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"If you cannot measure it, you cannot manage it" – Buildability and Performance-based appraisal

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ABSTRACT

Buildability has been a perennial issue in the Architecture, Engineering and Construction (AEC) industry, with advocates arguing for positive benefits related to cost, time, quality and safety in project development. Evidently, buildability has been seen to offer broader industry gains and efficiencies, and its assessment has been encouraged as a criterion in the regulatory approval process of some countries. If buildability offers positive outcomes in project development, how can these be introduced, measured and assessed in the project development process? In the absence of mandated buildability appraisal systems, does the industry develop its market mechanism to leverage the gains that its consideration offers? Detailed coverage is systematically reviewed with the aim to identify the current trends in buildability. Based on a comparative analysis of existing assessment models of buildability, this paper reviews the suitability of this model, by highlighting the potential difficulties of its adoption, against the current deregulated and highly performance-based context of the Australian construction industry. The outcome of this paper is to provide a research methodology to develop a buildability assessment tool for Australia.

1. Introduction

Buildability has been a perennial issue in the Architecture, Engineering, and Construction (AEC) industry, since the 1970s. The use of the term has increased in part due to the perception of confrontational attitudes between client, consultants and contractors (Naoum and Egbu 2015). Several approaches have been developed to identify different components of buildability from pre-project planning to the disposing phases of a building or building system. In addition, productivity, cost and sustainability performance have been added as indicators to measure buildability. However, the difficulty of developing objective criteria remains as one of the biggest hurdles for the wider application of buildability practice. If buildability offers positive outcomes in project development, how can it be introduced, measured and assessed in the project development process? In the absence of mandated buildability appraisal systems, does the industry develop internal market mechanisms to leverage the gains offered by buildability consideration? Using a comparative analysis of existing models of interpretation of buildability this paper reviews the suitability of this approach against the current deregulated and highly performance-based context of the Australian construction industry.

2. Buildability – Concept and Measurement

Reportedly, the term buildability was initiated in the UK and constructability in the US in the 1960s, though with a narrowness in scope in being confined to the design process (Bambang 2006; Wong et al. 2007; Zhong and Wu 2015). Both terms are used to illustrate the improvement in AEC industry performance. In general, buildability is used as a full word to explain efficiency in the whole process, and constructability related to the construction processes and means and methods for the construction phase (Kuo and Wium 2014; Wong et al. 2006). According to Douglas (2008), buildability is one of the key focuses in a constructability review. Wong et al. (2007) concluded that despite the different interpretations of buildability and constructability, the design stage is said to be the critical phase in the implementation of buildability and constructability. For the identification of criteria for buildability, different authors propose various methodologies in its application. These range from initial idea/concept, type and characteristics of a project, business model, country, location, access, legal requirements, the experience of the owner, consultant design team qualifications, procurement methods for all stages, duration of the stages, contractors teams qualifications, utilisation, maintenance and disassembly. Indicators of performance across such criteria can be identified to measure global buildability of a project.

Some researchers, for example, Wong et al. (2007) have identified not only the issue of consensus of definition but also where along the project lifecycle should criteria be established. Overlaid with this is the changing and dynamic nature of potential indicator evaluation in the construction industry. These include mandates for sustainability (Brennan and Venigalla 2016; Zhong and Wu 2015), and safety (Yustisia 2014) in the construction sector. Other factors include procurement methods (Love et al. 2008; Naoum and Egbu 2015; Osipova and Eriksson 2011), developing technologies (Wang et al. 2016), and evolving construction means and methods (Kannan and Santhi 2013) requiring concurrent buildability measures.

3. Buildable design score – Singapore’s experience

3.1 Buildable Design Appraisal System (DBAS)

A significant hurdle to the implementation of the buildability concept is the difficulty in measuring its tangible benefits to the construction industry. Researchers including Song and Chua (2006) and Jarkas (2015) highlighted that the construction industry still lacks methodologies for buildability measurement analysis. Pioneering in this area is the work undertaken by Singapore’s Building and Construction Authority (BCA 2005) which introduced the Buildable Design Appraisal System (BDAS) aiming to assess “the influence of design on site efficiency by means of calculating the buildable scores of the design”. Some researchers (Jarkas 2010) have argued that Singapore’s BDAS is the only tool available to quantify the effect of buildability on construction productivity. The BDAS was originally modelled after the Takenaka Corporation's in-house buildability appraisal system (Poh and Chen 1998) and has undergone several iterations. The BDAS focuses on three main principles of buildable design, known as the 3S:

1. Standardisation - repetition of grids, size of components and connection details
2. Simplicity - uncomplicated building construction systems and installation details; and
3. Single integrated elements - combining related components together into a single element that can be prefabricated and installed on site.

The appraisal system computes the buildable score of a design from three areas, namely the structural system, the wall systems, and other design features. As these account for a major proportion of site labour used in a project, it is considered that such an appraisal system is a useful tool in assessing buildability. In addition, bonus points are obtainable for these three parts for the use of productive technologies available in the industry. Table 1 provides a detailed breakdown of Singapore's Buildable Appraisal system.

1. The buildable score of the structural system focuses on the complete structural system of a building: $45[\Sigma (As \times Ss)]$ + Structural Bonus Points, where a range of labour-saving indices is set for the precast concrete system, structural steel system, cast in situ, and roof system. If various structural systems (As) are used for different areas of a building, the percentage covered by the structural system is used to multiply their corresponding labour saving index (Ss) to arrive at the score.
2. For the wall system, the method of computation is $45[\Sigma(Lw \times Sw)] + C$ + Architectural Bonus Points. It is the percentage areas covered by the external and internal wall system (Lw) multiplied with the corresponding labour saving indices (Sw). Bonus points for labour-saving structural systems are obtainable but are subject to BCA's assessment.
3. Other design considerations are assessed at the micro level (Poh and Chen 1998). Points are given for each labour saving method/design consideration adopted, up to a maximum of 10 points.

	Range of choices	**Mandatory components**	**Bonus**
Structural system (45%)	Precast concrete system (ranging from full precast to precast of single component (i.e. slab) Structural streel system Cast in-situ system Roof system (non-RC)	Use of welded mesh for cast-in-situ concrete floor (>65%)	Recommended precast joint types Mechanical connection for precast column joints, beam joints, wall joints Innovative structural steel connections High strength concrete (>grade 70, at least 5%) Self-compacting concrete (>30%) Diaphragm wall
Wall system (45%)	Dry wall Curtain wall/glass partition/dry partition wall/prefabricated railing	Dry partition wall for all internal dry areas	Design without high voids[1] Design without complex form[2]

	Precast concrete wall Lightweight concrete panel Cast in-situ RC wall Precision block wall Brick wall/block wall		
Other buildable design features (10%)	3 most common sized columns, beams, door structural openings and windows (Standardisation) Repetition of floor-to-floor height, structural floor layout (vertical) and horizontal grids Multi-tier precast columns, precast meter chambers, Prefabricated MEP risers, No screeding for any flooring, single floor level without drops/kerbs within apartment unit **Single Integrated Components** Prefabricated bathroom units Prefabricated household shelter Precast external wall with cast-in windows	Typical stories standardized to either 2.8m, 2.975m, 3.15m, 3.3m, 3.5m, or 3.6m height	**Finishes & Dry Construction** Drywall for party wall, wet areas Engineered timber flooring Carpet, vinyl and raised floor Engineered stone flooring finishes **Mechanical, Electrical and Plumbing (MEP)** Prefabricated and pre-insulated duct for air-conditioning system Flexible pinker dropper Flexible water pipes Common M&E bracket **Modern Construction Systems** Prefabricated prefinished volumetric construction (PPVC) Engineered Timber (CLT)
[1] High voids refers to heights that are more than 9m. Different percentage of high void is given different bonus points, the less percentage, and the more points to be given. [2] Complex forms refer to building façades that are tilted, tapered, twisted or of free form. A design that does not have complex form will get a maximum of 3 points.			

Table 1: Detailed breakdown of Singapore’s buildable appraisal system

Note: each element (items in the Bonus excluded) from the above has its correspondent's labour saving index). (Source: Adapted from BCA (2015))

3.2 BDAS on productivity, cost and sustainability

Productivity

Contractors in Singapore are required to operate a biometric authentication system at their project site to collect construction productivity data of the building works. Such data is used to assess the productivity level of the construction work. An early study was undertaken by Poh and Chen (1998) in which empirical results from 37 completed building projects in Singapore provide strong support that a larger buildable score results in greater labour efficiency, and higher site labour productivity. In the residential sector, a significant linear correlation between labour productivity and the buildable score is observed. Similarly, Low (2001) showed positive relationships between buildability, structural quality and productivity.

Such correlative support of the impact on buildability and productivity suggests that effective measuring mechanisms can be of benefit in the early design stages of a project. In Australia, with its performance-based regulatory approach where design resolution is transferred to the market, tangible productivity gains may be garnered with the adoption of effective buildability measures that may inform design choices. Furthermore, Australia has embraced building procurement systems that integrate design and delivery into a single package. This procurement approach with its single-point of responsibility may be leveraged via authentication data that brings together design decisions and efficient construction and labour management processes. Constructability research which investigates performance-based regulatory regimes and a broader range of project delivery mechanisms and the influence of such factors on the applicability of measures, however, remains largely absent.

Cost

In Poh and Chen's (1998) research, no distinct trends are indicating a significant relationship between construction unit costs and the buildability score. Three possible reasons were offered (Poh and Chen 1998):

1. The buildability appraisal system is concerned mainly with a building's structural system without taking the external wall design and the use of less labour-consuming elements into account;
2. The buildability score indices are fairly fixed for each design scheme regardless of the project's category, scale, number of storeys, quality of workmanship, and market conditions;
3. Other factors may have a greater impact on costs, such as contractor's management style and experience, weather and site conditions, as well as costs of labour and materials.

Sustainability

In 2006 Australia embraced requirements for energy efficiency under its building regulations for all building classifications. This, coupled with increasing adoption of the non-regulatory Green Star rating system, introduced in 2003, for non-residential construction provides support for Australia's interest in the application of sustainability principles in the construction industry. Despite this, little empirical research has been done to map out the relationship between sustainability and buildability. Singhaputtangkul et al.'s (2013) work, is one of the few which have identified a list of criteria for achieving sustainability and buildability. However, it is limited to the assessment of building envelope design. Such paucity of research brings into question the limitations that have been applied to date in the discussions that have transpired on relevant criteria for buildability. Buildability measures that are only linked to labour and material construction efficiency run the risk of ignoring equally pressing considerations such as sustainability or generating conflicts between performance-based regulations in meeting sustainability targets which are seen as having commercial value as evidenced by the uptake of the non-regulatory Green Star rating system.

4. BUILDABILITY RESEARCH IN AUSTRALIA

The buildability concept started in Australia in the latter periods of the 1980s and 90s (Francis 1994; Hon 1989), in a first approach directed to project management activity. Extended later (Hyde 1995) to the relationship of buildability to architectural design and developed further to integrate design with construction (Griffith and Sidwell 1997). Buildability was defined as a concept that focuses on the influence of design and its impact on ease of construction. And, constructability was defined as a concept that takes a more holistic perspective of all stages in the total building process.

The concept of buildability (constructability for design phase) in Australia was analysed by the Construction Industry Institute (CIIA, Australia) identifying twelve buildability issues, commencing with the concept of design and construction integration and finishing with the need for feedback mechanisms to verify buildability decision making. This approach resulted in several publications (Crowther 2002; Francis 1999) which looked at a whole of life process from concept stage until deconstruction consequences for buildability.

More recently research has been undertaken focusing on the impact of procurement methods to improve buildability. Early Contractor Involvement (Cintra 2005), for example, is seen as offering advantages against traditional construct only. The ECI process provides feedback from tenderers at the beginning of the process delivery management (PDM) until deconstruction. Design consultants can resolve ambiguities, discrepancies, and buildability issues and continuous design improvement in an early stage (Mashiah 2008). New research initiatives at the academic level have been developed to increase profession's relationship with both "ideas of making" and the "making of ideas".

5. Future research and methodology

This research in buildability has a potential to be a future research that has the aim to determine the best practices on buildability assessment tools and the level of applicability of successful existing tools for the Australian construction industry. Furthermore, in a performance-based regulatory system, the construction industry in Australia is predicated on a market determination of efficient solutions. It makes fertile ground for further research, should accurate measures of buildability measurements be developed to verify one of the major premises to support buildability as a cost mitigating tool in deregulated markets that have embraced alternative procurement systems. The proposed methodology will be using a sample, recruited with the help of Australian construction companies. Data will be collected using a self-administered questionnaire, based on Singapore's BDAS system, and sent to 100 design professionals working in that activity for more than 5 years. The results will be used to prepare the foundations for a new system to measure level of buildability of the design in the Australian construction industry.

6. Conclusion

The concept of buildability has been discussed largely on the last few decades. Singapore's buildable appraisal system, is a unique existing system which has developed some criteria to measure buildability and addresses buildability primarily as a construction system approach. It computes the extent to which the principles of standardisation, simplification, and single integrated elements are found (BCA 2015). This paper explored that such factors are not of themselves sufficient measures of buildability. In a permutation of an aphorism attributed to Peter Drucker, *if you cannot measure it, you cannot control it*, criteria for measurement in order to have a mechanism of verification, control and improvement is essential. Due to the broad meaning of the term, it is important to understand the different criteria that can be applied to measure buildability. The systematic review done in this research identified some authors that deal with buildability as a concept, others as a method and others as a process. However, clarification of what is important and where such parameters should apply in meeting project objectives and delivery is essential to make the analysis of the results compatible to the goals.

This research will provide a better understanding of the concept and applicability of Singapore's solution in Australian market. This will be great impact of the construction industry and the assessment of construction projects in the design stage helping to measure their performance to be managed to the desired level of productivity, cost and sustainability.

Reference

Bambang, T. (2006). "Case studies on implementation of constructability improvement by construction project owners in Indonesia." *Proc., Clients Driving Innovation: Moving Ideas into Practice*.

BCA (2015). "Code of Practice on Buildable Design." Building & Construction Authority, Singapore

Brennan, T. M., and Venigalla, M. (2016). "A constructability assessment method (CAM) for sustainable division of land parcels." *Land Use Policy*, 56, 47-57.

Cintra, M. A. H. (2005). *UMA PROPOSTA DE ESTRUTURA PARA ORGANIZAÇÃO DO CONHECIMENTO EM EMPRESAS DE EDIFICAÇÕES*, Tese – Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.

Crowther, P. (2002). "Design for buildability and the deconstruction consequences."

Douglas III, E. E. (2008). "Schedule Constructability Review." *AACE International Transactions*, PS161.

Francis, V. E. (1994). *Implementation of Constructability into Australian Construction Projects*, University of South Australia.

Francis, V. E. (1999). "Constructability [sic] strategy for improved project performance." *Architectural science review*, 42(2), 133-138.

Griffith, A., and Sidwell, A. C. (1997). "Development of constructability concepts, principles and practices." *Engineering, Construction and Architectural Management*, 4(4), 295.

Hon, S. L. (1989). *A Study of Buildability within a Project Management System*, University of Melbourne.

Hyde, R. (1995). "Buildability as a design concept for architects: a case study of laboratory buildings." *Engineering, Construction and Architectural Management*, 2(1), 45-56.

Jarkas, A. M. (2010). "Analysis and Measurement of Buildability Factors Affecting Edge Formwork Labour Productivity." *Journal of Engineering Science & Technology Review*, 3(1), 142-150.

Jarkas, A. M. (2015). "Effect of Buildability on Labor Productivity: A Practical Quantification Approach." *Journal of Construction Engineering and Management*, 142(2), 06015002.

Kannan, M. R., and Santhi, M. H. (2013). "Constructability Assessment of Climbing Formwork Systems Using Building Information Modeling." *Procedia Engineering*, 64, 1129-1138.

Kuo, V., and Wium, J. (2014). "The management of constructability knowledge in the building industry through lessons learnt programmes." *Journal of the South African Institution of Civil Engineering*, 56(1), 20-27.

Love, P. E., Davis, P. R., Edwards, D. J., and Baccarini, D. (2008). "Uncertainty avoidance: public sector clients and procurement selection." *International Journal of Public Sector Management*, 21(7), 753-776.

Low, S. P. (2001). "Quantifying the relationships between buildability, structural quality and productivity in construction." *Structural Survey*, 19(2), 106-112.

Mashiah, G. "Ensuring “Buildability” of Sewage Treatment Plant designs: Clarence Valley Council’s ‘Early Contractor Involvement’process." *Proc., Proceedings of 11th International Conference on Urban Drainage*, Citeseer, 1-8.

Naoum, S., and Egbu, C. (2015). "Critical review of procurement method research in construction journals." *Procedia Economics and Finance*, 21, 6-13.

Osipova, E., and Eriksson, P. E. (2011). "How procurement options influence risk management in construction projects." *Construction Management and Economics*, 29(11), 1149-1158.

Poh, P. S., and Chen, J. (1998). "The Singapore buildable design appraisal system: a preliminary review of the relationship between buildability, site productivity and cost." *Construction Management & Economics*, 16(6), 681-692.

Singhaputtangkul, N., Low, S. P., Teo, A. L., and Hwang, B.-G. (2013). "Criteria for architects and engineers to achieve sustainability and buildability in building envelope designs." *Journal of Management in Engineering*, 30(2), 236-245.

Song, Y., and Chua, D. K. (2006). "Modeling of functional construction requirements for constructability analysis." *Journal of Construction Engineering and Management*, 132(12), 1314-1326.

Wang, J., Wang, X., Shou, W., Chong, H.-Y., and Guo, J. (2016). "Building information modeling-based integration of MEP layout designs and constructability." *Automation in Construction*, 61, 134-146.

Wong, F. W., Lam, P. T., Chan, E. H., and Shen, L. (2007). "A study of measures to improve constructability." *International Journal of Quality & Reliability Management*, 24(6), 586-601.

Wong, F. W., Lam, P. T., Chan, E. H., and Wong, F. K. (2006). "Factors affecting buildability of building designs." *Canadian Journal of Civil Engineering*, 33(7), 795-806.

Yustisia, H. (2014). "The evaluation of constructability towards construction safety (Case study: Kelok-9 Bridge project, West Sumatera)." *Procedia Engineering*, 95, 552-559.

Zhong, Y., and Wu, P. (2015). "Economic sustainability, environmental sustainability and constructability indicators related to concrete-and steel-projects." *Journal of Cleaner Production*, 108, 748-756.