Identifying the KPIs for the design stage based on the main design sub-processes

Haponava Tatsiana,
University of Twente, the Netherlands (email: t.haponava@utwente.nl)
Al-Jibouri Saad,
University of Twente the Netherlands (email: S.H.S.Al-jibouri@ctw.utwente.nl)

Abstract

Process performance can be defined as the degree to which the process is meeting the desired project outputs. This implies the measurement of a set of desired targets, while the project is in progress. To be able to control any process, it is necessary to control the variability of the main sub-processes within the process. In this paper a model for identifying KPIs for the use in control of the design stage is proposed. The KPIs were identified based on a proposed framework which describes the process during the design stage. The main sub-processes which were identified have been compared with KPIs found in other studies. As a result, a number of KPIs for the design stage has been selected for experts to be validated through the interviews. The paper describes how KPIs enable control of the design processes while the project is in progress.

Keywords: process, control, performance indicators, design stage

1. Introduction

The design process is the main process in any construction project. It defines the product to be built and has a major influence on other consequent processes. It is widely known that poor design has a very strong impact on the level of efficiency of the project during the construction stage as well as the quality of the final product. In recent years, the increased complexity of construction projects has necessitated the need for improving the performance of the design process through process control.

Despite its importance, a relatively little research has been carried out on the control of the design process. Design is a process concerned with a solution and every designer approaches the design problem in a particular way. Several studies in the past have highlighted that individual design processes tend to be very unstructured and chaotic and hence difficult to control. It involves numerous decisions with numerous interdependencies that are normally carried in uncertain environment. All of this implies the need to control the process to minimize the effect of the process uncertainty and complexity.

The work described in this paper is part of a larger ongoing research project to identify and develop performance indicators for the whole construction process. The focus of the research has been set on public infrastructure projects because of the considerable risks they face; the long planning and complexity they involve; the involvement of many public & private stakeholders with conflicting interests; the big impact they have on public during the project execution; and the higher degree of changes they usually encounter compared to other types of construction projects [10].

This paper describes investigation related to the early period of the design stage. It covers the framework and methodology proposed for identifying design process-based performance indicators.

The main objective of the work described in this paper is to present the preliminary results of a research which aims at defining Key Performance Indicators (KPIs) that are intended to be used for controlling the various sub-processes during the design stage. This has been done using a research methodology that consists of several steps. First, the design process was mapped to provide a theoretical framework of the process using literature review. In parallel, existing design KPIs were also identified through a literature review and then matched with the main design sub-processes that require control. This resulted in a list of selected process-based KPIs for the design stage to be further validated by experts. The proposed KPIs are aimed not only at controlling the process, but also indicating where control action should take place if necessary.

2. Main shortcomings of the existing KPIs

Existing KPIs are mainly used to benchmark the construction projects against each other and to indicate whether improvement can be made. In recent years indicators have been developed to measure different aspects of project performance. A major characteristic of these however is that most of them are used primarily for benchmarking purposes but are of little use for controlling the performance during a project. There are few existing indicators that can be used to inform stakeholders of how well their processes are going during the various stages of the project. For example, in their work to develop tools on measuring performance, Feurer & Chaharbaghi [11] recommended to keep the focus of measurement on processes rather than on the functions of the project. Koskela [17] highlighted that process performance is an important feature of performance indicators to improve process transparency so that the relevant and invisible attributes of the process become visible. Pillai [20] also suggested to measure the construction processes rather than their outcomes. This suggestion was supported later by Marosszeky et al. [18], who proposed to identify the critical process targets so that the measurement reflects the proposed project direction and provides feedback in the process.

Despite the recommendations made by many authors about the importance for measuring process performance, very little work has been done on this front. This is highlighted in the work carried out by Beatham et al. [5] who has made a critical overview of the existing KPIs used in the construction industry. In addition to main shortcomings of existing KPIs highlighted

by their study, the authors also indicated that almost all indicators in construction are end-product oriented. They indicated a need for process-based KPIs to control the process while it is still in progress. This work is an attempt to address the shortcomings of the existing performance indicators and to identify process-based KPIs that can be used to control the various processes in construction. The emphasis of this paper is on the design stage.

3. Control of the design stage

In construction each project is unique but most of the project processes are similar [22]. A process can be defined as the transformation of a set of inputs into desired outputs using various actions, methods and operations. Hence, process performance can be defined as the degree to which the processes involved in the project execution are meeting the desired project outputs while the project is in progress. To control a process, it is necessary to control the variability of the outputs of its main sub-processes.

Table 1. *Summary of the literature review on design stage of the construction project*

Author	Name of the phases	Main sub-processes
SR [6]	Conceptual design	Develop spatial and architectonic idea of the project, check and adjust constructions and installations, conceptual estimation of construction costs, global insight in building of investments' costs
	Definitive design	Develop spatial and architectonic provision of the project, architectural integration of constructions and installations, materialization and dimensions of architectural work, detailed cost estimation
Kagioglou et al. [15]	Outline conceptual design	prepare cost plan, prepare outline concept designs; prepare work packages, revise project plan, business case, project execution plan, procurement plan, CDM assessment, process execution plan
	Full conceptual design	prepare full design concept, prepare maintenance plan
	Coordinated design	produce product model
Baldwin et al. [4]	Concept design	site planning, preliminary site investigation, drainage concept design, estimating costs, concept design report production
	Scheme design	site investigation, product outline project specifications, revise cost estimation, scheme structural design, scheme service design, external works scheme design, scheme drainage design, scheme architectural design
	Detailed design	
Austin et al. [3]	Conceptual design	develop business need into design strategy, develop design strategy into conceptual proposal
	Detailed design	architectural design, civil design, structural design, mechanical design, electrical design
Hughes, [13]	Detailed design	organize design team, complete user studies, review cost plan, detail design, engineering detail design, services detail design, cost studies, completed design, specification notes
Al-Reshaid et al. [1]	Preliminary design	formulation; analysis; search; decision; specification; modifications
	Detailed design and engineering	calculation and analysis; checking and assessment; cost estimate and value engineering; review and audit; use of information technology; approval.
	Tender phase	tender scheduling; milestones allocation; schedules monitoring and follow up
Handleiding opdrachtgevers, [23]	Structural design	shape of the product, global assessment of time and costs
	Current design	consequences for planning and costs
	Defined design	defined shape, place and dimensions of space, construction and installation; use of material; approvals

Koontz & Weihrich [16] indicated that to control the process performance of the design stage it is necessary to establish standards or desired targets, measure performance against set desired

targets and correct any deviations from desired targets by taking action). Establishing desired targets is a process of selecting the degree to which the performance of desired targets should be achieved so that the project managers can establish how the process is going. The actual performance should then be measured against the set desired targets. The corrective action should be taken in case there is evidence of mistakes, recognising lack of progress or identifying areas of poor quality [19].

The design stage is referred to as such in most publications, see, for example, Chan & Kumaraswamy [7]; Baldwin et al. [4]; Austin et al. [3]. Whilst in Kagioglou et al. [15] or Al-Reshaid et al. [1] it is referred to pre-construction stage. In this paper the design stage is defined based on the definition of Chan & Kumaraswamy [7] as the stage where the primary concept is translated into an expression of functional and technical requirements which satisfy the clients' requirements in an optimum and economic way.

Table 1 shows a summary of the literature review addressing the main sub-processes of the design stage in construction and their main sub-processes. It can be seen from the Table 1 that different authors include different levels of details to describe the various sub-processes within the design stage depending on focus of their work. Table 1 also shows that the design stage is represented by two or more phases depending on the scope of the sub-processes it includes. The scope of the main sub-processes varies from design strategy to the project design parameters and even tender preparations [1].

The design process with its sub-processes and main outputs is used in this paper as a basis for defining the process-based KPIs to control the design process.

4. Research methodology

The main questions concerning this research can be formulated as follows: "What KPIs can be used to control the construction project during the design stage while it is in progress?" and "How can design process be controlled using Key Performance Indicators?"

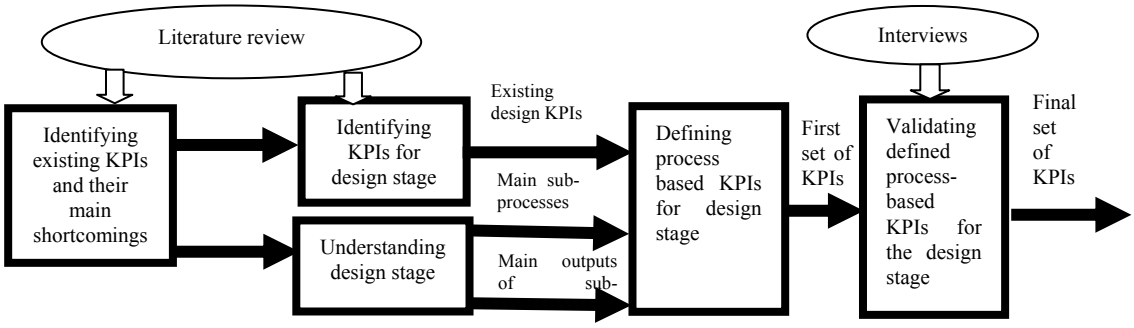

Figure 1. *Methodology of the research*

The research objective is to identify process-based KPIs that can be used by the project managers to control the design process. To achieve this objective, a research methodology has

been adopted that consists of a number of the steps: (1) review of the existing literature on the design process and its main sub-processes; (2) review of the existing literature on the existing design KPIs; (3) comparison of the main design sub-processes with the existing design KPIs; (4) identification of design process-based KPIs; (5) validation of the proposed set of design KPIs through a number of interviews. Figure 1 captures the methodology for identification of the process-based KPIs for the design stage.

To identify KPIs for control purposes a conceptual model is proposed to establish where the focus of control would be. The process KPIs are intended to be developed for project managers because of their overall responsibility of all of the sub-processes within the whole construction process and the design stage in particular.

4.1 Understanding the design stage: a conceptual model

Knowledge and information based resources are the type of knowledge that is possible to be delivered in written format. It is often called coded knowledge. In practise it may be manuals, drawings, text books, papers, web-pages and other computer systems.

A comprehensive literature review was conducted to identify the main phases, sub-processes and their outputs within the design stage. The main sub-processes identified are the focus of the control and the outputs of the identified sub-processes are the issues that should be controlled within these sub-processes.

As has been shown in Table 1, researchers divided the design stage mainly into three design phases with the same content but different titles of the phases. During the conceptual or preliminary stage the preliminary design concept is translated into potential design solutions. These potential design solutions are then analysed and the optimal design solution is then selected in the scheme design phase. The solution is then worked out in details in technical and functional terms to satisfy the client requirements during the detailed design phase. Figure 2 shows the main sub-processes included within each phase based on the literature review as described in Table 1.

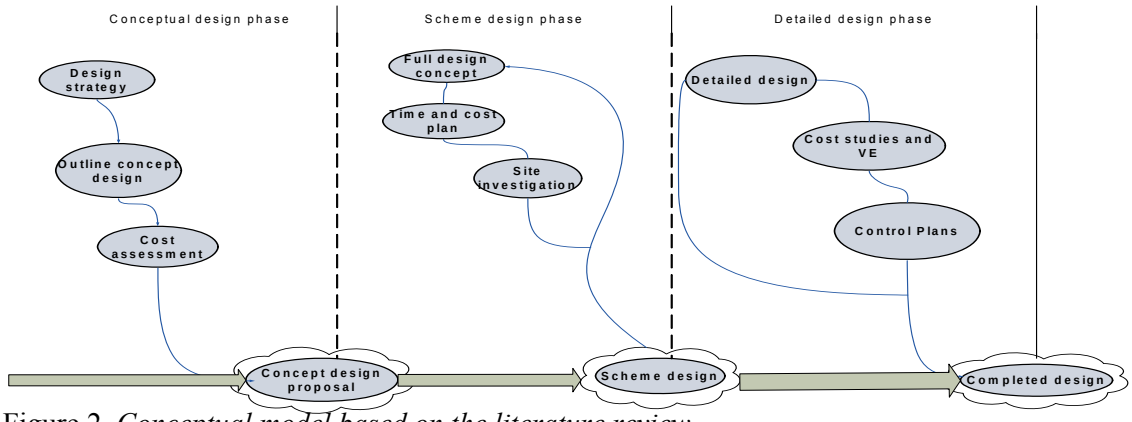

Figure 2. *Conceptual model based on the literature review*

A generic conceptual model of the design stage was proposed, in which the main sub-processes within the defined phases were mapped as shown in Figure 2.

The identification of the main sub-processes and their outputs proposed by this model was aimed at creating a basis for measuring how the design process is performing and to provide the control information necessary for project managers involved in the process.

4.2 Existing design KPIs

Regarding the design stage of the construction projects a number of design KPIs was developed to measure the performance of the projects.

Amongst the KPIs, proposed by the Construction Best Practice Program (CBPP) in the UK, predictability-cost and predictability-time are those related to the design stage. The indicators were developed for different construction sectors and include, for example, new build social housing, new build private housing, major infrastructure etc. [9]. However, the proposed KPIs were developed to benchmark the completed projects and are of little use for control of the design process.

CIRIA (Construction Industry Research and Information Association) developed its own CIRIA CDAPT Design KPI Assessment Tool. This tool provides measurement of both processes and outcomes of the project. The proposed design KPIs are: understanding client's needs, design process, integration of design with supply chain, internal cost/time management, risk, re-use of design experience, innovation and client/user satisfaction. The tool is developed to be used after the processes are finished [8].

Another tool - the Design Quality Indicator (DQI) – was developed to measure and manage the design of the buildings. The tool is based on involving all stakeholders in discussion on both objective and subjective design aspects of the on-going projects. The DQI measures three aspects: functionality, impact and build quality, where each of these aspects has its main attributes. DQI, however, is not an absolute measure and the focus of measurement is only on the design of the buildings [14].

Hansen and Vanegas [12] made an overview of the existing design KPIs that are also used to measure design quality of building projects. They proposed their own brief automation tool, which includes 12 performance parameters identified based on the existing design KPIs.

A summary of studied literature on design performance indicators described in different literature sources is presented in Table 2.

It can be seen from the Table 2 that the majority of the design KPIs are product-oriented, the others are either too generic (such as design process, risk, innovation) or are developed for

specific construction sectors such as the building sector. Only few KPIs are related to infrastructure construction projects.

Table 2. *Summary of the literature review on the existing design KPIs*

Source	**Design KPIs**	
Gann et al. [14] DQI_buildings	➢ Functionality (use, access, space, character & innovation) ➢ Impact (form &materials, internal environment, urban & social integration) ➢ Build quality (construction, engineering systems, performance)	
Hansen & Vanegas, [12]_buildings	➢ Contextual compatibility & response ➢ Functional performance ➢ Physical performance ➢ Cost ➢ Time ➢ Quality / reliability	➢ Safety / security ➢ Risk ➢ Constructability ➢ Maintainability ➢ Health and ➢ Sustainability
Anderson, D.K. & Merna, T. [2]	➢ Scope ➢ Concurrency ➢ Specifications ➢ Technical validation	➢ Commercial validation ➢ Practicality ➢ Quality ➢ Innovation
CIRIA [8]	➢ Design process ➢ Integration of design with supply chain ➢ Internal time/cost management ➢ Risk ➢ Reuse of design experience ➢ Innovation ➢ Client/user satisfaction	
DETR [9]	➢ Predictability-cost ➢ Predictability-time ➢ Waste (product was designed for minimum waste materials) ➢ Energy use (designed) ➢ Main water use (designed) ➢ Impact on biodiversity	
Ugwu and Haupt [21] _infrastructure	➢ Environmental impacts ➢ Innovative solutions that optimize the use of resources including design for durability, constructability and deconstruction ➢ Material reuse ➢ Recycle and waste management ➢ Impact of design decisions on the wider ecosystem ➢ Innovative construction methods and technology	

To answer the research question: "What KPIs can be used to control the construction process during the design stage while the project is in progress", the design KPIs identified through the literature review have been split into product-oriented and process-oriented measures. It was concluded that there is a strong misbalance between the two groups of the indicators. The main group of process-oriented indicators were developed by CIRIA [8]. These included design process, integration of design with supply chain, and risks. The process-oriented KPIs derived from the literature study were compared with the KPIs identified based on the main design sub-processes of the conceptual model to compose the final list the proposed process-based KPIs to be used.

4.3 Defining process-based KPIs for the design stage

The following step of the research is to verify the list of the identified process-based KPIs for the design stage by experts through interviews. The experts have already been selected based on their experience of working as project managers in the design stage of the infrastructure projects.

The interviews will be conducted based on the prepared questions. The purpose of the interviews will be to:

1) validate the process-based KPIs chosen based on the results described in the previous sections and
2) identify the focus of control within the proposed KPIs.

The questions for the interviews, designed to facilitate data collection, are split into two main sections. The first section involves the questions related to information about the experts' background, the techniques/tools used to control the design stage. The second section consists of the design process-based KPIs that were determined based on the literature review. The experts will be asked to assess their importance to the design stage and the issues they have to encompass. The received information will be analysed and the priorities in controlling certain issues within the proposed KPIs will be established. The identified KPIs will be developed further based on the issues selected by the experts.

5. Conclusions

Control of construction processes is important for achieving end-project goals. This is best done through a better understanding of the construction processes.

This paper has provided a review of existing KPIs in construction and their shortcomings. It highlighted the need to develop process-oriented indicators rather than product-oriented.

The paper described a conceptual model for mapping design process and identifying process-based KPIs that can be used to control it. The proposed model provided the main design sub-processes and their outputs. It intended to facilitate effective feedback into the process, since the main sub-processes can be monitored in a systematic way. The mapping process gave an adequate general view of the design process, which increases the process transparency. Based on the proposed model the process-based KPIs were identified and then compared with the existing design KPIs. As a result, a list of process-based KPIs relevant for control of the design stage selected to be validated by the experts.

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