EFFECTIVENESS OF CONSTRUCTABILITY CONCEPT IN THE PROVISION OF INFRASTRUCTURE ASSETS

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Abstract: The concept of constructability is to use construction knowledge and experience during all phases of a project, particularly in the earliest phases of planning and design. It facilitates project objectives before delivery stage, and decreases unnecessary costs during construction phase.

Despite the extensive use, constructability concept fails to address many issues related to Operation and Maintenance (O&M) of construction projects. Extending constructability concept, to include the O&M issues, could lead to the projects that are not fitted for construction purposes only, but also fitted for use.

This study reviews the literature of constructability implementation, its benefits and shortcomings during the infrastructure life cycle, as well as the delivery success factors of infrastructure projects. This contributes to the propose need of a model to improve the effectiveness and efficiency of infrastructure project by extending the concept of constructability to include O&M. Development of such a model can facilitate post-occupancy stakeholders' participation in a constructability program. It will help infrastructure owners eliminate project reworks, and improve O&M effectiveness and efficiency.

Key words: Constructability, Operation and Maintenance (O&M), Operability, Maintainability, Delivery Phases, Infrastructure Projects, Project Life Cycle, Constructability Extended Concept

1 INTRODUCTION

Infrastructure is the key to support a nation's social and economic developments. Governments around the world are constantly investing in infrastructure provisions for the development of their countries. Many stakeholders are involved in the provision of infrastructure project. Each has their own specific role, demand and objective. The various stakeholders for infrastructure will continue to demand value for money for their investment in infrastructure. To satisfy the conflicting demand of the various stakeholders, project managers must engage these stakeholders in order to develop infrastructure assets that are responsive to their needs. Constructability has been used in many construction projects where it uses the experience and knowledge of construction stakeholders during design and planning stages. Construction Industry Institute (1986) reported significant savings in project total costs for those projects that have implemented constructability in early two stages of conceptual planning and design. Constructability is, therefore, a good platform for owners to prevent unnecessary pre-occupancy charges by analysing experience of construction stakeholders in earliest project phases.

This paper aims to examine the effectiveness of constructability concept in the provision of infrastructure assets. A successful project is reliant to replying all stakeholders' expectations during whole project life cycle (Cleland, 1995) which is the vital structure for project management science (ASCE, 1990). A well designed project results in meeting all stakeholders' needs during construction stage, as well as O&M stages (Trigunarsyah & Skitmore, 2010). It is a must for owners to enter post-occupancy assessments into planning and design phase in order to increase effectiveness of their construction programs (Plockmeyer, 1988).

2 INFRASTRUCTURE PROJECT LIFE CYCLES

A well planned project can result in an effective management of stakeholders in different phases of project life cycle, which ASCE (1990) called it as "the basic framework for managing the project". Project life cycle can be divided into different numbers of phases. Project Management Institute (2008) states that a common project life cycle has four stages of project start, organization and preparation, project work implementation and project finishing. Kartam (1997) also divides construction project life cycle into four similar phases of concept, design, construction and operation, but Howes & Robinson (2005) believes a project life cycle includes more detailed stages of planning, design, construction, operation, recycling and disposal. The most significant difference among perceptions toward various types of life cycle phases is the evaluation of post-occupancy period. Project Management Institute (2008) and some similar literature consider delivery of the project to clients as the final stage of life cycle, whilst there are considerable number of studies which brings post-occupancy stage to life cycle as one of its important components (Howes & Robinson, 2005; Kartam, 1997).

The four main phases can be grouped as follows (1) Planning (2) development, (3) construction, and (4) post occupancy. Each phase plays an important role in the whole project life cycle. The planning phase includes defining the project purposes, selecting a suitable work site, endorsement of outline planning, and doing feasibility studies. Next, actual development phase involve the scheme and detailed design stages in order to fulfil client needs. Then, the construction phase covers all activities, equipment, materials, on-site elements and labour, based on complete realization of client interest. Finally, the post-occupancy phases include the O&M of the infrastructure assets. After reaching to intended design period, facilities should be reused, recycled or recovered, based on planning approvals (Howes & Robinson, 2005). Fig. 01 illustrates the four main phases of infrastructure development.

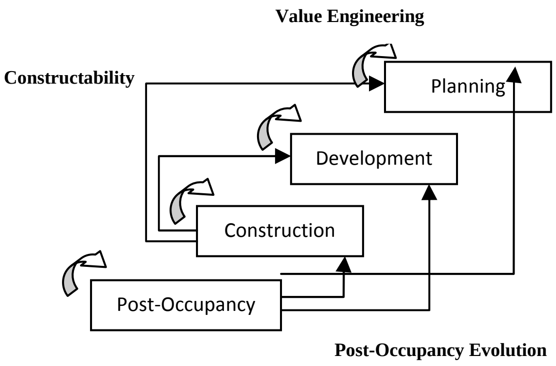

FIGURE 01: Project Life Cycle & Post-Occupancy Evaluation (adapted from Kartam, 1997)

Successful delivery of an infrastructure project requires the considerations of construction, operation and maintenance during the planning and design phases (Trigunarsyah & Skitmore, 2010). Past research has shown that constructability has always considered the construction experiences during the design phase (Construction Industry Institute, 1986). However, past maintenance and operation experiences are seldom considered during the design phase (See Fig. 02).

Consequently, many infrastructure projects failed to prevent project reworks and extra costs during post-occupancy phases of operation and maintenance. Evolution of project life cycle, illustrated by Russel (n.d.), shows the current advances in integration of post-occupancy phases to other project phases.

3 INFRASTRUCTURE PROJECT DELIVERY SUCCESS FACTORS

Critical success factors for delivery of an infrastructure project are divided into three by Trigunarsyah & Skitmore (2010). Firstly, provide an effective and efficient project delivery to obtain the overall aims of the project. Secondly, fit the final project for its intended use. Thirdly, maintain the equipments efficiently in order to postpone recycling and disposal of facilities. Constructability concept enriches the first significant issue by involving construction experience into whole pre-occupancy phases. Operability concept focuses on second criteria by bringing operation stakeholders into delivery phases, whilst maintainability issue concerns about involvement of maintenance stakeholders in delivery phases, which fulfils the third factor.

3.1 Constructability

Constructability or buildability is a term which has been used and implemented in different projects consciously or unconsciously. It is also defined by various researchers and institutes frequently. Construction Industry Institute (1986) as one of pioneers of this knowledge defines it as "the optimum use of construction knowledge and experience in the conceptual planning, detailed engineering, procurement and field operations phases to achieve the overall project objectives".

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 overal cost and value. It helps designers to design a more constructable project which causes better efficiency of actions and fewer troubles during field works (Fischer & Tatum, 1997; Trigunarsyah, 2004a). Jergeas G. & Van der Put (2001) call it a construction directed design and planning. Fig. 03 illustrates the ability to influence cost at different phases of infrastructure projects.

Constructability activities have been defined and applied in construction projects over the past years. Trigunarsyah (2004a) develops twenty six activities as constructability concepts which can be implemented over the project life cycle. Saghatforoush et al. (2009) also demonstrates level of construction contractors' understanding from implementation of these activities during their building projects. These literatures and many others (Building and Construction Authority, 2005; Construction Industry Review Committee, 2001; Glavinich, 1995; Gray & Hughes, 2001; Nima, Abdul-Kadir, Jaafar, & Alghulami, 2002; Uhlik & Lores, 1998) show that construction contractors are aware of the importance of implementing constructability during planning and design phases.

Impacts of constructability application on project performance have been discussed by different researchers (Construction Industry Institute, 1986; Construction Industry Review Committee, 2001; Francis, Mehrtens, Sidwell, & McGeorge, 1999; Geile, 1996; A. Griffith & Sidwell, 1997; Jergeas & Van der Put, 2001; Low, 2001; Oey, 2001; Paulson, 1976; Tatum, Vanegas, & William, 1986; Trigunarsyah, 2004b) during the past years. These researches mentioned lowered project costs and time as the direct influence of constructability application, as well as increased safety and quality of the projects. Having a formal constructability program during the project life cycle results in a better contribution of designers and construction contractors, as well as a beneficial teamwork throughout the project (Radtke & Russell, 1993).

3.2 Operability

An infrastructure project should be designed to be fitted for use. In order to do so, recognizing and defining user needs for development of the project is necessary. Planners and designers should understand how the final project will look like and what its purposes and uses are (Frame, 2003). Trigunarsyah & Skitmore (2010) suggested a backward-pass planning to help improvement of infrastructure projects' operation during a well designed constructability program. It helps lower level members

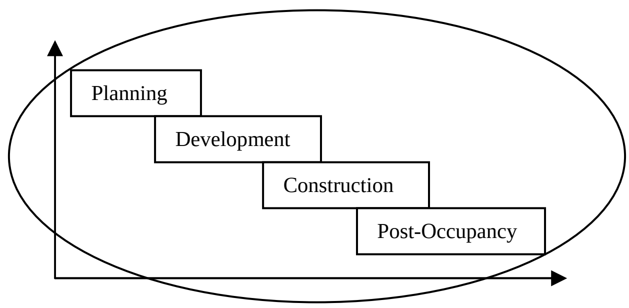

FIGURE 02: Evolution of project life cycle integration (adapted from Russell, n.d.)

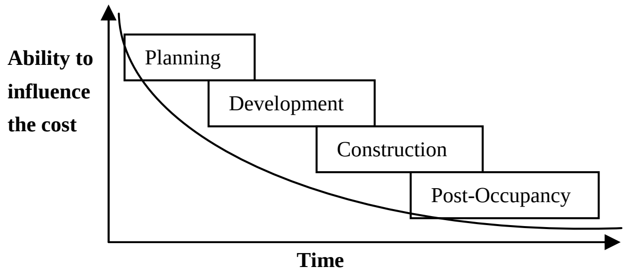

FIGURE 03: Cost influence curve (adapted from A. Griffith & Sidwell, 1997)

to find a quit perfect understanding of upstream project stakeholders who include operation members as well.

Ability to operate a system which is performing its intended use, is called operability (Uwohali-Incorporated, 1996). During an operability program, professional operation stakeholders of an infrastructure project cooperate with planning and design members. These stakeholders check whether needed quality and consistency considered in operation perception are achieved during the project planning and design (Trigunarsyah & Skitmore, 2010). In order to do so, operability concept should be added into constructability term. Geile (1996) argued that planning a project without taking clients' considerations into every phases causes money wastes; Hence considering customers viewpoints on O&M can result in significant savings during post-occupancy stage.

3.3 Maintainability

Maintenance of infrastructures can increase the life of infrastructure assets. It reduces the costs and raises benefits of final delivered project (Blanchard, Verma, & Peterson, 1995), through a smoother start up and fewer numbers of project reworks (Russell, n.d.). Trigunarsyah & Skitmore (2010) defines maintainability as the "Ability to maintain or ease of maintenance". Dhillon (1999) also defines it in more detail as "the measures taken during development, design, and installation of a manufactured product that reduce required maintenance, man-hours, tools, logistic cost, skill levels, and facilities". Maintainability should be optimally implemented in order to result in best outcomes. An optimal maintainability is defined by Dunson & Williamson (1999) as "the design characteristic which incorporates function, accessibility, reliability, and ease of servicing and repair into all active and passive system components, that maximizes costs, and maximizes benefits of the expected life cycle value of a facility".

Meier & Russell (2000) recommend creating a maintainability alert for both project managers and maintainability guarantors as early as possible in the projects. They insist on consulting all post-occupancy stakeholders during this process. As an another approach, maintenance factors should be inserted into constructability considerations in order to facilitate a better maintainability process (Dunston & Williamson, 1999). It needs more efforts during planning and design phases, but causes lower total cost lastly (See Fig. 04).

Nayanthara et al (2004) states eight key factors of improvement of maintainability in construction projects as "use of Design and Build (D&B) procurement system, life cycle criterion for tendering, availability of life cycle cost data, scoring device for maintainability, defects liability periods, designers and suppliers

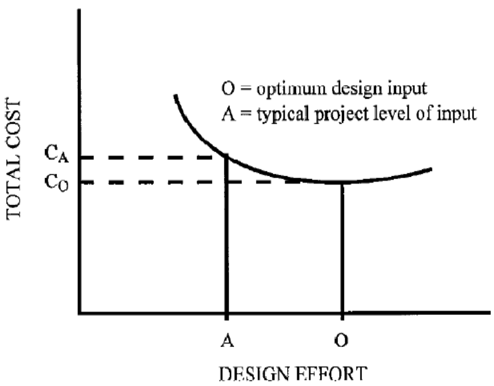

FIGURE 04: Optimum design input (J. F. McGeorge, 1988)

role in providing information, developing maintainability guidelines and providing training programmes". All these prevent neglecting maintenance costs during design phase which results in a more efficient project.

A facility manager who provides operation and maintenance of an infrastructure project is in contact with through-life costs rather than initial costs of projects, so a well sketched design is always needed to cover facility stakeholders' involvement as well as construction contractors (Ivory, Thwaited, & Vaughan, 2001). Dhillon (1999) also suggests such an incorporation of maintainability concept into design stage.

4 EXTENSION OF CONSTRUCTABILITY CONCEPT

Time, cost and quality have always been main three critical components of project success triangle. Bakti & Trigunarsyah (2003) point out that implementation of constructability during planning and design phases has a significant influence on increasing project performance. This can resolve up to 75% of field problems and mistakes, as mentioned by Mendelsohn (1997). Moreover, project clients expect to pay minimum amount to use and maintain their premises. Constructability implementation is a solution which can lead the projects to this path. Benefits comes out of constructability implementation is discussed by different researchers (Construction Industry Institute, 1987; Alan Griffith & Sidwell, 1995; S. L. McGeorge, Chen, & Ostwald, 1992; Russell, Gugel, & Radtke, 1994). Among them, a well organized quantitative and qualitative benefits of constructability implementation are indicated by Russell et al (1994) in Fig. 05.

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

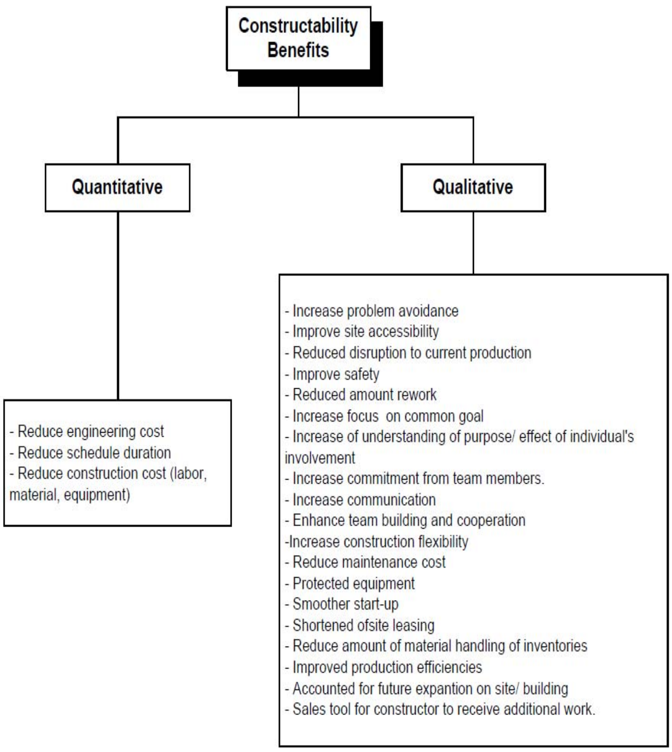

FIGURE 05: Constructability Benefits (Russell, et al., 1994)

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).

Constructability definition has always been a strong source for most of researches during a long period of time, but it has always missed post construction activities such as maintenance of designs and operability of facilities. Lack of understanding of designers from system needs and facts causes major problems for maintenance stakeholders (Dunston & Williamson, 1999). Difficult and expensive maintenance costs is mentioned by the Ministry of Manpower and Ministry of National Development (1999) in Singapore as the result of lack of care to maintainability issue during design phase. So inserting O&M facts and requirements into constructability implementation process results in an extended constructability model which is in fact main spirit of constructability implementation process.

"Buildings may fail for a number of reasons: faulty design, faulty construction, faulty maintenance, faulty materials and faulty use" (Flores-Colen & Brito, 2010). Based on today's increasing maintenance costs, maintenance management plays an important role to reduce number of faults by selection of most cost-effective strategies (Chew, Tan, & Kang, 2004). Meanwhile, some other approaches are also tested to perform a successful management of O&M like: usage of different maintenance policies, usage of different building materials, User perception analysis, prediction of building services life and etc (Flores-Colen & Brito, 2010).

All these help the concept of 'design for use' which results in longer project life cycle and also significant savings during post-occupancy stages of a project. Verma (1995) demonstrates a similar model with the same meaning as well. This model insists on satisfaction of customers by changing 'responsive up' concept with 'service' concept. O&M lower charges are among highest priorities of customers' interests.

In spite of implementing constructability in construction projects, it is project management group's responsibility to provide industrial and systematically organized structure to decrease life cycle costs rather than design and construction costs (Ivory, et al., 2001). Project owners are still suffering from costs of reworks during O&M of their projects, whilst these two phases include around 50% to 80% of the total life cycle costs (Griffin, 1993). It demonstrates that influences of the O&M stakeholders on total project objectives is quite equal to or even more than design and construction stakeholders' effects during the delivery (planning, design and construction) phases of project lifecycle (See Fig. 06).

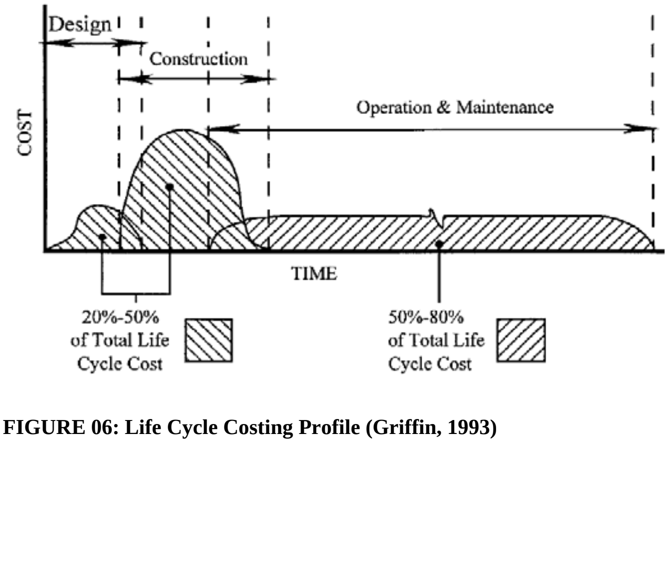

FIGURE 06: Life Cycle Costing Profile (Griffin, 1993)

Such charges wasted during the O&M phases, as a financial crisis, illustrate the need for a model that can prevent or at least reduce it as much as possible. Constructability concept, with all its respected consequences on total project savings, as it is currently used is inadequate to have an impact on the O&M considerations. It should be noted that some models are suggested by many researchers which minimizes maintenance costs by modelling of equipments and components (Keller & Al-Saadi, 1992), describing economic maintenance practices based on availability (Madu, 1990), optimization of time (Thomas, 1985), deterioration and replacement attributes of system (Valdes-Flores & Feldman, 1992), etc. Preventive maintenance is also used by few researchers (Cooke & Paulsen, 1997; Kobbacy, Fawzi, Percy, & Ascher, 1997), but the future research project output will be a model which manages O&M stakeholders in a way to be able to insert their beneficial feedbacks to constructability implementation process during delivery phases of infrastructure projects.

Thus the constructability concept need be extended to cover O&M phases in order to have a positive outcome for infrastructure projects.

5 CONCLUSIONS

This paper examines the current constructability implementation and proposes a need to extend it to include O&M phases for a successful infrastructure delivery. In another word, the evaluations illustrated in this study confirms the need for implementation of 'design for use' concept in all infrastructure projects in order to increase the life of infrastructure assets by eliminating infrastructure life cycle problems.

By improving the effectiveness and efficiency of infrastructure projects' operation (operability) and maintenance (maintainability), significant amount of savings in the whole project life cycle costs can be expected. This model will also be applicable to eliminate/reduce project reworks during the O&M phases of infrastructure projects. Such a formal process will be able to minimize constructability application problems throughout a project life cycle. An extension of the constructability concept can bring all project stakeholders ideas during the design phase to prevent whole project life cycle mistakes and overcome its barriers. O&M stakeholders' comments in earliest phases of conceptual planning and design result in a more practical plan which causes a more efficient implementation process of projects.

O&M costs are more critical and complex in multifaceted infrastructure projects, like medical centres and hospitals. It is highly recommended to lead the upcoming research trend to focus on these particular sorts of infrastructures.

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