BUILDABILITY ASSESSMENT OF BRAZILIAN PROJECTS WITH INTERNATIONAL METHODS

AVALIAÇÃO DE CONSTRUTIBILIDADE DE PROJETOS BRASILEIROS COM MÉTODOS INTERNACIONAIS

EVALUACIÓN DE CONSTRUCCIÓN DE PROYECTOS BRASILEÑOS CON MÉTODOS INTERNACIONALES

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ABSTRACT
In the construction industry, it is usual to find that a design is harder to build than originally expected. This difficulty can be generally explained and assessed through the concept of buildability, which is also used to obtain better designs for projects. To assess buildability an assessment model well-adapted to the practices and aims of the local construction sector is required. This, in turn, demands consensus among industry players. This paper investigates the potential of applying and adapting existing buildability assessment methods to projects in foreign countries, serving as an easier route for general adoption. A case study was conducted in which the buildability of several Brazilian project designs was assessed, using foreign methods conceived for different places and contexts. It was found that the adaptation process required for the assessment was mostly successful, especially when the domestic designs matched the construction practices, size, and purpose of the original buildings for which the assessment method was conceived. However, the potential to direct designers to more buildable solutions was still limited in most cases.

KEYWORDS
Buildability; constructability; design optimization; construction industry.

RESUMO
Na indústria da construção, é comum descobrir que um projeto é mais difícil de construir do que o inicialmente esperado. Essa dificuldade pode ser geralmente explicada e avaliada através do conceito de construtibilidade, que também é utilizado para obter melhores projetos para empreendimentos. Para avaliar a construtibilidade é necessário um modelo de avaliação bem adaptado às práticas e objetivos do sector da construção local. Isto, por sua vez, exige consenso entre os players do setor. Este artigo investiga o potencial de aplicação e adaptação de métodos existentes de avaliação de construtibilidade para projetos em países estrangeiros, como um caminho mais fácil para adoção geral. Foi realizado um estudo de caso no qual foi avaliada a construtibilidade de diversos projetos brasileiros, utilizando métodos estrangeiros concebidos para diferentes lugares e contextos. Verificou-se que o processo de adaptação necessário para a avaliação foi bem-sucedido, especialmente quando os projetos domésticos corresponderam às práticas de construção, tamanho e finalidade dos edifícios originais para os quais o método de avaliação foi concebido. No entanto, o potencial para direcionar os projetistas para soluções mais edificáveis ainda foi limitado, na maioria dos casos.

PALAVRAS-CHAVE
Construtibilidade; otimização do projeto; indústria da construção

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RESUMEN

En la industria de la construcción, es común descubrir que un proyecto es más difícil de construir de lo inicialmente esperado. Esta dificultad generalmente puede explicarse y evaluarse a través del concepto de constructibilidad, que también se utiliza para obtener mejores proyectos para emprendimientos. Para evaluar la constructibilidad, es necesario un modelo de evaluación bien adaptado a las prácticas y objetivos del sector de la construcción local. Esto, a su vez, exige consenso entre los actores del sector. Este artículo investiga el potencial de aplicación y adaptación de métodos existentes de evaluación de la constructibilidad para proyectos en países extranjeros, como un camino más fácil para la adopción general. Se realizó un estudio de caso en el que se evaluó la constructibilidad de diversos proyectos brasileños, utilizando métodos extranjeros diseñados para diferentes lugares y contextos. Se encontró que el proceso de adaptación necesario para la evaluación fue exitoso, especialmente cuando los proyectos locales se correspondían con las prácticas de construcción, el tamaño y la finalidad de los edificios originales para los cuales el método de evaluación fue diseñado. Sin embargo, el potencial para orientar a los diseñadores hacia soluciones más constructibles aún fue limitado, en la mayoría de los casos.

PALABRAS CLAVE

Constructibilidad; optimización del proyecto; industria de la construcción.

1. INTRODUCTION

In the construction industry, the term fragmentation is often used to describe the knowledge gap between the design of a building and the construction process of the same building (MOORE, 1996). Good design practices, better communication between players, and the increasing use of technological resources, such as Building Information Modelling, are some of the solutions proposed to help to narrow this knowledge gap. Nevertheless, this issue is far from being solved.

The idea of buildability addresses the problem by defining the "ease of construction ", by which a less fragmented design process can provide better results for the overall project. Being studied since the 1980s, this concept has been developed and addressed from various perspectives. Measuring buildability as an attribute of the design is an idea that has found acceptance in some countries, often leading to more precise communication between stakeholders, when incorporated successfully and seamlessly in daily practice (OSUIZUGBO *et al.*, 2023; GAO; LOW; NAIR, 2018).

The buildability assessment methods available were often crafted with the intent of being country-specific, or even region-specific (JARKAS, 2016; ABREU, 2020). This is one of the factors that hindered a more widespread use and consideration of the buildability concept in the global scenario. This paper evaluates the use of well-studied, region-specific methods in a foreign territory, focusing on matching the specific design cases with the context used to derive the assessment methods.

Several designs of Brazilian buildings were evaluated through the BDAS and BAM buildability assessment methods, which are the better recognized and adopted methods for general construction both in the academy and the global market. Special attention was given to the adaptation processes necessary to accommodate the Brazilian design and construction context to that used to form the referred assessment methods, paying attention to the technology gap, which served as a basis for discussions and simulations.

It is noted that a BIM-based workflow promotes the participation of builders and environmental specialists in the initial stages of the project. Less polluting and more efficient projects can be developed by considering sustainability and constructability in the early design phases (AUGUSTO; BARROS; SOTELINO, 2023). Based on the results, and taking into consideration the continuous advancement of BIM design in buildability revisions in Brazil (PRAIA *et al.*, 2024), it was possible to discuss the feasibility of adapting such methods to generate procedures and recommendations for the review and optimization of local projects.

2. LITERATURA REVIEW

A common characteristic of the construction sector is the separation between the activities of design and construction of a building. Frequently, the architectural design is the first to be finished, over which subsequent designs such as structural and MEP are specified. The construction processes then start with the intent of following the design instructions as closely as possible. This sequence not only divides the activities but also the knowledge and responsibility of the parties involved. Professionals tend to work separately and maintain a low degree of communication throughout project phases, a trend often referred to as “fragmentation” (ARDITI; ELHASSAN; TOKLU, 2002). Thus, it is not uncommon that designers are unable to see the project from the contractor's perspective, and vice versa, exposing the project to further risks regarding productivity and quality of the delivered product (GRIFFITH, 1986; DING; SALLEH; KHO, 2020).

The study of buildability emerged as a way to address these fragmentation issues (GAO; LOW; NAIR, 2018) and the term can be defined as “the extent to which the design of the building facilitates ease of construction, subject to the overall requirements for the completed building” (CIRIA, 1983). This idea can be traced back to the Emmerson Report of 1962, a report commissioned by the British Government, which advocated for new relationship frameworks between clients, designers, contractors, and other professionals (FRANCIS *et al.*, 1999).

Today, it can be said that there are two different approaches to the concept, accompanied by different terminology: buildability and constructability. Buildability looks at the issue through a narrower scope, focusing on the general assessment and measurement of a design’s ease of construction. The more American term, constructability, tends to be used when other ideas are factored into the analysis, such as quality and environmental factors, looking beyond the design phase, up to project delivery (CHEETHAM; LEWIS, 2001). This generalization is not always true, which is evidenced by the interchangeable use of both terms in Australian publications (FRANCIS *et al.*, 1999).

Among the various definitions for the concept of buildability (or constructability), the guiding principles of simplicity, standardization, and clear communication (ADAM, 1989, apud CROWTER, 2002) tend to be a common ground for discussion.

2.1. Buildability assessment

Almost as old as the concept itself is the discussion about how to assess buildability. If certain factors are known to influence buildability, assessing them early in the project can help make decisions with lower cost than later. Initially, the idea of assigning a value to buildability was met with mixed reactions, as many saw the subject as too complex to base decisions on generic recommendations (AKINTOYE, 1994). More criticism came from designers who felt that rationalizing design in favour of construction practices could hinder design creativity, especially since "standardization" is one of the core principles of a more buildable design (MOORE, 1996).

Some of the main expected benefits of increasing buildability or constructability are summarized below (CII, 2012; WONG, 2007):

- Reduction of intensive work.
- Increased speed of execution.
- Better quality of the finished product.
- Reduction of rework.
- Increased productivity.
- Improved crew relationships.
- Higher client satisfaction.

It is widely accepted in the literature that intervening in favour of more buildable solutions is better done sooner rather than later in the project (SAMIMPEY; SAGHATFOROUSH, 2020), as it is much easier to alter decisions in earlier stages. However, buildability assessment is not a common practice in many parts of the world. The Brazilian construction industry, which is the primary focus of this study, does not see buildability as a determining factor for project feasibility and most of its players are not aware of the concept (ABAURRE, 2014).

2.2. Buildability assessment methods

Authors such as Wong (2007) and Zhang (2016) reference and compare several buildability assessment methods according to their attributes, such as "scope of application," "assessment principles," and "benchmarks provided." In this context, an assessment method is a set of procedures and rules to evaluate and, to a variable degree, score the buildability of a design. The various methods available in the literature can fit into different categories, with scope of analysis being one of the main points of differentiation. The scope determines whether the assessment looks at the whole design of the building or focuses specifically on certain subsets and systems.

Purely qualitative methods frequently rely on the opinion of a buildability specialist and do not provide repeatable results; that is, two specialists can significantly diverge about the constructability score of the same project (ESLAMI; SAGHATFOROUSH; RAVASAN, 2018). Today, with the increasing adoption of computer-aided design, automating buildability assessment is a possibility. However, it is made harder when it is heavily dependent on human subjectivity (DELEGREGO, 2017; ZOLFAGHARIAN, 2016).

As described by Maestri (2018), from the existing methods some of the more relevant are: BDAS - a system used to calculate the buildability scores of whole designs as a statutory requirement for government approval in Singapore (BCA, 2005); BAM - a system developed and used in Hong Kong to calculate buildability scores aimed at the high-rise sector of construction (WONG, 2007); a knowledge-based model for understanding conflict solving and automated buildability assessment (UGWU *et al.*, 2004); a multi-attribute system intended for assessment of a project according to six measurable principles (ZIN, 2004), and a quantitative method associated with a decision-making framework for early-stage assessment of the construction design (YANG *et al.*, 2003).

2.3. Choice between new and existing methods

In the literature regarding buildability assessment, new methods are often developed specifically for the case and context of the study. Wong (2007) used this process by incorporating the calculation procedures from Singapore's BDAS into his BAM method, as BDAS has already demonstrated applicability in the industry. However, Wong (2007) also introduced new variables, weights, and indices when proposing changes for BAM.

Developing a new method for each case study offers the advantage of increased specificity, as the calculation criteria can be tailored to the project context and validated by experienced professionals, as defined by the researchers (ABREU, 2020). However, this approach also sacrifices the learning and improvement already achieved by existing and validated methods. They require almost starting from scratch every time the project context changes significantly, such as location, purpose, or construction method.

One example where past learning is useful is in dealing with the differential perception of buildability among various professionals and parties involved in construction (RODRIGUES, 2005). In such cases, using methods that are already tailored can direct the assessment results to a middle ground. For instance, Lam *et al.* (2011) showed in the context of BAM that the increased use of prefabrication led to a perception of increased buildability for most professionals, which was an expected result. However, construction of projects that occurred in restricted spaces and at altitude presented challenges related to lifting structural components, which could be made more difficult without adequate planning and crew familiarization with the process.

Some authors suggest testing and using existing methods first to ensure a continuity of past and future learning, but this view is not often addressed in studies. One, for instance, is Ying and Pheng (2007) which advocated the use of BDAS in Chinese construction, where the subsequent modification of the method would only occur over time and according to user requests based on practice.

When deciding between a new method or the use of an existing one, the objectivity of the criteria must also be considered. Zhang *et al.* (2016) proposed a buildability calculation process that used existing and validated methods, arguing that they already cover most of the variables in buildability analysis. Furthermore, Zhang *et al.* (2016) added new variables of qualitative assessment only when the analysis would be enriched and facilitated by BIM data, that is, visual as well as documented information contained in BIM models. Delegrego (2017) demonstrated in addition that the use of BIM data can assist in the automation of assessment based on existing methods, its variables, weightings and computation procedures.

In summary, the choice between a new or existing buildability assessment method is a decision to be made by the researchers, considering their aims and the project context. A new method should bring more specificity to the analysis, while the use of an existing one can be a faster and safer route for adopting buildability considerations in projects. In either case, objectivity and applicability of the method must be ensured.

3. METHOD

The research followed the steps presented below:

a) The general concept of buildability was discussed with local construction companies of various sizes, emphasizing the potential benefits of buildability assessment in a project.

b) Various design documents of local building projects (6) were obtained, representing a general cross-section of construction practices in the region.

c) Assessment methods were selected from the literature to best fit the evaluation of such designs.

d) The selected methods were applied and adapted to the designs, and the results were discussed and summarized.

	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
Built Area	170 m²	1998 m²	4462 m²	8062 m²	6030 m²	3369 m²
Funding	Public	Private	Private	Private	Private	Private
Storeys	1	4	6	32	25	30
Purpose	Social Care Centre	Residential Class C	Residential Class B	Residential Class A	Residential Class A	Residential Class A
Modelling Process	BIM	CAD	BIM	CAD	CAD	CAD
Context Category	A	A	A	B	B	B
Assessment Method	BDAS	BDAS	BDAS	BAM	BAM	BAM

Table 1: Project Charactheristics

Source: Authors

3.1. Selection of project designs

Several meetings were conducted with representatives of institutions, including government agencies and construction companies restricted to the state of Santa Catarina in Brazil. The objectives of the research were explained, and the parties agreed to provide all necessary documentation. In some cases, access to engineers and personnel at the site was also granted, considering that most of the projects were either under construction or in the pre-construction phase. A more detailed description of this selection process can be found in the original studies (DELEGREGO, 2017; MAESTRI, 2018).

Project 1 is a model project for the state government. Projects 2 and 3 were selected from construction companies around Florianópolis, capital city of the Brazilian state of Santa Catarina, with a diversified construction market. Additionally, a more specific set of project designs (Projects 4 to 6) was obtained from a single company in Balneário Camboriu, a city known for its high-rise, luxury residential buildings, that hosts eight of the ten tallest buildings in Latin America. As a result, a total of six designs were evaluated, with some of their characteristics shown in Table 1. From the variety of projects selected, a diverse cross section of designs and characteristics were selected.

From the selected projects, the authors identified two categories of construction contexts:

A. General urban design: these are multipurpose buildings that use low-skilled labour, minimal machinery, and the most common materials in Brazilian construction, such as cast-in-situ reinforced concrete and non-structural brick walls. Such projects can be found in any urban area in the country.

B. High-rise littoral buildings: these are prevalent in the higher-end littoral areas and require specialized contractors, suppliers, and more qualified labour. Most of the construction companies working in this market are fully focused within that niche. Although the basic materials of category A are still used in such buildings, more technological and refined options are frequently incorporated.

3.2. Selection of buildability assessment methods

To select the best assessment method for each project, a broad spectrum of buildability literature was consulted, focusing on the different concepts and history of buildability assessment. The review started from academic theses and proceeded to referenced and correlated peer-reviewed articles on Google Scholar.

A pre-selection of buildability assessment methods was obtained from previous works that reviewed the method literature (MAESTRI, 2018; ZHANG *et al.*, 2016; WONG, 2007), namely: BDAS, BAM, UGWU, ZIN, YANG, ZHANG, JIANG, CII, CONPLAN. More information on each method can be found in the previously referenced sources (DELEGREGO, 2017; MAESTRI, 2018). Other methods exist but tend to be adaptations with still little practical validation or no significant innovation in calculation procedure.

Then, a process of elimination was conducted according to four criteria:

a) Breadth of scope: the method must assess the entirety of the building design;

b) Ease of use: the method must allow the assessment to be conducted with regular design documentation, delivering consistent results;

c) Context matching: the context from which the methods were derived must have similarities with the case study context categories of this research;

d) Practical use history: the method must have some form of market validation. This could range from continued adoption in a country to smaller local trials with results.

Most methods did not fulfil all four criteria above. Assessment procedures such as Ugwu (2004) and Jiang *et al.* (2015) were not selected because they concentrated only on the assessment of specific systems, components, and construction methods, not conforming with item (a) of the criteria.

Due to item (b), methods such as CII (1986) had to be discarded for not offering clear steps of assessment, focusing primarily on improving the processes for managing buildability. In addition, considering that Brazilian companies are mostly unaware of the concept of buildability, applying the CII method would bring challenges of its own because it depends on the collaboration of multiple parties. Other methods like Yang *et al.* (2003) were not eligible because they used complex procedures, such as fuzzy calculations, which do not produce consistent results among different practitioners. Due to Item (d) CONPLAN was eliminated as it was intended to be conceptual and was not calibrated or validated by real designs.

Method	Content	Scope of Application	Assessment Principles	Assessment Aspects
BDAS (BCA, 2005)	A system used to calculate buildability scores as a statutory requirement for goverment approval.	Virtually all new residential, commercial, industrial, and insitutional buildings, as well as major alrerations and additional works. There are some exceptions.	- Standardization - Simplification - Individual Integrated Elements	- Structural systems and roof systems - Wall systems (including finishing systems applied) - Other constructive features - Provision of bonus points for individual built in elements
BAM (WONG, 2007)	A system used to calculate buildability scores, aimed at the Hong Kong construction industry.	Virtually all new residential commercial, industrial, and institutional buildings, as well as major alterations and additional works. There are some exceptions.	- Standardization - Simplification - Individual Integrated Elements - Prefabrication	- Structural systems - Slab systems - Envelope systems - Roof systems - Internal wall systems - Finishing systems - Aspects of construction services - Construction elements Site-specific factors

Table 2: Comparison between the buildability assessment methods applied in this study
Source: Authors

After the elimination phase, two methods remained which fulfilled all four criteria, being the BDAS and BAM methods. Their positive aspects for the purpose of this research were the simple and deterministic calculation process, the use of pondering factors to weigh the significance of subsystems in the design, and the consideration of several building materials and construction methods. A brief comparison of their characteristics can be seen in Table 2.

According to criteria (c), the context category A designs were assessed through the Buildable Design Appraisal System (BDAS) method. Mainly developed by the Building and Construction Authority (BCA) of Singapore, its original intent was to reduce the country's dependency on foreign labour, with successful results throughout the years due to its widespread use in that country (POH; CHEN,1998; ONG, 1999; PHENG LOW, 2001). Passing a minimum BDAS score is now mandatory for almost every new design with a built floor area of more than 2000 m². The general urban buildings in the city of Florianópolis are best suited for this method. However, there are differences between the Brazilian construction industry and that of Singapore.

To factor in the technology lag between countries, the 2005 version of the rules and documentation was used (BCA, 2005), even though there are newer versions. That is because BDAS is being continuously tailored for the Singaporean industry, which is already dependent on off-site production and prefabrication, has the government actively pushing for an even lower dependency on manual labour through BDAS, among other measures. This scenario is already challenging for some Singaporean firms (GAO; LOW; NAIR, 2018). Therefore, the older and less strict version of the BDAS method was selected for this study.

Through the BDAS method, the value of buildability is calculated by dividing the design into construction systems, with scores attributed to each of them. The values are then weighted by their proportional presence in the project and their relevance to overall buildability. This is determined by the Labour-Saving Indices (LSI), according to the tables and rules provided in the method's documentation (BCA, 2005). Adding the individual results gives the final buildability score. The method is based on three principles: simplicity, standardization, and single integrated elements, the last of which refers to modular construction technologies.

In turn, the Buildability Assessment Method (BAM) was developed specifically for the context of tightly packed high-rise buildings in Hong Kong and is closely related to the developments in the city of Balneário Camboriu, which are represented by the three projects in context category B. The researchers who developed BAM tried to emulate the simplicity and exactness of the BDAS. One significant difference is that while BDAS was derived by regressing productivity data, BAM was crafted from structured interviews with construction professionals of different backgrounds (WONG, 2007).

The resources for BDAS can be found on Singapore's Building and Construction Authority website, including the legislation and its code of practice (BCA, 2005). Those for BAM come from academic publications outlining its construction and application (WONG, 2007; LAM, 2007; LAM, 2012). The resources are all in the English language.

In terms of calculation procedures, BAM and BDAS are similar methods. For projects 1, 2, and 3, the BDAS score was assessed according to the method's manual. The design was divided into three systems: "structural system," "wall system," and "other buildable features," with the addition of bonus points when eligible. The limiting top value is 50 for structural systems, 40 for wall systems, and 10 for other buildable features. Accordingly, projects 4, 5, and 6 were assessed with BAM. This method divides the design into nine building systems plus a "free score" of up to 10% of the maximum possible score.

Where specifications had to be adapted, the most similar Brazilian match was sought. If that was not possible or deemed unsuitable, the differential score associated with that section was ignored in the computation but discussed in the analysis. After obtaining the initial scores for each design, some thought experiments were conducted where qualitative characteristics of each project were modified, mainly materials specification and construction methods, in accordance with regular industry practices. The intention was to give plausible suggestions to enhance the buildability of the designs according to the formulae. Results were, then, compared.

4. RESULTS AND DISCUSSION

The assessment process is summarized below.

4.1. Project 1

It is a standardized design for a social assistance centre, with the architectural design presented in Figure 1. Since it has less than 200m² of floor area, it is legally exempt from BDAS compliance in Singapore. Therefore, it is also an evaluation of the method's applicability in smaller buildings.

According to the BDAS manual, the design can be best described as an institutional, one-story reinforced concrete building with concrete cast-in-situ. The wall systems are made of ceramic bricks with finishing. The materials and construction practices implied by the design are standard in Brazil, but very labour-intensive compared to East-Asian standards.

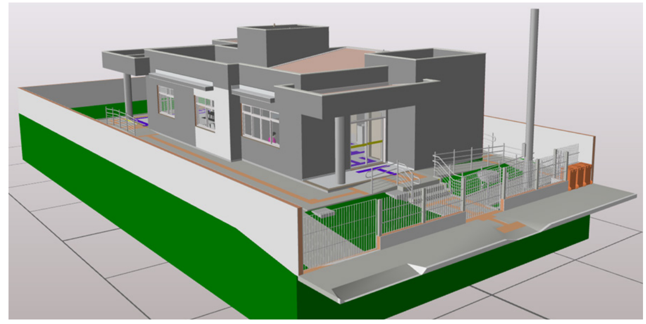

Figure 1: Architectural design of Project 1 in BIM
Source: Authors (Design provided by LaBIM-SC)

The assessment process was straightforward as most values and qualitative data were automatically extracted from the BIM model. The structural and wall scores are respectively shown in Table 3 and Table 4.

No score was attributed to the "other" category because it mostly relates to standardization within a design, and the building was too small to meet the standardization criteria as specified.

The use of cast-in-situ technology was heavily penalized by BDAS, so other design alternatives were explored. The recommended changes for increased buildability were to replace the ceramic roof tiles with metallic tiles and the cast-in-situ concrete with prefabricated beams and columns (Table 5). These structural options are common enough to prevent disruption or avoid insecurity to the project if adopted.

Floor	Description	BDAS Adaptation	LSI	Area (m^2)	Coverage	Score
Ground floor	Cast in situ concrete beams and columns	Two-directional beam (slab/ beam 2) ≤ 10)	0.50	170.5	34%	8.51
Service floor	Cast in situ concrete beams and columns	Two-directional beam (slab/ beam 2) ≤ 10)	0.50	170.5	34%	8.51
Roof	Ceramic tiles on timber frame	Tiled roof on timber beam	0.75	160.0	32%	11.98
			Total	501.0	100%	29 (58% of max.)

Table 3: Structural System score of unmodified Project 1
Source: Authors

Floor	Description	BDAS Adaptation	LSI	Lenght (m)	Coverage	Score
Ground floor	Ceramic brickwall	Brickwall	0.30	96.1	61%	7.34
Attic	Ceramic brickwall	Brickwall	0.30	60.35	39%	4.66
			Total	155.4	100%	12 (30% of max.)

Table 4: Wall system score of unmodified Project 1
Source: Authors

Floor	Description	BDAS Adaptation	LSI	Lenght (m)	Coverage	Score
Ground floor	Precast concrete slab	Precast slab only	0.75	170.5	0.34	12.76
Service floor	Precast concrete slab	Precast slab only	0.75	170.5	0.34	12.76
Roof	Metallic roof over timber frame	Metal roof on steel truss	0.85	160.0	0.32	13.75
			Total	501.0	100%	39 (78% of max.)

Table 5: Structural System score of Project 1 with combined adaptations
Source: Authors

In addition, the ceramic brick wall system was replaced by drywall on the internal areas of the ground floor (Table 6). Although this adaptation would require further analysis of acoustics, thermal comfort, and general space usage, it was deemed a feasible suggestion and would not pose any technical or financial challenges to the project.

Floor	Description	BDAS Adaptation	LSI	Lenght (m)	Coverage	Score
Ground floor	Ceramic brickwall	Brickwall	0.30	30.4	0.2	2.35
Service floor	Drywall	Dry partition wall	1.00	64.6	0.42	16.64
Attic	Ceramic Brickwall	Brickwall	0.30	60.3	0.39	4.66
			Total	155.4	100%	24 (59% of max.)

Table 6: Wall system score of Project 1 with combined adaptations
Source: Authors

By implementing these design changes, the original buildability score of 41 for Project 1 could increase by 53%, reaching 63 points, which is above the BDAS legal threshold score of 60 required for the approval of institutional buildings.

For the following projects, the individual system tables are omitted as the calculation process followed a similar procedure to Project 1.

4.2. Project 2

The second project consists of six identical residential buildings on the same land area, along with shared leisure and service areas. As the buildings are identical, the analysis was restricted to a single design.

The structural system is made using precision structural concrete blocks, precast slabs, and cast-in-situ beams. This is a popular method in Brazil, especially for lower-end housing construction. The total structural system score was 38, which is 77% of the maximum value. In the assessment, the structural bearing brick walls were included in the wall system, as prescribed in the BDAS methodology. This was applicable to the entire building, with the only differentiation being whether it was an external or internal piece of wall. The total wall system score was 15, which is 37% of the maximum value. This low buildability score of the wall was expected as the method is very labour intensive. For the "other" score, the productivity benefit stemming from the repetition of the layout on multiple floors was accounted for, resulting in the addition of 2 points to the final score.

4.3. Project 3

The third project is a residential building composed of two annexed towers with underground garages. At the time of the calculation, not all design specifications had been completed, including the structure. Thus, the first assessment was already carried out on a proposed design for better buildability.

From the architectural design, the wall types were divided into curtain walls, concrete walls, and ceramic brick walls. These categories were found in BDAS, and the calculation was straightforward. The calculation was also made easier using BIM quantity take-off functions. The total wall system score was 34% of the maximum.

All the structural elements were accounted for as prefabricated concrete pieces. Steel frames were not considered because they are still unusual in Brazil for context category A buildings. The focus of BDAS on steel structures is an indication of cultural differences between the construction industries and the governments of Brazil and Singapore. Metallic tiles were applied to the roof. This scenario resulted in a high buildability score of 48 out of 50 (96%).

4.4. Projects 4-6

Projects 4-6 are luxury high-rise buildings designed and built by the same construction company. The architectural facades of Projects 4, 5, and 6 are shown in Figure 2.

Calculating the BAM score was more challenging than for previous designs as context category B buildings use a wider variety of materials and construction methods, which had to be fit into the relatively few categories of BAM. For example, finishings such as plaster, PVA coat and

PVA based paint; plaster, PVA coat or texture with acrylic paint; plaster and acrylic paint; and plaster with acrylic paint and signaling strips were adapted to "traditional plaster and paint" as the only available option in BAM.

Figure 2: Façades of buildings from projects 4,5 and 6, respectively
Source: Company X

The higher number of factors to be considered in BAM compared to BDAS and the fact that the quantitative information was obtained mainly from CAD drawings also increased the overall laboriousness of the process.

Table 7 summarizes the scores attributed to project designs 4,5 and 6 after the assessment, with almost no difference in the final buildability scores, despite differences in layout and size. In such cases, the similar selection of materials and construction methods has essentially defined the buildability scores for each system. Also, an optimized scenario for Project 6, included in the table, was explored as to give it a score greater than 80% of the maximum.

During the optimization process, Project 6 underwent the following design modifications:

- Adoption of prefabricated concrete elements, such as prefabricated stairs, slabs, toilets, and shafts, allowing for more speed and ease of execution.
- Greater standardization of components and structural elements.
- Change of the internal brick walls to drywall.

Since Project 6 initially had a very similar buildability score compared to Projects 4 and 5, the suggested changes above could also be applied to the latter designs with similar results.

Table 8 and Figure 3 contain a summary of the results obtained from the assessment of each design. The "Adapted Systems" column shows the options deemed the best fit for the actual construction scenario. Additionally, the "Observations" column summarizes and compares the most significant assumptions and observations obtained from the buildability assessments.

System	Project 4	Project 5	Project 6	Optimized Project 6
Structural	52.39	52.39	52.39	57.71
Finishing	1.23	1.23	1.22	1.22
Building servi-ces aspects	1.54	1.55	1.55	2.26
Building elements	1.82	1.88	1.89	2.56
Site specific factors	9.29	9.52	9.52	9.29
Total	66.27	66.57	55.57	73.05
Percentage of maximum	74%	74%	74%	81%

Table 7: Partial Buildability Scores of projects assessed through BAM
Source: Authors

https://doi.org/10.29183/2447-3073.MIX2025.v11.n1.29-44

Project Index	Adapted Systems	Buildability Score	Observations
1	Cast-in-situ concrete beams and columns Ceramic tiles on timber frame Brickwall	41	Less than 2000m2 of floor area, would be legally exempt of BDAS in Singapore. Although a repeatable standard design, no learning process is factored in the score. The use of cas-in-situ technology was heavily penalized by BDAs; Using metallic roof tiles and prefabricated structure of beams and columns, the score would increase to 63.
2	Precast slab only Metal roof on timber truss Precision block wall	53	Consists of six identical residential buildings in the same land. There was no socre change due to the replicability of the design. The roof support is made of timber but was adapted to "steel truss" as the closest approximation. No suggestion for buildability improvement was offered due to the inflexibility of this construction method.
3	Full precast One-directional banded beam Metal roof on steel truss	82	At the time of assessment, the structural system and toher characteristics were only propositions. The calculation was eased by the use of BIM qantity take-off functions. It was decided not to use steel for this scenario because it is not yet usual in Brazil for this type of building. The access ramps were factored in the analysis as "One-directional banded beam". The structural project was later designed with a waffle slab solution, with a buildability score of approximately 42.
4, 5 & 6	Structural: Cast-ini-situ reinforced concrete frame and slab. Walls: Curtain wall, Brick, Traditional Plaster and Paint (Site applied), Tiling on Screed. Ceiling: Traditional Plaster and Paint (Site applied); No finishes (Fair Face). Floor: Granite; Tiling on Screed (Site applied), Tiling on Screed (Stie applied) Roof: Metal Roof Decking - Composite type.	66 - 67	The materials and construction methods adopted are practically identical for each building. There was little diversity of options to be chosen for some systems, including ceilling and floor finishing methods. The ceiling areas of the garage do not have finishing, this contributed positively with the BI of 1,00. There was a clear sequencing of activities with the vertical design adding to the simplicity attribute. The level of structural standardisation within floors and from floor to floor was no very significant, lowering the BS relarred to standardisation. This included free span lenght, story height and beam and column dimensions, Projects were well cordinated, and components could easily be installed on site with simples instructions. Also, designs were well adapted to be built according to the local expertise of workers and partners. The difference in design, volume and shape of the buildings do not interfere significantly with the BAM buildability score.

Table 8: Summary of results and observation of the buildability assessment using foreign methods

Source: Authors

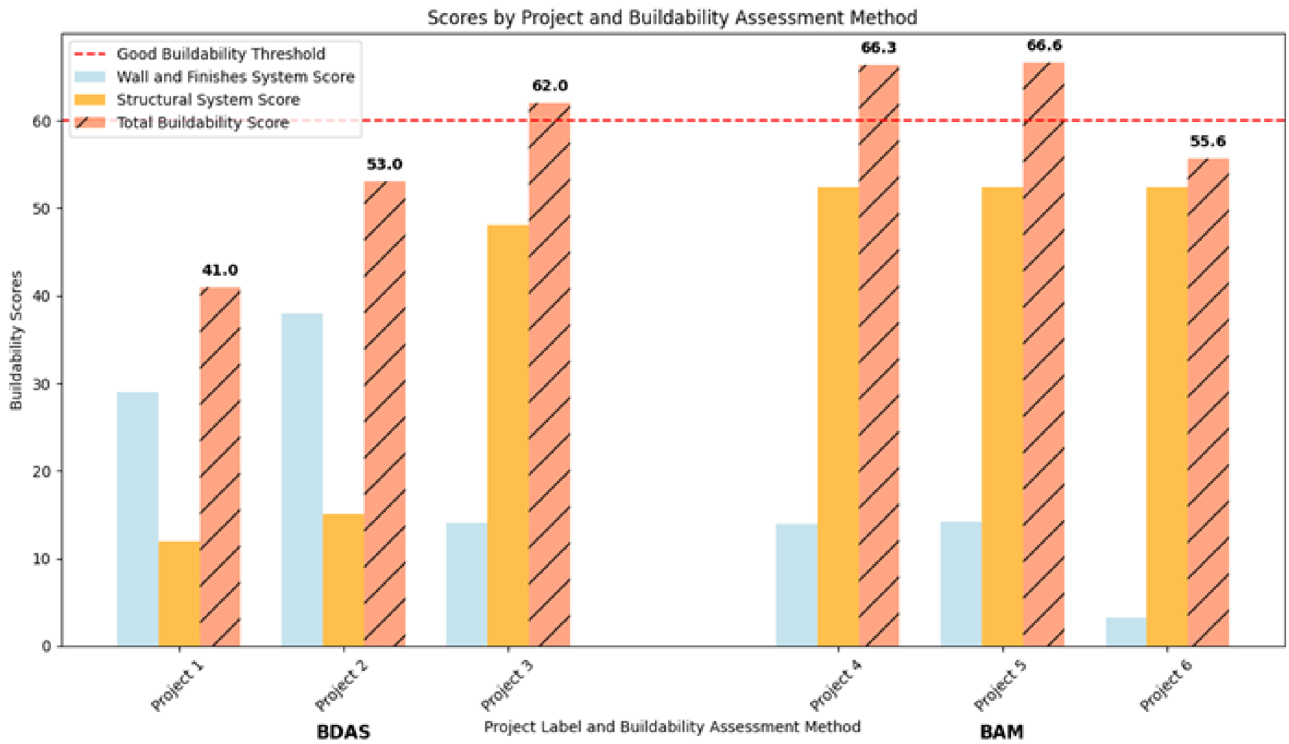

Figure 3: Graphic comparison of unmodified buildability scores and assessment methods for each project.

Source: Authors

5. DISCUSSION

The study found that both the BDAS and BAM assessment methods were applicable to the Brazilian projects studied, with no major hindrance in using the standard tables and calculation procedures specified in the methods' documents. Occasional adaptations were required, such as finding the best match for finishing materials that do not have an exact fit to the Brazilian construction market. The potential problems arising from the technology lag of the Brazilian construction market were successfully avoided by choosing older versions of the methods.

However, the study also found some limitations of the methods. BDAS was found to be rigid in giving buildability scores for repeatability, only considering repetitions within the same building. This was evident in Project 1, a repeatable public building, where the learning curve that would naturally be associated with its sequential construction should grant some additional repeatability score. For BAM, which focuses on bespoke high-rise buildings, this consideration did not seem so relevant.

The biggest limitation of the methods was their lack of support in aiding and influencing redesigns. This is important when there is enough flexibility regarding budget and technical requirements in the beginning of a project, and changes can be made without excessive disruption on budget and schedule expectations. The study found that gains in buildability score could be achieved by changing the structural and wall construction methods to more usual options for the Brazilian sector, as was the case for the designs of Project 1 and 3.

For Project 2, however, any change in construction method preconized by BDAS would mean big changes in cost, schedule, and labour qualification. Constructions using structural precision blocks have a reputation for being inflexible and it is hard to increase such designs and keep them financially sound. When evaluated by BDAS, very few optimization options are possible, and none that would justify any change. Thus, this is a construction method that is bound to receive a low buildability score, regardless of other design optimizations.

The study also found that the methods were unable to quantify the buildability differences dependent on the shape and layout of already completed designs. The equal scores attributed to projects 4 to 6 showed that significantly different architectural decisions and construction details, such as external rounded areas and openings, were not adequately considered in the assessment. Thus, there is still much room for improvement in the most adopted buildability assessment methods by looking at spatial characteristics of the designs that go beyond standardization of distances and object dimensions.

Keeping in mind the limitation that the present work does not have the pretense of making a general assessment of current Brazilian constructability standards, the generalized results show a construction industry that is still emergent and in evolution in respect to the South Asian market and, as seen from Table 8 and Figure 3, barely or not at all eligible for a theoretical construction and competitive for receiving the label buildable construction in a global market.

To address this issue, one possible solution is to explore new methods for computing differences in shapes, sizes, openings, and finishes of the projects, using BIM data. By leveraging the openBIM IFC model, automated procedures could be developed to improve upon these factors while retaining the original features of existing assessment methods. It is recommended that further research be conducted in this area to bridge this gap in buildability literature.

Nevertheless, the study found that the methodology of assessment proposed in the paper offers great potential for qualitative optimization of materials and construction methods when performed early in a project, as was the case for Project 3. Therefore, the research recommends the adaptation and application of the BDAS and BAM as a potential support tool for early design decisions.

6. CONCLUSION

The research investigated the adaptation and implementation of international buildability assessment methods for the Brazilian construction industry. This was accomplished by matching the methods developed in foreign countries with the socioeconomic and market context behind each project design. A total of six projects were obtained from local construction companies in the state of Santa Catarina, Brazil, and then divided into two context categories: the first containing more general construction designs found in Brazil, and the second focusing on luxury high-rise buildings in littoral areas. Two buildability assessment methods were chosen from the literature based on specific criteria: BDAS to evaluate the projects in the first contex t category, and BAM for those in the second.

For each design, a buildability score was calculated. The process was mostly straightforward, attributing values according to the methods' manuals and reference tables. Adapting the original Brazilian specifications to those of the methods proved feasible. However, the methods were heavily biased towards prefabricated structures and finishes, penalizing the usual construction methods in Brazil and providing little assistance in improving those designs.

In other cases, it was found that the assessment oversimplified or ignored design decisions, particularly those related to shapes and layouts, which are sure to impact buildability. Generally, the designs received low or average buildability scores, as defined by each method. Attempts were made to use the methods' criteria to optimize the design, which proved effective for some designs but impossible for others.

Considering both the benefits and drawbacks, this research recommends using the proposed adaptation methodology of buildability assessment as a powerful tool for qualitative design optimization during the early design stages, including materials and construction method selection. There is still room for improvement in the adaptation methodology, and further research focused on early design support tools, the interaction with BIM, and local adoption is encouraged.

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