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OPTIMIZATION OF CONSTRUCTION WASTE MANAGEMENT THROUGH AN INTEGRATED BIM API

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ABSTRACT: Estimate waste generated in civil construction accurately is vital for minimizing them in the project stage. This vision allows designers to visualize and explore possible corrective measures in order to increase construction efficiency. In addition, it can enable contractors to identify critical processes in waste generation and plan control strategies. By integrating several projects into a single model, Building Information Modeling (BIM) can assist the solution of this challenge. The main goal of this work was to develop an integrated BIM API to optimize construction waste management. The chosen method for this research was Design Science Research (DSR). Throughout the development, one building, built with 3 (three) construction methods was evaluated. The result was a construction waste index in order to classify buildings according to their construction waste generation.

KEYWORDS: Construction. Waste. BIM. Design. Building.

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1 INTRODUCTION

BIM can be classified as a set of policies, processes and technologies that, combined, generate a methodology to manage the process of designing a building, rehearsing its performance, and managing its information and data through its entire life cycle [2]. BIM has been developed with the aim of facilitating analyses and simulations since the beginning of the project. A BIM model provides the integration of information from the entire life cycle of the building and can enable performed simulations, such as:

- Structural analysis;
- Simulations of energy consumption;
- Thermal and thermodynamic studies;
- Natural ventilation studies;
- CO2 emission levels;
- Sunstroke and shading studies.

Through automatic quantitative extraction and parametric modeling, these analyses become faster and more efficient. However, the use of specific and complex softwares makes these simulations more difficult. With the aim of facilitating these simulations, there is an effort in the development of small applications integrated with BIM softwares, these applications are called API (application program interface). API's, if developed correctly, can enable designers who don't have full knowledge of sustainable design practices to perform simple simulations.

One of the most important sustainable aspects of a building is waste generation, during its construction and/or its demolition, since it represents a large part of the landfill material. In China, approximately 1.13 billion tons of C&D waste was generated in 2014 [6]. In Brazil, 45.1 million tons were collected in the year 2016 [1]. In the United Kingdom 32% of the landfill material is waste from the C&D [7]. The construction industry is responsible for 25-30% of all waste generated in the European Union [3] and 20% in Japan [5].

Quantifying waste generation is then essential for its effective management, therefore regarding this aspect there is yet not much development. Existing methods are not sufficiently convenient because they require much time and effort. BIM in turn, can fulfil this need [4]. Consequently, the main goal of this study was to develop an API integrated with BIM able to extract automatically waste quantities during construction in order to optimize construction waste management, and enable the reduction of construction waste due to the study of different construction methods, and its waste generation index, within one single model.

2   METHOD

The chosen method for this study was Design Science Research (DSR), since it includes a development of a new method of construction waste quantification based in BIM.

In order to accomplish the goal established, a study of all possible means of developing a BIM API was necessary.
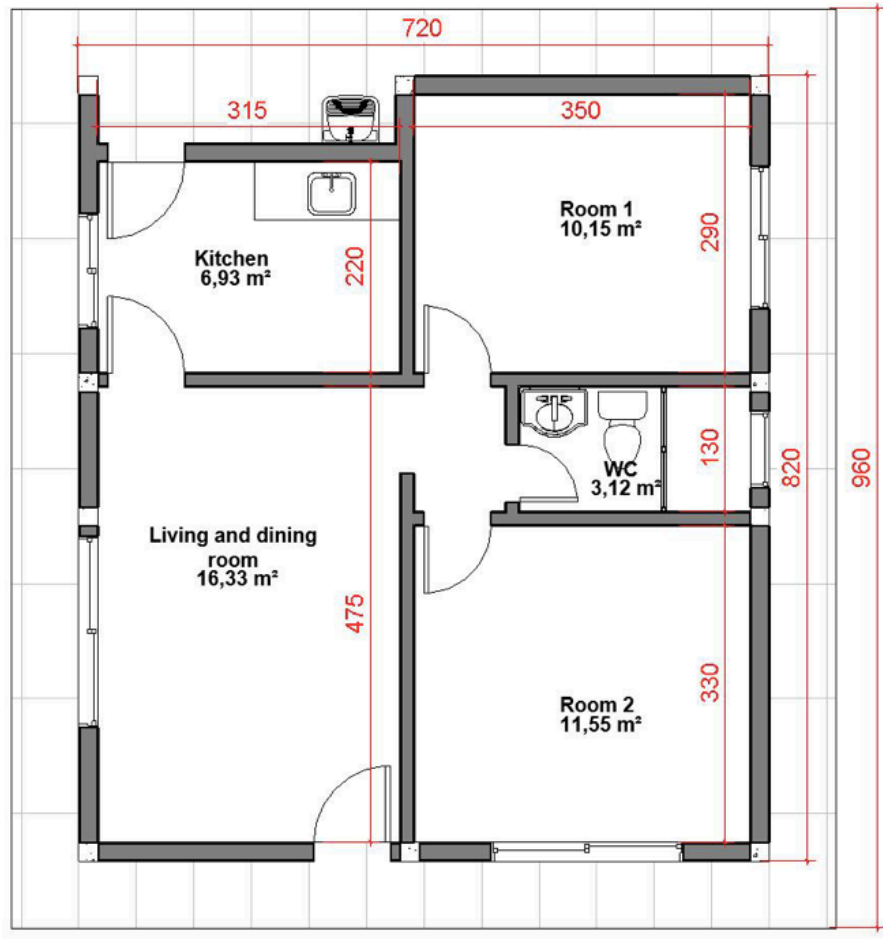
Figure 1: Floor plan of the studied building

The validation of the created method was made by the application of the API within a building built with three different construction methods: masonry, wood frame and light-steel frame. The chosen building was a 2-bedroom and 1-bathroom residential house, its floor plan is illustrated in Figure 1 below. The measures are in centimeters.

The house was modelled in Revit from Autodesk. The illustrated perspectives of the studied building are in Figure 2 below.
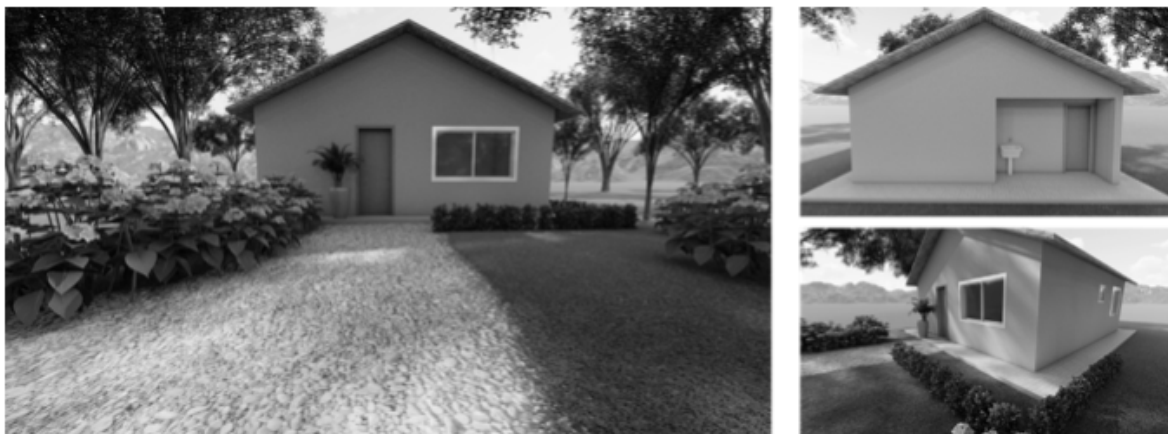

Figure 2: Render of studied building

3   DEVELOPMENT

The development of an API requires first the acknowledgment of its computational framework. The framework required is illustrated in Figure 3 below. This framework was developed in order to organize the API's functions.

As a result, the framework was divided between two big groups of functions: project optimization and site management. At project optimization, the application should be used in order to emit results regarding the project waste generation. Within this function, one can verify if the waste generation performance is equal, greater or less than expected and make the changes necessary for the project to be optimized.

Once the project is finished, at site management, the application should be able to calculate the amount of waste generated according to the work schedule. This quantitative will then promote a report on the waste that will be recycled and/or reused, ensuring better planning for the builder.
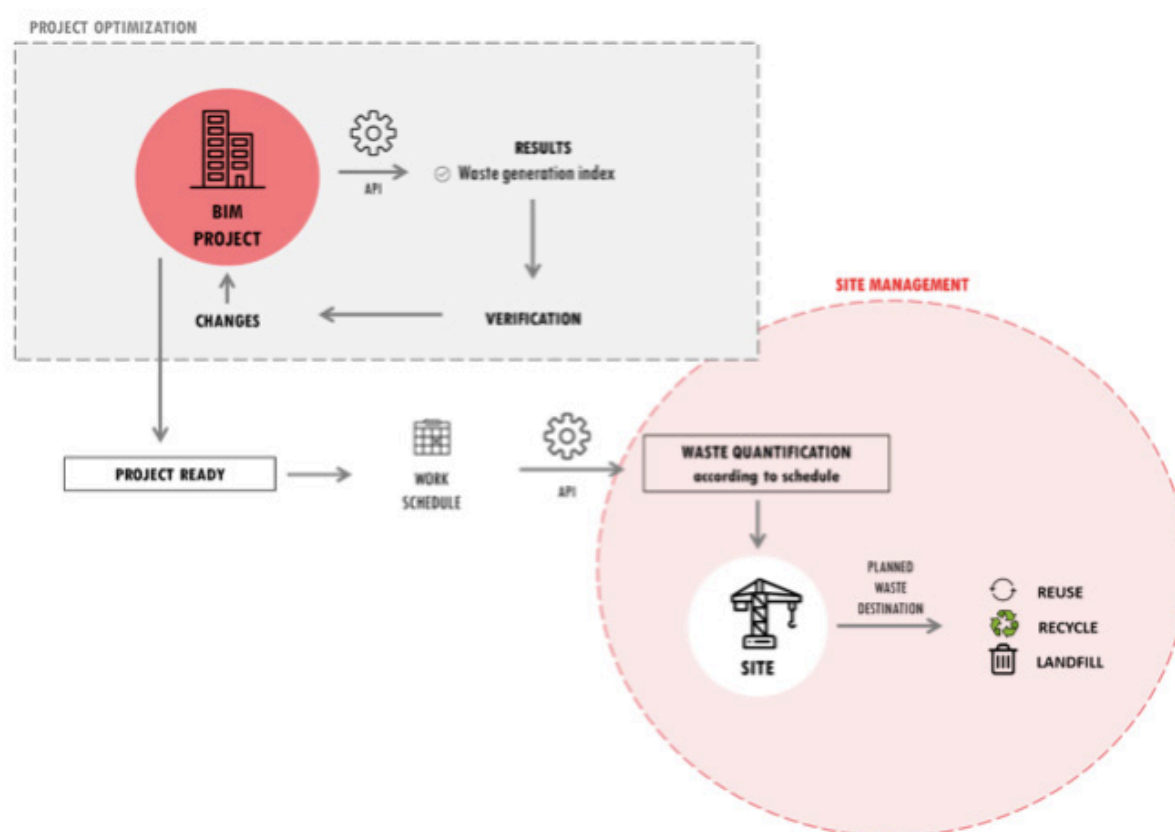

Figure 3: API's framework

After developing the conceptual framework, it was necessary to decide which digital platform would be used in order to program this API. Because of its popularity and known advantages of visual programming, the chosen platform was Dynamo, which is from Autodesk and integrated with Revit. Also, for the development of the API it was necessary to utilize Microsoft Excel and VBA programming. The API's interface is illustrated in Figure 4 below, and it is called "WasteBIM". A part of the Dynamo code is illustrated in Figure 5 and its complete structure is in Figure 6.
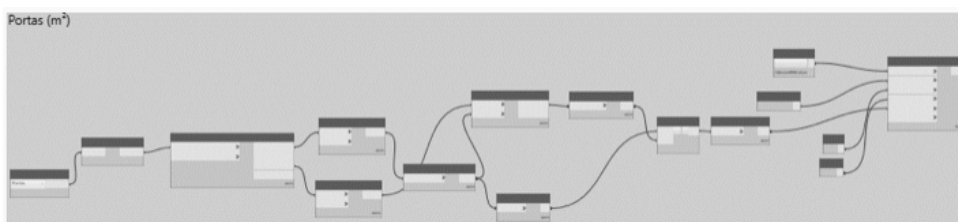
Figure 4: API's interface

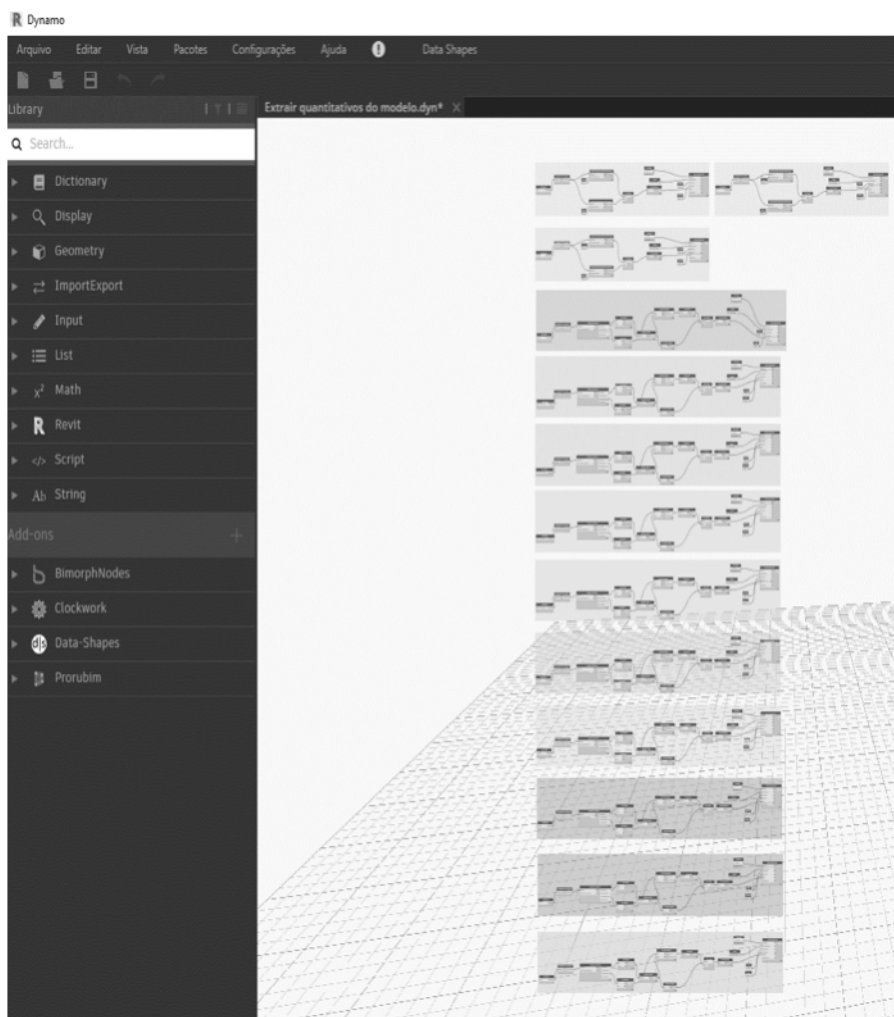**Figure 5**: Part of Dynamo code

Figure 6: Complete Dynamo code

The structure of the developed API involved a series of multiplications of the quantification of materials extracted from BIM model to the waste index of each material, represented at (1).

$$W = P \, x \, I \quad (1)$$

Where:

- W = Amount of waste generated (m³ or kg);
- P = Amount of materials employed in the building (m³ or kg);
- I = Waste index (%).

The waste index for each material was determined from a systematic review of the literature regarding all possible methods of waste quantification. The result of this systematic review was Table 1 below.

Table 1 - Waste index/material

Material		Waste index %
Brick		22,34
Concrete block		10,67
Concrete		6,23
Steel		7,47
Concrete forms		12,50
Aluminium		2,87
Wood		6,41
Wires and cables		3,17
PVC Tubes		3,48
Roof Tiles		29,23
Dry-Wall		7,75
Grout	Settlement	18,65
	Roughcast	16,68
	Plastering	10,38
	Floor	19,84
Paint	External	13,50
	Internal	11,00
Ceramics	Walls	9,17
	Floors	9,34
Plaster		30,00
Glass		3,46
Marble and rocks		4,37

4 RESULTS

4.1 REPORTS

As illustrated in Figure 4, "WasteBIM" has a user-friendly interface, and with the click of one single button, the API can generate two kinds of reports: the SCWR and the general report.

Before generating the reports, the user is requested to inform project data regarding documental information. This information is necessary for completing the reports with: name and documentation of the company responsible for the work, name of the responsible engineer or architect, name of the building, environmental license, total built area. Also, it is necessary to inform the schedule of the works that are going to be executed and if there is going to be any demolition or excavations before the work starts, as seen in Figure 7.

Figure 7: Insert work data interface

Once all data is informed, the two reports can be generated. The SCWR report means Simplified Construction Waste Report, this report prints legal information and can be used to request environmental licenses for the work site. It involves the "Project Optimization" stage of the API, since its final result is a single number – the total volume of waste generated. One example of a small part of the SCWR report is illustrated in Figure 8.

PGRCC

CONSTRUCTION WASTE MANAGEMENT REPORT

WASTE CARACTERIZATION AND QUANTIFICATION

CLASS	TYPE	VOLUME (m³)		TOTAL
		DEMOLITION	CONSTRUCTION	
A	Soil		20,00	20,00
	Ceramics	0,12	3,84	3,96
	Concrete	1,22	4,67	5,88
	Mortar	1,52	19,82	21,35
	Asphalt materials			
	Others (specify)			
	TOTAL Class A:	2,86	48,33	51,59
B	Plasticts	0,03	0,22	0,25
	Paper	0,03		0,03
	Metals	0,00	0,07	0,07
	Glass	0,00	0,00	0,00
	Wood	0,06	84,37	84,43
	Plaster	0,06	0,00	0,06
	Others (specify)			
	Total Class B:	0,19	84,66	84,85
C	Asphaltic mass			
	Glass mass			
	Polyurethane tubes			
	Others (specify)			
	Total Class C:	0,00	0,00	0,00
D	Paints		3,44	3,44
	Solvents			
	Oils			
	Asbestos materials			
	Others (specify)			
	Total Class D:	0,00	3,44	3,44
TOTAL (A+B+C+D):				139,88

Figure 8: PGRCC report

The general report involves graphics and simplified data that can help the constructor plan waste destination and it is necessary at "Site Management" stage. One example of graphic extracted from the general report is illustrated in Figure 9.

CLASS	TYPE	TOTAL	%
A	Soil	0,00	0%
	Ceramics	3,84	3%
	Concrete	4,67	4%
	Mortar	19,82	17%
	Asphalt materials	0,00	0%
	Others (specify)	0,00	0%
	TOTAL Class A:	**28,33**	**24%**
	N° OF TRUCKS:	8,00	7%
B	Plasticts	0,22	0%
	Paper	0,00	0%
	Metals	0,07	0%
	Glass	0,00	0%
	Wood	84,37	72%
	Plaster	0,00	0%
	Others (specify)	0,00	0%
	Total Class B:	**84,66**	**73%**
	N° OF TRUCKS:	18,00	15%
C	Asphaltic mass	0,00	0%
	Glass mass	0,00	0%
	Polyurethane tubes	0,00	0%
	Others (specify)	0,00	0%
	Total Class C:	**0,00**	**0%**
	N° OF TRUCKS:	0,00	0%
D	Paints	3,44	3%
	Solvents	0,00	0%
	Oils	0,00	0%
	Asbestos materials	0,00	0%
	Others (specify)	0,00	0%
	Total Class D:	**3,44**	**3%**
	N° OF TRUCKS:	1,00	1%
TOTAL (A+B+C+D):		116,43	
TOTAL NUMBER OF TRUCKS		27,00	

% OF WASTE PER CLASS

■ Class A   ■ Class B   ▫ Class C   ■ Class D

0% 3%

24%

73%

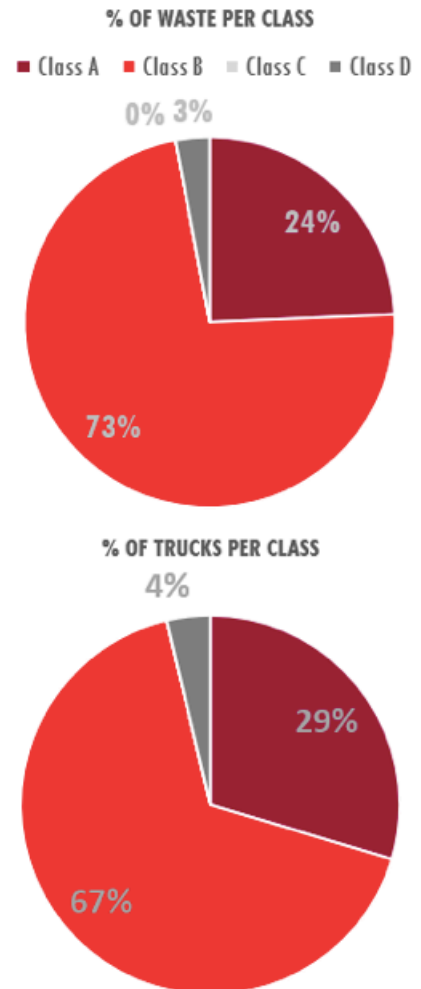**% OF TRUCKS PER CLASS**

4%

29%

67%

Figure 9: General report

4.2 VALIDATION

In order to validate the developed API one building built with three different construction methods was modelled in Revit (Figure 10) and, the API calculated waste generated in these three situations.

Masonry   **Wood frame**   **Light steel frame**

Figure 10: Building in three construction methods

The results obtained are in Table 2, and illustrated in Graphic 1, below. Masonry is the construction method that generates the bigger amount of construction waste and light steel frame the smaller. However, when comparing the amount of waste generated divided by the amount of materials employed, wood frame seems to be the most efficient construction method.

Table 2 - Volume of materials and waste generated

Construction method	Total volume of materials employed (m³)	Total volume of waste generated (m³)	Waste/Materials
Masonry	993,23	116,43	11,72%
Wood Frame	261,32	24,57	9,40%
Light Steed Frame	190,31	20,55	10,79%

Graphic 1: Materials employed x waste generated

4.3 CONSTRUCTION WASTE INDEX

By dividing the total volume of waste generated with the total built area, in this case 82,56 square-meters, the result is a construction waste generation index that can be used to estimate the volume of waste generated by the constructions of other buildings, built with these three construction methods.

Table 3 illustrates the results obtained by this division. According to this result we can assume that the Light Steel Frame construction method is the one which produces less construction waste. And masonry is the one which produces more.

Table 3 - Construction waste generation index

Construction method	Total volume of waste generated (m³)	Volume of waste generated / built area (m³/m²)
Masonry	116,43	1,41
Wood Frame	24,57	0,28
Light Steed Frame	20,55	0,25

5 CONCLUSIONS

Waste generation is an important sustainable impact that has to be considered during project stage. However, it is not yet considered due to the difficulty of establishing construction waste index.

The API developed at this study can fulfil this need since it results in an automatic waste quantification method.

With "WasteBIM" it is possible to calculate and recalculate waste generated with three different construction methods in an easy way providing designer information necessary to support decisions of changing construction materials.

The construction index obtained in Table 3 can be used to extrapolate the solution to different kinds of buildings and have an approximate result of the construction waste generation. This construction index can replace the use of the "WasteBIM" for quick estimations and analysis.

Although light-steel frame it is the solution that generates less construction waste it is necessary to verify others sustainable impacts like carbon emissions, or other aspects, in order to determine if it is the most sustainable option.

One suggestion for future works would be the development of a similar API also integrating life cycle analysis (LCA) of carbon emissions or other impacts.

6 ACKNOWLEDGMENTS

OTIMIZAÇÃO DO GERENCIAMENTO DE RESÍDUOS DE CONSTRUÇÃO POR MEIO DE UM BIM API INTEGRADO

RESUMO: A estimativa exata de resíduos gerados na construção civil é vital para minimizá-los na fase do projeto. Essa visão permite aos projetistas visualizar e explorar possíveis medidas corretivas para aumentar a eficiência da construção. Além disso, pode permitir que os contratados identifiquem processos críticos na geração de resíduos e planejem estratégias de controle. Ao integrar vários projetos em um único modelo, o Building Information Modeling (BIM) pode ajudar na solução desse desafio. O principal objetivo deste trabalho foi desenvolver um BIM API integrado para otimizar o gerenciamento de resíduos de construção. O método escolhido para esta pesquisa foi Design Science Research (DSR). Ao longo do desenvolvimento, foi avaliado um edifício construído com 3 (três) métodos de construção. O resultado foi um índice de resíduos de construção para classificar os edifícios de acordo com a geração de resíduos de construção.

PALAVRAS-CHAVE: Construção. Resíduos. BIM. Design. Edifício.

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