Adequacy level of Brazilian constructive systems to the Open Building: a research methodology

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ABSTRACT: The Open Building approach has been broadly considered in several countries while little investigated in Brazilian building production processes, architectural research or teaching. Exploring the theory from its technological aspects, this paper presents a research methodology proposal whose objective is to evaluate Brazilian building systems, subsystems and components adequacy to Open Building principles, through gathering, processing, crossing-checking and analysing mapped data on such elements. These building elements are organized by layers – site, structure, façade, roof, internal closure, services and furniture – based on Duffy, Brand and Geraedts' proposals, considering their behavior as support and/or infill. This information will constitute a database that will feed a research tool, allowing different combinations, and enabling people to develop a multiple-criteria analysis through some evaluation parameters and architectural categories. Inspired by Prins, the evaluation parameters will be cost, lifespan, building execution time, compatibility with other systems (measured by their modularity and connectivity), execution complexity, modification and reuse potential. The categories will be attributes such as architectural types, finishing standards and development scales of construction companies operating in Belo Horizonte, Brazil. Finally, a dynamic digital graphic interface might be created from this research to assist architects, researchers, entrepreneurs, developers, contractors and autoconstructors in making decisions on flexible and adaptable buildings.

KEYWORDS: Brazilian building systems. Building layers. Multiple-criteria analysis methodology. Open Building. Modularity and connectivity. Digital interface.

INTRODUCTION

Brazilian studies have criticized the standardized and mass production of housing carried out in the country, from small to large scale, by public or private agents, for lower or higher income classes (MORADO NASCIMENTO & TOSTES 1998a; ANITELLI 2011, 2015; LAMOUNIER 2017). Furthermore, surveys also reveal a contingent of dissatisfied people, living in spaces that do not meet their changing housing needs at that time (PRAXIS-EAUFMG 2014; LAMOUNIER 2017).

This article, which is the result of ongoing research[1], aims to propose alternatives to the problematic spatial rigidity and the consequent lack of possibilities for dwellers regarding space. The investigations presented here are based on N. J. Habraken's *Theory of Supports* and *decision-making levels* from Open Building, as well as the multi-criteria analysis method.

More specifically, the research in Brazil has investigated systems, subsystems and constructive components which are suitable for the Open Building approach in terms of its technological aspects enunciated in the 4th Principle of the movement, which proposes:

> the interface between technical systems allows the replacement of one system with another performing the same function. (such as different fit-out systems applied in a given base building) (KENDALL 2004)

The LabFlex Group[2] has developed a tool to evaluate the adaptive capacity of these elements, i.e. their degree of flexibility. This text presents a research methodology that investigates the proposition of this tool. It is intended for architects, engineers, property owners, builders, entrepreneurs, autoconstructors, researchers, professors and students in the decision-making process for the production of adaptable residential buildings.

The research on constructive systems from the Open Building perspective is justified exactly because of the proposal of the distinction between the levels of decision-making, both collective and individual, as being the differential of the theory. Such levels are fundamentally political in nature, but are represented physically in the parts of a building, through support (elements of long durability and less changeable) and infill (separable units with shorter useful life).

The majority of the research which has been developed with a presupposition of this separation between the levels of decision-making focuses on design strategies, constituting a logical approach to the production of open buildings which is extremely relevant. Geraedts et al. (2014; 2015; 2016a; 2016b), who propose the FLEX method, and Osman et al. (2011), who propose the Adaptability Assessment Tool (AAT), are some examples. Such research is intended to evaluate (and examine in detail) the adaptive capacity of, as a priority, preexisting buildings, from the analysis of spatial attributes that refer to strategies or design characteristics. However, such strategies are closely related to the technology used in the projects and the present research focuses on this aspect.

The tool proposed here differs from those previously mentioned because it is currently restricted to the evaluation of physical constructive components per se. While it is a future research goal to establish correlations of technology with design strategies, such connections are not addressed in this article. In this sense, the tool can be applied to the analysis of constructive systems, or part of them, present in preexisting buildings, as well as new buildings to be produced in the future.

The criteria, or evaluation parameters, of the components were created in the light of the *Theory of Supports* and Open Building. In other words, it is important to know the extent to which each constructive component meets the requirements of open architecture, enabling and facilitating the physical separation between different decision-making levels and thereby promoting flexibility – either *adaptation*, *expansion* or *rejection* (Geraedts & Prins 2014).

In Brazil, this is a fertile field of investigation precisely because this country does not boast production that considers the issue of spatial flexibility and the participation of the dweller as an active agent in the process. However, the research in development that deals with the subject does not associate these issues with technological investigations on constructive systems.

1.0 THE TOOL

1.1. Decision level, building Layers and elements

Duffy (1992), Brand (1994) and Geraedts & Prins (2015a) propose, with different but similar objectives, that a building be divided into layers, due to its different functional, technical and economic (cost) life cycles (Figure 1). Duffy (1992), for example, asserts that “our basic argument is that there isn’t such a thing as a Building [...] a building properly conceived is several layers of longevity of built components”, since its object of analysis is the use of the building at that time, made possible by its transformations.

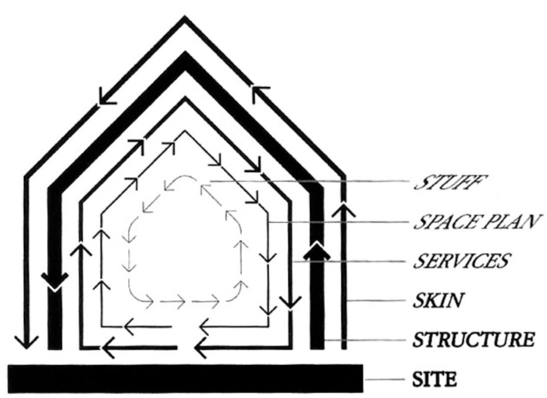


Figure 1 – Building Layers. Source: (Brand 1994)

In light of the distinction between the decision-making levels proposed by Habraken, layered logic has been used in this research in order to develop the aforementioned instrument to evaluate the adaptive capacity of a constructive component, or its degree of flexibility. It was adopted the concept of *adaptive capacity*, first defined by Hermans (2014) and consequently adopted by Geraedts et al. (2014; 2015a; 2015b; 2016):

> The adaptive capacity of a building includes all characteristics that enable the building to keep its functionality through changing requirements and circumstances, during its entire technical life cycle and in a sustainable and economic profitable way. The adaptive capacity is being considered as a crucial component when looking into the sustainability of the real estate stock.

By analogy with the procedures adopted by Duffy (1992), Brand (1994) and Geraedts et al. (2016), seven layers were created for this research: site, structure, roof, façade, services, internal closure and furniture (Table 1), in order to structure, locate and group the mapped constructive systems, subsystems, elements and components. For some layers it was necessary to define certain types of sub-layers, referred to as *elements* - a term based on Lopes, Bogéa and Rebello (2006). In the first phase of the research, the focus was on the investigation of the *structure, façade* and *internal closure* layers, albeit in the last only the *partition* element was considered, as highlighted in Table 1.

Table 1 – Building layers adopted by this research. Source: Authors, based on (Duffy 1992; Brand 1994 and Geraedts & Prins 2015a)

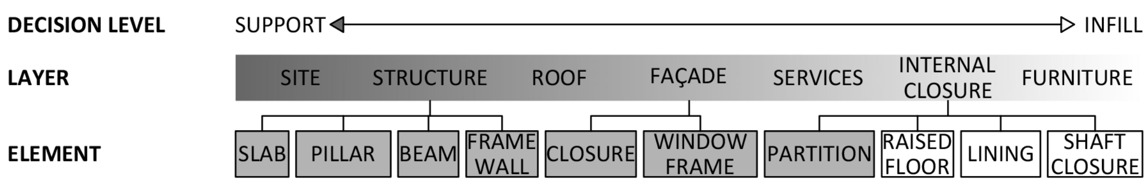


Table 2 and Table 3 below illustrate the *structure* layer and the *closure* element of the *façade* layer, added hierarchically to the next features of the constituent elements of a constructive system, as well as the *components* family. This categorization has also been investigated in terms of modes of *production* (*on-site* or *prefabricated)* and types of *materials* (concrete, steel, ceramics etc.).

Table 2 – Subdivision of the *structure* layer. Source: (Authors 2018)

ELEMENT	PRODUCTION	MATERIAL	COMPONENT
SLAB	IN LOCO		SOLID
			MUSHROOM
			RIBBED
			PRESTRESSED
			STEEL DECK
			OSB
	PF.		ALVEOLAR
			PRECAST
PILLAR	I.L.	CONC.	SOLID
			REINFORCED MASONRY
	PREFABRICATED		PREFABRICATED
		STEEL	CIRCULAR HOLLOW
			RECTANGULAR HOLLOW
			LIPPED CHANNEL
			HOT ROLLED H
BEAM	I.L.	CONC.	SOLID
	PREFABRICATED		PREFABRICATED
		STEEL	CIRCULAR HOLLOW
			RECTANGULAR HOLLOW
			LIPPED CHANNEL
			HOT ROLLED H
FRAME WALL	IN LOCO	CE.	MASONRY
		CONCRETE	SOLID
			MASONRY
	PF.		PREFABRICATED
		ST.	STEELFRAME

PF: PREFABRICATED, I.L.: IN LOCO, CONC.: CONCRETE, CE.: CERAMIC, ST.: STEEL

Table 3 - Subdivision of the *closure* element of the *façade* layer. Source: (Authors 2018)

ELEMENT	CLOSURE									
PRODUCTION	IN LOCO				PREFABRICATED					
MATERIAL	CE.	CONCRETE								ST.
COMPONENT	MASONRY	MASONRY	CELLULAR	SOLID	PRECAST	AUTOCLAVED	PREFABRICATED	PREFABRICATED W/ CE.	ALVEOLAR	FRAME W/ CEM. BOARD

CE.: CERAMIC, ST.: STEEL

1.2. Evaluation parameters

Taking into consideration the distinction between Habraken's decision-making levels and the Open Building approach, associated with the concept of adaptive capacity, and to some parameters defined by Prins[3] (1992), as well as to other important attributes that must be taken into account in choosing a constructive system for a particular work, it was noticed that the multi-criteria analysis procedure would be very useful in the construction of this tool. As Bryman (2016, p.153-154) explains, the adoption of multicriteria analysis methodology, or multiple-indicators,

> 'is a recognition that there are potential problems with a reliance on just a single indicator:
> 1. it is possible that a single indicator will incorrectly classify many individuals. […]
> 2. A single question may need to be of an excessively high level of generality and so may not reflect the true state of affairs for the people replying to it. […]
> 3. You can make much finer distinctions."

Thus, an attempt was made to define the evaluation parameters for specific constructive components that considered all the factors that could influence their adaptive capacity.

For this research, 7 general parameters of flexibility assessment of a particular constructive component were defined, with some variations (or 'sub-parameters'). No weight differentiation has yet been established for the parameters exhibiting such variations. All sub-parameters received the same weight as the general parameters, thus it was defined a total of 10 parameters: [1] average cost; [2] lifespan; [3] work execution time; modularity and connectivity in their attributes of [4] minimum module, [5] maximum measure and [6] connection type; execution requirements such as [7] the level of labor or company to be contracted – manpower and [8] necessary tools or equipment; besides [9] reapprovement potential and [10] modification potential.

Costs for components, inputs or services in civil construction vary greatly in terms of unit of measurement. They can be by area, length, volume, weight, piece, unit sums etc. After consultation with specialists, manufacturers and suppliers and in order to interrelate the costs of each component installed, a scale of values in percentage terms of the total cost of the work was established (Table 4). An explanation of this conversion follows in the next section.

The average lifespan of the building components has been defined in years, based on consultation with several Brazilian manufacturers and suppliers, which is largely in line with the lifespan of the Open Building approach (support level – 100 to 200 years; house allocation – 25 years; infill level – 10 to 20 years).

As for the work execution times, Coutinho et al. (2012) warn that the execution time of civil works depends on some important factors: season of the year – whether winter/dry or summer/rainy – in the case of Brazil, as well as building area, total cost of the work, operational capacity of the company, type of service (whether construction or renovation), among others. In general, short execution times are considered as *the best* (scale 4), just as very extended times are regarded as *the worst* (scale 1). Just as in the *cost* parameter, a range of scale for *execution time* was defined that varies in percentage times of the total work time. The calculations made for the definition of the *execution time* ranges of each element considered the average between the times spent in the respective services of a more industrialized or more manufactured form. A residential work with a total time of 2 years and an average variation of 30% for each service, whether more manufactured or more industrialized, was considered as a reference.

In the case of the connectivity and modularity parameters, the definition of the grading scale for *minimum modulus* was based on the Brazilian Technical Standard for Modular Coordination for Buildings, NBR-15,873, whose standard minimum modulus for buildings is 10cm, and on the *tartan* band grid (of 30cm =10cm+20cm) developed by SAR[4] in the 1960s and which has become the standard for modular coordination adopted in construction throughout Europe.

With regards to maximum measures, surveys were carried out with several Brazilian suppliers and measurements were established in meters. The type of connection varies from *monolithic*, which practically prevents substitutions, to *direct*, without the necessity of a third piece, being connected and disconnected more immediately.

The complexity of execution was defined in terms of the degree of specialization of the labor or company required to execute or install the component, and the type of tool or equipment necessary. The first parameter varies from D.I.Y (Do It Yourself) as being *the best*, to *the worst* when it would be necessary to hire a specialized company. The second varies from the *domestic* tool, being *the best*, to the *exclusive domain*, as *the worst*.

The potential for reapprovement refers to the possibilities of reuse, recycling or reduction of resources, offered by a specific component. The more possibility of reapprovement in similar situations (with the same function or not), the better the component will be evaluated.

Finally, the potential of modification of a given component refers to the degree of modification required in the other components and layers. The less disturbance it causes in the preexisting elements, the better it will be evaluated.

Therefore, a numerical scale ranging from 1 to 4 was defined for all the evaluation parameters, corresponding to the four qualitative evaluation levels: *worst* (1), *bad* (2), *good* (3) and *best* (4). Thus, the aim was to generate a scale with an even number of scores, either positive or negative, revealing a clear tendency of the component to an evaluation consistently above or below the average.

Table 4 – Assessment values per parameter and per element. Source: (Authors 2018)

ELEMENTS	SCALE	01. AVERAGE COST (% OF BUILDING TOTAL COST)	02. LIFESPAN (DURABILITY IN YEARS)	03. WORK EXECUTION TIME (% OF BUILDING TOTAL EXECUTION TIME)	MODULARITY AND CONNECTIVITY			CONSTRUCTION COMPLEXITY		09. REAPROVEMENT POTENTIAL (% OF REUSE, RECYCLING OR REDUCTION)	10. MODIFICATION POTENTIAL (DISTURBANCES iN OTHER SYSTEMS)
					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)		
SLAB	1 - Worst	> 8%	< 60	> 10%	Other or none	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
	2 - Bad	6% to 8%	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	4% to 6%	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	< 4%	> 200	< 7%	Multiple of 60	> 12	Direct	D.I.Y.	Domestic	> 70%	None significant
PILLAR	1 - Worst	> 13%	< 60	> 5%	Other or none	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
	2 - Bad	10% to 13%	60 to 100	4.2% to 5%	Multiple of 5	3 to 4.5	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	4.5 to 6	By third piece	Some experience	Specialized and purchasable	30% to 70%	In the same layer
	4 - Best	< 7%	> 200	< 3.5%	Multiple of 60	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
BEAM	1 - Worst	> 18%	< 60	> 5%	Other or none	< 3	Monolithic	Specialized company	Exclusive domain	None	Unfeasible
	2 - Bad	14% to 18%	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	10% to 14%	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	< 10%	> 200	< 3.5%	Multiple of 60	> 12	Direct	D.I.Y.	Domestic	> 70%	None significant
FRAME WALL OR STRUCTURAL WALL	1 - Worst	> 31%	< 60	> 10%	Other or none	< 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	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
CLOSURE	1 - Worst	> 9%	< 30	> 9.75%	Other or none	< 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	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
WINDOW FRAME	1 - Worst	> 9%	< 30	8.3%	Other or none	< 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	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant
PARTITION	1 - Worst	> 5,5%	< 25	> 6.85%	Other or none	< 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	> 6	Direct	D.I.Y.	Domestic	> 70%	None significant

1.3 Adjusting process of the average cost parameter

Whilst in the process of defining the scales of scores of the respective elements, it was noticed that the *cost* parameter had to undergo an adjustment, which is common in the methodological construction by analysis with multi-criteria. As stated earlier, the costs of the various building components reported by manufacturers, suppliers and specialists vary greatly from their unit of measurement – cost per square meter; per cubic meter; per piece; by weight etc.

With the practical impossibility of directly converting the costs of each specific component into percentage values of the full cost of the work as described in the scale of notes of Table 4, it was decided to carry out the conversion from the simulation of a simplified constructive volumetric model (Figure 2). In order to perform the operation, at least two different types of generic components (*elements*) were chosen for the study layers (*structure*, *façade* and *partition* for the *internal closure*). As a prerogative, two quite opposite combinations were chosen regarding to the degree of adaptability generated in the construction models: [1] a monolithic structure, which, by definition, offers a very low degree of flexibility; and another, [2] an independent structure that offers a greater degree of flexibility.

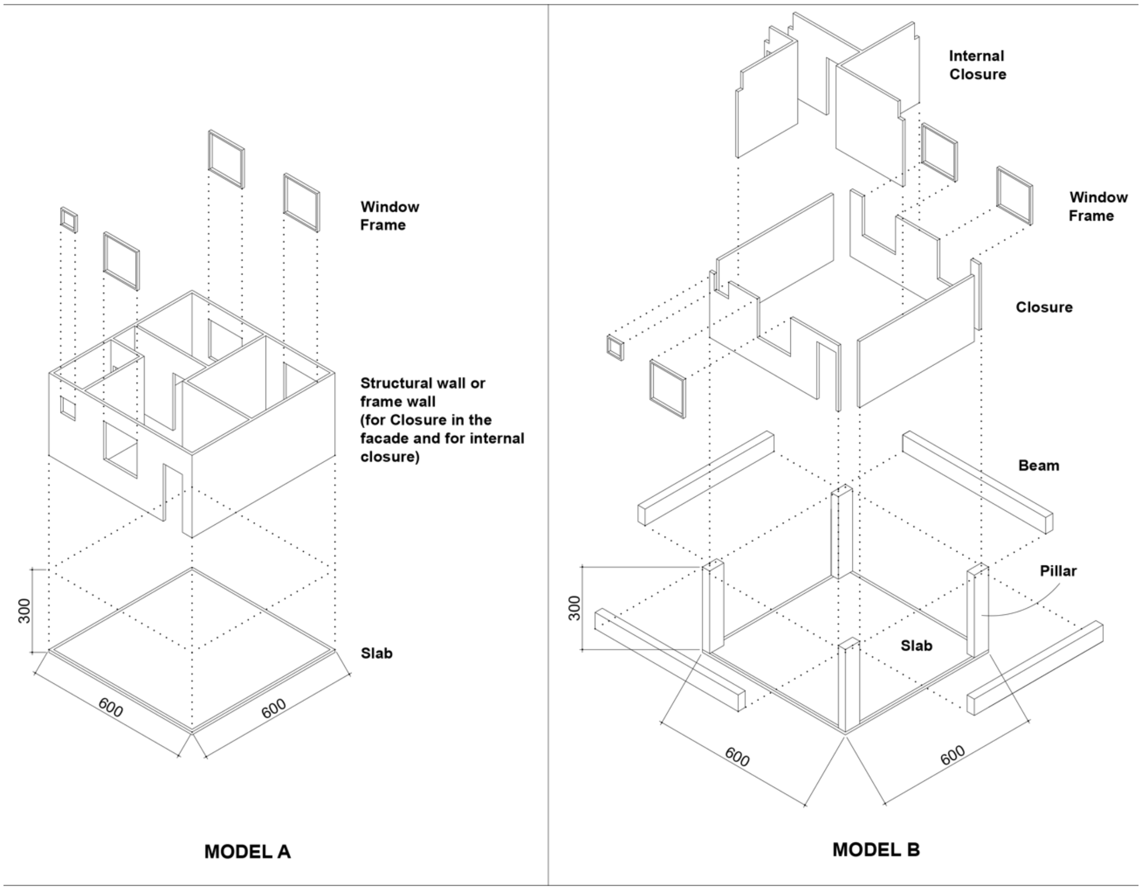


Figure 2 – Diagrams of the constructive models. Source: (Authors 2018)

Model A combines a type of slab cast on-site with structural wall for the *structure* layer. The structural wall also forms the *closure* element for the *façade* layer and the *partition* element for the *internal closure* layer. The model also presents the *window frame* as an element of the *façade* layer.

Model B combines a type of slab, beam and pillar more prefabricated (industrialized) for the *structure* layer. The *façade* layer has the windows frames as in model A. Furthermore, the *closure* elements of the *façade* layer and *partitions* of the *internal closure* layer are independent of the others.

The two models have the same final dimensions (6mX6mX3m), which makes possible to convert the cost of each element (generic component) in the way it is practiced in the market (per square meter, per cubic meter, by weight, etc.), in cost per square meter of construction. For this first conversion, the costs per square meter of construction defined by CUB-Sinduscon[5] was used as reference maintaining the average percentage values per *layer* or *element* as defined in Table 4. For example, the cost of the *structure* layer corresponds in average to 30% of the total cost of the work; the cost of the *closure* element of the *façade* layer corresponds to 7% and that of *window frames* 13%. This is regardless of the specific component chosen.

1.4 Assessment and weighting values

As well as for the evaluation values (assessment) defined in section 1.2, a scale with 4 levels was also defined for the weighting values: [1] unimportant; [2] slightly important; [3] important; [4] very important (Table 5). The tool under construction will present a score for all the constructive components under study, but proposes that the user assigns weighting to the parameters, precisely because in each context and depending on the decision-making criteria, some parameters may weigh more than others, even if the adaptive capacity of the building is desired.

Table 5 – Evaluation parameters, assessment and weighting scales, and scores per specific constructive component. Source: (Authors 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)									

The final score (S) of the component relative to its degree of flexibility or adaptive capacity in the building will be, for each user and scenario studied, calculated by the sum of the multiplication of the evaluation value (A) by the assigned weight factor (W) attributed to each parameter.

$$S = W1xA1 + W2xA2 + W3xA3 + W4xA4 + W5xA5 + W6xA6 + W7xA7 + W8xA8 + W9xA9 + W10xA10$$

2.0. DATABASE

This research has mapped, built and structured, within a database, several Brazilian constructive components employed or capable of being employed, in housing production, with any standard of finishing. For each component, the systematization of information is restricted to the 10 parameters of evaluation of its flexibility. Table 6 illustrates this mapping with the drywall component of the *internal closure* element. The majority of the information has been sought from the respective manufacturers and suppliers, or from experts in the field.

Table 6 – Example of evaluation parameters to the drywall component. Source: (Authors, 2018)

LAYER	ELEMENT	COMPONENT	PRODUCT	PRODUCER	AVERAGE COST	LIFESPAN (YEARS)	WORK EXECUTION TIME
INTERNAL CLOSURE	PARTITION	DRYWALL	DRYWALL STANDARD	KNAUF	110BR/ m2	FRAME: ≥ 100 BOARD: ≥ 30	10% TOTAL TIME

MINIMUM MODULE (cm)	MAXIMUM MEASURE (m)	CONNECTION TYPE	MANPOWER	TOOL/ EQUIPMENT	REAPPROVEMENT POTENTIAL	MODIFICATION POTENTIAL
MULTIPLE OF 20	3,6	THIRD PIECE	SKILLED LABOR	SPECIALIZED AND PURCHASABLE	< 30%	UNFEASIBLE

In order to initially feed the database, structural components more commonly used in Brazilian housing production were chosen, such as: [1] *on-site* cast concrete structures (pillar and beam or wall-concrete systems); [2] structural masonry (with ceramic or concrete blocks); [3] metallic structures (sections with shape H, tubular or rectangular, in addition to steel frame); [4] precast concrete structures (square, rectangular and circular section, in addition to concrete structural walls); [5] *on-site* cast slabs: solid, mushroom, ribbed or pre-stressed; and prefabricated slabs with beams, lattice work, trellised or alveolar panels.

In the case of the components of the other layers, the most utilized systems in the construction of non-residential buildings, but which could be adopted for such a function, have also been mapped.

In the case of *façades*, different types of *prefabricated* concrete, ceramic, metallic or *on-site* walls and panels have been classified. Similarly, research has also been performed on various *internal closure* components for *partitions* (internal masonry walls with various materials, dry wall or wood frame), *linings*, *raised floors* and *shaft closures* in the most diverse variations of materials and modes of execution.

The database under construction will include a selection of the main components available in Brazil, for all layers of the building, except for *terrain* and *furniture*. All the components will include scores attributed by the tool under construction and refer to the parameters of evaluation. This will enable the user in the decision-making process, to cross-reference, assigning weight to the most important parameters for the scenario being studied.

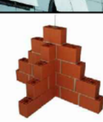
3.0. CASE STUDY: PARTIAL VERIFICATION PROCESS AND APPLICATION OF THE TOOL

In order to test the tool in development, verify its partial validation and compare the degree of flexibility of some constructive components of the same function, there was an attempt to apply it to some known cases.

To exemplify the procedure, the specific components were chosen as shown in Table 7.

It should be emphasized that the evaluation of a specific constructive component is not, at this moment, linked to its combination with another component, nor to a specific scenario. Thus, scores were assigned from the database under construction and according to the scale of scores previously presented in Table 4. These are as shown in Table 7, below.

Table 7 – Application example of the tool in development. Source: (Authors 2018)

ELEMENT	PRODUCT	PRODUCER	PICTURE	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.	SUBTOTAL
SLAB	PRECAST CONCRETE	INCOBRAZ		4	4	2	1	2	2	3	3	1	1	23
	ALVEOLAR CONCRETE	PRECON		4	4	4	1	4	3	2	2	3	2	31
PILLAR	PRECAST CONCRETE	PRECON		2	4	3	3	4	3	2	2	2	3	27
BEAM	PRECAST CONCRETE	PRECON		2	4	3	3	4	3	2	2	2	3	27
FRAME WALL OR STRUCTURAL WALL	SOLID CONCRETE	IN LOCO		4	4	4	1	1	1	1	1	1	1	19
CLOSURE	CERAMIC MASONRY	BRAÚNAS		2	3	2	1	3	2	3	3	1	2	22
	AQUAPANEL W384	KNAUF		1	2	4	4	4	4	3	3	2	4	31
WINDOW FRAME	PRÁTIKA STEEL LINE	SASAZAKI		3	2	3	3	1	2	2	3	3	2	24
	SOLUTA LINE	KAWNEER		1	3	3	4	4	4	2	1	3	3	28
PARTITION	CERAMIC MASONRY	BRAÚNAS		2	3	2	1	3	2	3	3	1	2	22

Considering the scores assigned in Table 7, and considering as an example of application of the tool an equal weighting factor for all the evaluation parameters, it appears that the *alveolar slab* presents a higher score than the *prefabricated slab*; the *precast structure* receives better evaluation than the *concrete-wall structure*; the *Aquapanel closure* has better flexibility performance than *ceramic masonry* and the *Kawneer Soluta window frame* line is also more flexible than the *Sasazaki line*. That is, the more independently the components behave in a construction (Model 2 in the Figure 2), allowing their easier replacement, more adaptable in time the building will be.

Since the weighting value will be assigned by the tool-user, logically the final score of each component can be changed according to the weight given to each evaluation parameter. For example, the parameters 4 to 10 can be seen in a more direct relation to the component's flexibility performance, due to its physical, structural, functional etc. nature. However, other parameters such as *cost*, *lifespan* and *work execution time*, may or may not influence the final evaluation, depending on other aspects of user demand.

It should be noted, however, that *cost* and *lifespan*, while apparently not determining parameters of the high flexibility performance of a specific constructive component, should be analyzed together, depending on the *future value* inherent in the adaptive capacity of the buildings.

CONCLUSIONS: RECOMMENDATIONS AND NEXTS STEPS

As presented earlier, this article was an important step in the development of an instrument to evaluate the adaptive capacity of Brazilian constructive components.

The following steps are to be taken:

- Better develop and structure the *layer*, *element, component* and *product* concepts, refining the description of the evaluation criteria of the adaptive capacity of Brazilian constructive components;
- Make necessary adjustments in the scales of the parameters evaluation and their variations, in the assessment and weighting scales;
- Simulate calculations to define classes of final scores for the parameters;
- Complete the structuring of the database;
- Study more complete and complex scenarios, seeking to better represent reality, thus better illustrating and discussing the applicability of the tool;
- Associate the tool with design strategy for flexibility.
- Discuss and evaluate the methodology together with potential users;
- Develop a digital graphic interface for consultation on database, tool application and visualization of results;

In the end, the research results will allow describe better about the adaptability of Brazilian constructive systems available nowadays. The tool is expected to offer the target users greater resources in the decision-making process towards the production of more adaptable buildings.

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ENDNOTES

[1] "Systems, subsystems and construction components adhering to the Open Building methodology" of the group LabFlex, based at the Centro Universitário Metodista Izabela Hendrix (CEUNIH), Belo Horizonte, Minas Gerais, Brazil, coordinated by Professor Rosamônica da Fonseca Lamounier. Participating in the project are Professors Ana Maria Ferreira Saraiva and Carolina Albuquerque de Moraes, researcher Rodrigo Rocha de Freitas and students Edésio Rocha Júnior, Ruben Gonçalves do Vale, Henrique Nogueira Pereira and Júlia Cristina Carneiro. The project has partnerships with Architecture and Urbanism Course of UFOP, with a research group supervised by professors Dr. Clécio Magalhães do Vale and Ms. Giselle Oliveira Mascarenhas, and PRAXIS-EA/UFMG group, led by Professor Denise Morado Nascimento.

[2] LabFlex Group is a research group of CNPq, created in 2018, based at CEUNIH, Belo Horizonte, Minas Gerais, Brazil, coordinated by Professor Rosamônica da Fonseca Lamounier. The central objective of the LabFlex is investigate the housing production in Brazil under the bias of the spatial flexibility, adaptive capacity of the buildings, being in this imbricated the decision power of the dwellers.

[3] Matthijs Prins, in his Doctoral Thesis (1992), defines a series of useful terms for the development of a system to support decision-making in design processes that involve flexibility and costs. His work has been useful in understanding the importance of parameters such as lifetimes (technical, economic or use-oriented) as well as costs related to both flexibility demand and its supply. The author also discusses the types of flexibility (re-allocation, re-use, replacement and repair) associated with the life of the building components.

[4] Stichting Architecten Research (Foundation Architectural Research), created by Habraken and some researchers, investors and industrialists in The Netherlands in 1960's.

[5] The Basic Unit Cost of Construction (CUB) is a monetary indicator of the construction sector that is calculated by Civil Construction Industry Unions throughout Brazil per federal state. It determines the overall cost of the work for legal compliance purposes. The costs per square meter are calculated monthly in different scenarios, considering use, formal architectural typology, scale and standard of finishing. For the year presented here, the values considered were those calculated for Minas Gerais in the base month June 2018, from the weighted average of the values presented for residential uses, considering different typologies (individual, with 4, 8 and 16 floors, in addition to projects of social interest) and standard of finishing (low, medium and high). The value per square meter found for the cost of each component was divided by this average to arrive at the cost of each component in percentage terms of the total cost of the work.