tools, such as FindItems and Setscreation. Editing the estimation worksheet can be done either in Navisworks® or by importing a .xml file (Quantification/ImportCatalogModule). In this case, CEF's estimate was copied and pasted into an Excel template in .xlsm and exported to .xml.

Figure 9 - Steps for the quantification of masonry > 6 m² with openings
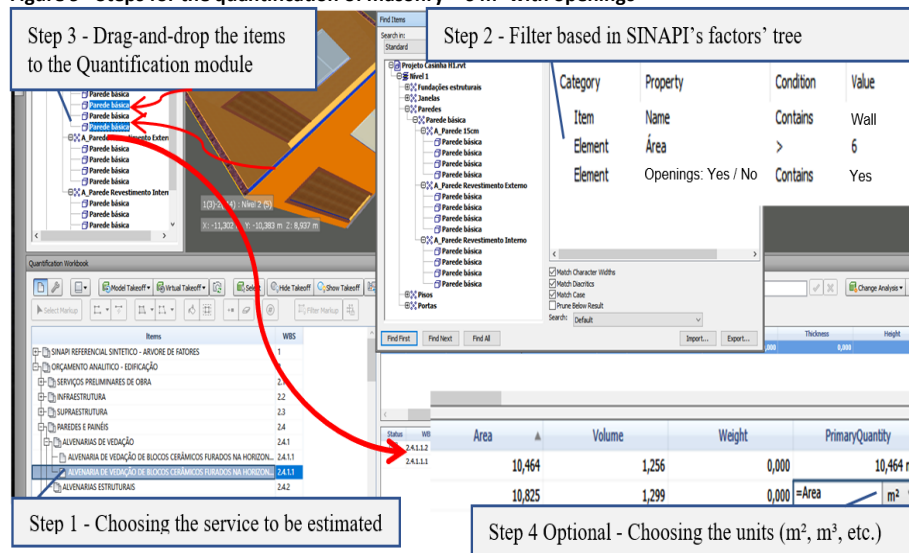
Source: the authors.

To produce an estimate requires: (1) elements to be chosen through the Navisworks® filter based on the SINAPI's 'factor's tree' elemental costs; (2) the selected elements to be dragged into the quantification module; and (3) the units to be selected from the various properties supplied for the element to be estimated, such as area, volume, perimeter, height, and width. Once the quantities' assessment is complete, the Navisworks® worksheet is exported into Excel® using the 'ExportQuantitiesto' command in the 'Quantification' module. Table 2 presents an example of an extracted report.

Table 2 - Navisworks report with services estimated according to the SINAPI compositions

WBS/RBS	Description	Group2	Group3	Item	Primary Quantity	Units
2						
2.4.1.2	87520	Walls and Panels	Non-Structural Masonry	Non-structural masonry built with clay hollow blocks 9x19x19cm (9cm width); wall area ≥ 6m²; with openings; manually mixed mortar. AF_06/2014	21.289	m²
	2.4.1.2.1	Walls and Panels	Non-Structural Masonry	Non-structural masonry built with clay hollow blocks 9x19x19cm (9cm width); wall area ≥ 6m²; with openings; manually mixed mortar. AF_06/2014	10.825	m²
	2.4.1.2.2	Walls and Panels	Non-Structural Masonry	Non-structural masonry built with clay hollow blocks 9x19x19cm (9cm width); wall area ≥ 6m²; with openings; manually mixed mortar. AF_06/2014	10.464	m²
2.4.1.1	87504	Walls and Panels	Non-Structural Masonry	Non-structural masonry built with clay hollow blocks 9x19x19cm (9cm width); wall area ≥ 6m²; without openings; manually mixed mortar. AF_06/2014	30.360	m²
	2.4.1.1.1	Walls and Panels	Non-Structural Masonry	Non-structural masonry built with clay hollow blocks 9x19x19cm (9cm width); wall area ≥ 6m²; without openings; manually mixed mortar. AF_06/2014	15.360	m²
	2.4.1.1.2	Walls and Panels	Non-Structural Masonry	Non-structural masonry built with clay hollow blocks 9x19x19cm (9cm width); wall area ≥ 6m²; without openings; manually mixed mortar. AF_06/2014	15.000	m²

Source: the authors.

SINAPI's Elemental Costs Association and Final Estimate

SINAPI's elemental costs can be obtained free of charge from the CEF website. In this study, a SINAPI Synthetic Estimate was adopted by selecting the unit costs for the city of Florianopolis/SC in July of 2017 (as SINAPI updates its database monthly for all the Brazilian state capitals). The association between the SINAPI unit costs and the quantified building's elements exported from Navisworks® was undertaken in Excel® using the VLOOKUP command and using it as a search key for the elemental costs' codes.

Table 3 illustrates the final estimate. These quantities and their monetary values were compared with CEF's estimate. The unitary prices are expressed in the Brazilian currency (the average exchange rate in September/2020 was 1 US$ = 5,47 R$).

**Table 3 - Extract of an estimate made for the non-structural masonry**

	NAVISWORKS				MS EXCEL			
WBS	SINAPI	Discrimination	Unit	Qty.	Unit. Price	BDI	Unit. Price plus BDI	Total
2.4		Walls and Panels						3,445.05
2.4.1		Non-Structural Masonry						3,445.05
2.4.1.2	87520	Non-structural masonry built with clay hollow blocks 9x19x19 cm (9 cm width); wall area ≥ 6 m²; with openings; manually mixed mortar.	m²	21.289	58.37	20,0%	70.04	1,491.08
2.4.1.1	87504	Non-structural masonry built with clay hollow blocks 9x19x19 cm (9 cm width); wall area ≥ 6 m²; without openings; manually mixed mortar.	m²	30.360	53.63	20,0%	64.36	1,953.97
		GRAND TOTAL						3,445.05

Source: the authors.

Implementation and evaluation on multi-family residential building

Observing the respective SINAPI classifications, the 'FindItems' command was used to classify masonry walls bigger or smaller than six m². A visual selection was made in each subset to select those with or without openings, which resulted in the four wall types described in Table 4. Each selection was saved as a 'Set Selection' and then dragged into the Quantification module to enable quantification. Each service must have its primary quantity defined (as m² for the walls' area). Figure 10 shows the masonry walls, and those smaller than six m² without openings are highlighted.

Figure 10 - Wall elements representing the masonry
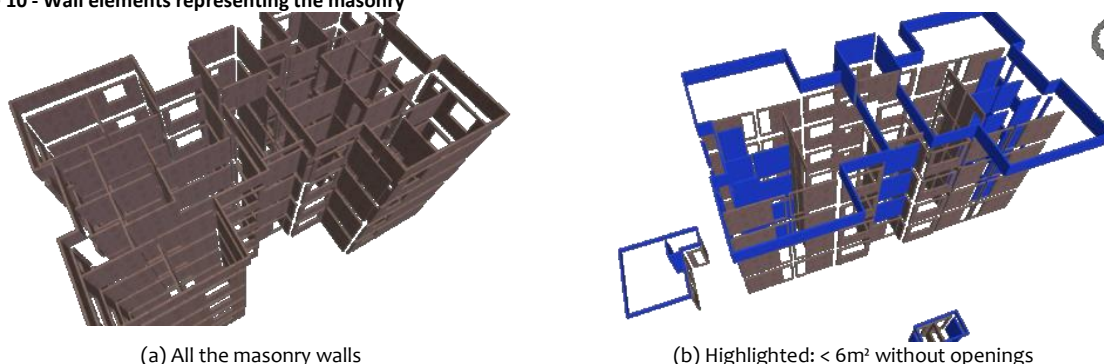
(a) All the masonry walls

(b) Highlighted: < 6m² without openings

Source: the authors.

Masonry Quantification

It was revealed that some masonry walls in the CEF model did not correctly follow SINAPI's 'factors' tree.' For example, in Figure 11, it can be seen that CEF's model had a masonry wall as not having an opening when it has one. Table 4 summarizes and

compares the CEF's masonry quantities with the research that has been presented. Besides, the differences are visually represented in Figure 12.

As the residential building had only four storeys, the walls were manually selected. However, if the building were taller, this process would be labor-intensive and time-consuming to undertake as the walls would need to be assigned to SINAPI's elemental cost. In this case, selections from a single floor plan were made, and the results multiplied by the number of identical floor plans in the 'Quantification' module. Alternatively, using Revit® parameters can be created to enable filters based on the 'SINAPI's factor tree' to be implemented with occurred in the CRAS case.

**Figure 11 - Wall with opening erroneously modelled by CEF**

Item Name: Parede básica
Item Type: Paredes: Wall: BLOCKS < 6 M2 WITHOUT OPENINGS
Element Área: 4,145 m²
Element Volume: 0,373 m³
Element Comprimento: 2,500 m
Element Altura desconectada: 1,850 m

Source: the authors.

Table 4 - Masonry summary

Elements	CEF (m²)	Research (m²)
Masonry < 6m² without opening	382.24	288.79
Masonry ≥ 6m² without opening	286.51	397.85
Masonry < 6m² with opening	352.04	361.32
Masonry ≥ 6m² with opening	460.03	432.82
Total (m²)	1,480.82	1,480.78

Source: the authors.

Figure 12 - A visual summary of the masonry
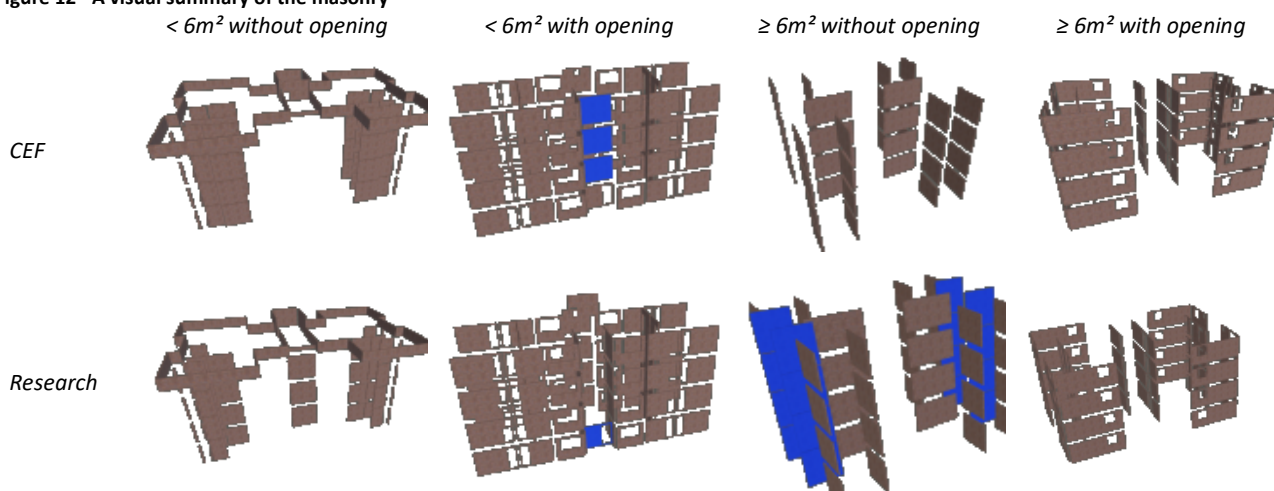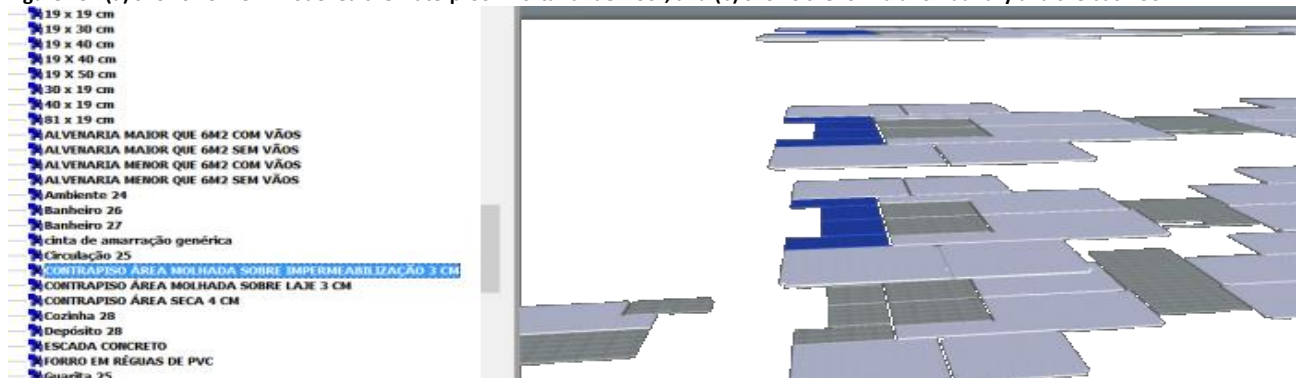

Source: the authors.

Quantification of Floors, Ceilings and Ceiling Finishes

The internal flooring has 14 estimated construction services, such as mortar beds, tiling, skirting boards, and door thresholds. The ceilings can be finished either by a single element (PVC panels) or using several components such as a slurry mortar bond, basic

mortar renders in ceilings, sanding in ceilings, primer, and painting. As CEF modelled floors and ceilings as clustered elements (Figure 13), it was not possible to individually select them. Thus, most of these services were estimated using the Revit®' Environment' family category, which provides each room's area and perimeter. Therefore, environments were dragged as elements for the desired service and multiplied by the number of repetitions in the building. For the water tank room, the individual floor elements were added. In general, the quantities were equal to or lower than those in CEF's model. Each room's floor and ceiling services are computed from the walls' finished faces. However, the floor mortar bed needs to be computed from the masonry faces. In this case, as Figure 14 shows, the following formula is used:
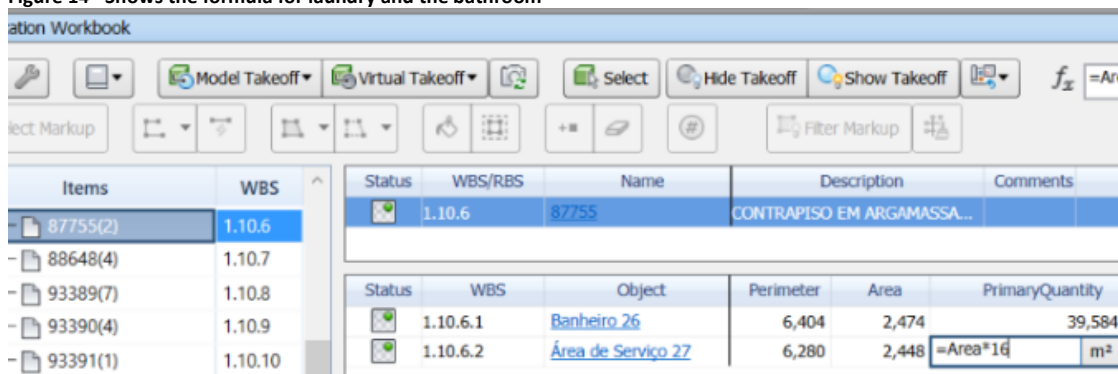
Primary Quantity = (area + (perimeter x 3cm)) x 16

Figure 13 - (a) shows how CEF modelled the waterproof mortar underfloor, and (b) shows the formula for laundry and the bathroom

Source: the authors.

Figure 14 - Shows the formula for laundry and the bathroom

Source: the authors.

## Quantification of waterproofing

The CEF model represented the waterproofing services through several walls, floor, and ceiling elements (Figure 15). For example, the waterproofing elements are calculated by determining the area of each floor's beams (dark red elements in Figure 15) by multiplying their length and width. This formula was inputted into Navisworks, enabling it to be replicated for each floor.

Figure 15 - Representative modelling of waterproofing
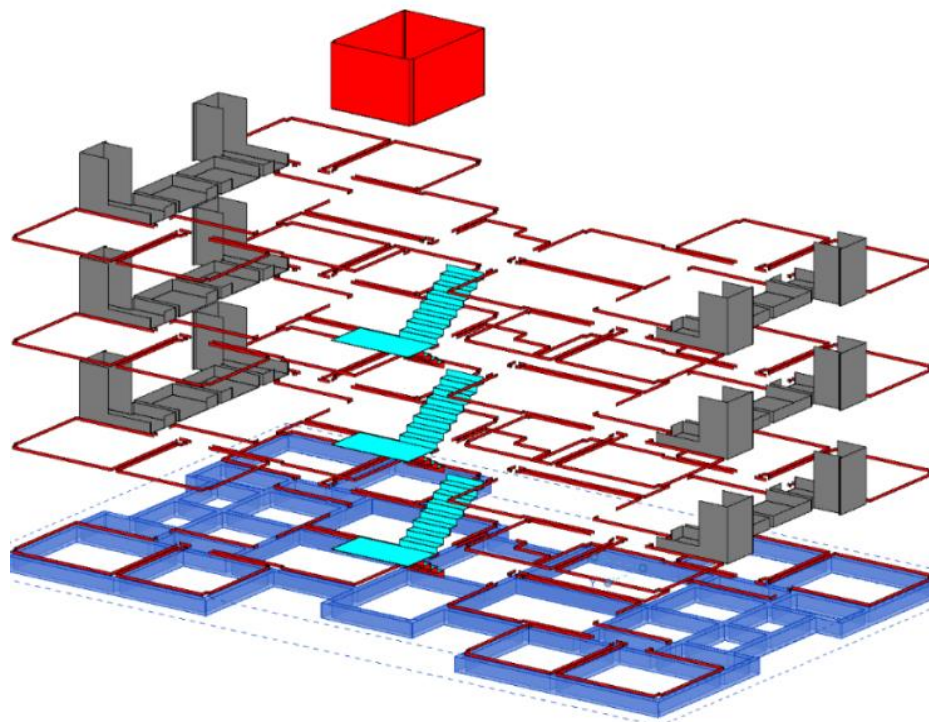
Source: the authors.

Quantification of foundations and superstructure

Concreting and its pouring are quantified by volume, selecting them from the 'SelectionTree' into the 'Quantification' module to be estimated. In the formwork case, the same columns, beams, and slabs were used, adopting the necessary formulas to generate areas. The reinforcement steel was assessed by applying a rate to the volume of concrete, considering the type of elemental cost developed by CEF. The quantification of the other services linked to foundations and superstructure followed similar procedures.

Analysis of Results: Multi-family Residential Building

Table 5 provides an overview of the estimate produced. Highlighted in green are the macro items which were not examined in this research. It can be seen that the remained scrutinized macro items represent, in financial resources, more than 80% of the total CEF estimate.

Only the services of lintel beams and ceilings had significant differences, -24.95% and + 5.72%, respectively. It was impossible to verify the criteria adopted to quantify these elements as CEF did not model them. To assess the lintel beams and the window sills, we dragged the doors and windows' elements. According to the descriptive memorandum, we adopted the width parameter (added of 20cm for each side for the lintel beams). Nonetheless, the quantities' differences persisted, with negative variations of up to 33%. The remaining macro items fluctuated only up to ± 2.5%, highlighting that some services had larger internal variations.

Considering the total monetary difference of -0.3%, it is concluded that the use of the proposed guidelines for the assessment of a pre-tender estimate is accurate and reliable. However, as previously reported, it was necessary to make several manual selections, which was a time-consuming process. Thus, a second test using the CRAS model was performed, aiming to improve the process.

Table 5 - Estimate summary

#	MACRO ITEM	CEF	WEIGHT	RESEARCH	WEIGHT	DIFF.
1	Preliminary Services	3,650.66	0.40%	3,650.70	0.40%	0,00%
2	Infrastructure	27,911.31	2.70%	28,049.82	2.80%	0,50%
3	Superstructure	247,456.43	24.40%	252,846.50	25.00%	2,18%
4	Walls and panels	100,552.26	9.90%	99,633.17	9.80%	-0,91%
5	Lintels and window sills	19,242.44	1.90%	14,441.70	1.40%	-24,95%
6	Windows and doors / glass / hardware	132,977.38	13.10%	132,977.42	13.10%	0,00%
7	Roofs and protections	24,807.86	2.40%	25,012.09	2.50%	0,82%
8	External finishes	122,261.21	12.00%	121,035.42	12.00%	-1,00%
9	Internal finishes	66,578.62	6.60%	66,144.96	6.50%	-0,65%
10	Internal paving	66,145.77	6.50%	64,556.61	6.40%	-2,40%
11	Ceilings	4,861.19	0.50%	5,139.24	0.50%	5,72%
12	Electrical / Phone / TV installations	96,838.37	9.50%	96,838.37	9.60%	0,00%
13	Hidraulic installations	12,222.95	1.20%	12,222.97	1.20%	0,00%
14	Rainwater installations	4,173.50	0.40%	4,173.50	0.40%	0,00%
16	Toilets, lavatory, sinks and hardware	18,657.31	1.80%	18,657.31	1.80%	0,00%
17	Final services	11,902.55	1.20%	11,902.58	1.20%	0,00%
18	Wastewater installations	19,922.06	2.00%	19,922.10	2.00%	0,00%
20	External paving	1,421.31	0.10%	1,421.53	0.10%	0,02%
21	Ceiling finishes	33,490.83	3.30%	33,747.66	3.30%	0,77%
	Grand Total	1,015,074.01	100.00%	1,012,373.65	100.00%	-0.30%
	Modelled Items	847,706.61	83.50%	845,006.12	83.50%	-0.30%
	Non-Modelled Items	167,367.40	16.50%	167,367.53	16.50%	0.00%

Source: the authors.

Implementation and evaluation on the social assistance and reference centre (CRAS)

Numerous elements within the CRAS model had been separately modelled and therefore this simplified the cost estimation process. Ceilings and floors were already modelled by each room, allowing the generation of various associated services, such as mortar or concrete bedding, floors, skirting boards, slabs, and ceilings. A single parameter was created in Revit® to determine walls and their openings. The model was then imported into Navisworks®, and the quantification procedures were performed. In this second test, searches with the FindItems command and the creation of SetsSaveSearch were prioritized, facilitating the updating of the model and the estimated quantities. Figure 16 shows a search to find ceiling services with an area between 5 and 10 m².

**Figure 16 - Search with command Find Itens, for ceilings between 5 and 10m²**
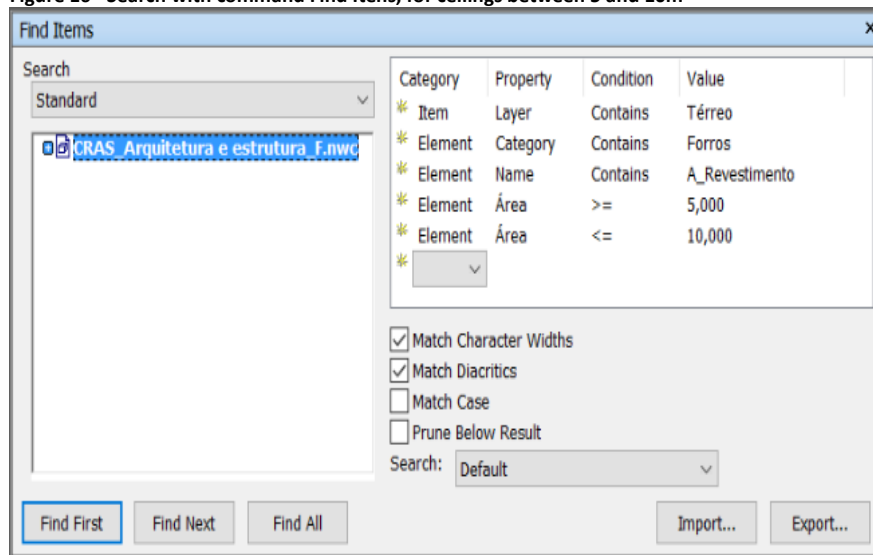
Source: the authors.

Elemental discrepancies

Several elemental discrepancies were identified. For example, the CEF had estimated one aluminum sliding door, while two were designed. A 3cm waterproof mortar had been estimated over the entire area (including under the roof), but it was only specified on the uncovered floor slab. Besides, some elements were modelled differently from their 'factors' tree,' as was the case in the residential building. Figure 17 exemplifies a wall's finishing estimated with an area between 5 and 10 m² when it has only 2.25m².

Figure 17 - Finishing of wall modelled with area superior to the real
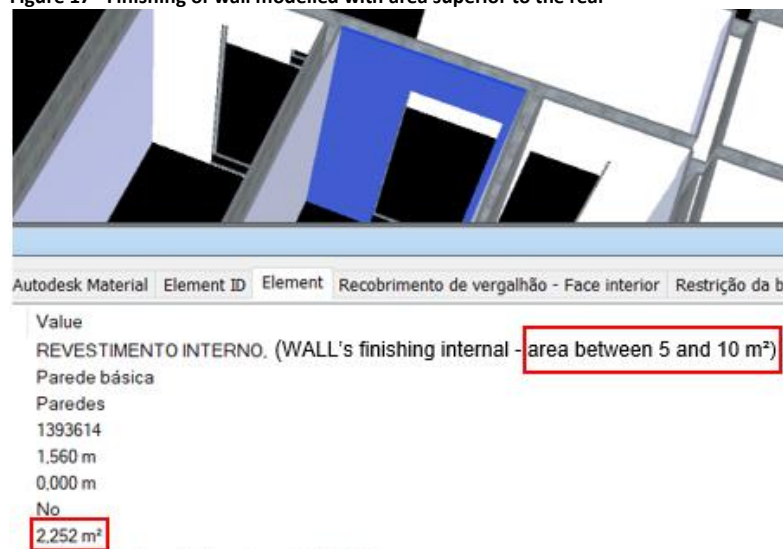
Source: the authors.

Analysis of Results: CRAS

Table 6 summarizes the differences between the estimations for the macro items. Also, CEF considered 142 m² for all the services linked to the ceiling's finishing, while the survey estimated 149 m². The criterion adopted by CEF for the lintel beams' quantification was unclear, as they were not modelled (the research adopted the width of the doors and windows plus 20cm for each side).

Table 6 - Differences between the estimations for the macro items

#	MACRO ITEM	CEF	WEIGHT	RESEARCH	WEIGHT	DIFF.
2	Preliminary Services	3,911.81	1.70%	3,911.83	1.70%	0,00%
3	Foundations	13,417.64	5.90%	13,660.41	6.00%	1,81%
4	Superstructure	36,656.95	16.20%	36,506.43	16.10%	-0,41%
5	Walls and panels	18,589.72	8.20%	18,568.13	8.20%	-0,12%
20	Windows and doors	22,123.77	9.80%	24,160.26	10.70%	9,20%
21	Roofs and protections	30,161.29	13.40%	25,222.42	11.20%	-16,37%
22	Internal finishes	15,392.67	6.80%	15,438.08	6.80%	0,30%
30	Paving	13,926.43	6.20%	17,198.67	7.60%	23,50%
31	Electrical / Phone installations	19,398.40	8.60%	19,398.44	8.60%	0,00%
32	Wastewater installations	7,217.52	3.20%	7,217.58	3.20%	0,00%
33	Rainwater installations	4,674.17	2.10%	4,674.19	2.10%	0,00%
34	Fire installations	227.6	0.10%	227.6	0.10%	0,00%
35	Toilets, lavatory, sinks and hardware	3,509.27	1.60%	3,509.27	1.60%	0,00%
37	Final services	456.2	0.20%	456.206	0.20%	0,00%
38	External finishes	19,033.48	8.40%	18,721.20	8.30%	-1,64%
39	Ceiling finishes	8,470.96	3.80%	8,872.19	3.90%	4,74%
40	Lintels and window sills	3,991.38	1.80%	3,898.02	1.70%	-2,34%
41	Hidraulic installations	4,424.55	2.00%	4,424.57	2.00%	0,00%
	GRAND TOTAL	225,583.81	100.00%	226,065.49	100.00%	0.20%
	Modelled Items	181,764.29	80.60%	182,245.80	80.60%	0.30%
	Non-Modelled Items	43,819.52	19.40%	43,819.69	19.40%	0.00%

Source: the authors.

The total monetary difference between the two CRAS estimates was 0.2%, reinforcing the consistency and precision of the proposed guidelines for assessing pre-tender estimates. However, unlike the residential building, it took less time to generate the CRAS estimate due to the search tool (FindItems) and the parameter 'opening or no opening in walls'. Thus, if an indicator 'modelling time versus estimating time' was considered, it is expected that the use of these guidelines would also present satisfactory results since the time spent on modeling is usually reflected in gains in later stages of construction.

Proposed Guidelines

Aiming to improve the proposed method's effectiveness, the research presents the guidelines to be observed by models considering Brazilian laws and SINAPI's 'factor tree' methodology. In Brazil, a pre-tender estimate is typically based on a LOD 300 and standard details. However, some elements such as walls and openings may be modelled to LOD 200 as such detail is not required to estimate.

Modelling techniques

The floor and ceiling elements shall be independently modelled by their location, as the family category can be used to determine their area and perimeter. This modelling approach enables items such as floor, slabs, ceilings, skirting boards, waterproofing of floors, and walls combined into a single element. Specific formulas can be developed to determine the exact quantities for items; for example, to calculate the area that needs to be waterproofed, the following is used:

Waterproofing area = floor area + perimeter x height to be waterproofed in the walls.

If several layers are detailed, it is desirable to have three single-layer elements juxtaposed, as follows: a floor category for all elements/constructions works above the slab; a category of structural floor to represent the slab; and a ceiling category to represent the elements/construction works below the slab, such as slurry mortar bond, plaster, painting, and PVC panels. The reinforced concrete structures volume and formwork are obtained from the modelled geometry. The quantity of reinforcement is derived as a ratio to the volume of concrete. Other elements such as doors and windows are not required to be modelled beyond a LOD of 100. Doors and windows (including lintels and sills) can be counted, and their area determined by their size. Thus, this enables the quantity of primer and painting to be calculated.

Text parameters

The text parameters are the simplest way to apply the proposed guidelines. Parameters can be used to indicate the openings in walls, to specify substrates and wall finishes, floors, ceilings, coatings, and other elements such as doors or windows. Text parameters make it easier to search Navisworks using the FindItems command and associate each element to the corresponding 'SINAPI factors' tree' elemental cost. This approach enables search rules between user-entered text parameters and geometry parameters imported from the model to be defined according to the 'SINAPI factors' tree,' thus improving the estimating process.

If a user chooses to perform part of the estimation in the modelling tool itself, the guidelines proposed in this paper can also be applied directly in Revit®. It is possible to obtain the quantities of the modelled objects in a grouped way according to the parameters created and the area of the elements. Modelling to LOD 300 and using text parameters to indicate productivity factors, material specifications, and element names

(e.g., doors type) is sufficient to obtain the quantities using the 'SINAPI factors' tree' methodology. The estimation related to the representative elements can be finalized in a conventional, non-model spreadsheet editor. Chart 1 presents the basic parameters that need to efficiently create and apply these guidelines according to the 'SINAPI factors' tree' elemental costs.

Chart 1 - Suggested parameters for applying the guidelines

Category of the Elements	Parameter	Droplist
Walls (masonry and finishings)	Has openings:	Yes or No
	Type of finishing:	Tiling to the ceiling Tiling to ½ height Latex painting Acrylic painting
	Type of substrate:	Slurry mortar bond Mortar rendering (single layer) Mortar rendering (base coat)
Floors (tiling, mortar bed, waterproofing, structural floor)	Type of area:	Dry or Wet
	Waterproofing:	Yes or No
	Type of mortar bed:	Common Acoustic Self-levelling
	Thickness:	3 cm 4 cm 5 cm 6 cm 7 cm
Ceiling	Type of ceiling:	PVC panels Wood Metal Plaster panels Dry wall
	Type of substract:	Slurry mortar bond Mortar rendering (single layer) Mortar rendering (base coat)
Slab	Type of slab:	Pre cast Flat or grid Any kind of slab

Source: the authors.

Conclusion

This paper presents an approach for developing a pre-tender estimate for public sector infrastructure using BIM with elements modelled up to LOD 300 following the 'SINAPI factors' tree' methodology. The BIM cost estimation guidelines that have been proposed provide the ability to develop accurate pre-tender estimates that fulfill the Brazilian laws regarding public engineering projects. However, the aspects of the guidelines may be developed by other governments, though this will be dependent on their procurement laws and regulations.

The developed guidelines were demonstrated using the two case examples: (1) a four-story residential building; and (2) single-story Social Assistance and Reference Centre (CRAS). The residential building's pre-existent BIM model had a pre-tender estimate of 0.3% greater than the value obtained in this research. The CRAS project was tested with no changes in the original BIM model. However, a new parameter was created in Revit® that accommodated the presence or absence of openings in the walls. It resulted in a pre-tender estimate of 0.2% smaller than the pre-tender estimate assessed following the proposed guidelines.

Notably, the case projects were originally modelled in Revit® by CEF, with LOD higher than 300, and the pre-tender estimates were assessed using the Navisworks BIM tool of analysis. Thus, several elements and all layers of materials were disregarded. With only

a few modelled elements, it was possible to obtain the various associated services, whose SINAPI's elemental unit costs were incorporated into Microsoft® Excel®. This research assessed all the macro-level items that could be scrutinized; namely, the architectural and structural elements modelled by CEF. The macro-level items examined exceeded 80% of each project's total value and were compared to the respective values available on CEF's website, which is the main indicator of precision and consistency of the proposed guidelines.

We demonstrated that text parameters could be used to identify material specifications, the geometry of elements (e.g., openings in walls), specify substrates, and wall finishing, floors, ceilings, and coatings. The approach can improve the process to estimate the 'SINAPI factors' tree' elemental costs. The use of text parameters does not change the visual appearance of a model. It reduces the modelling effort needed to improve the accuracy and efficiency of the cost estimation process.

Thus, the following contributions of this research are expected: a) obtaining detailed pre-tender estimates using models up to LOD 300, facilitating the work of cost estimators and public managers, and reducing the risk of under-and-over pricing of construction works; b) reduction of the modelling effort in the preparation phase of the basic project in order to obtain pre-tender estimates; c) facilitating the assessment of the pre-tender estimate even by professionals who did not participate in the design phase; d) allowing to detect flaws in the pre-tender estimates; e) improving transparency in the use of public resources; f) improving the effectiveness and speed in public auctions; g) and for the Academy, an advance in knowledge proposing the connection of the SINAPI's factor tree with BIM.

Acknowledgements

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