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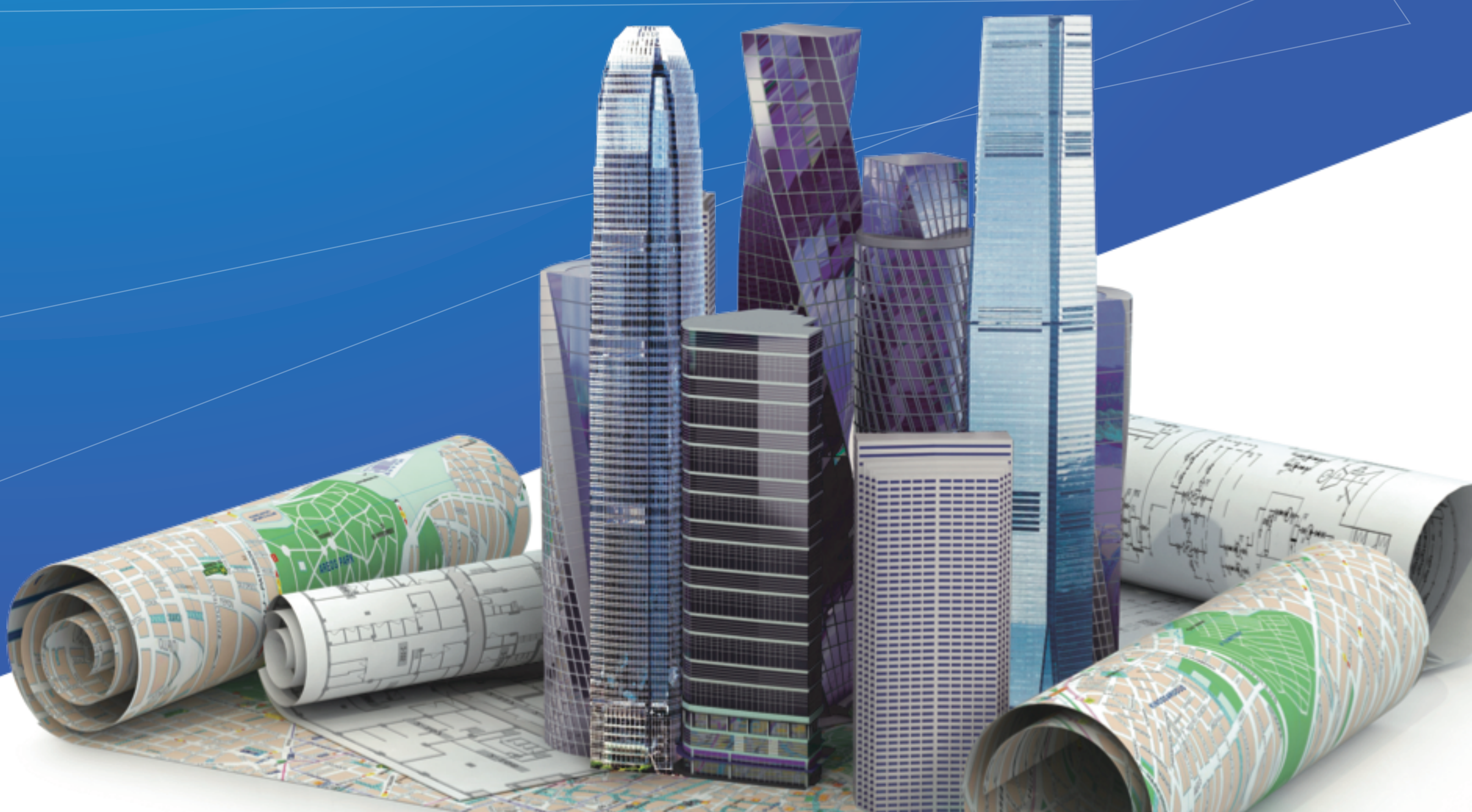

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Adequacy level to the Open Building approach of constructive systems applied in Brazil: an evaluation tool (2nd version)

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Abstract

This work fits into recurring discussions about smart cities in a critical and quite disparate way. There is an emerging awareness in the architecture field as the need to approach how technology has shaped our cities (socially constructed) and transformed the urban and everyday life. A more holistic and user-centered view is proposed here, which raises the discussion about how technologies are imagined, developed and used in the spatial production, especially in housing provision and management. The high level of buildings adaptive capacity over time is an important indicator of a smart architecture seen through its *use* dimension. This article presents results from a research that evaluates the adequacy to the Open Building approach of constructive components applied in Brazil, exploring the theory from its technological aspects. Although widely considered in several countries, the Open Building has been slightly investigated in Brazilian production, research and teaching. Such constructive components are structured in a collected, adjusted and systematized data set. Ten evaluation parameters – average cost, lifespan, work execution time, minimum module, maximum measure, connection type, manpower, tools/equipment, reaprovement potential and modification potential – receipted assessments and weighting scales by building layers so defined: site, structure, roof, façade, services, internal closure and furniture. In addition, a final scores classification by component was created. The tool will can allow architects, researchers, entrepreneurs, investors, builders and autoconstructors make combinations of different architectural types, finishing standards or development scales, in different scenarios, defining the behavior of each layer or component as support or infill, in the proposition of adaptable buildings through a multi-criteria analysis. Future results will compose a digital interface as the first instrument in Brazil to evaluate the flexibility level of constructive components. The database could also enable to cross information with other proposals for highly adaptable buildings, such as those that approach design strategies.

Keywords: Brazilian constructive systems, Open Building, Adaptive capacity of buildings, Flexibility, modularity e connectivity, Multi-criteria analysis.

1. Introduction

In 2018 an article was presented at the Open Building for Resilient Cities Conference, in Los Angeles, entitled *Adequacy level of Brazilian constructive systems to the Open Building: a research methodology* (LAMOUNIER *et al*., 2018). The present text consists of its revision and enhancement, as it is a piece of research[1] which is still in progress, whose objective is to develop a tool to evaluate the adaptive capacity[2], or degree of flexibility, of systems and constructive components employed in Brazil, with a residential production as a case study.

As discussed in Lamounier *et al*. (2018), the research aims to propose alternatives to the standardized and massed Brazilian heteronomous residential production that has not addressed the contemporary housing needs of dwellers, especially with regard to necessary modifications over time. This second version presents [1] a revision of the concepts, consolidating the terminology adopted in the construction of the tool; [2] an extension of the study object with complementation of the research data and of the evaluation criteria referring to a greater number of constructive components collected and studied; and [3] a deeper analysis and discussion of the results.

The approach to the concept of sustainability derived from the prolonged use of buildings, made possible by their ease of adaptability, contributes to the building of smarter cities[3]. In this sense, besides the universe of new housing production, the tool presented here can also be applied to the analysis of empty or unfinished buildings, which could be reclassified. In Brazil, there is a contradiction when comparing data on the housing deficit of more than 6 million homes (FUNDAÇÃO JOÃO PINHEIRO – FJP, 2018), and a real estate vacancy of the same size (FJP, 2018). Therefore, the solution to the scarcity and spatial rigidity in housing is facilitated by adaptability both in new and pre-existing buildings, which, due to the sustainability bias of use, contributes to smarter cities.

In Brazil, there is no widely accepted method as a criterion for evaluating flexible buildings, nor involving the constructive systems employed. Therefore, this study is a first attempt.

As detailed in Lamounier *et al*. (2018), the theoretical basis of the research is sustained by Habraken (*Supports Theory*, 1961); the Open Building principles (KENDALL, 2004) and the multi-criteria analysis method (BRYMAN, 2016).

2. The tool

2.1 Levels of decision making, building layers and elements

During the 1960s, when developing *Supports Theory*, Habraken suggested the identification of constructive components by their different lengths of lifespan (long and short), by the different construction scales (urban tissue, support/building and infill), by distinguishing between levels of

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1 "Sistemas, subsistemas e componentes construtivos aderentes à metodologia Open Building" (Systems, subsystems and constructive components adhering to the Open Building methodology), of the LabFlex Group, headquartered at Centro Universitário Metodista Izabela Hendrix (CEUNIH, the Izabela Hendrix Methodist University Center), Belo Horizonte, Minas Gerais, Brazil, coordinated by Professor Drª. Rosamônica da Fonseca Lamounier. Participating in the project are Professor Ms. Carolina Albuquerque de Moraes, researcher Rodrigo Rocha de Freitas and students Edésio Rocha Júnior, Gabriel de Lima Barbosa, Henrique Nogueira Pereira, Rômulo Vinícius dos Santos and Ruben Gonçalves do Vale. The project has a partnership with a research group of the Architecture and Urbanism Course of UFOP, coordinated by Professor Dr. Clécio Magalhães do Vale and Professor Ms. Giselle Oliveira Mascarenhas, with the participation of students Carlos Alexandre Ribeiro Thomaz, Marina Miranda de Faria and Matheus Edgard Moreira de Alencar. The research also has a partnership with the PRAXIS-EA/UFMG group, coordinated by Professor Drª. Denise Morado Nascimento.

2 Concept defined according to Geraedts, 2016.

3 The theme of CIB World Building Congress 2019, 'Constructing Smart Cities', to which this article was submitted.

decision making (collective/support and individual/infill) and by their fixed or separable (disconnectable) nature.

Considering [1] Habraken's ideas – foundations that generated the Open Building movement; [2] the logic of a building divided into constructive layers according to Duffy (1992); [3] enhanced by Brand (1994) and [4] redeveloped by Geraedts *et al*. (2016); and [5] in the Brazilian literature on constructive terminologies (LOPES, BOGÉA & REBELLO, 2006); Figure 1 shows a hierarchical deepening of what was proposed in the first version of the tool. It is important to mention that the *site* and *furniture* layers are not being explored in this article, while the *roof* and *services* layers are being studied, as well as the *structure*, *façade* and *internal closure* studied earlier. It should be noted that, due to the Brazilian constructive culture, it was more appropriate to deploy the *skin* layer (as treated by BRAND, 1994 and GERAEDTS, 2016) in *roof* and *façade*, as well as to adopt *internal closure* instead of *spatial plan*, due to the deployment of this layer.

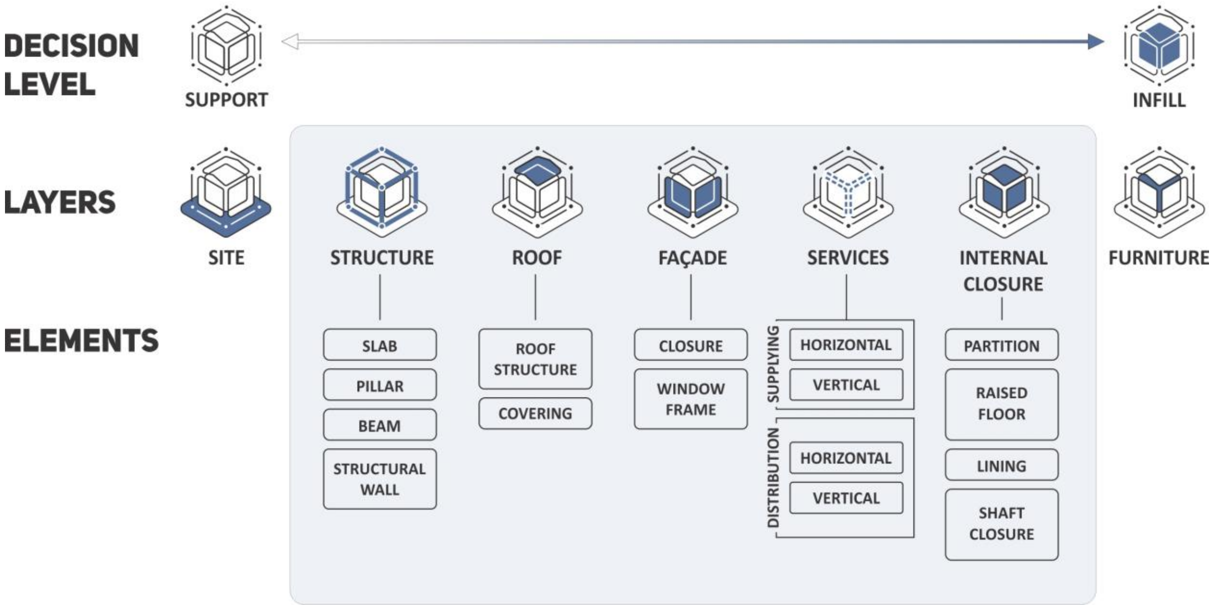


Figure 1 – Building layers and elements adopted by this research. Source: Authors, 2019.

Appendix 1 presents the 5 layers studied, hierarchically deployed in their respective elements and families of components, plus information regarding material and mode of production.

2.2 Evaluation parameters

In order to evaluate the adaptive capacity of each specific constructive component (product), ten evaluation parameters were defined at the beginning of the research: [1] average cost, [2] lifespan, [3] work execution time, [4] minimum module, [5] maximum measure, [6] connection type, [7] manpower, [8] tool/equipment, [9] reapprovement potential and [10] modification potential. Such parameters are described in detail by Lamounier *et al*. (2018) and since then adjustments have only been necessary in the description of the *reapprovement potential* parameter. This parameter refers only to the *reuse* possibilities offered by the component when uninstalled and reinstalled (reutilized) in another location, retaining or not its original function. For example, the possibility of recycling has been excluded, as originally envisaged.

The score ranges for the *roof* layer had not yet been created for the first article. These ranges followed the same criteria adopted in the definition of classes of scores for the other layers: from the survey of a large number of products, together with consultations with manufacturers, suppliers, specialists, specialized literature on the subject, cost compositions involving inputs and services in general from varied sources etc. For this layer scores were created for the *roof structure* and *covering/roofing* elements. For the *services* layer, scores ranges have been created, but this layer was discussed just in terms of *supplying* and *distribution*, both vertical and horizontal. Thus, products for this layer weren't mapped.

It should be noted that some elements can be considered from different layers, depending on the interpretation of each user and the adequacy of the component in the construction. For example, *shaft closure* has been interpreted as an element of the *internal closure* layer, but also could be of the *services* layer, because in this case translates into a solution (apart from a product) of architectural dimension.

Table 1 shows the relationship of the evaluation parameters, considering the five constructive layers studied and all their respective elements, in an enhanced version of the first article. Each parameter is assigned a score range from 1 (worst) to 4 (best).

Table 1 – Assessment values per parameter and per element. Source: Authors, 2019.

						MODULARITY AND CONNECTIVITY			CONSTRUCTION COMPLEXITY			
LAYER	ELEMENT	SCALE	01. AVERAGE COST (% OF BUILDING TOTAL COST)	02. LIFESPAM (DURABILITY IN YEARS)	03. WORK EXECUTION TIME (% OF BUILDING TOTAL EXECUTION TIME)	04. MINIMUM MODULE (cm)	05. MAXIMUM MEASURE (m)	06. CONNECTION TYPE (BEST PERFORMANCE)	07. MANPOWER (LOWEST LEVEL OF SPECIALIZATION REQUIRED)	08. TOOLS/ EQUIPMENT (LOWEST LEVEL OF SPECIALIZATION REQUIRED)	09. REAPROVEMENT POTENTIAL (% OF REUSE)	10. MODIFICATION POTENTIAL (DISTURBANCES IN OTHER SYSTEMS)
STRUCTURE	SLAB	1 - Worst	> 18%	< 60	> 10%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 14% to 18	60 to 100	> 8.5% to 10%	Multiple of 5	3 to 6	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	10% to 14%	> 100 to 200	7% to 8.5%	Multiple of 10	> 6 to 12	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 10%	> 200	< 7%	Multiple of 60 or unattached	> 12	Direct	D.I.Y.	Domestic	> 70%	None significant
	PILLAR	1 - Worst	> 8%	< 60	> 5%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 6% to 8%	60 to 100	> 4.25% to 5%	Multiple of 5	3 to 4.5	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	4% to 6%	> 100 to 200	3.5% to 4.25%	Multiple of 10	> 4.5 to 6	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 4%	> 200	< 3.5%	Multiple of 60 or unattached	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
	BEAM	1 - Worst	> 13%	< 60	> 5%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 10% to 13%	60 to 100	> 4.25% to 5%	Multiple of 5	3 to 6	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	7% to 10%	> 100 to 200	3.5% to 4.25%	Multiple of 10	> 6 to 12	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 7%	> 200	< 3.5%	Multiple of 60 or unattached	> 12	Direct	D.I.Y.	Domestic	> 70%	None significant
	FRAME OR STRUCTURAL WALL	1 - Worst	> 31%	< 60	> 10%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 24% to 31%	60 to 100	> 8.5% to 10%	Multiple of 5	3 to 4.5	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	17% to 24%	> 100 to 200	7% to 8.5%	Multiple of 10	> 4.5 to 6	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 17%	> 200	< 7%	Multiple of 60 or unattached	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
ROOF	ROOF STRUCTURE	1 - Worst	>7%	< 20	> 0.10	Other	< 6	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 5% to 7%	20 to 25	> 0.07 to 0.10	Multiple of 5	6 to 9	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	3% to 5%	> 25 to 30	0.04 to 0.07	Multiple of 10	> 9 to 12	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	<3%	> 30	< 0.04	Multiple of 60 or unattached	> 12	Direct	D.I.Y.	Domestic	> 70%	None significant
	COVERING	1 - Worst	> 4.2%	< 10	> 0.025	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 3% to 4.2%	10 to 20	> 0.02 to 0.025	Multiple of 5	3 to 4.5	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	1.8 to 3.0%	> 20 to 40	0.0125 to 0.02	Multiple of 10	> 4.5 to 6	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 1.8%	> 40	< 0.0125	Multiple of 60 or unattached	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
FAÇADE	CLOSURE	1 - Worst	> 9%	< 30	> 9.75%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 7% to 9%	30 to 60	> 7.3% to 9.75%	Multiple of 5	3 to 4.5	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	5% to 7%	> 60 to 100	6.8% to 7.3%	Multiple of 10	4.5 to 6	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 5%	> 100	< 6.8%	Multiple of 60 or unattached	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
	WINDOW FRAME	1 - Worst	> 9%	< 30	> 8.3%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 7% to 9%	30 to 60	> 7.05% to 8.3%	Multiple of 5	3 to 4.5	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	5% to 7%	> 60 to 100	5.8% to 7.05%	Multiple of 10	> 4.5 to 6	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 5%	> 100	< 5.8%	Multiple of 60 or unattached	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant

SERVICES	SUPPLYING	1 - Worst	> 11%	<20	> 9%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 9% to 11%	20 to 25	> 7.5% to 9%	Multiple of 5	3 to 4.5	Not planned	Skilled labor	Specialized and locable	<30%	In various layers
		3 - Good	7% to 9%	> 25 to 30	6% to 7.5%	Multiple of 10	> 4.5 to 6	By third piece	Some Experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 7%	> 30	< 6%	Multiple of 60 or unattached	> 6	Direct	D.I.Y	Domestic	>70%	None Significant
	DISTRIBUITON	1 - Worst	> 7%	<20	> 6%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 6% to 7%	20 to 25	> 5% to 6%	Multiple of 5	3 to 4.5	Not planned	Skilled labor	Specialized and locable	<30%	In various layers
		3 - Good	5% to 6%	> 25 to 30	4% to 5%	Multiple of 10	> 4.5 to 6	By third piece	Some Experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 5%	> 30	< 4%	Multiple of 60 or unattached	> 6	Direct	D.I.Y	Domestic	>70%	None Significant
INTERNAL CLOSURE	PARTITION	1 - Worst	> 5.5%	< 25	> 6.85%	Other	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 4% to 5.5%	25 to 50	> 5.8% to 6.85%	Multiple of 5	3 to 4.5	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	2.5% to 4%	> 50 to 75	4.8% to 5.8%	Multiple of 10	> 4.5 to 6	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 2.5%	> 75	< 4.8%	Multiple of 60 or unattached	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
	RAISED FLOOR	1 - Worst	> 5%	< 10	> 2.5	Other	< 0.15	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 4% to 5%	10 to 20	> 2 to 2.5	Multiple of 5	0.15 to 0.4	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	3% to 4%	> 20 to 30	1.5 to 2.0	Multiple of 10	> 0.4 to 1	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 3%	> 30	< 1.5	Multiple of 60 or unattached	> 1	Direct	D.I.Y.	Domestic	> 70%	None significant
	LINING	1 - Worst	> 7.4%	< 10	> 5	Other	< 0,6	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 4.6% to 7.4%	10 to 20	> 4 to 5	Multiple of 5	0.6 to 3	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	1.85% to 4.6%	> 20 to 30	3 to 4	Multiple of 10	> 3 to 6	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 1.85%	> 30	< 3	Multiple of 60 or unattached	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
	SHAFT CLOSURE	1 - Worst	> 1.4%	< 10	> 2.5	Other	< 0.6	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
		2 - Bad	> 1.2% to 1.4%	10 to 20	> 2 to 2.5	Multiple of 5	0.6 to 1.8	Not planned	Skilled labor	Specialized and locable	< 30%	In various layers
		3 - Good	1% to 1.2%	> 20 to 30	1,5 to 2.0	Multiple of 10	> 1.8 to 3	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
		4 - Best	< 1%	> 30	< 1.5	Multiple of 60 or unattached	> 3	Direct	D.I.Y.	Domestic	> 70%	None significant

Although the research focuses on the physical aspects of the building components to measure their degree of flexibility, the evaluation parameters investigate the components not only under flexibility technical aspects, but also functional, economic and socio-environmental. The *connection type*, *average cost* and *reapprovement potential* parameters exemplify, respectively, the three aspects of this intention.

2.3 Adjusting process of the average cost parameter

Lamounier *et al*. (2018) explain that it was necessary to carry out certain cost conversions of the various construction components according to the different units (per square meter, per weight, per piece etc.) with which they are marketed. A simplified constructional volumetric model (Models A and B in Figure 2) was utilized in order to proceed with the cost conversion operation. This model includes the 5 constructive layers of a building studied to date (Figure 1) and represented by their respective elements. Model A adopts previously imagined solutions with a lower degree of flexibility and model B with a higher degree expressed especially by the independent structure and not with load-bearing. The first conversion was the unit of the original average cost of the component (per weight, per piece, per volume, etc.) for its average cost per square meter of execution (cost referring only to the execution of this component) [4]. The second conversion was the average cost per square meter for the percentage of the total cost of the work, when monetary indicators of the Brazilian civil

[4] The cost of the product for that particular situation (according to the unit marketed in the market) was divided by the area of the model.

construction sector were utilized[5]. In this way, the cost percentage of each element was reached in relation to the total cost of the work. As some elements have not yet been considered by the research, such as *foundation* and *finishes*, the sum of the average cost percentages in the several layers studied, does not yet total 100%.

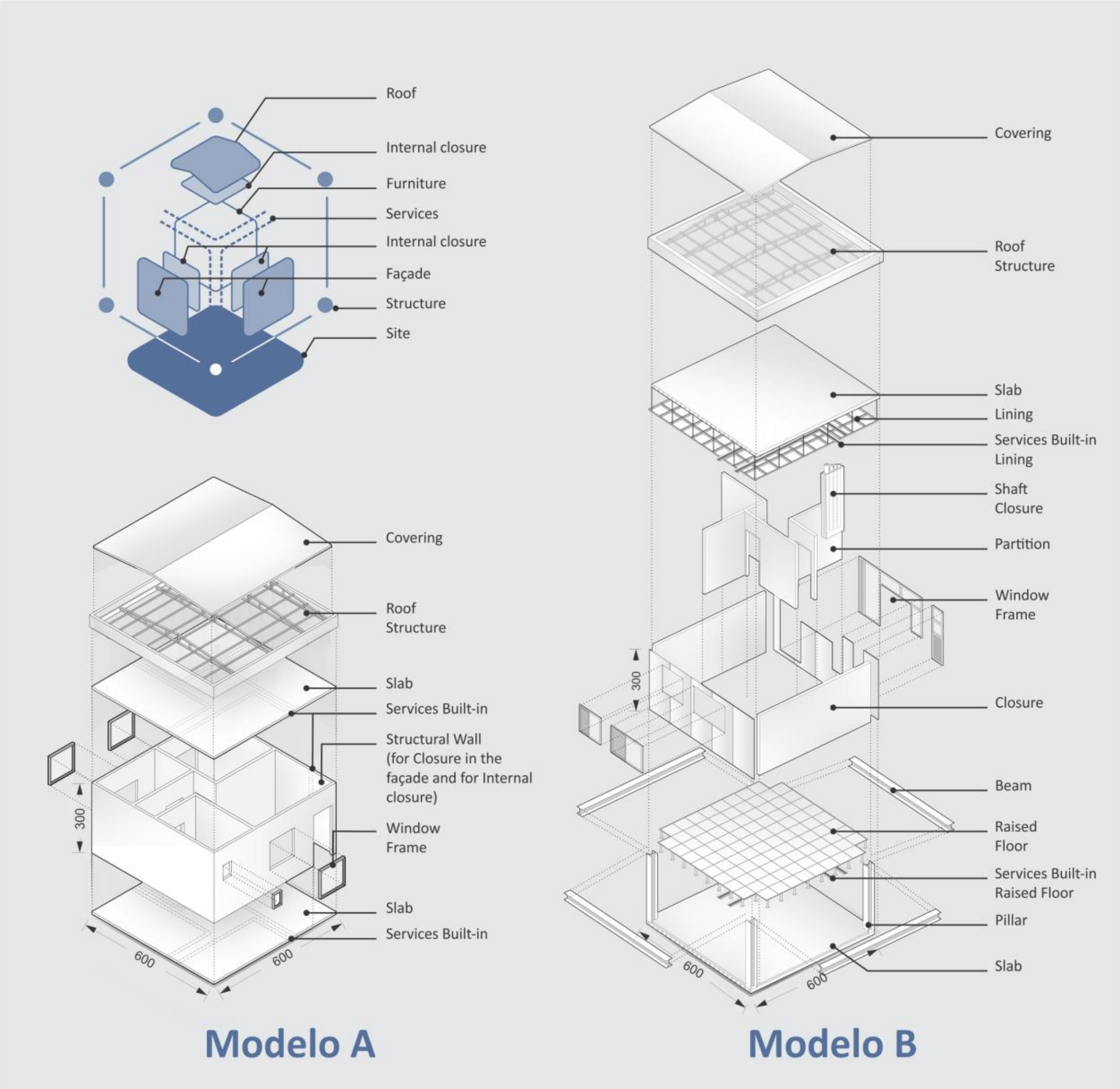


Figure 2 – Diagrams of the constructive models completed with the other layers and elements not contemplated in the first version of this paper. Source: Authors, 2019.

2.4 Assessment, weighting values and score classes

There were no changes in the scale of scores and weights per parameter defined at the beginning of the research (1 to 4), nor in the final product score, calculated by the sum of the multiplication of the

[5] The average cost provided by Sindicato da Construção Civil do Estado de Minas Gerais (SINDUSCON-MG – the Civil Construction Union of the State of Minas Gerais) was considered. In view of the fact that the agency provides costs for different typologies (individual, with 4, 8 and 16 floors, in addition to projects of social interest) and for different finishing standards (low, medium and high), the typology of 8 floors and 4 units per floor was adopted along with the volumetric model, since it is the only typology for which SINDUSCON provides construction costs for all finishing standards. It was also considered the average cost of all finishing standards. As this index excludes costs with, for example, several projects and calculations, foundations, air conditioning, heating, urbanization and landscaping, accounting costs and the developer's remuneration, the cost per square meter according to SINDUSCON was increased by forty percent for these services, as recommended by some specialists from the sector, as well with reference to the Brazilian Standard ABNT-NBR 12.721.

evaluation value (A) by the weight factor (W) attributed by the user to each parameter (Table 2). The weight will be a value assigned by the tool user, depending on the importance given to each parameter and in each situation.

Table 2 – Evaluation parameters, assessment and weighting scales, and scores per specific constructive component (product). Source: Lamounier et al. (2018)

EVALUATION PARAMETERS	ASSESSMENT (A)				WEIGHTING (W)				SCORE
	01	02	03	04	01	02	03	04	
01. AVERAGE COST									
02. LIFESPAN									
03. WORK EXECUTION TIME									
04. MINIMUM MODULE									
05. MAXIMUM MEASURE									
06. CONNECTION TYPE									
07. MANPOWER									
08. TOOLS/EQUIPMENT									
09. REAPROVEMENT P.									
10. MODIFICATION P.									
FINAL SCORE (S)									

As the final scores of a product can range from 10 (10x1x1) to 160 (10x4x4), a scale of flexibility classes was created for its final score as shown in Table 3.

Table 3 – Flexibility Classes for specific components (products)

FLEXIBILITY CLASSES FOR A SPECIFIC CONSTRUCTIVE COMPONENT	SCORE RANGE
Class 1: Not flexible	10 a 39
Class 2: Not very flexible	40 a 69
Class 3: Limited flexibility	70 a 99
Class 4: Very flexible	100 a 129
Class 5: Highly flexible	130 a 160

3. Database

A large database has been structured and fed into this research stage. To date, 461 products have already been researched, cataloged and with data recorded according to the two model spreadsheets below (Figure 3 and Figure 4). The first worksheet refers to general product information: code, product name, family of components in which they are inserted, material, production mode, manufacturer, type of system, typology to which it applies, location in the building, sources consulted, date of registration, responsible researcher, among others. The second worksheet presents the product information for each of the ten evaluation parameters. The two worksheets are linked together and identified in the spreadsheet header by the name of the research project, the layer and element to which the products refer, and the educational institution responsible for the data feed.

PROJECT : Adequacy level of the open building approach of constructive systems applied in Brazil: an evaluation tool (2nd version)
LAYER : INTERNAL CLOSURE
ELEMENT : RAISED FLOOR
RESPONSIBLE : IHENDRIX | Gabriel de Lima Barbosa

CODE	PRODUCT	MATERIAL	COMPONENT	LOCATION	SYSTEM	EXECUTION MODAL	OTHER	REFERENCE	DATE	RESPONSIBLE
FIN-PE-4-12-B-P01	**Internal Raised Floor Remaster with Fixed Pesdestal**	Thermoplastic Recycled	Pedestal and board	Internal	Open	Prefabricated	Weight = 12 kg / m² * (3x lighter than steel) Dispenses electrodes, conduit and others. It uses its own system, flexible, cable separation. * kg / m² = kilogram / square meter	http://arcoweb.com.br/projetodesign/tecnologia/tecnologia-diversidade-pisos-usos https://www.aecweb.com.br/cont/m/rev/pisos-elevados-sao-ideais-para-ambientes-corporativos_6368_0_1	30/10/18	Gabriel de Lima Barbosa

Figure 3 – Spreadsheet model with general information per product. Source: Authors, 2019

PROJECT : Adequacy level of the open building approach of constructive systems applied in Brazil: an evaluation tool (2nd version)
LAYER : INTERNAL CLOSURE
ELEMENT : RAISED FLOOR
RESPONSIBLE : IHENDRIX | Gabriel de Lima Barbosa

CODE	PRODUCT	AVERAGE COST	LIFESMAN (YEARS)	WORK EXECUTION TIME	MINIMUM MODULE	MAXIMUM MEASUREMENT	CONNECTION TYPE	MANPOWER	TOOL / EQUIPMENT	REAPROVEMENT POTENTIAL	MODIFICATION POTENTIAL
FIN-PE-4-12-B-P01	Internal Raised Floor Remaster with Fixed Pesdestal	R$150,00/m² m² = square meter	20 years	400m²/day m² = square meter	50x50 60x60	15cm high cm = centimeter	Fitting	low-skilled	Tools: Circular Saw, Bench Saw Blade, Rubber Hammer, Blister Level, Laser Level, Aluminum Ruler, Glue Applicator. Equipment: Helmet, Goggles, Ear Protector, Gloves	Recyclable	Very high

Figure 4 – Spreadsheet model with data related to evaluation parameters. Source: Authors, 2019.

These two types of spreadsheets feed the database twofold: [1] the first set of spreadsheets contains the information as collected in the literature, together with manufacturers, suppliers, builders and other informants; [2] the second set contains the scores attributed by the research to each product, with values coming from the comparison of the original data collected with the score scale previously created.

The code standard for each product was created in a way that facilitates its immediate identification, as shown in the example in Figure 5. The Appendix 1 shows the acronyms of all layers, elements, production mode, material and components.

LAYER	ELEMENT	COMPONENT	MATERIAL	ON SITE / PREFABR	PRODUCT	EXAMPLES
EST	**PD**	**001**	**01**	**A**	**P01**	EST-PD-001-01A-P01 EST-PD-001-01B-P01
STRUCTURE *ESTRUTURA*	**STRUCTURE WALL** *PAREDE ESTRUTURAL*	**COMPONENT** *COMPONENTE*	**concrete** *concreto* 01 **steel** *aço* 02 **ceramic** *cerâmica* 03 **wood** *madeira* 04	**ON SITE (A)** *IN LOCO* **PREFABRICATED (B)** *PRÉ-FABRICADO*	**PRODUCT** *PRODUTO*	EST-PD-001-01B-P02 EST-PD-001-01B-P03 EST-PD-001-02B-P01 EST-PD-001-02B-P02 EST-PD-001-03A-P01 EST-PD-001-04B-P01

Figure 5 – Example of the code for the structural wall product. Source: Authors, 2019.

The figure presented in Appendix 1 reveals the extent of sampling of components and products mapped until that time. In order to choose the majority of these components (for example those that apply to the *structure* layer), it was necessary to delimit certain scenarios of residential buildings produced in the Metropolitan Region of Belo Horizonte: [1] horizontal residential complex with duplex/detached houses; [2] economic building of up to 5 floors whic, in Brazil, can dispense with the use of elevator and [3] vertical building of up to 16 floors. That is, the selection of the products that fed the database was restricted to the application for these three typologies. The definition of the score ranges for the *average cost* parameter was based on the costs for an 8-storey vertical building, according to the figures provided by SINDUSCON-MG and explained above.

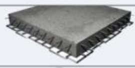
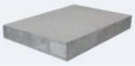
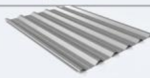
It should be remembered that not only products that have been routinely used in the Brazilian construction of residential buildings have been mapped, but also products commonly applied only in other uses, yet *could* also be used for housing, especially for highly adaptable spaces.

The tool will allow investors, builders, autoconstructors, architects, researchers, professors and students to evaluate and compare the different building components available in Brazil as to their suitability for the Open Building approach, especially for residential buildings.

4. Tool Application

In order to exercise and to exemplify the application of the tool, at least two product specifications were listed for each element of the studied layers, with scores attributed as shown in the Table 4, except for the services layer. As previously mentioned, this last layer needs to be studied more carefully, maybe with another methodology. It should be noted that for concrete materials, although it is historically possible to observe in practice its longer useful life, the adopted limit for the concrete material was approximately of 50 years, in agreement with the Brazilian literature in general.

Table 4 – Attributed assessments for two products of each studied element. Source: Authors, 2019.

		PRODUCT	PRODUCER	PICTURE	AVERAGE COST	LIFE SPAM	WORK EXECUTION TIME	MINIMUM MODULE	MAXIMUM MEASURE	CONNECTION TYPE	MANPOWER	TOOL/ EQUIPMENT	REAPROVMENT POTENCIAL	MODIFICATION POTENCIAL	TOTAL
STRUCTURE	SLAB	Precast Concrete 15cm	Incobraz		4	1	4	3	3	2	3	3	1	2	**26**
		Alveolar Concrete 15cm	Precon		3	1	4	2	4	3	2	2	2	3	**26**
		Solid Concrete 15cm	Construction Company		4	1	4	4	3	1	3	3	1	2	**26**
		Steel Deck MF50 17cm	Metform		3	1	4	1	2	3	2	2	1	2	**21**
		Wood and Cement Masterboard	Brasilit		4	1	1	2	1	4	2	3	4	3	**25**
	PILLAR	Precast concrete 30x40cm	Precon		1	1	4	4	4	3	2	2	2	3	**26**
		Solid Concrete 30x60cm	Construction Company		4	1	1	4	4	1	3	3	1	2	**24**
		Rectangular hollow section 26x26cm(steel)	Century Tubos		4	2	2	4	4	3	2	2	4	3	**30**
		Timber 15x15cm	Madeireira Santos		4	1	4	3	1	4	2	3	4	3	**29**
	BEAM	Precast concrete 40x60cm	Precon		1	1	4	4	3	3	2	2	2	3	**25**
		Solid concrete 20x60cm	Construction Company		3	1	1	4	4	1	3	3	1	2	**23**
		Lipped channel "I" section 46x19cm	Gerdau		1	2	2	4	4	3	2	2	4	3	**27**
		Timber 15x8cm	Madeireira Santos		4	1	4	3	1	4	2	3	4	3	**29**
	STRUCTURAL WALL	Solid concrete	Construction Company		2	1	2	4	4	1	2	3	1	1	**21**
		Concrete masonry	Braúnas		4	1	1	3	3	2	3	4	3	1	**25**
		Steel frame	ConstruAgil		1	4	4	3	2	3	2	3	4	2	**28**
		Double OSB board	Espaço Smart		4	1	1	4	3	3	2	3	4	2	**27**
ROOF	ROOF STRUCTURE	Wood truss	Construction Company		4	4	1	4	2	4	2	3	4	4	**32**
		Steel truss	Construction Company		4	4	1	4	2	3	2	2	4	4	**30**
	COVERING	Asbestos cement roof cladding	Brasilit		4	3	1	3	3	3	3	3	3	4	**30**
		Galvanized steel roof cladding	Calha Forte		3	4	1	3	4	3	3	3	3	4	**31**

		PRODUCT	PRODUCER	PICTURE	AVERAGE COST	LIFE SPAM	WORK EXECUTION TIME	MINIMUM MODULE	MAXIMUM MEASURE	CONNECTION TYPE	MANPOWER	TOOL/ EQUIPMENT	REAPROVMENT POTENCIAL	MODIFICATION POTENCIAL	TOTAL
FAÇADE	CLOSURE	Concrete masonry	Blojaf		3	2	4	3	2	2	3	4	2	2	**27**
		Aquapanel W384	Knauf		2	3	4	4	2	3	1	1	4	4	**28**
		Precast concrete board ARQ 03	Stamp		1	2	4	4	4	3	2	2	2	3	**27**
	WINDOW FRAME	Shine line	Selbach		1	2	4	4	1	3	2	3	3	3	**26**
		Prátika line	Sasazaki		4	3	4	4	1	3	2	4	4	1	**30**
		Gold line	Alcoa		4	3	4	4	3	3	2	3	4	4	**34**
		Veneza line	3A Alumínio		1	3	4	3	1	3	3	3	3	2	**26**
INTERNAL CLOSURE	PARTITION	Ceramic masonry	Braúnas		1	2	1	3	3	2	3	4	3	1	**23**
		W111 board	Knauf		3	2	3	3	3	3	2	3	4	3	**29**
		Double OSB board	Madeireira Santos		4	1	3	4	3	3	2	3	3	3	**29**
		Double plywood board	Madeireira Santos		4	1	3	4	3	3	2	3	3	3	**29**
	RAISED FLOOR	Adjustable pedestal floor	Remaster		1	2	4	4	1	4	4	4	4	4	**32**
		Agglomerated floor 01056	Stamp		1	3	4	4	4	4	2	2	4	3	**31**
		Monolithic floor	Werden		1	4	1	3	1	1	2	2	2	1	**18**
	LINING	Angelim wood rafters	Madeireira Santos		3	4	1	1	2	3	2	3	3	2	**24**
		Plaster board with PVC film	Trademix		2	4	4	1	4	3	3	2	3	1	**27**
		PVC rafters	Araforros		4	4	4	2	3	3	3	2	3	3	**31**
		Agglomerated and wood Tile Natura	Hunter Douglas		1	4	4	4	4	3	3	3	4	4	**34**
	SHAFT CLOSURE	Ceramic masonry	Braúnas		4	3	2	3	4	2	3	4	2	2	**29**
		Polystyrene board	Merc Kits		4	2	4	2	3	3	3	3	4	4	**32**
		Fiberglass board	Artglass BH		4	1	4	2	3	3	4	4	4	4	**33**

Considering the values in the *Total* column of Table 4 and weight 1 for all the products, just as an example[6], and following the Classes Scale showed in

[6]As previously explained, weight is an attribute defined by the tool-user, and thus any product can experience variation in the

Table 5 as well as the products exemplified in the first article (LAMOUNIER *et al*., 2018), it can be observed that:

- Doesn't have much difference among slab types in terms of flexibility. Just the Steel Deck is much less inflexible than the other. Slab in steel, wood, precast and solid concrete have limited flexibility and Steel Deck isn't very flexible.
- Pillars in steel or in wood are very flexible and pillars in concrete (both prefabricated and concreted on site) have limited flexibility. In case of beams, wood beam is the most flexible (very flexible) and the other have limited flexibility.
- Regarding the structural walls, steel frame offers greater flexibility, but even so presents as from Class 3 (limited flexibility). Concrete walls built on site are not very flexible (Class 2).
- In the roof layer, roof structure in wood are a little more flexible than in steel, but both are from Class 4 (very flexible). Besides that, covering in galvanized steel or in fiber-cement are very flexible too.
- For the façade layer, the Aquapanel System are more flexible than external structural walls and concrete masonry. In terms of window frames the Gold Line from Alcoa is more flexible than the other.
- Internal partitions with prefabricated materials and systems like boards/panels are more flexible (very flexible) than masonry (limited flexibility).
- In the same way raised floor more industrialised like Remaster and Stamp are more flexible (very flexible) than monolithic raised floor, which has limited flexibility.
- Modulated linings such as those from Hunter Douglas brand are more flexible than plaster and PVC that win in flexibility to wood lining.
- As the services layer wasn't investigated with that methodology, there weren't evaluated products.

Table 5 – Scores for the products adopting the value 1 for the weightings (W). Source: Authors, 2019.

FLEXIBILITY CLASSES FOR A SPECIFIC CONSTRUCTIVE COMPONENT ADOPTING WEIGHTING (W) 1	SCORE RANGE
Class 1: Not flexible	10 a 16
Class 2: Not very flexible	17 a 22
Class 3: Limited flexibility	23 a 28
Class 4: Very flexible	29 a 34
Class 5: Highly flexible	35 a 40

In some cases, the scores were attributed in their best performance. It has been realised throughout the research that more and more the final score and class will depend on the context in which the product is being used. This research has been very important and it excites other complementary research, more rich and complete, like those inserted in real scenarios and involving design strategies. Then, at this moment of the research, the possibility of advances in the construction of the tool has been discussed, leading to its application in that scenarios, in a more systemic way and not only in isolated products. Although the tool was initially thought of as an isolated product evaluation method, parameters such as the *reuse potential* or the *modification potential* may be influenced by the score, depending on the scenario in which the product is being used and its combination with another product in the same or another layer. For example, the *alveolar slab* is more flexible as much to the type of connection, or *reuse* or *modification potentials*, as to when associated with the *metal structure* than as when associated to the *precast concrete structure*. The tool construction process has shown that these parameters received more qualitative rather than quantitative score ranges, given the subjectivity of the information found and the degree of interpretation required for this creation. The scores were constructed using 'ranges' exactly to cover these differences and the product can generally be rated at its best flexibility performance. These subtleties, however, need to be better investigated in future stages of the research.

In any case, the insertion of the products into scenarios is not a condition for using the tool, which was

score regarding its performance of flexibility. What is presented here is just an example of how to use the tool - the question of weight can make a product less flexible due, for example, to its high cost or its long execution time. These are less determinant parameters in terms of a "technical" degree but they can be very important in certain scenarios.

initially intended to evaluate constructive components in isolation.

Another issue currently under discussion and subject for future research is the extension of the employment of the tool in the evaluation of constructive components in scenarios with uses other than residential.

5. Conclusion and next steps

This article was an important step in the development of the tool to evaluate the adaptive capacity of constructive components used in Brazilian housing production. This paper open opportunity to:

- Expand the number of products surveyed, assigning scores to new components and completing the analysis of layers not contemplated
- Discuss and evaluate the methodology with potential users through a university extension project, seeking to validate the tool, both with specialists and companies active in the area – the supply side of flexibility – and with potential users of the space –the side that demands flexibility
- Study more complete and complex scenarios, seeking to better represent reality, while also better illustrating and discussing the applicability of the tool
- Develop a digital graphic interface for query database, tool application and results visualization
- Develop and analyse projective strategies from the results obtained with the use of the tool. In addition, cross the principles of the tool with similar methods such as those dealing with design strategies for flexibility.

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References

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. (2004) NBR 12.721: Avaliação de custos de construção para incorporação imobiliária e outras disposições para condomínios edilícios. Rio de Janeiro, ABNT.

BRAND, S. (1994) How buildings learn: What happens after they're built. New York, Penguin Books.

BRYMAN, A. (2016) Social Research Methods. Oxford, Oxford University Press.

DUFFY, F. (1992) The Changing Workplace. London, Phaidon Press.

FUNDAÇÃO JOÃO PINHEIRO (2018). Déficit Habitacional no Brasil: 2015. Available from: hhttp://www.fjp.mg.gov.br/index.php/docman/direi-2018/estatistica-e-informacoes/797-6-serie-estatistica-e-informacoes-deficit-habitacional-no-brasil-2015/file [Accessed 20th December 2018].

HABRAKEN, N. J. (2011). Supports: an alternative to mass housing. U.K., Urban International Press.

GERAEDTS, R. (2016) FLEX 4.0: a practical instrument to assess the adaptive capacity of buildings. In: Kurnitski, J. (eds.) Sustainable Built Environment Tallinn and Helsinki Conference 2016: Build Green and Renovate Deep. SBE16 Tallinn and Helsinki Conference, 5-7 October 2016, Tallinn and Helsinki, Finland. Available from: https://www.sciencedirect.com/science/article/pii/S187661021630741X [accessed 27th April 2017].

KENDALL, S. (2004) Open Building Concepts. Available from: http://open-building.org/ob/concepts.html [Accessed 11th August 2018].

LAMOUNIER, R. F. *et al*. (2018) Adequacy level of Brazilian constructive systems to the Open Building: a research methodology. In: Editor Dr. Stephen Kendall, Council Open Building. Open Building for Resilient Cities Conference 2018, December 6-8, 2018, The A+D Museum, Los Angeles, California, USA. Pp. 123-134.

LOPES, J.M.; BOGÉA, M.; REBELLO, C.P. (2006) Arquiteturas da Engenharia ou engenharias da Arquitetura. São Paulo, Mandarim.

Appendix 1

LAYER	ELEMENT	PRODUCTION	MATERIAL	COMPONENT
STRUCTURE (EST)	SLAB (LJ)	IN LOCO (A)	VARIOUS	SOLID
				MUSHROOM
				RIBBED
				PRESTRESSED
				STEEL DECK
				OSB
		PRE FABRICATED (B)		ALVEOLAR
				PRECAST
	PILLAR (PL)	IN LOCO (A)	CONCRETE	SOLID
				REINFORCED MASONRY
		PRE FABRICATED (B)		PREFABRICATED
			STEEL	CIRCULAR HOLLOW
				RECTANGULAR HOLLOW
				LIPPED CHANNEL
				HOT ROLLED H
			WOOD	TIMBER
				GLULAM
	BEAM (VG)	IN LOCO (A)	CONCRETE	SOLID
		PRE FABRICATED (B)		PREFABRICATED
			STEEL	CIRCULAR HOLLOW
				RECTANGULAR HOLLOW
				LIPPED CHANNEL
				HOT ROLLED H
			WOOD	TIMBER
				GLULAM
				LVL
	STRUCTURAL WALL (PD)	IN LOCO (A)	CERAMIC	MASONRY
			CONCRETE	SOLID
				MASONRY
		PRE FABRICATED (B)		PREFABRICATED
			STEEL	STEELFRAME
			WOOD	OSB
				CLADDING
ROOF (COB)	ROOF STRUCTURE (ES)	IN LOCO (A)	STEEL	SCISSOR BEAM
				RAFTER
			WOOD	SCISSOR BEAM
				RAFTER
	COVERING (CO)	IN LOCO (A)	CERAMIC	TILE
			CONCRETE	TILE
			STEEL	TILE
			CEMENT	TILE
			GLASS	TILE
FAÇADE (FCH)	CLOSURE (FF)	IN LOCO (A)	CERAMIC	MASONRY
			CONCRETE	SOLID
				MASONRY
			SOIL-CEMENT	MASONRY
		PRE FABRICATED (B)	CERAMIC	PANEL
			CONCRETE	PANEL
				PRECAST PANEL
				AERATED PANEL
				ALVEOLAR PANEL
				FIBERGLASS PANEL
			STEEL	PANEL
				STEELFRAME
	WINDOW FRAME (EQ)	PRE FABRICATED (B)	STEEL	CASING
			PVC	CASING
			ALUMINIUM	CASING
			WOOD	CASING

LAYER	ELEMENT	PRODUCTION	MATERIAL	COMPONENT
SERVICES (INS)	SUPPLYING (PR)			
	DISTRIBUTION (DI)			
INTERNAL CLOSURE (FIN)	PARTITION (DV)	IN LOCO (A)	CERAMIC	MASONRY
			CONCRETE	MASONRY
			SOIL-CEMENT	MASONRY
			PLASTER	MASONRY
		PRE FABRICATED (B)	STEEL	DRYWALL
			WOOD	NATURAL
				PLYWOOD
				OSB
				CLADDING
				MDF
	RAISED FLOOR (PE)	IN LOCO (A)	MINERAL	SOLID
		PRE FABRICATED (B)	STEEL	PEDESTAL-BOARD
			PLASTIC	PEDESTAL-BOARD
	LINING (FR)	PRE FABRICATED (B)	PLASTER	BOARD
			PVC	BOARD
			AGGLOMERATE	BOARD
			ZINC ALUMINIUM	PROFILE
			WOOD	WAINSCOT
				MOLDING
	SHAFT CLOSURE (FS)			