AN ANALYTICAL FRAMEWORK FOR INTEGRATING DESIGN AND CONSTRUCTION

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ABSTRACT: A major contributory factor to poor performance in the construction industry is known to be the lack of integration and coordination between the different disciplines involved in various stages of the procurement process. However, attempts by researchers to address this problem have met with limited success, so far, because they have focused mainly on adapting integration techniques originally developed for use in the manufacturing industry. There is therefore a need to develop a detailed understanding of the fundamental sciences that underpin the problem of integrating the procurement process across the construction project life-cycle. This paper discusses a framework for addressing major methodological issues in the analysis of design/construction relationships.

KEYWORDS: Design process, Construction performance, Project integration, Research methodology, Project procurement, Information technology

1. INTRODUCTION

The turnover of the construction industry represents about 10% of the GDP of most countries (Olomolaiye *et al* 1998). The construction industry is therefore a vital element of the economy in most countries and has a significant effect on the efficiency and productivity of other industry sectors. However, studies in different countries have shown that the construction industry generally performs poorly, when compared to other industries (Business Roundtable 1983; Royal Commission 1992; Latham 1994; DIST 1998). A major contributory factor to the industry's poor performance has been found to be the fragmented nature of the industry, which in turn has resulted in a lack of coordination and integration between the different disciplines involved in various stages of the project procurement process (Ireland 1988; Love *et al* 1998). There are therefore significant opportunities to improve the performance of the industry by implementing strategies which facilitate the integration of the different project disciplines. For example, it has been shown that savings of the order of 16-23% of the original estimate are achievable through undertaking a review of the construction process implications of a building design (Kirby *et al* 1988).

Researchers have attempted to address the problem highlighted above by applying integration techniques developed for use in the manufacturing industry to integrate and automate the design and construction processes across the project life-cycle (Amor 1998). However, research efforts in this direction have met with limited success so far. A major reason for this is that the fundamental sciences required to provide an enabling framework for the integration and automation of the design and construction processes have remained largely unaddressed. This paper presents an analytical framework for integrating the design and construction phases of a project's life-cycle, based on an empirical abstraction of the interactions that occur between design and construction. The framework addresses major methodological issues in analysing design/construction inter-relationships and providing a computational basis for the development of IT applications for integrating and automating design and construction.

2. BACKGROUND

In the manufacturing industry, design for manufacturing (DFM) methodologies have been developed to improve product value by incorporating the manufacturability of a product into the product development process (Stoll, 1988). In many manufacturing enterprises, DFM has become an integral part of the product development process and has increased product quality, saved cost and reduced time to market (Swift 1987). In an attempt to achieve similar benefits in the construction industry, researchers in construction management have adapted DFM methodologies to construction projects (Luiten and Fischer 1998). However, methodologies that have been successfully applied in the manufacturing industry to integrate and automate design and production processes may not necessarily be effective when applied in the construction industry. A construction project presents a unique problem to those involved in managing the project procurement process. Each project is different and must be carried out at a different location each time. Furthermore, the project must be formulated and executed by integrating the efforts of a large number of different organisations and individuals, all of whom have different and often conflicting priorities and objectives (Bennett and Ormerod, 1984).

Bjork (1997) and Fenves (1996) discussed the need for a scientific basis for the application of computer technologies in civil and structural engineering and recommended the development of a scientific understanding or abstraction of the planning, design, and management of engineering processes. Koskela (1997) observed that there is a bottleneck in the application of information technologies to solve construction problems. Koskela has suggested that the bottlenecks are not the result of the deficient application and capability of IT, but as a result of a deficient understanding of the specific construction problems being addressed.

The research study reported in this paper addresses the issue of developing a methodological framework for measuring the impact of decisions and undertaking what-if analyses. This issue is being addressed for two major reasons:

- Firstly, a quantitative analysis of the impact of design decisions on construction performance is a key to understanding the interrelationships that exist between the different elements of the design and construction processes. This will enable project delivery time and out-turn costs, risks and constructability of competing design and construction methods to be accurately forecasted. Therefore, developing theoretical foundations at this level is a crucial first step in integrating and automating the design and construction phases of the project life-cycle.
- Secondly, the evaluation of design/construction interactions has not been sufficiently addressed by research studies. Consequently, the mechanics and dynamics of design/construction interactions are not well understood.

Figure 1 illustrates a simplified model of the conceptual framework that is being used in this study to address potential integration issues between design and construction. Design decisions are the primary independent variable set in the model with construction process variables as the dependent variable. However, the dynamic nature of construction projects is also taken cognisance of in the model by using output feedback from the construction process as input to decision-making in the design process.

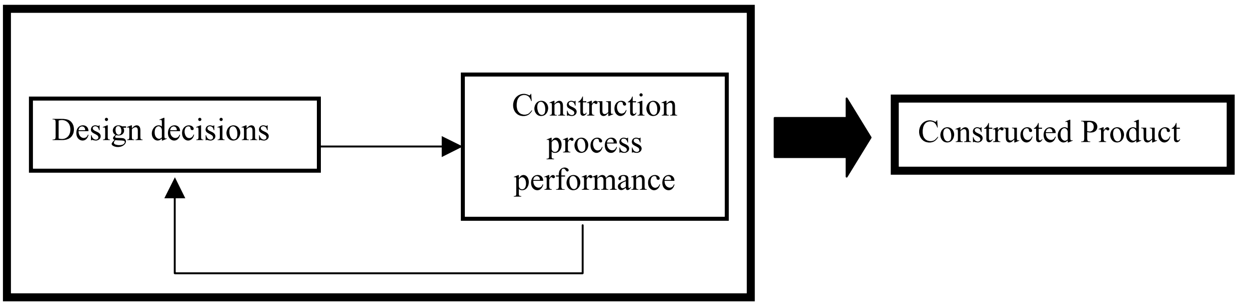

Figure 1. Simplified Model of Design/Construction Integration Framework

The model can be expressed mathematically as follows:

i. Construction process performance = *f*(Design decisions)
ii. Design decisions = *f*(design process variables, feedback from construction process)

3. METHODOOGICAL ISSUES FOR A DESIGN/CONSTRUCTION INTEGRATION FRAMEWORK

The development of an enabling framework for solving design/construction integration problems requires the abstraction of the design/construction interrelationship into an explicit analytical framework. However, the abstraction of a problem into an explicit analytical model requires the concept being studied to be represented as identifiable components or variables. In the context of the design/construction integration problem, this requires the development of schema for representing design attributes and construction process performance as structured variables. Major methodological issues relating to the development of structured variables for design and construction are discussed below.

3.1 Characterisation scheme for design attributes

The representation of design attributes as structured empirical knowledge (in the form of quantitative and qualitative variables) is essential for exploring interrelationships that may exist between design and construction. Quantitative variables depict the dimensions of a design object e.g. its physical dimensions, weight cost etc. Qualitative variables, on the other hand, describe the general form of the object being designed. Thus while quantitative variables are measurable and are associated with defined well-defined units of measurement, qualitative variables are discrete, and associated with subjective properties. Various researchers have proposed different methodologies for incorporating both quantitative and qualitative attributes into design data sets (e.g. Li and Love 1998). However, these methodologies have been mainly based on the assumption that design decisions can be aggregated in a structured manner leading to the ranking of alternatives. Although intuitive judgement plays an important role in decision-making during the design process, the methodologies do not contain any explicit function or rule to govern and underpin the rating of the variables. Consequently, the design decision may not be represented consistently and cross-referencing between of evaluation cases is difficult. The research issue here is therefore to streamline the decision analysis process for design and produce a design evaluation scheme that reflects designers' value systems and judgements, while maintaining tractability and simplicity.

3.2 Deriving a composite construction performance index

Typically, parameters used to determine the performance of a construction project include time, cost, quality, safety and environmental impact. Researchers have developed various predictive models for determining construction process performance (measured using these typical parameters) from project designs. For example, Fischer (1991) developed an expert system for determining the constructability of alternative project designs. Similarly, Alarcon *et al* (1994) developed a model for predicting the environmental impact of alternative project designs using cross-impact analysis and probabilistic inference concepts. Moeller *et al* (1999) also developed a model for predicting the construction safety performance of alternative project designs using possibility theory concepts. However, when applied individually, these parameters measure isolated aspects of the overall performance of a project. Thus, the applicability of such parameters is limited in several respects. The studies have therefore been fragmented and have focused on isolated aspects of the problem. The studies have also not considered the effect of the dynamics of the feedback from the construction process impacting on design decisions.

A truly meaningful investigation of design/construction interactions requires a holistic approach in which all relevant factors are considered. In order to have an indication of the overall performance of a project, there is a need to develop a comprehensive measure which incorporates the individual performance parameters. This will require the aggregation of individual parameters in such a way that the overall performance is optimised. Nevertheless, aggregate performance is vague by definition because of the interdependence that is likely to exist between the diverse components that are being aggregated. There is also no common denominator, or unit, by which the performance of these different aspects can be aggregated to form an overall summary. Methodological issues that need to be addressed in order to develop a composite performance indicator for the construction process include:

- What information should a composite construction performance index contain?
- How will the significance of individual performance parameters relative to overall project performance be determined, so that appropriate weighting factors can be allocated?
- What is an appropriate technique for aggregating the individual parameters?

4. CONCLUSION

There is a need to acquire an in-depth understanding of the fundamental sciences that underpin design/construction relationships if research efforts in the area of design/construction integration are to achieve any significant degree of success. This paper has reviewed some key methodological issues which need to be addressed in this regard. Firstly, the abstraction of the design/construction integration problem into an explicit analytical model is a key element in understanding the nature of the underlying relationships that exist between design and construction. However, the development of an explicit models of design/construction interactions requires the representation of the design and construction processes as structured variables. A major methodological issue here is the assignment of values to subjective attributes in design data sets such that design decisions are consistently represented and cross-referencing of evaluation cases can be achieved. Another major methodological issue is the aggregation of individual construction performance parameters into a performance index that incorporates and optimises individual construction performance indicators. The resolution of these and other related methodological issues will enable the development of an analytical model capable of providing a computational basis for developing IT applications for integrating and automating the design and construction phases of the project life cycle.

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