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Early design BIM-based Target Value Design for public facilities: An application to a healthcare facility case

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Abstract

The objective of this article is to develop an agile application based on BIM for the integration of Target Value Design into the design process, in order to offer a resource to support decision-making process from the early design stages. The research applies the operational research method by the methodological steps: (a) Identify input data sources and develop the input setup; (b) Develop BIM-based cost estimation of visual programming and apply program in one case; (c) Discussion of the potentialities and challenges of the proposed approach to outline the research findings. A direct link between cost estimation and BIM objects was created to promote Target Value Design in the design process through visual programming. The necessary agility was obtained through semi-automation of the process of incorporating the cost data within the parametric modelling family and extracting cost estimate totals from the model to a pre-defined spreadsheet, allowing the continuous updating of models.

Keywords

BIM, building information modelling, BIM-based target value design, BIM-based cost estimation, decision-making support, early design process state

Introduction

Digital cost estimation tools have been highly developed over time and have become sophisticated enough to achieve advancements in building information modelling (BIM) to fully improve the building design process, optimizing the time required for accurate cost estimations.[1] A less explored perspective in BIM is target cost and target value design.[2] The development of such design tools offers support for a strategic approach to the

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design in the building life-cycle project, as it allows anticipating and making explicit a cost-benefit orientation from the initial phases of the design, in order to improve the building life-cycle global costs.[3]

BIM's proposal is for the project to be modelled virtually by using computational tools, prior to its actual construction, at the construction site, which is a process that brings together those involved in a virtual project. Thus, it is possible to ensure that each professional's knowledge is incorporated in a single data source, reducing problems within the design compatibility.[4]

Regarding the design cost estimation,[5] states that the development of BIM's potential to obtain cost estimates has gained momentum, and that avant-garde project cost management companies have begun to realize the competitive advantages of adopting this approach. Moreover, there are several initiatives at an international level to establish the implementation of the BIM process as a requirement in the development of public equipment projects, in order to enrich their level of detail, facilitating the extraction of budget estimates and minimizing changes and complications that potentially generate the majority of delays and additional costs, especially in the construction phase.

The implementation of BIM has shown the limitations of the architecture, engineering, and construction industry to update itself with technological developments, where more creative solutions are necessary to adequately integrate modelling tools with cost estimation and construction planning software.[1,6]

There are several computational applications dedicated to detailed cost estimation integrated to BIM platform, however, previous research[7-9] has shown that most of them consider cost estimation at an additional detailed design level, lacking applicability in the initial design stages, to support cost-based decision-making. Even less explored are the computational applications that allow designing dynamically and explicitly balancing the value of the project.

Therefore, this paper aims to develop a simplified BIM-based application for the integration of cost estimation index and design requirements of public buildings in the BIM platform, from the initial design phases, as a resource to support decision-making.

Literature review

BIM-based cost estimation approaches and tools

BIM 5D consists of integrating the "costs" dimension, allowing the instant production of cost estimations of the model concerning time.[5] This is possible through the extraction of quantities of the analyzed model.

In addition, the cost analysis extracted from the 5D model can also be used to scale the financial performance of the current state of construction.[10] This is due to the ability of each BIM tool to extract the number of components, areas and spatial volumes, quantification of materials, and inform various schedules about the project.[4]

However, Sakamori[11] points out that for correct cost estimation in a BIM modelling process, all construction elements and objects must be properly classified. Even so, according to Monteiro,[12] the ability to assign values to building elements supports and streamlines, to a certain extent, the budget processes.

Balali et al.[1] presented a method for a BIM model to be converted into a virtual reality, and its potential to implement synchronous modifications and cost updates in relation to design options. Such an approach would allow the designers to choose object materials concerning its preliminary cost estimation. The proposed method integrates BIM models with embedded data and converts them into virtual models through a workflow using a reusable C# script.

Kim et al.[13] addressed how quantity discrepancies were allocated and exceeded typical loss rates for several materials, identifying that the major causes of such discrepancies were unnecessary representation or modelling.

Lee et al.[14] presented a development method for the automated deduction of the most adequate element based on work conditions through the use of semantic technology. The approach pointed out the use of BIM

information to automate the search of appropriate building elements and materials. The authors compared existing estimation methods to the proposed one and demonstrated that the ontologies and semantic reasoning ruling could be applied to real conditions.[14]

Cheung et al.[7] developed an intuitive method to integrate cost estimates from the initial design stages, as a module within Google SketchUp, which could also be implemented to other environments and early-stage estimation higher-end systems.[7]

Ma et al.[15] regarded the main issues for semi-automated and prescription-compliant bidding of cost estimates for building projects based on the interoperable data, to change the typical human-intensive process into a semi-automatic task compliant to a strictly specific specification.

The research reported by Monteiro and Martins[16] shows that the BIM-based cost estimation process is often not straightforward due to a series of strict rules that ensure quantification consistency. The rules for quantity take-off are applied to the features parameterization and modelling process, and model adaptation to the take-off process may generate conflicts with other modelling features such as appearance and clash detection.

The research of Vigneault et al.[17] aimed at an innovative BIM framework for construction cost management through a systematic review of the BIM-based solutions, as well as interviews with experts from the industry. Eighteen software solutions were found and analyzed against the cost management practices, resulting in knowledge creation based on the available solutions for future needs on cost management requirements.

Xu et al.[18] identified construction cost estimation activities using new measurement rules. In addition, a case was applied to state the use of modelling by field experts in the development of a consistent cost estimation framework that meets industry requisites. By dissociating syntax, semantics, and pragmatics, the patch may be understood, and the specialists' expertise can be applied to computing. Moreover, it has a direct effect on the application of such knowledge-based systems in the industry, where the issue of ontology is usually separated from the expertise-based processes.[18]

Wang et al.[19] made significant contributions to the literature regarding the use of BIM data procurement and storage capabilities to fill schedule information. The model proposed by the authors states the criteria to be applied in the search take-off feature to precisely recognize elements to extract quantities integrated to using the keynote, assembly code, and family type functions to facilitate the input of cost information in BIM objects in a semi-automated way.

Ma and Liu[20] stated that the current method to develop BIM applications with reasoning support and representing rules by coding has shown cost and efficiency issues. In order to address such issues, a method was developed using an ontology-based BIM platform with reasoning support, whose functional requirements were outlined, and a method to convert BIM into ontology data was developed according to the following stages: calculation, filter, and translation.

Cost estimation and target value design

Cost estimation or budgeting can be defined by as a product that informs the amount, term, and conditions necessary for the realization of a certain amount of planned services or products.[21,22]

Vigneault et al.[17] outlines—on the Project Management Institute[23] guidelines—cost estimation as a procedure that enables to identify the financial resources needed for a construction project as a parameter to deal with the project's cost performance.

Limmer[24] points out that budgeting can occur in any stage of a project, with precision about the real value directly proportional to its development stage—as more advanced phases provide larger amounts of details. However, it is important to highlight that, at the earlier design stages, the central role of cost estimation is to support decision-making based on a project's budget viability.

One of the difficult aspects to consider is to adequately assess the design's result, not only in relation to the cost resulting from the solution presented, but also the measurement of the benefits achieved.[2,25]

Target Value design (TVD) is an approach introduced in the AECO sector, since mid-2005 and 2007, from the study of Target Costing (TC),[26,27] as a means of mediation and evaluation of the cost-benefit ratio.[28]

TVD comprises actions that impact all design process, involving negotiations with supply-chain agents, service providers, designers, and clients/user/customers. This dimension shifts/transfer the focus of TVD away from the conventional design process, making Ballard suggest the adoption of "Target Value Delivery."[29] Studies have been developed in this direction, relating TVD to Opportunity Management[30] and IPD.

However, TVD is still about making the owner's value the main design' drive, improving the design program definition and keeping active the target value throughout the decision-making process, thus optimizing the design phase.[31,32]

One of TVD purposes is to allow resource management involving stakeholders and identify the better investment disposition for the project purpose among the design options.[32] A central aspect of successful TVD implementation depend that the iteration between design and evaluation takes place from the design beginning.[27]

A TVD tool oriented to the design concepts comparison must offer a balancing system in which different weights are attributed to the elements that constitute the solutions of the system built in a building, in order to balance the weight of the expenditure made on these elements. Thus, the solution obtained with an element or an entire subsystem that meets one or more requirements identified as important to the customer, has attributed a higher permissible cost than those elements that do not impact its perceived benefit.[33] The need for spending on fundamental elements, while not perceived, needs to be balanced, in order to minimize the impact on the elements that add value to the result.

Although this principle is relatively simple, it is important that TVD occurs from the early design stage and involve key players, including customer representation, in addition to the reorganization of the project process and contractual regime.[33] This means that quick manipulation tools appropriate are necessary so that the evaluation of the experimentation and negotiation, customary at the beginning of the process, is not rendered unfeasible for lack of subsidy. Such computational tools are lacking.

A window of opportunity to incorporate TVD into project design was opened with several countries' state initiatives to subscribe to international legislation and standards for the application of BIM methods and tools.[34]

Target-cost and value design software in AECO

In the specific case of Brazil, where the present study is developed, the National Dissemination Strategy for Building Information Modelling was recently established, where a part of its objectives is the dissemination of BIM and the structuring of the public sector for its implementation.[35] Also, it establishes the use of BIM in the direct or indirect execution of engineering works and services carried out by federal public administration entities, where mandatory BIM project budgeting is foreseen for the second stage of implementing the legislation, starting in 2024.[36]

In that direction, Porwal and Hewage[37] proposed a construction project procurement framework for the public sector. Those authors described an approach to facilitate BIM implementation and a collaborative framework for the construction process and presented different approaches to support project teams and overcome organizational, technical, and procedural challenges. The authors stated a diverse approach is needed for collaborative BIM development in the public procurement context, where organizations should work out the best method to embody the current protocols in different project stages.

Ciribini et al.[38] performed a case study, describing how the initial Italian official endeavor to adopt BIM in the public sector demand allowed the research group to understand how the management regulations comprised by Italian contractual frameworks could fall from the potential benefits inherent to digitized modelling. Despite several potentials of this original method, cultural obstacles hindered the BIM features and management processes, highlighting the reluctance of project stakeholders in coordinating their own tasks and collaborating in the implementation of BIM process.

Logothetis and Stylianidis[39] present a survey on the open-source BIM software in comparison to the most used commercial ones in the UK construction industry. There is a wide range of commercial applications available for detailed cost estimation integrated to BIM platform, that is, Autodesk Revit and ArchiCAD (Graphisoft) native tools, Arquimedes (Multiplus), Primus IFC (Acca Software), Orça Fascio, Autodesk Navisworks, Presto (Aminfo), Vico Office Suite (Trimble), among others. Some of them are cost estimation dedicated tools, while others are modelling software with native bidding features.

However, as referred in the literature,[7-9] it is important to notice that most of them are dedicated to detailed cost estimation at a very technical detailed design level, which are too complex to be currently used throughout the design process, from the earlier stages, to provide cost-based decision-making.

Problem, question, and objective

According to the literature review, research efforts to instrumentalize the project design and TVD activity—which needs to be dynamic and interactive—need to be addressed.

At this point, one of the central questions is how to streamline the iteration between the conception of design options, their estimated cost and contribution to meeting project requirements.

The first challenge is to establish parameters so that designers can demonstrate that the committed costs are justified with the adequacy of the solution to the customer's requirements. The second challenge is that this balance should be carried out with sufficient agility so that the conception time is not delayed to the point of harming the interests of the parties involved.

Thus, this research piece focus to develop a simplified BIM-based application prototype to provide semi-automated cost estimation and target value design outputs throughout the design process, from its early stages, to support decision-making.

Method

The present research applies the operational research method to assist the decision-making process by determining the alternatives to designing, planning, and operating systems.[40,41] Problems are divided into smaller-pieced components and worked out in steps, through modelling and simulation, to better understand the studied system, identify issues, development of strategies, and to support the decision-making process, as a model is defined by such scientific methodology as a representation of the real world to systematically assist approached situations.[40,41]

The operational research method takes part in the systems thinking approach, by considering the aspects as a holistic approach, system elements interaction, hierarchy of systems levels, and, strongly, the role of people acting according to different purposes or rationalities.[42] Therefore, it is relevant to highlight that any addressed process can only approach a specific slice of a larger issue of the modelled situation, again considering the aftermath of human action.[43]

The described method applies to this research as it uses the features of existing information modelling tools, and discussion about the current knowledge scenario, as a source for new developments in the BIM-based cost estimation practices.

Thus, the methodological steps are set in the stages: (a) input data sources and setup, (b) BIM-based cost estimation visual programming application development, and (c) discussion of results for decision-making when a comprehensive discussion about the potentials and challenges of the proposed approach aims to outline the research findings.

Data source and systematization

The application developed by this research proposes a systematization artefact for the insertion of cost estimation and design requirement input data embedded in BIM elements and extraction of budgeting estimates and a target value design support.

The research assumes that most of the available construction cost estimation indexes provide pre-aggregated data, at the component level. Thus, the research deals with the development of the tool from the insertion stage of cost estimation index data in the BIM type properties.

The data source to be applied in the visual programming BIM-based cost estimation tool is a hypothetical index, since the research aims to develop a semi-automated cost estimation methodological tool, and the paper is not focused on the bidding results themselves. Similarly, the value parameters presented are illustrative, since the importance index given to each requirement that allows the balance of the estimated cost depends on a particular process of analysis and negotiation of the project proponents.

However, it is important to emphasize that the proposed visual programming application is fully open, reproducible, and adaptable to any other indexes of civil construction provided at the same level of data aggregation. Likewise, the importance given to the performance attributed to BIM objects is adequate to the condition of each project.

Input data was first setup in a Microsoft Excel template spreadsheet, to allow adequate data linkage to a preformatted BIM template, using a visual programming algorithm, as described later on.

BIM-based cost estimation application development

Within a BIM platform tool, Autodesk Revit, "cost" parameters were assigned to be fulfilled by cost estimation index data, at a component level, to draw the cost estimation profile of design and construction options, from the early design stages.

A visual programming artefact was developed—using Dynamo software—to perform the automated insertion of the cost estimation index data embedded in BIM objects.

The visual programming consists of structuring a sequence of actions in an executable software, employing a graphical interface. As an alternative to writing in a typical programming language like Python, Java, and C#, for instance, it is possible to make connections among preconfigured nodes in a chain that turns into a script. Thus, visual programming tools allow working within a graphical process, through component connections to establish relations and sequences that result in customized algorithms which may be appliable for several uses.[44]

Input data—previously set in a prearranged spreadsheet—was then imported to fulfill the "cost" type properties field, into the BIM model template.

An additional visual programming artefact was also developed—using Dynamo software—to extract the cost estimation totals for each design option from the modelling template to a preformatted output spreadsheet.

The output template was setup to provide designers with numerical and graphical information regarding total cost estimation and detailed contributions of design alternatives.

The aim of the output interface is to provide clear and useful information to support decision-making regarding the cost contributions of building components and design choices.

BIM-based target value design application development

The cost estimates raised through programming are input to the value analysis. The procedure is performed using a matrix that lists cost and the importance index of a project requirement. The General Importance Index (IGI) is a weight defined by comparing "what matters most" to add value. Thus, in a context in which the designer needs to balance cost and benefit, he can direct the choice of the project based on an explicit reference. The IGI is arbitrated with the collaboration of customers and stakeholders directly related to the project design and can be updated through negotiation during the design process.

Results

The procedural steps for developing semi-automated cost estimation data importation and exportation routines are detailed in this section.

The routine was developed by applying Dynamo software, combined to Autodesk Revit, for information modelling, and Microsoft Excel, for spreadsheet setup. The choice of the last-mentioned software is due to the fact they are widely used, facilitating the dissemination of the research findings.

Methodological stages are shown in the flowchart (Figure 1) and are fully detailed in the following sections.

Input data and template setup

As the research approaches a new methodological artefact for BIM-based semi-automated cost estimation process, the input information from the cost estimation index was gathered and organized into a spreadsheet template, to systematize data entry regarding denomination, format, and organization.

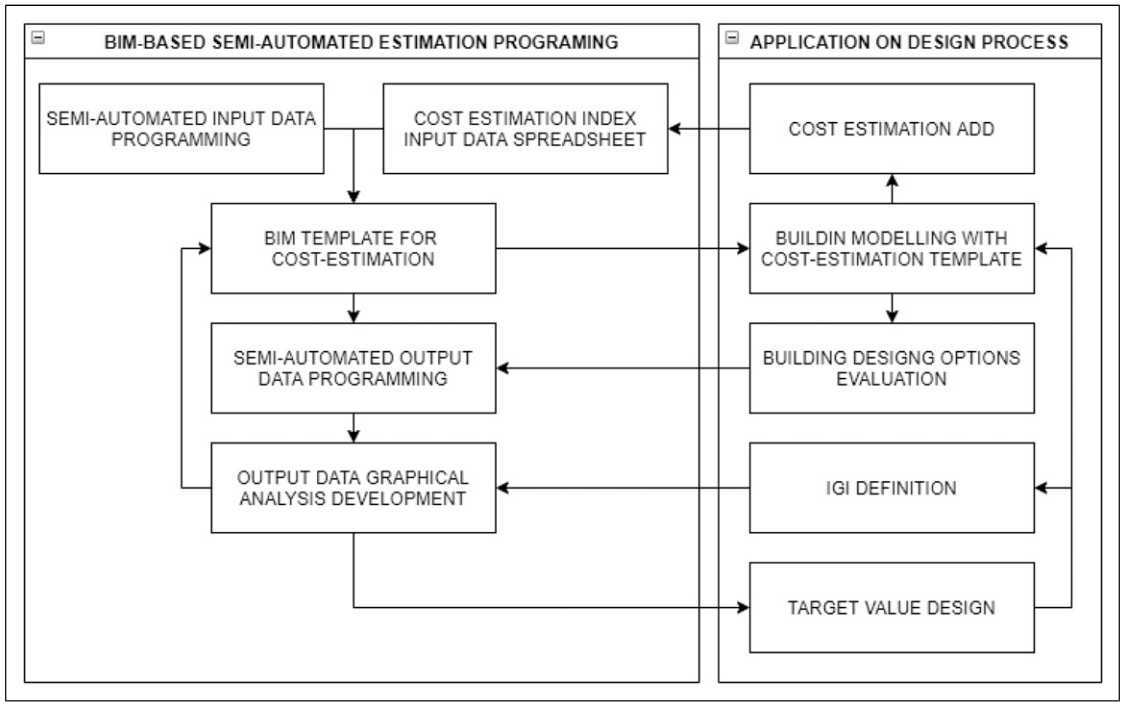


Figure 1. Research methodological development.

This input data template is essential, once the visual programming requires referencing to a setup the file, spreadsheet, rows, and columns naming, to provide the correct data association for the targeted BIM model type parameters.

The same requirements apply to the BIM software template, which comprised families and types that need to be named according to the respective cost estimation index applied to input data, since such nomenclature coordination is a prerequisite for the correct visual programming associations and performance.

In addition to the cost input data that the schedule relates to the project model, the identification of the UBS relative deficiencies raised through the Mudge Technique is input (Figure 2). The weights assigned to each function indicate a "relative importance" index, which is used to balance the weight of the value.

Visual programming

Once a spreadsheet configuration with cost estimate data and BIM model parameters was defined, the next step was the development of visual programming to automate the process of inserting or extracting cost estimate data.

The programming processes were organized in two main artefacts, namely, cost estimation data insertion and cost estimation profile extraction. For each of those, a programming artefact was developed in order to partition them and avoid excessively heavy files.

Regarding the insertion of the cost estimation index data for the BIM model, the visual programming builds a link between the input file and the model, setting up from each spreadsheet, row, and column of the input data to be removed, and informing which parameters (by name) to be filled in by the referred data. As previously recognized, such linking is only possible by applying the nomenclature of the corresponding components in spreadsheets and BIM objects.

An individual programming module is required for each family, regarding its modelling specificities. Figure 3 shows the cost estimation data insertion programming for the System Family, as an illustrative sample of the developed artefact.

Objective: Define the weight greater to that function that is more important than its peer compared.

Obs.: the values indicated in red were changed during the design of the project, in accordance with the "voice of the customer", in order to adapt the importance of the functions to their real impact to meet the customer's requirements. Without the management of the importance assignment of functions, the iteration between problem-solution is not considered, distorting the evaluation of results.

Score for applying the Mudge Technique

Score	Classification
1	Little important function
2	Significantly important function
3	Very important function

Source: Csillag (1995)

	Line points	UBS FUNCTIONS	MUDGE TECHNIQUE FOR IDENTIFYING RELATIVE NEEDS - UBS	∑ Function points	relative importance
A	0	INSTALLING THE SITE	A: B 2 C 2 D 2 E 3 F 3 G 3 H 3 I 3 J 3 K 2 L 3 M 1 N 3 O 3 P 2 A 2	0	0,00%
B	3	FOUNDATION	B: B 2 C 2 D 2 E 3 F 3 G 3 H 3 I 3 J 3 K 3 L 3 M 2 N 1 B 1 P 2 Q 1	5	1,96%
C	1	STRUCTURES	C: D 1 E 3 F 3 G 3 H 3 I 3 J 3 K 3 L 3 M 3 N 2 O 1 P 1 C 1	3	1,18%
D	1	STRUCTURES + SEALING	D: E 3 F 3 G 3 H 3 I 3 J 3 K 1 L 1 M 1 N 3 O 3 P 1 D 1	6	2,35%
E	8	EXTERNAL MASONRY	E: F 1 G 1 H 1 I 1 J 2 E 1 E 1 M 1 N 1 E 1 E 3 E 2	20	7,84%
F	11	INTERNAL MASONRY	F: G 1 F 1 F 3 J 1 F 1 L 3 M 1 F 1 F 2 F 1 F 2	24	9,41%
G	15	COATING AND PAINTING	G: G 1 G 1 G 1 G 1 G 1 M 1 G 2 G 3 G 2 G 3	29	11,37%
H	16	INTERNAL PAVING	H: H 3 H 1 H 1 H 1 M 1 H 2 H 3 H 2 H 3	29	11,37%
I	7	COVERAGE SYSTEMS	I: J 1 I 2 I 2 M 1 N 1 I 2 I 3 I 2	20	7,84%
J	9	HYDRO-SANITARY FACILITIES	J: J 2 J 2 J 1 N 1 O 1 J 3 J 1	25	9,80%
K	1	ELECTRICAL AND TELEPHONE INSTALLATIONS	K: K 1 M 1 N 1 O 1 P 1 Q 1	12	4,71%
L	5	FRAMES	L: L 1 L 1 L 1 L 1 L 1	20	7,84%
M	8	AIR CONDITIONING AND VENTILATION	M: M 2 M 3 M 2 M 1	21	8,24%
N	4	SHELTER	N: N 1 N 2 N 1	17	6,67%
O	1	CLOSING LAND LOTS AND OTHERS	O: O 1 Q 2	10	3,92%
P	0	EXTERNAL PAVING	P: Q 1	7	2,75%
Q	0	LANDSCAPE	Q	7	2,75%
			TOTAL	255	100,0%

SUM OF POINTS IN THE COLUMN

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
0	2	2	5	12	13	14	13	13	16	11	15	13	13	9	7	7

Figure 2. Mudge technique to identify the relative needs of the UBS.

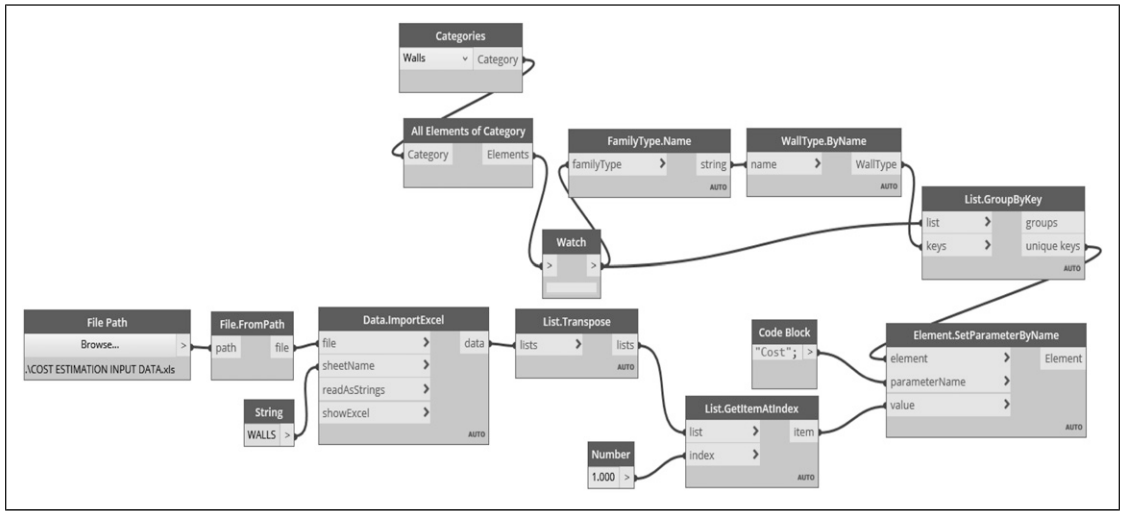


Figure 3. Sample cost estimation data insertion programming.

Regarding the extraction of the cost estimation data—total cost quantification of modelling objects comprised in a model—from the model to the spreadsheet data, the visual programming artefact retrieves the cost estimation data by the respective cost parameter (by name) from each family type. This value is multiplied by the number of respective instances for such type within the model, and a new linkage is built to an established output spreadsheet file, which will obtain the total cost estimates, by type of family, and provide the total cost estimate for the analyzed model.

Again, an individual programming module is needed for each family, but the output information is all going to the same file. Thus, individual programming is needed to combine and organize all converging families to a "list transpose" node. Figure 4 presents the Walls System Family data extraction programming, as a partial instance of the proposed application.

The visual programming framework applied in this paper was based on previous research,[45] where routines of data insertion and extraction were developed to integrate Life Cycle Assessment studies in the BIM platform, also since the initial stages of the design process. The possibility of adapting such algorithm for different applications demonstrates its flexibility, opening the horizon for the discussion of a greater variety of applications.

Output data and system operation process

The dynamic character of the design process, especially in its early stages generally does not correspond to the complexity of quantity take-offs and cost estimation applications, which requires significant technical detailing definitions to provide decision supporting outputs. Therefore, it is likely to simplify input requirements, such as presenting output data, to support non-technical stakeholders in the decision-making process.

To ensure the reliability of the results, this application provides both, numerical and graphical results, as illustrated in Figures 5 and 6.

Other items such as "foundation," "structure," and "fence" are of little importance in adding value because they offer contributions that are basic to the performance of the building, so they are of high perceived importance to add additional value to the building. This relative importance can be changed if the designer

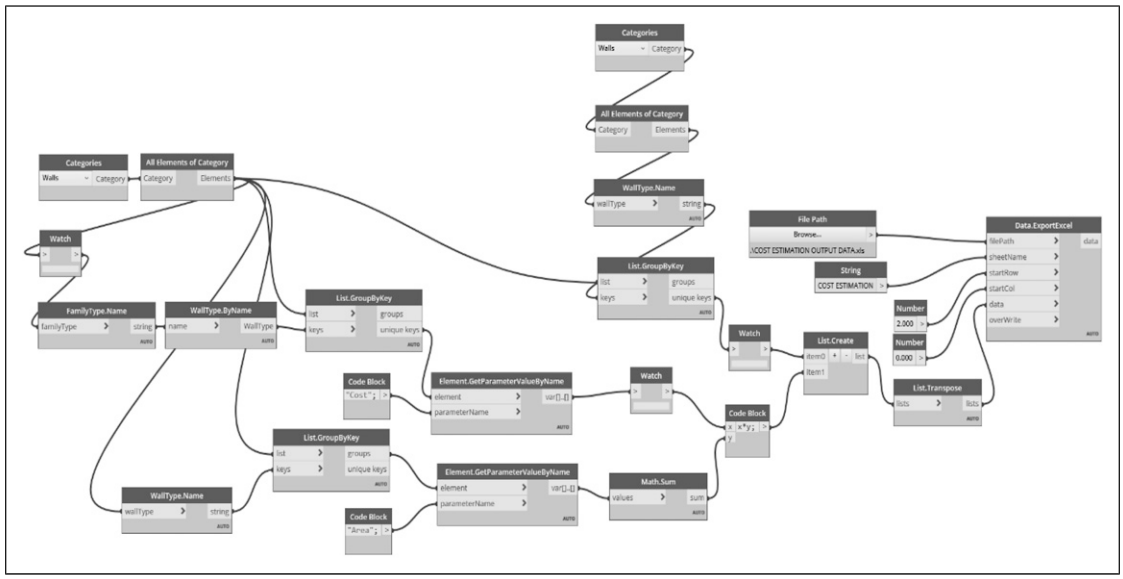


Figure 4. Partial cost estimation data for exportation programming.

presents a sealing solution that offers a performance superior to the expected basics. In this case, a change in the weights initially elaborated in the Mudge Technique is agreed with the client. Such an adjustment is expected to adapt the transposition of meeting the expectation to value the systems

Application on building design process

The simulation of the artefact developed in a sample building model allows to analyze and understand its main potentials and limitations. Therefore, this application uses hypothetical cost estimation indexes, and it is not focused on the quantitative final values outputs themselves, but in the semi-automated cost estimation process itself, and whether it fits the dynamics of the design process since its early stages.

The simulated basic healthcare facility building model consists of a ground floor construction, of approximately 225 square meters.

In this research, only some building subsystems were considered for cost estimation simulation: walls, roofing, structure, doors and windows, and plumbing fixture. The other cost estimates were raised manually to compose the cost of the other elements of the subsystems.

The building subsystems applied to the core and shell were external walls of structural masonry in clay blocks, with internal drywall partitions and some masonry concrete blocks, and fiber cement tile roofing with wooden structure; the structural loads are based on structural masonry walls, placed over concrete pile foundations.

At first, the initial semi-automated input data programming ran as expected, with the generation of errors or missing information, filling the “cost” property field only according to the index input spreadsheet (Figure 7).

The output results presented in Figure 8 show that in the process of cost estimation extraction from the BIM model, it also ran accordingly, providing the expected outputs.

Such data were used to supplement the cost composition summarized in the “compare chart” shown in Figure 6.

COMPARISON GRAPHIC: RESOURCE CONSUMPTION X RELATIVE NEED									
Construction services			Functions (verb + noun)	Initial cost	Initial resources	Final cost	Final resources	Relative importance	classified functions
				(R$)	(%)	(R$)	(%)	(%)	B/SN/S
preliminary services	construction site installation	A	construction site installation	40.346,38	6,6%	40.346,38	6,6%	0,00%	SN
superstructure	foundation	B	Transmitting vertical efforts	55.232,35	9,0%	55.232,35	9,0%	1,96%	SN
	structures	C	Transmitting vertical and horizontal efforts	32.448,14	5,3%	32.448,14	5,3%	1,18%	SN
	structures + sealing	D	Transmitting horizontal efforts	30.827,50	5,0%	26.118,99	4,3%	2,35%	B
walls and panels	external masonry	E	Limit the building and external sealing	27.826,85	4,6%	28.587,81	4,7%	7,84%	B
	internal masonry	F	Limit indoor environments	17.395,58	2,8%	18.156,54	3,0%	9,41%	B
coatings and paints	coating and painting	G	Coating vertical surfaces	77.442,21	12,7%	77.442,21	12,7%	11,37%	B
	indoor paving	H	Coating internal horizontal surfaces	39.734,68	6,5%	39.734,68	6,5%	11,37%	B
coverage	coverage systems	I	weather Protection	34.799,65	5,7%	34.799,65	5,7%	7,84%	B
Hydro-sanitary installations	Hydro-sanitary installations	J	Provide hydro-sanitary use	75.744,82	12,4%	71.594,62	11,7%	9,80%	B
electrical inst. and tele.	electrical and telephone installations	K	Provide electricity and telephony	49.278,85	8,1%	49.278,85	8,1%	4,71%	B
	frames	L	Allow lighting and ventilation	104.748,76	17,2%	76.978,92	12,6%	7,84%	B
air conditioning systems	air conditioning and ventilation	M	Provide building comfort	4.584,72	0,8%	12.147,00	2,0%	8,24%	B
special installations	shelters and trash	N	Provide equipment and storage	11.119,76	1,8%	11.119,76	1,8%	6,67%	SN
complementary services	lot closure and others	O	Limit lot area	18.334,80	3,0%	18.334,80	3,0%	3,92%	SN
	external paving	P	Enable access to UBS	9.413,49	1,5%	9.413,49	1,5%	2,75%	SN
landscaping	landscaping	Q	Provide access to nature	4.025,38	0,7%	4.025,38	0,7%	2,75%	S
COST-GOAL	**610.500,00**		**TOTALS**	**633.303,92**	**103,7%**	**605.759,58**	**99,2%**	**100,0%**	

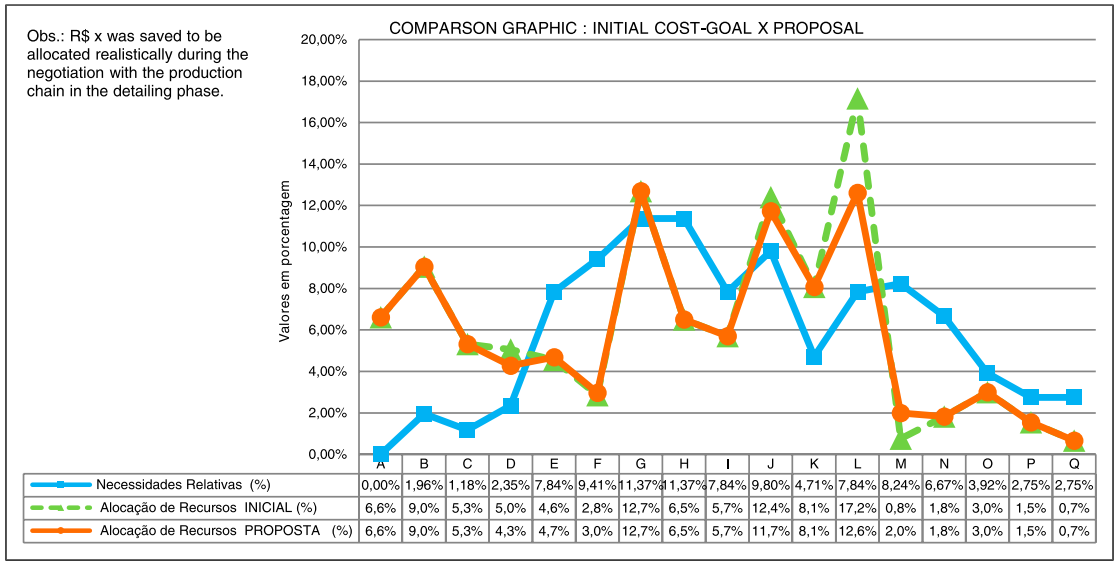
Figure 5. Output interface overview: numerical results.

For this application, only some building systems were considered, however, with the development of the artefact, its continuous use can provide significantly helpful results. In an actual design process, where some concurrent designs have been developed for a given building program, such a semi-automated and dynamic cost estimation process, which accompanies the project development process, could provide significant support on the cost-based decision-making.

Discussion

During the application of the investment in TVD, it was observed that the extraction of the quantity of some design changes that were studied required the elaboration of new stacks of visual programming not contemplated in the previous programming.

Such a condition was a limiter for the experimentation of alternative solutions that involved such changes; or the designer would need to interrupt the study to program the new battery; or this variable would not be incorporated into TVD.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Necessidades Relativas (%)	0,00%	1,96%	1,18%	2,35%	7,84%	9,41%	11,37%	11,37%	7,84%	9,80%	4,71%	7,84%	8,24%	6,67%	3,92%	2,75%	2,75%
Alocação de Recursos INICIAL (%)	6,6%	9,0%	5,3%	5,0%	4,6%	2,8%	12,7%	6,5%	5,7%	12,4%	8,1%	17,2%	0,8%	1,8%	3,0%	1,5%	0,7%
Alocação de Recursos PROPOSTA (%)	6,6%	9,0%	5,3%	4,3%	4,7%	3,0%	12,7%	6,5%	5,7%	11,7%	8,1%	12,6%	2,0%	1,8%	3,0%	1,5%	0,7%

Figure 6. Output interface overview: graphical results.

However, among the alternative solutions that the number of batteries allowed, the following is the change of plan, from a "U" shape to an "L" arrangement. This change offered gains in lighting and natural ventilation, widely used in the socio-environmental context in which the doorman operates.

The alternative increased the cost of external walls. This cost was attributed to the ventilation gain, which improved the cost-benefit ratio. Thus, the designer pursued the cost reduction, incorporating a sealing technology that allowed to eliminate the mechanical protective coating of the seal.

It was observed that the decision to replace the sealing technology would imply a change in the solution of electrical, hydraulic, and mechanical installations, with an impact on the execution of the installation at the work site. It was evident that some cost variables would need more sophisticated budget work, appropriate to the subsequent phases of the design process.

The identification of this impact must be part of a TVD report as the balance is reviewed and updated with the progress of the project. The option to adopt the Mudge technique allows greater flexibility to adjust the importance index of the subsystems through negotiations in change management meetings. This procedure allows adapting TVD to the decisions that are taken at each stage. In the initial stages, adjusting the conformation of the plant, in a more advanced stage, balancing aspects of the impact of a rationalized technology on the construction that could not be adequately dealt with in the previous state, since they referred to costs related to the reduction of waste and negotiation of the contracting of hands of adequate workmanship.

In addition to the functioning of the presented procedure, one of the conditions for implementing TVD in a design process is to map how the presented TVD sub-process fits into the general process. As there may be different project organizations, it is necessary to assume a known reference to exemplify such integration. The RIBA Plan of Work 2020[46] presents well-defined steps, where it is possible to identify which are the existing entries that address information of interest for balancing project value, such as customer requirements, construction attributes, and costs, and thus situate the TVD (Figure 9).

The "stage 0 - Strategic Definition" presents the client's requirements as the main result and, for that, it is necessary to define a budget and evaluate previous cases. The budget is the basis for defining the TVD target

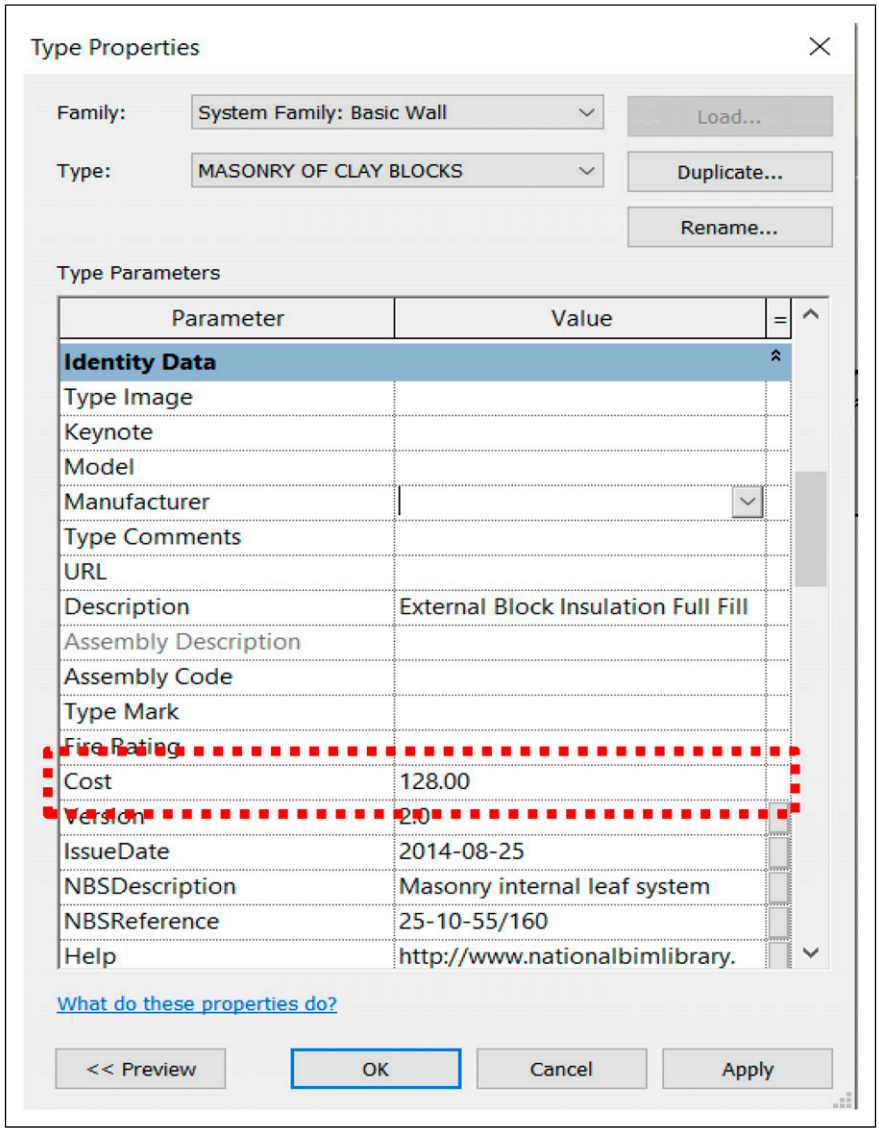


Figure 7. Example of cost information semi-automated filling.

cost and permissive cost (check if we still use these two concepts). The definition of requirements, if accompanied by a hierarchy of priorities, is a subsidy to guide the definition of importance and weights to be carried out in the following stages.

The definition of the general index of importance is based mainly on the hierarchy of requirements, however, it also depends on some project presets, such as spatial requirements, quality aspirations presented in the Project Brief. Thus, the definition of the IGP must occur in "stage 1 - Preparation and Briefing." At this stage, the distribution of initial costs is based on a cost plan estimated from related cases and market

	WALL SYSTEM	ROOFING SYSTEM	STRUCTURE AND FOUNDATIONS	DOORS AND WINDOWS	PIPING AND PLUMBING FIXTURES
PROJECT TOTALS	$38.954,58	$24.025,14	$1.229,84	$104.087,89	$43.624,02
External Wall - Clay Blocks Masonry -	$6.907,23				
External Wall - Clay Blocks Masonry	$2.203,02				
External Wall - Clay Blocks Masonry -	$1.384,51				
Internal Wall - Clay Blocks Masonry	$2.826,86				
Internal Wall - Clay Blocks Masonry -	$1.462,84				
Internal Wall - Clay Blocks Masonry -	$5.640,15				
Internal Wall - Clay Blocks Masonry -	$685,86				
Internal Wall - Clay Blocks Masonry -	$1.241,47				
Plateau Wall - Clay Blocks Masonty	$8.156,50				
Internal Wall - Steel Frame - Dry Wall	$1.171,76				
External Wall - Concrete Blocks	$7.274,39				
Roofing - Fiber Cement Tiles		$24.025,14			
Structural Column - Concrete - 250mm			$1.229,84		
Door - Single Flush - 80x210cm - Wooden				$4.696,86	
Door - Single Flush - 90x210cm - Lead				$20.397,16	
Door - Single Flush - 90x210cm - Wooden				$4.781,28	
Door - Single Flush - 90x210cm - Wooden				$5.655,79	
Door - Quadruple Sliding Glazing -				$14.000,00	
Door - Double Sliding Glazing - 2500mm				$14.000,00	
Door - Sliding - 90x220cm				$5.026,00	
Window - Double Maxim-air - 1100x0600mm				$3.414,60	
Window - Triple Maxim-air -1,500x0,600				$3.414,60	
Window - Double Maxim-air - 1200x0600mm				$3.414,60	
Window - Triple Maxim-air - 2,50x1,00				$3.414,60	
Window - Triple Maxim-air - 3,35x1,00				$3.414,60	
Window - Triple Maxim-air - 3,60x0.60				$3.414,60	
Window - Triple Maxim-air - 2,50x1,30				$3.414,60	
Window - Double Sliding - 2000x2.200mm				$4.799,40	
Window - Modular Tilting - 2,50 x 2,20				$3.414,60	
Window - Triple Maxim-air - 2,350x0,600				$3.414,60	
Washbasin - Pedestal					$2.811,60
Washing Tank					$3.425,10
Countertops - Granite - 1500mm					$7.125,84
Toilet - Flushing Cistern - Montana					$16.150,20
Washbasin - Corner					$14.111,28

Figure 8. Sample numerical simulation output.

parameters. The initial results of the TVD subsidize the Feasibility Studies, as well as the commitment of those involved with the agreed budget.

The consolidation of the balance of the TVD happens in "stage 2 - Concept Design," when the answers to the requirements are defined through the Architectural Concept. At this stage, it is possible to define the

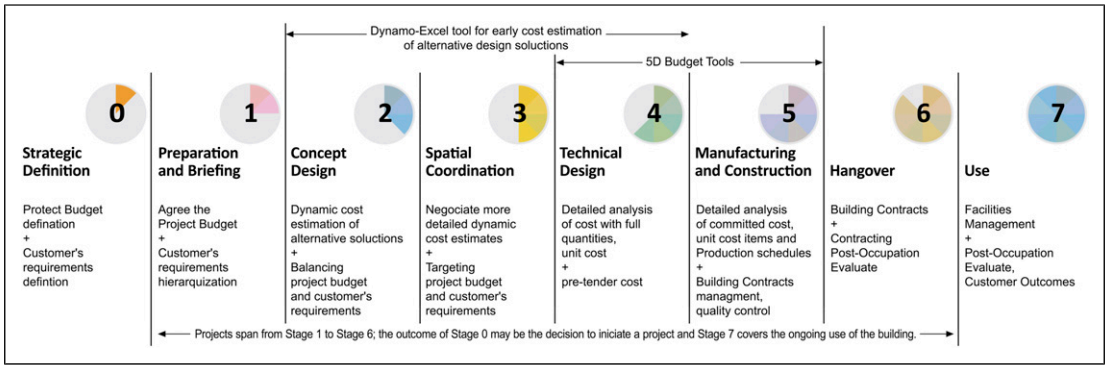


Figure 9. Plan of work RIBA 2020 and cost estimation solution.
Source: Adapted from RIBA plan of work template 2020.[46]

weights for the different attributes of the architecture, as they respond to the customer's requirements. Approval of the architectural concept by customers and interested parties is subject to agreement with the project adjustments, necessary to adjust the relationship between met requirements and projected cost.

During "stage 3 - Spatial Coordination" and "stage 4 - Technical Design," the costs referring to the attributes of the architecture are refined with the detailing of the solution. The outline specifications are updated with more accurate information about the building systems, obtained through consultations and negotiations with project stakeholders. This information makes it possible to more accurately estimate the cost of the elements that make up the architecture. In stage 3, change control procedures begin, when adjustments to the architecture are made to adapt to the technical and production specifications of each construction system. In this process, which takes place throughout stage 4, the TVD aims to arbitrate for technical solutions that meet the customer's requirements within the agreed budget.

The following stages, related to "Manufacturing and Construction," "Handover," and "Use," are opportunities to confirm the results obtained, through post-occupancy evaluations and performance evaluations. The success of the undertaking can be measured with the confirmation of the TVD. Depending on the contractual incentives, rewards can be foreseen for those involved who worked to obtain the expected results.

Application adoption in public facilities/buildings bids

The study presents the technical and operational feasibility of a project information extraction application for TVD. This is a step to enable less cost-centered bids, as it establishes a balance between cost and compliance with requirements. In this organizational context, the contractor determines the "initial allocation of resources" with the help of a specialized consultancy or competent department. This is the permissive cost. The rules for extracting and linking with the client's requirements are determined by the contractor and must be used by the bidder to submit the proposal. These rules can be changed at the request of bidders, during a period at the beginning of the bidding process. After this period, the scheduled extraction rules are part of the bidding terms and can be audited.

The bidder presents the "proposal resource allocation" made from the template with the programmed rules. It must seek the target cost presented by the contractor and not exceed the permissive cost without a technical justification. The bidder with the best proposal is contractually obliged to submit periodic reports or at least during the course of each delivery, which include confirmation of resource allocation and/or reasoned justification for reallocation of resources. This is the same format for recording the graphic results delivered in

the bidding process, with increasing detail. Thus, reallocations that do not impact total cost or importance indices are documented, monitored, and managed. If the report points to any change that alters the total costs or importance indexes, the contractually provided project change management mechanism is activated, which may result in fines and/or amendments. Again, the data presented are relevant documentation for assigning responsibilities, supporting decision-making, and mediating between parties.

Conclusions

The possibilities for automating data extraction are conditioned by the programmed batteries. A change in system composition requires an overhaul of the batteries. This limitation is a problem for design requirements without technological constraints. However, on several occasions, client organizations promoting the project restrict the technologies that can be used in the project in order to adapt them to the standardized building management conditions. In these cases, it is feasible to make the programmed batteries available for the extraction of quantities of materials used in the project. Thus, the resource becomes part of the set of subsidies to the project offered to the service provider. The availability of value data becomes a contractual obligation that guarantees greater predictability to the process. The designer demonstrates the adequacy of the solution by means of project delivery milestones. The conditions are validated or negotiated with the client, in order to subsidize the change management even in the initial phases of the project.

In projects where the use of technologies is not directed to the adoption of this increment of DTV, it becomes an operation that requires a specialized mastery of battery programming by the team of designers. This condition was weighted based on a limitation of performance observed in the study, when the verification of the impact of the value of a project adjustment was made impossible by the lack of the appropriate programming stack for the quantitative extraction. To overcome this limitation, either the designer needs to be able to design a new suitable stack, which will later need to be validated by the customer, or else the designer needs to have available an extensive library of programming stacks that meet a wider range of possibilities for quantifying technologies and different materials. This second possibility raises questions about the conditions to enable the construction and availability of a library for a wide sector of AECO, which have political and governance implications.

Another possible perspective is to develop a computerized system that allows composing the data extraction items for the TVD without having to add or even program new programming stacks. It is an existing procedure on the market that, properly integrated with the value balancing system, will offer a powerful instrument for evaluating and validating the results obtained in the initial phases of the project that can be used by the competent agents without needing a programming domain visual, as in the case of this study. This characteristic seems particularly important for the insertion of TVD there throughout the entire life cycle of the project, in which a designer, budgeter, construction manager, acquisition manager, among others, will need to collaborate for TVD.

The scope of this research piece was to develop a user-friendly TVD artefact applicable since the early design stages and overcome the lack raised concerning its betimes implementation and data management—since the programming semi-automates the cost index databases linking towards model elements.

Thus, a direct link between cost estimation indexes and BIM objects was created through visual programming, semi-automating the process of embedding cost data within the parametric modelling family's parameters. Such semi-automatic cost parameter feeding enables continuous updating of models and templates concerning value indexes.

Furthermore, visual programming was also applied to the extraction of model cost estimation totals towards a pre-set spreadsheet, providing automated graphical actualization results. Such artefact allows stakeholders to easily compare building design and construction options regarding the project's budget since the early design stages, with no need to handle extra tools.

Regarding the RIBA Plan of Work 2020[46] building project stages, the developed artefact should fill in the gaps of cost estimation and TVD at early design stages of Concept Design and Spatial Coordination, while the dedicated 5D detailed tools must be further applied at Technical Design, Manufacture and Construction, and Handover stages.

It is important to note that the artifact produced by the present research, as it focuses on the agility of using the TVD for decision-making from the initial stages of the project, can have its level of detail directly correlated with the LOD of the BIM modelling. Thus, in its present form, the artifact applies specifically to the initial stages of design, related to the Riba phases of Concept Design and Spatial Coordination, when using a LoD that can vary from 100 to 200.[47]

However, it is noteworthy that the visual programming developed, open source, can be easily expanded to new specifications and modelling elements, allowing the application of TVD concepts for more specific and advanced decision-making in the project life cycle, such as, for example, the Technical Design stage, where LoD 300 can allow decision-making in relation to the performance of equipment and building systems, or even, in a LoD 400, in the Manutacture and Construction stage, focusing on the choice of different production systems.

Thus, the focus of this work was on the agility of decision-making in the initial stages of the design process, but the flexibility of the artifact developed in open source allows the incremental development of new research, focusing on later stages of the design process.

The developed features can improve and facilitate the value management process in decision-making its early design stages and throughout the building design process, since it allows to consider several scenarios of design options to obtain the project goal, while it is necessary to make decisions that impact the product value.

An important challenge to be highlighted concerns programming issues of data insertion and extraction for or from building model objects (Figure 1, addition of cost estimate). The visual programming modules are not fully replicable, requiring adaptations and repeated running iterations, making it a significantly time-consuming task.

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