Development of buildability and constructability

What is buildability or constructability? Is design for buildability or constructability is approachable? Can buildability concepts and theories enhance designers awareness of construction knowledge and buildability issues and reduce rework and increase construction productivity? , or can it inadvertently limit designer’s creativity? At the heart of this review paper are debates about the potential of buildability concept and the usability of construction knowledge in design to sustain and develop buildable designs.

Construction is the world’s largest and most challenging industry [R. L. Tucker, 1986]. In 1997, the US construction industry accounted for 10% of Gross Domestic Product (GDP) and employed over 10 Million, making the industry the largest in the country [E. Allmon, C. T. Hass, J. D. Borcherding and P. M. Goodrum, 2000]. On the other hand, a 10% increase in construction labour productivity would yield annual savings of about £1 Billion to the British economy [R. M. W. Horner, B. T. Talhouni and H. R. Thomas, ” (1989).]; a similar conclusion was echoed by Stoekel and Quirke [S. Adams, (1989).]. Several factors affect project productivity but, buildability is among the most important [R. M. W. Horner, B. T. Talhouni and H. R. Thomas, 1989)., S. Adams, ” (1989)].

In practice, design and construction processes are normally carried out in a sequential manner. Since 1805 the construction industry has benefited from the various advantages this approach (Dunican, 1984). It allows the different parties in the project to compete and provide the best results for the project while defending and upholding their rights and duties within their respective disciplines (Griffith, 1986).

Although the separation of design and construction allows the construction processes to be managed systematically between the various stages and disciplines, the industry is still being criticised for poor performance, being under productive, lack of competitiveness, and consuming longer product development time.

Various studies have revealed that since 1950, the construction industry has realised the important of analysing design for construction implications, if the production work on site is to be effectively performed (Gray, 1986). To overcome this inherent problems from the separation of design and construction, a concept known as buildability in the UK and constructability in USA is established and ‘ marketed’ to the industry (Illingworth, 1984; CIRIA, 1983; NEDO, 1975; Griffith, 1985; Gray, 1983; Moore, 1996). By using the buildability concept as a means to improve the construction industry, many ideas have been put forward by various researchers to remove the disadvantages of separating the design and construction process (Illingworth, 1983; CIRIA, 1983; CII, 1986; Tatum, 1987).

The issue of buildability – and academic research in the field for that matter – has been an evolving one over the last three decades; moulded by reaction to changes in the procurement environment and in the case of academic buildability research, to advancements in the science of methodology. Regarding the latter, developing techniques such as neural networks, fuzzy decision making, buildability scores system and 3d/4d technology technologies have witnessed application among a range of assessing buildabilty problems (ref.).

This paper will review and synthesise the existing research efforts in order to establish state of the art collective knowledge in relation to buildability problems causes and effects. It aims to create two separate taxonomies, which are comprehensive collections of all project change causes and change effects identified in previous studies. A simple case study is presented to demonstrate how the taxonomies provide a useful framework for construction professionals to manage project changes. However, they are not management tools that can be used directly in practice. Instead, they provide a basis for developing project management solutions and toolkits. While the industry focus of this study is construction, the developed taxonomies can be modified and adopted for other project-based industrial sectors (change).

Aim and objectives of this study

This backcloth of “ evolvement” brings matters conveniently to the focus of this study, the aim of which was to critically appraise academic research within the field of construction buildability, published over a time window of circa 30 years prior to 2011.

Objectives related to this aim included particular consideration of:

(1) the foci of that research;

(2) stated research drivers;

(3) favoured methodological approaches;

(4) research tools employed; and

(5) the products of research effort. Buildability assessment method

(6) Buildability attributes

Based on observation of outcomes resulting from satisfying these objectives, the contribution of published academic research is considered, and future research direction intimated.

The literature review:

The principal method for this study is literature review and analysis. A preliminary review found that studies on buildability assessment fall into a broad spectrum, covering buildability problems causes and effects, buildability attributes, as well as assessment methods and techniques.

Given the large volume of published work, there was a need to set a limit to the scope of the review. The study was chosen to focus on buildability assessment models and the stages of its implementation, because a good understanding of buildability models is a prerequisite for effective. Such a decision excluded papers from the review.

The targeted literature sources are limited to refereed academic journals, published in English. They are a good representation of the breadth and depth of research achievements; and they have been scrutinised through peer review. In recent years, most academic journals began to provide online access. The emergence of a number of publication index databases has greatly assisted the literature search task. As for the date of publication, no explicit restriction was set. However, because few pre 1990s publications

were covered by the online index databases the number of papers identified for that period is very small. This will be revealed in the following analyses.

Development of buildability and constructability concept:

The word buildability appears to have first entered the language in the late nineteen seventies [D. W. Cheetham and J. Lewis, ” (2001).]. Concerns on the disparate phases in building development was raised in the early 1960s when a series of studies, such as Emmerson (1962), Banwell (1964), Tavistock (1965), EDC (1967) and NEDO (1975), were carried out in the UK.

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To gain a better understanding of buildability problems, especially their causes and effects, has been a long-standing research challenge.

Emmerson Report:

An early attempt to address buildability can be credited to Sir Harold Emmerson (1962) when he suggested the development of a new form of relationship between designers and constructors. The point of concern was the lack of cohesion between designers and constructors and the inability of both parties to see the whole construction process through each other’s

eyes. The report was the first that has emphasised that the inefficiencies in the construction industry stemmed from inadequacies of communications and coordination. The quality of the relationship between the professions and subcontractors was seen as affecting the efficiency of building operations. Emmerson criticised the lack of cohesion existing within the industry.

Banwell Report:

In the UK, since the Emmerson Report (1962), numerous researches had been carried out to identify the causes of buildability problems and search for solutions for improvement. Banwell 1964 highlighted the fragmented characteristics of the industry and inefficient designs produced by designers deficient in construction knowledge without involvement of contractors. Banwell 1964 suggested that: ‘ design and construction must be considered together and that in the traditional contracting situation, the contractor is too far removed from the design stage at which his specialised knowledge and techniques could be put to invaluable use’

The report called for more attention to be given to pre-contract planning and design formulation and criticised professionalism as being narrow sighted, giving rise to unnecessary and inefficient construction practices. It was suggested that: clients define their building requirements clearly at the start of the design stage; the building process should better integrate the stages of design and construction; and that traditional construction practices should be reviewed to seek interdisciplinary approach.

A subsequent study (Economic Development Council 1967) reported that the recommendations made in the Banwell Report had not been successfully implemented within the construction industry and that flexible approaches to traditional procedures should be sought and new initiatives developed if meaningful change within the industry was to be achieved.

The Wood Report in the mid-1970s (National Economic Development Office 1975) suggested that in the decade following the Emmerson and Banwell reports some improvements had been made in the quest for integrating better the processes of design and construction. In general however, the original problems remained and it was suggested that efforts should be directed towards increasing the level of awareness for the problems and designing measures to bring together the design and construction processes such that the construction stage might directly capitalise on design initiatives.

Tavistock:

Later, the report of the Tavistock (1965) highlighted that the causes of the communication problems between contracting parties could be attributable to the division of responsibilities and the pattern of relationships. Since then, the need to integrate disparate development phases has triggered a large number of studies in different countries.

Griffith:

Griffith (1984) suggested inviting construction expertise early at the design stage, using contractual arrangements that facilitate the improvement of buildability. Griffith (1984) further pointed out that the capability of project

management embracing suitable procurement approaches would contribute to improved buildability with concomitant benefits for overall project performance.

Griffith and Sidwell (1997) also maintained that decisions taken early in a project’s life cycle have greater potential to influence the final outcome of the project, based on the Pareto Principle.

Griffith and Sidwell (1997) highlighted that buildability must be considered from the first notional idea suggested by the client, and is quite simply a prerequisite throughout what may be considered to be a staged process.

Griffith and Sidwell [17] identified several similar problems, which are lack of consideration on interrelationship between different construction elements and skills required; and less flexibility of design and leeway within design details for materials, components, plants and craft tolerances.

Constructability includes number of activities during all project life cycle phases. Griffith & Sidwell (1995) believe that application of these activities during early stages of total construction projects causes more influences on overall cost and value.

Constructability must always remain as the ingenious thinking throughout the project life cycle to overcome project difficulties and barriers. Griffith & Sidwell (1997) illustrate some of these difficulties such as “ low level of awareness; demarcation; lack of incentives; reticence; and competitive stance adopted by construction professionals”. So identification, mitigation and review of constructability barriers and barrier-breakers, which affect

directly on efficiently implementation of a constructability program, is a must during project life cycle (O’Connor & Miller, 1994, 1995).

Griffith (1987) suggested a compromise between consciously making the design more buildable and accommodating the many factors imparting an influence upon design, including quality, aesthetics, time and cost.

It is essential to consider constructability at an early stage in the total construction process, because the ability to influence project cost, and so value for money, from the client s viewpoint, diminish as the project progresses in time. (Griffith & Sidwell, 1995).

Construction projects can be divided into different stages as conceptual planning and briefing, design, procurement, construction and post construction (start up and use) (Alan Griffith & Sidwell, 1995).

Generally, there are many all-around benefits of good constructability; these are measurable not only in cost and time, but also in terms of the physiological and psychological gains for the participants in the total construction process (Alan Griffith & Sidwell, 1995).

Griffith (1987) suggested a compromise between consciously making the design more buildable and accommodating the many factors imparting an influence upon design including quality, aesthetics, time, and cost.

Methods should be sought to improve constructability by designing for economical use of labor and widely available and versatile tools, plant and equipment.

Griffith (1984 &1985) also added that managerial aspects have the greatest potential to increase productivity and achieve good buildability.

A subsequent research study (Griffith 1984; Griffith 1985a) was similarly narrow in scope, but recognised in its findings the fundamental weakness in focusing narrowly on the attributes of design to aid construction on site. It was suggested that concentrating on design was important, but that project site and management-based factors must also be considered. The difficulties surrounding the determination of conceptual boundaries for buildability have been discussed in further studies (Bishop 1985; Griffith 1985b). It was the narrow focus, together with the complexities of the traditional contractual processes, that led to the diminishing interest in buildability concepts within the UK construction industry during the late 1980s.

Creating a building that is easier to construct cannot be the sole aim of the client (Griffith & Sidwell 1995).

Further research by Griffith and Sidwell (1995) presents an outline for developing a constructability strategy at each key stage of the construction process. This considers many of the factors suggested by Chen and McGeorge. This approach sought to stimulate creative thought about the nature of each stage such that important questions and considerations about the building process would not be missed and to encourage action to be taken by the respective participants to pursue constructability.

In the strategic consideration of constructability it is likely that future research and practice might focus on: the more holistic view of constructability to develop more encompassing strategies to be developed

for considering constructability at each stage in the total building process; the concentration on a fewer number of factors which influence constructability such that greater reliability can be built in to the strategies developed; and the formulation of management methods that are readily adaptable to the individual project situation, including non-traditionally procured projects.

CIRIA:

Thereafter, the Construction Industry Research and Information Association (CIRIA) (1983) in the UK introduced the concept of “ buildability” and the Construction Industry Institute (CII) (1986) in the US developed the notion of “ constructability”. The CIRIA (1983) defined buildability as “ the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building”. It indicates the importance of design considerations geared towards buildability improvement. Subsequently, a similar concept of constructability was introduced by the CII (1986) as “ the optimum use of construction knowledge and experience in planning, design, and procurement and field operations to achieve overall project objectives”. It dealt with the optimal integration of construction expertise and experience at various project stages to achieve the overall project goals. Since then, numerous studies have been conducted in order to strive for better project performance through improving buildability. For examples, Francis et al. (1999) found that better buildability could contribute to early completion of projects; Jergeas and Put (2001) as well as Low and Abeyegoonasekera (2001) showed that buildable designs would lead to saving in project costs and costs of change orders; others such as

Trigunarsyah (2004a, 2004b) and Low (2001) pointed out that buildable designs would bring about improved quality and safety performance, as well as higher productivity levels, and mitigate the risks of unforeseen problems. Despite these developments, it has become evident that the progress of resolving buildability problems is still unsatisfactory. Construction industry review reports typically found contractors having little input into the design (Egan, 1998), or consultants putting little emphasis on buildability (CIRC, 2001). The ensuing review by Wolstenholme (2009) of the UK construction industry also points to the need for better integration of the construction supply chain using a whole life cycle approach. More specifically, some good examples of involving the contractors early in the design process have been cited, indicating the need to improve buildability.

In view of these findings, a set of principles targeted at designers under the traditional procurement system was drawn up by the Construction Industry Research and Information Association (CIRIA).

Following the reports of Emmerson and Banwell, the Construction Industry Research and Information Association (CIRIA) supported a major research initiative to investigate what they regarded to be, the principal problems of construction practice. Their attention focused on a concept which they referred to as buildability, suggesting that building designs were not providing value for money in terms of the efficiency and effectiveness in the way in which the building process was then being carried out (change). The report of their investigations, Buildability: An Assessment, (CIRIA 1983) presented seven categories of buildability principles to: carry out thorough investigation and design; plan for essential site production requirements;

plan for a practical sequence of operations and early enclosure; plan for simplicity of assembly and logical trade sequences; detail for maximum repetition and standardisation; detail for achievable tolerance; and specify robust and suitable materials. CIRIA stated that their methodological approach provided data that ‘ were too limited to be certain that the categories identified were final and universal’, although they had sufficient confidence to publish the categories as provisional guidelines. It is from this original study that buildability research and practice evolved (change). The initial CIRIA report was followed by a further study (Adams 1989) in which the original seven categories of buildability principles were further developed to present 16, more definite, principles. This study is most purposeful since, although it still focuses on design, it does begin to widen the perspective of buildability and point the way towards recognising the true complexity and multifaceted nature of the issues involved.

The first CIRIA study, while laudibly raising general awareness to the concepts and principles of buildability and therefore achieving its basic objective, was unfortunately restricted in focus.

Egan Report:

More recently, the Egan Report (1998) awakened attentions that the general buildability performance was far from being satisfactory. Contractors were also found to have little input into the design in the UK’s construction scene, thus constituting a comparatively lower productivity figure for the industry (Graham and Bird, 2001).

Egan (1998) claims that too much time is spent in construction on site trying to make design work in practice. He adds that contractors have little input into the design and this is indicative of a fundamental malaise in the industry – the separation of design from the rest of the project. This is mainly because the traditional procurement method of design-bid-build remains rooted within the industry (Arditi et al. 2002; Song et al. 2009; Kent and Becerik-Gerber 2010). Egan (1998) subsequently encouraged longer term procurement relationships in favour of selective methods, as a mechanism to achieving quality and efficiency improvement; while in a second report (Egan, 2003), arguably rooted the term “ integrated supply chains” into procurement dialogue. More recently, the Egan Report (1998) awakened attentions that the general buildability performance was far from being satisfactory. Contractors were also found to have little input into the design in the UK’s construction scene, thus constituting a comparatively lower productivity figure for the industry (Graham and Bird, 2001).

Over the years since the definition of buildability has been put forward by the CIRIA 1983, lots of studies have highlighted the prospective benefits to be brought about by improved constructability Arditi et al. 2002; McGeorge and Palmer 2002; CIRC 2001; Francis et al. 1999; CIIA 1996; CII 1986; Griffith 1984; Gray 1983. With the potential benefits as incentives, methods and practices have been proposed for more efficient designs minimizing construction wastages on site. However, as time passes by, the progress of resolving constructability problems is still regarded as being unsatisfactory CIRC 2001; Egan 1998. The underlying reasons are multifaceted Ma et al. 2001; Uhlik and Lores 1998; Griffith and Sidwell 1995; O’Connor and Miller

1994, which have led to the current sluggish use of pull factors in the pursuit for better design constructability. More recently, push factors have been put in place by the Singaporean Government, which has enforced a legislation to enhance constructability by requiring minimum “ buildable scores” to be attained before building plans are approved. The calculation of buildable scores is based on the buildable design appraisal system BDAS, which was modeled from the in-house buildability appraisal system of a major Japanese contractor, Takenaka Corporation Poh and Chen 1998. After the implementation of BDAS, follow-up studies have demonstrated the correlations between higher buildable scores and the improvements of site productivity, construction quality, and manpower consumption Lam 2002; Low 2001; Poh and Chen 1998.

Buildability is a major issue across global construction industries and in particular the UK industry.