CONCEPTUAL FRAMEWORK OF INFLUENCING FACTORS FOR DESIGN DOCUMENTATION QUALITY

Akampurira Emmanuel; Windapo, Abimbola Olukemi
Department of Construction Economics and Management, Faculty of Engineering and Built Environment, University of Cape Town, Rondebosch 7701, Cape Town, Western Cape, South Africa

Abstract
Globally and in South Africa, inadequacies in construction design documents negatively impact upon the implementation of engineering construction projects. To date, research studies have focused on the ranking of the factors within the design process that influence the quality of design documentation. However, there has been limited attempt to explore the nature of the interrelationships amongst these factors or to quantitatively illustrate their collective impact on design documentation quality. The overall goal of this on-going research is to develop and test a structural equation model empirically illustrating the nature of interrelationships and collective impact of these factors within the context of the South African construction industry. This paper details the initial stage involving the development of the conceptual model. A comprehensive literature review was undertaken to identify indicators of and factors within the design process that influence the quality of the design documentation. Thirty-seven factors were identified. These were categorised into four latent constructs namely; Industry, Client, Design professional and Design firm related factors. Furthermore, six indicators of design documentation quality were identified. These findings provided the basis for the development of a conceptual model illustrating the hypothesized interrelationship amongst the factors and their impact on quality of design documentation. The conceptual model provides preliminary support and a foundation for further empirical investigation aimed at refining and validating the model within the context of the South African construction industry.

Keywords: Design documentation quality, Design process, Influencing factors, South Africa

1 Introduction

The construction industry is widely recognized as a significant contributor to the social economic development of countries. The provision of physical infrastructure through the implementation of construction projects provides employment opportunities, increases economic productivity and improves the quality of life of citizens (Kessides, 1993; World Bank, 1994).

A typical engineering construction project has three principal role players namely; Project owners or clients, who set the operational criteria for the completed project, provide indication of acceptable costs and delivery period for the construction project; designers who are responsible for producing the design documents that meet the needs of the project owner, and the contractors who are responsible for the execution of the work in accordance to the design documents as prepared by the designer (Oberlender, 1993). Thus in traditionally procured engineering construction projects, there is a separation between design and construction.

Engineering design is described as the process of applying various techniques and scientific principles for the purposes of defining a device, process, or a system in sufficient detail to permit its physical realisation (Reymen, 2001). It is a collective effort combining the skills and knowledge of a number of individuals often working within a design organisation (Emmitt, 2007). A key product of this process is the design documents. These include drawings, project specifications, bills of quantities, construction site specific documentation e.g. geotechnical and topographical surveys. The design documents serve as the link between the design and construction phases of a project and by extension provide the means through which the client's needs are realised. Therefore, it is crucial that the contractor is provided with good quality design documentation containing all information necessary to enable the physical construction activity to be carried out as required, efficiently and without hindrance (Tilley *et al.*, 1999).

The International Standards Organisation (ISO) defines quality as "the degree to which a set of inherent characteristics fulfil requirements." Degree in this definition means the level to which a product or service satisfies. Characteristics are features of the product that are meant to satisfy. Requirement refers to the needs of the customer (ISO 9000:2005.,). Adopting this definition for the research, with the customer being the contractor; it is then implied that the design documents need to embed certain characteristics and meet the expectations of the project participants in order to be described as being of either poor or good quality. Subsequently, good quality design documentation is characterised by being complete, internally consistent, unambiguous and providing the relevant information on time (Ballard and Koskela, 1998; Emmitt, 2007; Tilley *et al.*, 1999). Tilley *et al.*, (1999) assert that the desired characteristics or attributes associated with the quality of design documentation are: accuracy, completeness, coordination, conformance, clarity, consistency, relevance, standardisation, certainty and representation.

Despite the recognised importance of the construction industry and the associated significance of good quality design documentation, globally inadequacies in construction design documents have been identified as negatively impacting upon the implementation of construction projects (Assaf and Al-Hejji, 2006; Hwang *et al.*, 2009; Josephson *et al.*, 2002; Love and Li, 2000; Love, 2002; Love *et al.*, 2006). Similarly in South Africa, the poor quality of design documentation is identified as a significant contributing factor to project delays (Baloyi and Bekker, 2011; Ramabodu and Verster, 2013); cost overruns (Baloyi and Bekker, 2011; Ramabodu and Verster, 2013; Ramabodu and Verster, 2005) and poor quality (cidb, 2011; Emuze, 2012; Emuze and Smallwood, 2011; Simpeh *et al.*, 2011).

The studies undertaken in South Africa, although not specifically examining the quality of design documentation, provide anecdotal evidence indicating that the quality of design documentation is problematic within the South African construction industry. Notwithstanding this, no known research has been undertaken to specifically investigate the quality of design documentation and the factors that influence it within the context of the South African construction industry. Although lessons could be drawn from studies undertaken in different countries (Abdalaziz, 2009; Love *et al.*, 2006; Minato, 2003; Mohammed, 2007; Philips-Ryder *et al.*, 2013; Samuel, 2011; Slater and Radford, 2012; Tilley *et al.*, 1997; Tilley *et al.*, 1999) and in South Africa (Windapo and Cloete, 2012), a significant number of these studies were undertaken in the context of developed countries in Europe and Asia and focused on identifying and ranking the factors within the design process that influence the quality of design documentation. There has been limited attempt to explore the nature of the interrelationships amongst these factors or to quantitatively illustrate their collective impact on design documentation quality.

The overall goal of this research is to develop and empirically test a structural equation model illustrating the nature of interrelationships and collective impact of these factors on design documentation quality within the context of the South African construction industry. Specifically, this paper details the initial stage involving the development of the conceptual model based on a comprehensive review of pertinent literature.

2 Literature review

In addition to communicating the design intent, design documents play a significant role on construction projects. They influence the attainment of the construction project performance objectives of quality, cost and time, facilitate the identification and allocation of risk amongst the parties (Yong and Mustaffa, 2011; Chua *et al.*, 1999); and in the case of Bills of quantities, these are used for cost estimation and cost control purposes throughout the lifespan of the construction project. (Davis *et al.*, 2009). Results from studies undertaken in a number of countries: Australia (Mclennan and Parminter, 2001; Slater and Radford, 2012; Tilley *et al.*, 1997; Tilley *et al.*, 1999), Japan (Minato, 2003), Lithuania (Samofalov and Papinigis, 2010), UK (Samuel, 2011) and Saudi Arabia (Darwish, 2007) indicate a general perception of the existence of poor and a continued decline in the quality of design documentation.

The inadequacies identified in the design documentation include missing information, uncoordinated and conflicting information in the various documents provided, incomplete information, non-applicable details, lack of clarity and failure to use standard details where suitable (Darwish, 2007; Minato, 2003; Samuel, 2011; Tilley *et al.*, 1999).

Whilst there is general agreement on the issue of poor quality of the design documentation, the nature of inadequacies varies from country to country. In the Japanese construction industry, contractors identified incomplete design documentation specifically failure to obtain regulatory approvals prior to construction, as the most significant design document related problem (Minato, 2003). Within the UK construction industry, Samuel (2011), established that, lack of clarity and inaccuracy of project specifications, engineering drawings and bill of quantities negatively impacted upon the efficiency and effectiveness of the tender process. Arain *et al.*, (2004) identified insufficient details on the working drawings as a significant cause of discrepancies during the construction phase of a project.

The above variances suggest that issues related to the quality of design documentation are influenced by the local or context-specific characteristics of the construction industry in question. These unique characteristics need to be taken into consideration in efforts aimed at addressing the quality of design documentation.

2.1 Indicators of quality of design documentation

In a significant number of studies, the quality of design documentation was determined based on the perceived level of incorporation of the design documentation quality attributes (Darwish, 2007; Minato, 2003; Slater and Radford, 2012; Tilley *et al.*, 1999). However, some authors suggest alternative and objective indicators that could be used to gauge the quality of design documentation. These indicators consist of revisions to drawings; Request for Information (RFI); issuance of new engineering drawings; the number of variation orders; submission of Early Warning; and Field technical queries (NEC, 2005; Philips-Ryder *et al.*, 2013; Tilley *et al.*, 2002; Tilley *et al.*, 1997) . The notation Q1-Q6 is used to refer to the above indictors in in the conceptual framework.

Philips-Ryder *et al.*, (2013) argue that design documentation issued during the construction phase is often aimed at correcting deficiencies in the original documentation and, therefore, is a good indicator of the quality of the original design document. Similarly, Tilley *et al.*, (1997) reports using information obtained from drawing registers and the RFI process as indicators of

quality of design documentation. The New Engineering Contract suite of documentation specifically refers to the early warning as the means of notification of events that could affect the project costs and timelines. In practise, the Early warning system is often used to provide notification with respect to delay in the provision of information and cost impact of changes to design drawings. This is used in conjunction with the risk register and compensation event clauses (NEC, 2005).

2.2 Review of factors influencing the quality of design documentation

Several studies have reported on the factors that influence the quality of design documentation (Abdalaziz, 2009; Darwish, 2007; Love and Li, 2000; Love *et al.*, 2006; Mclennan and Parminter, 2001; Minato, 2003; Philips-Ryder *et al.*, 2013; Slater and Radford, 2012; Tilley *et al.*, 2002; Tilley *et al.*, 1997). A number of the studies have used different approaches to categorise these factors. Tilley *et al.*, (1999) within the context of project delivery, categorised the factors based on the typical construction project phases (that is project initiation phase, design phase, tendering phase and construction phase) while Abdalaziz (2009) grouped the factors into client related factors, tender procedures and designer related factors.

Hales and Gooch (2004) identify a number of factors that influence the engineering design process and as a consequence, the products of the process. These factors are grouped based on the level of influence namely macro-economic, micro-economic and corporate / organisational level factors. Considering the context of this research, the influencing factors for design documentation quality within the design process were categorised under four main latent constructs (see Table 1). Two of the categories, namely Design professional and Client related factors; were based on the major role players on a construction project. The influence of the economic environment and the design organisation was reflected in the choice of the categories of Industry and Design firm related factors respectively.

Table 1 presents a summary of the four latent factors and their respective indicators as identified from the literature review. The frequently reported Client related factors influencing the quality of design documentation are client expectations with respect to time required for design, quality of project brief; and no focal person on client team responsible for design coordination and providing information. Lack of quality control practices and procedures in the generation of design documentation, failure to adopt quality assurance systems and failure to provide relevant training to staff are highlighted with respect to the Design Firm related factors. While low design fees and the use of inexperienced designers were identified as the Industry and Design Professional related factors respectively.

Table 1. Factors influencing the quality of design documentation

	INDICATORS/ATTRIBUTE	SOURCE									
		Tilley *et al.*, (1999)	Love & Li (2000)	Tilley *et al.*, (2002)	Minato (2003)	Love *et al.*, (2006)	Darwish (2007)	Abdalaziz (2009)	Slater & Radford	Mcleannan & Pariminter (2001)	Phillips-Ryder *et al.*, (2013)
CLIENT (CR)											
C1	Client expectations with respect to time required for the design.			✓	✓		✓		✓	✓	
C2	The quality of the project brief provided.				✓	✓	✓		✓		
C3	No focal person responsible for design coordination and providing information.				✓		✓	✓		✓	
C4	Clients lack of relevant project experience.				✓		✓			✓	
C5	Changes to client requirements.				✓		✓	✓			
C6	Insufficient and missing information input			✓	✓			✓			
C7	Provision of wrong information by the client.			✓	✓			✓			
C8	Failure to review the design documentation.				✓		✓	✓			
C9	Provision of conflicting information.							✓			
C10	Client expectations with respect to time required for construction.				✓						
C11	Client's insistence to commence construction prior to completion of the detailed design phase.						✓				
DESIGN FIRM (DF)											
D1	Lack of quality control practices and procedures.		✓							✓	✓
D2	Failure to adopt quality assurance systems e.g. ISO 9001.				✓				✓		✓
D3	Failure to provide relevant training to staff.				✓		✓	✓			
D4	Inadequate design review processes.			✓				✓			
D5	Work overload on designers due to low staff levels						✓	✓			
D6	Poor allocation of time with consideration to available workload.					✓		✓			
D7	Lack of relevant software.								✓		
D8	High staff turnover.					✓					
D9	Inadequate supervision of junior design staff.						✓				
INDUSTRY (IR)											
E1	Low design fees.	✓		✓	✓		✓	✓	✓		
E2	Selection of design firms on the basis of lowest price offered.				✓		✓	✓	✓	✓	
E3	Shortage of civil engineering skills				✓		✓		✓	✓	
E4	Low emphasis on professional standards.						✓		✓		
DESIGN PROFESSIONAL (DR)											
F1	The designer is inexperienced.			✓	✓		✓	✓	✓	✓	
F2	Lack of coordination between different design disciplines.		✓		✓	✓		✓	✓		✓
F3	Limited time available for checking and coordinating all design documentation.			✓	✓	✓		✓		✓	
F4	Improper use of design software.				✓	✓	✓		✓		
F5	Reuse of design documents and details from previous projects without effective review.						✓	✓		✓	
F6	Designer's unfamiliarity with construction techniques and materials.				✓			✓	✓		
F7	Heavy work load on the designer.				✓			✓	✓		
F8	Poor communication amongst multi-disciplinary teams.				✓				✓		
F9	Failure to understand the client brief.				✓						
F10	Lack of experience on similar projects.							✓			

3 Research Method

A comprehensive literature review was undertaken to identify factors within the design process that influence the quality of design documentation. In addition indicators of design documentation quality were sought. Google scholar was used as the primary electronic search engine to narrow down the literature consulted to peer-reviewed articles. The keywords used included design documentation, design documentation quality, construction design management, construction design documentation, South Africa construction industry and a combination thereof. After a preliminary perusal of the literature, additional keywords such as contract documentation and Request For Information (RFI) were used to identify other relevant articles for inclusion in the study. The reference lists of these articles were also used to identify additional articles that could contribute to the research. This paper reports specifically on the findings with respect to factors within the design process that influence the quality of design documentation.

4 Proposed Conceptual framework

The findings from the literature review provided the theoretical framework for this study and a basis for the development of a conceptual model. It is hypothesised that factors that are attributed to the industry (IR), the design firm (DF), the client (CR) and design professional (DR) collectively influence the quality of the design documentation. It is further hypothesised industry related factors (IR) may influence the occurrence of client (CR) and design firm (DF) related factors. This influence could, for example, be through legislation regarding selection criteria for engineering design consultants and levels of professional fees paid for their services. Engineering design is often undertaken by designers with complementary skills and experience working within an engineering design firm. It is this set of complimentary skill and experience that the client seeks when appointing a design firm to find a solution to a problem. On this basis, it is assumed that through this interaction, the client related factors influence the occurrence of the design firm related factors. In addition, considering the umbrella role played by the design firm, it is hypothesised that the design firm mediates the influence of industry and client related factors on the design professional.

The proposed model shown in figure 1 explores and it illustrates the hypothesized interrelationship amongst the factors and their impact on quality of design documentation. The latent variables that represent the constructs in the research are shown in the oval symbols while the indicators or measurable attributes of the constructs are shown in the rectangles. The number notation for the indicators is the same as that shown in Table 1. The direction of the arrows represents the hypothesised influence in the model.

The conceptual model provides preliminary support and a foundation for further empirical investigation aimed at quantitatively illustrating the nature of interrelationship and collective impact of these factors on the quality of design documentation within the context of the South African construction industry. In order to examine the nature of the relationship between the design process factors and the quality of design documentation, the research sets out the following hypothesis:

Hypothesis 1: The occurrence of industry related factors (IR) in the design process negatively impacts upon the quality of design documentation.

Hypothesis 2: The occurrence of client related factors (CR) in the design process negatively impacts upon the quality of design documentation.

Hypothesis 3: The occurrence of design firm related factors (DF) in the design process impacts upon the quality of design documentation.

Hypothesis 4: The occurrence of designer related factors (DR) in the design process negatively impacts upon the quality of design documentation.

In order to examine how the design process factors influence one another, the research sets out the following additional hypothesis:

Hypothesis 5: Industry related factors (IR) in the design process interacts with client related factors (CR) to influence the quality of design documentation

Hypothesis 6: Industry related factors (IR) in the design process interacts with design firm related factors (DF) to influence the quality of design documentation.

Hypothesis 7: Client related factors (CR) in the design process interacts with design firm related factors (DF) to influence the quality of design documentation.

Hypothesis 8: Design firm related factors (DF) in the design process interacts with designer related factors (DR) to influence the quality of design documentation.

5 Limitations and Implications for Further Research

The conceptual model presented was developed based on a literature review. It therefore, provides a starting point and a foundation for further empirical investigations and validation within the context of the South African construction industry.

It is recognised that the factors have been identified from studies undertaken in the context of Europe and Asia. As part of the subsequent phases of this research, the relevance and applicability of the identified factors within the context of the South African construction industry will be assessed through an initial round of semi-structured interviews conducted with South African civil engineering consulting professionals. The engineering professionals will be purposefully selected and based in Cape Town. The selection of the professionals for this phase is influenced by the locality of the researcher.

The next stage of the research will involve refining the conceptual model. To achieve this, personal interviews using semi-structured interview protocols will be conducted with twelve experienced engineering consulting personnel identified nationally. Respondents will be requested to verify the existence of the proposed links and influence direction amongst the variables, and include any perceived missing interactions to the conceptual model. The constructs included in the refined model will be tested and validated using information obtained through a nationally administered survey questionnaire to civil engineering consulting professionals. The Structural Equation Modelling technique will be used to establish the statistical significance of the hypothesised relationships between the constructs in the model.

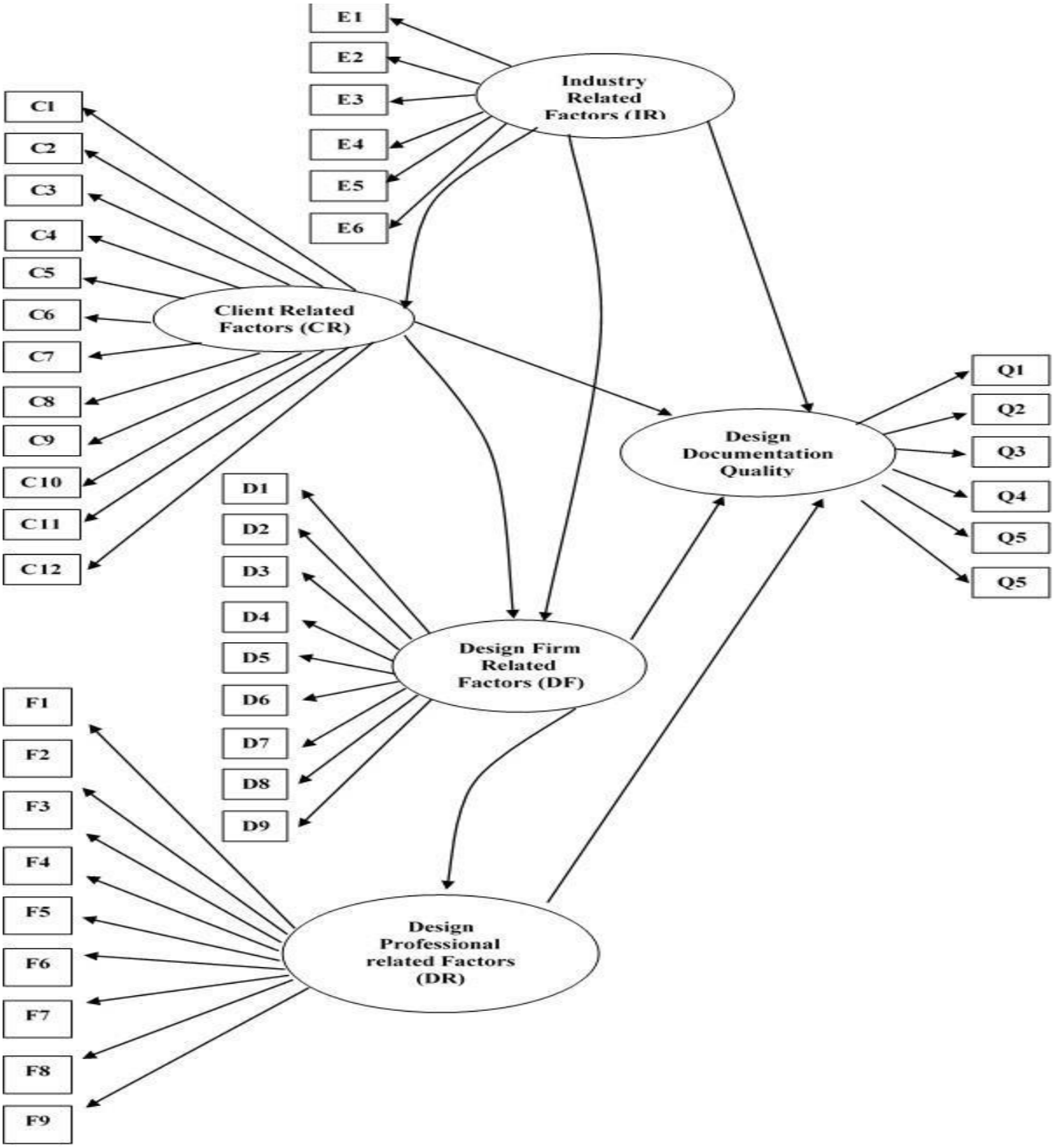

Figure 1. Conceptual model showing hypothesized interrelationship between variables

6 Conclusion

Poor quality of design documentation has been identified as a significant contributor to inefficiencies experienced in the implementation of construction projects, leading to delays, cost overruns and rework. Whilst a number of studies have identified and ranked factors within the design process that influence the quality of design documentation, the nature of interrelationship among the factors, although alluded to remains unexplored.

Following a comprehensive literature review, thirty-seven factors were identified and categorized under four latent constructs namely; Industry, Client, Design professional and Design firm related factors. In addition six objective indicators of design documentation quality were identified. A conceptual model incorporating the categorised factors and illustrating the hypothesized interrelationships among the factors and their impact on design documentation

quality was developed. Using the model as a foundation, a brief discussion is provided on proposed further work aimed at refining and empirically validating the model within the context of the South African construction industry.

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