An Empirical Study of the Relationship between Buildability and Productivity in Singapore – Lessons for Hong Kong SAR

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Abstract: In simple terms, “Buildability” is a measure of the ease of construction arising from building design decisions. Singapore is one of the few countries in the world which has pioneered with the development of quantitative benchmarks through its “Buildable Design Appraisal System”. Ever since its formative stage, investigations had indicated that there are positive correlations between buildability and productivity, which is the driving force for cost effectiveness and competitiveness. Through a comprehensive study of these investigation results, the relationship between buildability and productivity is examined with respect to different types of buildings. With the upcoming introduction of a voluntary Buildability Assessment Model in Hong Kong SAR in the near future, it is expected that this study will throw some light on the potential benefits that will be brought about by buildability assessment in this city where the construction environment is comparable to that in Singapore.

Keywords: Buildability; Productivity; Assessment; Singapore; Hong Kong SAR

1 Introduction

Contractors who are appointed after the design stage used to complain about the insufficiency of thoughts given to the construction process by the design team. CIRIA (1983) attributed this allegation to “the comparative isolation of many designers from the practical construction process. The shortcomings as seen by the builders were not the personal shortcomings of particular people, but of the separation of the design and construction functions”. Whilst this is generally true from the perspective of procurement approach, the choice of construction systems and the method of site management and organization do affect construction efficiency to a certain extent.

This paper is focused on the choice of construction systems and hence, the term “buildability” is preferred to the almost synonymous term of “constructability”, except for the wider connotation given to the latter term, as used particularly by American and Australian writers on the subject. It is worth mentioning these countries at the start to set out the international context of this topic, although again this paper will zoom into Singapore and Hong Kong SAR only, due to the limit of writing space and also because these two vibrant cities have sufficient similarities in their construction environments for meaningful comparison to bring forth the theme of this paper.

This term “Buildability” has been defined in an influential report (CIRIA, 1983) as “the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building”. As such, the same report proposed that “Good buildability leads to major cost benefits for clients, designers and builders”. Others (Tan, 2000; CIRC, 2001) believe that higher buildability leads to higher productivity. Common belief is that building cost and productivity are intrinsically related. As suggested succinctly by Yeo (2003), “….projects with highest (sic) productivity will result in lower cost of construction. This may be contributed by more buildable design, better site management and planning, resulting in minimum / no time and cost overrun, less wastages, more efficient use of resources available, better construction methodology used and economy of scale…….”.

Whilst previous claims on the relationships between buildability, productivity and cost can be regarded by the cautious skeptics as conjecture, it is now possible to examine the issues more closely with empirical evidence made available by quantification tools as pioneered by major Japanese contractors (such as Takenaka Corporation) and the then Construction Industry Development Board (CIDB) of Singapore (now renamed as Building and Construction Authority – BCA).
2 The Buildable Design Appraisal System (BDAS)

Modelling after Takenaka’s in-house buildability assessment system, Singapore published the first version of the BDAS in 1993. It was established based on the 3S principle, namely, Standardization, Simplicity and Single Integrated Elements. Standardization refers to the use of repetitive grids, layouts and components with modular co-ordination. Simplicity denotes uncomplicated installation details. Single Integrated Elements combine related components and work stages into unitized elements, which are self-sufficient and capable of being jointed to other elements (e.g., prefabricated toilet cubicles complete with finishing, sanitary fittings and pipes ready for jointing).

The BDAS is a set of scoring metrics comprised initially of structural components, wall components and “Other Buildable Design Features” reflecting the 3S principle. Each component score is arrived at by summing up the multiplication products of the proportionate quantity of each construction system and the corresponding Buildability Index. As it evolves into its latest known version (September 2005) at the time of writing, the formula for Buildability Score is expressed as shown in Table 1:-

| Total buildability score of building | = Buildability score of Structural System (including Roof System) + Buildability score of Wall System + Buildability score of Other Buildable Design Features + Bonus points |
| or | = 50[Σ(As x Ss)] + 40[Σ(Lw x Sw)] + N + Bonus points |

where 
- As = Asa / Ast
- Lw = Lwa / Lwt
- As = Percentage of total floor area using a particular structural design
- Asa = Floor area using the particular structural design
- Ast = Total floor area which includes roof (projected area) and basement area
- Lw = Percentage of total external and internal wall length using particular wall system
- Lwa = External and internal wall length using particular wall system
- Lwt = Total wall length excluding external basement wall for earth retaining purpose
- Ss = Labour saving index for structural design
- Sw = Labour saving index for external and internal wall design
- N = Buildability score for other buildable design features
- Bonus points = Bonus points for single integrated components

Source: BCA’s Code of Practice on Buildable Design – Sept 2005

An example of calculation has been depicted in a paper presented at an earlier CRIOCM conference (Lam, 2000) and would not be repeated here. Interested readers can follow through the example in that paper as cited in the reference section herein.

Since its earliest version, the BDAS has undergone a series of gradual refinements and minor modifications in terms of its measurement conventions (such as wall lengths being used instead of the previous wall elevational areas for simplicity purpose) due to feedback from the industry. Yet, the essence of the
quantification concept remains intact. There was one major development in 2001, in that BDAS started to be used as the metrics for calculating a mandatory minimum Buildability Score for statutory building plan submission for stipulated development projects. The earlier versions were just used as an administrative rule for all public sector building projects and then as the basis for awarding “Best Buildable Designs” on a voluntary participation basis for private sector projects. The shift was seen as a move by the Singapore government to emphasize on the reduction of site labour deployment (which was then becoming a scarce resource) and enhancement of productivity, which was an explicit drive in an industry-wide campaign called “C21”.

3 Relating Buildability to Productivity and Cost

There have been much research efforts devoted to investigate the relationship between buildability and productivity and construction cost in Singapore, even before the BDAS was officially rolled out in 1993. Lee (1992) carried out a survey on 68 building projects (comprising 33 residential projects, 15 industrial projects, 4 institutional projects and 13 commercial projects) by collecting data on the production rates expressed in terms of “square meter of floor area completed per manday” and making informed judgment on their respective buildability based on an arbitrary 3-point scale related to percentage mark ranges (“low” buildability meaning 0 to 30%, “medium” buildability meaning 31 to 60% and “high” buildability meaning 61 to 100%). The results of his survey are depicted in Fig. 1a to Fig. 1d.

Fig. 1a shows that the productivity of residential buildings (especially high-rise public housing) can be increased substantially by increasing the buildability of their designs. This is also true for industrial buildings and institutional buildings (Fig. 1b and 1d) to a noticeable extent. The effect is not obvious in commercial buildings, which comprise of hotels, offices and shopping complexes, for which standardized designs are less likely (Fig. 1c).

Chan and Er (1994) carried out similar study using 9 projects and demonstrated similar relationship between buildability and productivity (Fig. 2a). He also recorded the construction cost per sq. m. and showed that the cost of
commercial buildings can be lowered with high buildability, whilst two of the lowest cost commercial projects with medium and high buildability were Design & Build projects (Fig. 2b).

Whilst the above 2 researchers focused on the buildability of designs, Tan (1993) studied the effect of the choice of construction methods on productivity. When comparing between fly-form construction (a type of large table form hoisted into position by tower cranes) and conventional timber formwork construction for reinforced concrete buildings, he demonstrated with 95 per cent level of confidence statistically that there was a productivity gain of 76 per cent for formwork, 15 per cent for rebar and 14 per cent for concreting in his samples.

The abovementioned studies were carried out before BDAS was applied to sufficient number of samples for analysis. Hence, Poh and Chen (1998) waited until Buildability Scores were obtained for 37 projects in Singapore. Again, they demonstrated a positive relationship between Buildability Scores and productivity, especially with residential buildings, for which linear correlations could be established statistically (with linear regression coefficients “R^2” at 0.632 and 0.878 for large scale developments (those over 200 units) and smaller scale developments respectively. However, they could not find distinct trends between Buildability Scores and construction cost data for these projects. Three possible explanations were given: (i) the focus of BDAS was on structural system and external wall design, whereas M & E element were not assessed, but the latter did form significant portions of the construction cost data; (ii) Buildability Indices were fixed regardless
of the quality of finishes and building heights, which affected building costs; and (iii) many factors apart from buildability, e.g., weather conditions and contractors’ management, could influence construction costs.

In a study on the management of precast concrete for building, Ong (1999) plotted a series of diagrams, adapted as Fig. 3a to Fig. 3d herein, all showing the positive relationship between Buildability Scores and productivity for various types of projects. Fig. 3e is a combination of all samples, which make the trend obvious. He attributed the increased use of precast concrete elements in Singapore to the BDAS, which gives higher scores for the use of prefabricated technology.

Low (2001) is another researcher looking into the relationship between Buildability Scores and productivity in Singapore. He also demonstrated that higher Buildability Scores are associated with higher productivity. To balance against the favour for precast concrete, he mentioned in his paper that designs with simple cast in place construction can also yield high Buildability Scores.

![Fig. 3a](image1)

![Fig. 3b](image2)

![Fig. 3c](image3)

![Fig. 3d](image4)
Yeo (2003) took more recent samples in Singapore and continued with the efforts to demonstrate the positive relationship between Buildability Scores and productivity. He also collected building cost data and showed it alongside productivity data as follows:

(Sources of data: Ong (1999) and BCA, Singapore)
Fig. 4e and Fig. 4b show a fall of construction cost with increased productivity and Buildability Scores for public housing, which used a lot of prefabricated components (such as precast walls, slabs and staircases) and standardization.

Fig. 4c and Fig. 4d show increasing productivity for private condominium projects as Buildability Scores get higher, but construction costs fell initially with increasing Buildability Scores, but rose again as Buildability continued to improve. Presumably, this was due to an increased specification level for high quality condominiums, for which developers also stipulated the achievement of high Buildability Scores well above the statutory minimum. This adds prestige to the projects concerned in a competitive seller market.

For institutional projects, such as schools and military camps, Fig. 4e and Fig. 4f show how increased productivity brought about by higher buildability scores suppressed costs. This could be due to the benefits arising from increased standardization as repetitive units are used beyond a certain point. This could be possible with designs for standard classrooms and officers’ accommodation.

Although it is clear from the above studies that productivity gains can be achieved with increased buildability, there can be other limiting factors inhibiting the further use of prefabrication and standardization techniques. For example, space in a city centre site can be so limited that there is no proper operational area for manufacturing prefabricated components or storage space for buffer stocks. Low and Choong (2001) studied the implications of Just-In-Time management for prefabricated components and recommended, amongst other suggestions, the sharing of saving between precast suppliers and contractors. This will further impart on construction costs.

4 Relating Buildability to Quality

Low (2001) is one of the few researchers who investigated the relationship between Buildability Scores and construction quality in Singapore. By correlating Buildability Scores with quality scores produced by the BCA under the Construction Quality Assessment System (CONQUAS) for 10 public sector buildings, he demonstrated a positive relationship (although linearity is weak with correlation coefficient at 0.465) between Buildability Scores and the structural components of CONQUAS scores. The possible reason behind this positive correlation could be due to the increased use of precast and prefabricated components, which have inherently better quality control in their production environment. Low and Abeygoonasekera (2001) also attributed the relationship between buildable designs with quality to the integration of ISO 9000 system through the case study of a condominium project. He highlighted the importance of design review and contract review in ensuring that the end products meet the client requirements for a buildable design, namely speed and ease of construction, as well as a quality building.
5 Lessons for the Hong Kong SAR

Hong Kong SAR (abbreviated as “Hong Kong” below) has undergone a rapid pace of development in the construction industry, very much like the situation in Singapore. The construction market in Hong Kong is as open as that in Singapore in that competition is the usual basis for awarding contracts to contractors and design consultants, both of local or foreign origin. As such, world class technologies for design and construction are available, although the spread and scale of implementation may be concentrated and smaller than overseas countries due to the limited geographical size of these two cities.

Spurred by some quality mishaps in the construction industry in the late 90s, a comprehensive review was initiated by the Hong Kong government and culminated in the publication of the CIRC report (2001) by a special task force. Amongst other things, the CIRC report pointed out that buildability of designs was not emphasized to the detriment of productivity and hence construction costs. A lot of construction waste was also generated partly due to non-buildable designs. Hence, a research team led by the first author at the Hong Kong Polytechnic University started to work on a Buildability Assessment Model (BAM) for Hong Kong since 2002. Recently, a prototype BAM has been established (Lam, Chan, Chan et al, 2006), making reference to the BDAS in Singapore but using different methodology for local data collection and taking consideration of Hong Kong’s characteristics such as site constraints and sloping terrain. In addition, building services aspects and more detailed finishing categories were incorporated, together with a bonus allowance for innovative designs leading to improved buildability.

Establishing the BAM is only the starting point in an effort to improve buildability in Hong Kong. In the process of validating the BAM, it was found that many projects in Hong Kong still adopted conventional construction systems (e.g., insitu reinforced concrete) in their designs, hence resulting in low Buildability Scores. Yet, Hong Kong is not short of cutting edge construction technology at all, since some landmark buildings have achieved very high Buildability Scores under the BAM. Taking Singapore as a comparison, where the need to improve buildability has been brought to the attention of the critical mass, initially through encouragement and recently through legislation, the effects of improved buildability can be more abundantly felt. Yet, it must be said that the positive impacts of BDAS were not instantly achieved, but through a prolong period of benchmarking efforts for over 13 years to-date. The then CIDB (and currently BCA) in Singapore is a state agency charged with specific missions and power, which enables efficient collection of data necessary for the beneficial benchmarking exercise as well implementing the scheme. To achieve successful benchmarking of buildability, designers and contractors need to co-operate in making their design documents and pertinent information for different categories of buildings available to the assessors.

6 Potential Cost and Benefits for the Hong Kong SAR

In Hong Kong, without sustainable data collection and benchmarking, one cannot relate any efforts spent in making buildings more buildable and the resultant productivity, cost and quality of their construction. From piecemeal information collected in the course of the research project and from anecdotal descriptions, those projects with higher buildability scores do attract shorter construction periods, less claims and a smooth construction process. As far as construction cost is concerned, preliminary data (Tam, 2003) points to a slight increase (2 per cent) in the use of precast concrete facade compared with insitu concrete. This additional cost has been more than offset by the increase in Gross Floor Area (GFA) permitted under the “green” incentive provided by the Hong Kong government, but this gain is only limited to residential buildings using non-structural prefabricated external walls (JP Note No.2, 2002). That explains why private developers are keen to benefit from this incentive, with over 30 building plan submissions incorporating this feature in the first 3 years of implementation.

In a case study multi-storey residential project (in Tuen Mun district) using structural precast concrete walls, metal formwork and skim coat plaster, data was obtained during a site visit arranged by a professional body. The increase in cost was around 4 per cent compared with conventional construction, but there was 6 per cent gain from GFA. Apart from this, there was an overall estimated saving in site manpower of 30 per cent and a reduction of construction waste for tiles (60 per cent), rebar (25%) and concrete (35 per cent). The overall
construction period was shortened by 1 to 2 months due to time saving in external wall tiling (which was incorporated in the facade in factory) and there was no need for taking down conventional bamboo scaffolding. Owing to the better quality of precast components, defect rectification costs were also reduced. According to the contractor, finance charge was thus lowered. Hence, although there could be a slight increase in the initial cost of prefabrication, one has to look into the overall cost and time picture before passing any judgment on the success of such projects with respect to improved buildability, especially in the long run.

7 Conclusion

This paper has depicted the empirical evidence demonstrating the success of improved buildability in raising productivity as well as the associated cost and quality implications in Singapore. This evidence is made available due to the use of the BDAS, which allows an objective assessment of buildability. The data so made available is being used for benchmarking purpose with an ultimate aim to further improve buildability across a wider spectrum of the construction industry in a sustainable manner.

Although one could argue that productivity can be affected by factors other than buildability of designs, it would not be too presumptuous to relate a gain in productivity by measures taken with the 3S principles in mind. One must, however, not presume that buildability should then become the dominant factor in deciding the priority of design, unless the pursuit of productivity gains is the utmost concern of the client, which is rarely the case. More often, an interplay of aesthetics, functionality, cost, quality and productivity would create the fine balance necessary to meet the client's requirements.

In the case of Hong Kong, preliminary data has shown that some tangible benefits could be brought about by conscious efforts in improving buildability, but it remains to be seen if such efforts are sustainable and capable of being practiced by the critical mass. With a proposed BAM now being available, it is hoped that more building projects can be assessed for buildability such that similar benchmarking and incentive exercises as in Singapore can be carried out in Hong Kong. It is only through continued self-monitoring and encouragement that practitioners will feel the need and exert the drive to raise productivity and quality, whilst making building operations more cost effective in Hong Kong.

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References


