Synthesising performance in the construction industry: An analysis of performance indicators to promote project improvement

Felipe Mellado

School of Mechanical, Aerospace and Civil Engineering, University of Manchester, Manchester, UK.

Innovation Centre of Applied Engineering, Universidad Católica del Maule, Talca, Chile.

Eric C.W. Lou

School of Engineering, Manchester Metropolitan University, Manchester, UK.

Christian L. Correa Becerra

Innovation Centre of Applied Engineering, Universidad Católica del Maule, Talca, Chile

Abstract

Purpose: There is a long-standing interest in performance improvement within the construction industry. Approaches based upon cost, time and quality, (often called the Iron Triangle), have been the focus of attention despite criticism of the validity of the Iron Triangle as a performance measure due to its simplistic approach. Furthermore, little emphasis has been placed on synthesising performance to understand whether this concept has evolved from the traditional view. An analysis of prominent literature was reviewed by classifying performance indicators which establish criteria for measuring performance in the construction industry. The purpose of this paper is to review the literature (1998-2018) on performance at a project level to determine a final rank of KPIs which will establish how projects are currently being measured.

Design/Methodology/approach: This paper uses a combined qualitative and quantitative approach - a comprehensive literature review on overall performance at a project level and the statistical Kendall's W test to find concordance among the authors on performance in the construction industry to determine a final rank of KPIs.

Findings: The results demonstrate there is no congruent correlation on what performance is and the traditional iron triangle of 'cost-time-quality' is still the preferred method of analysing performance, despite it being proven to be ineffective.

Originality/Value: Performance is an ambiguous concept that can be interpreted differently by the construction industry's stakeholders. Despite this lack of concordance, a starting point on the definition of performance can be obtained from the literature. The paper presents a final rank of key performance indicators (KPIs)

1. Introduction

Performance improvement has become one of the construction industry's main targets. Organisations are on a route of continuous improvement, seeking to increase efficiency in their businesses and project processes to deliver better results (Savolainen et al., 2015; Souza and Alves, 2018). For this reason, organisations have focused their resources on investing in new products, improving their processes and/or building new services (Humaidi and Said, 2011). Following the Latham (1994) and Egan (1998) reports where the inherent industry problems are described and guidelines and recommendations on how to achieve best practices are proposed, the construction industry in general is still failing to meet those standards. The industry's inherent characteristics have been acknowledged as a barrier to improve performance despite efforts made to reduce the inefficiency levels it is known for (Egan, 1998; Latham, 1994) - fragmentation, lack of research and development, low profitability and dissatisfaction from clients are some of the reasons impacting directly on how the final product is delivered (Demirkesen and Ozorhon, 2017; Yang et al., 2010). As a consequence, construction organisations are implementing project performance measurement systems, aiming to provide an idea to where they are moving towards, as well as to increase their profits and maintain a long-term sustainability (Abd et al., 2013; Khalfan et al., 2001; Lin and Shen, 2007; Luu et al., 2008; Robinson et al., 2005). Neely et al., (1995) stated that measuring performance is the "the process of quantifying effectiveness and efficiency of actions". In this sense, organisations can assess where improvements need to be made, potential areas of future problems can be early identified and internal business can also be improved by committing the entire organisation (Waggoner et al., 1999).

One way to assess how construction organisations and their projects are behaving is by measuring performance and promote improvements according to a set of key performance indicators (KPIs) which give an outlook on performance in both, company and project level (Radujković et al., 2010; Swan and Kyng, 2004). These KPIs are used as a key measurement system and when implemented correctly, provide useful and powerful performance information for organisations, where they can action process improvement.

In this paper a review of performance indicators focused on the construction industry was conducted to assess the evolution of this concept through time and to determine whether traditional assessments are still the preferred method of analysing performance. Currently, there is no agreement on which performance indicators are suitable for measuring construction projects because they have unique characteristics making them different from each other (Bryde and Brown, 2004; Chan et al., 2004; Toor and Ogunlana, 2010).

Literature from 1998 to 2018 on construction project performance was reviewed to understand the concept through the view from different authors in order to determine what the industry is measuring. The lack of studies synthesising the meaning of the performance concept in construction is one of the main aims of this paper. The majority of work found during the process was on proposing different ways of improving performance but there both is a lack of clarity and lack of demonstrable interconnections between improvement efforts and performance parameters. It is certain that generalising the taxonomy of the KPIs may seem unsuitable because every project is different, but it is important to interpret the view of the KPIs from different stakeholders on different scenarios, so future lessons can be obtained and later applied in future project contexts.

The concept of performance in the construction industry is always debatable, as are its quantification. The usual criteria for measuring success are open to discussion due to the rapid evolution of the industry which has made other measures to emerge along this constant change. Therefore, a comprehensive review is necessary.

The construction industry has evolved since the publication of the Latham (1994) and Egan (1998) reports where changes on how the industry should operate were proposed to promote improvements. For this reason, the main objective of this paper is analysing the literature on performance in the construction industry at a project level to determine how this concept has evolved through time from the view of different authors who have studied this topic. A clear definition on this concept could be provided and gaps could also be identified. The main limitation of this review is that the process was carried out mostly analysing papers in English. The process consisted of selecting journals from databases which are constantly updated, then filtered and selected based on a combination of keywords and limited to a period of time. Therefore, there is the possibility of not considering all the available information despite following a structured approach.

2. Literature review

2.1 Traditional view on performance

Construction projects are complex and difficult - efforts have been made to strategically manage them but still failing (Nguyen and Chileshe, 2015). Commonly, successful project performance in construction is viewed as meeting requirements of time, cost and quality, known as the "Iron Triangle" (Belassi and Tukel, 1996; Walker, 1995). However, according to Kagioglou et al., (2001) the Iron Triangle" does not give a balanced view on project performance and its implementation in construction is mostly carried out at the end of the project which is considered to be a "lagging" measure of performance rather than leading. .

The evolving nature of the construction industry in terms of functionality, users demand, environmental issues, deem as necessary to evaluate other aspects which have been studied but used mainly for benchmarking purposes and not to control performance (Haponava and Al-Jibouri, 2009; Toor and Ogunlana, 2010). The construction industry is project oriented; projects are different from each other, have a different scope, limited to a period of time and have different objectives, resources, activities and deliverables; therefore performance is more focused on this category rather than on an organisational level (Kagioglou et al., 2001;

Love and Holt, 2000). This situation demonstrates that different criteria for measuring success is the correct way of evaluating projects (Lauras et al., 2010; Wegelius-Lehtonen, 2001; Yu et al., 2005). For this reason, the iron triangle is criticized since projects are much more complex to be only measured by time, cost and quality parameters (Pheng and Chuan, 2006; Ward et al., 1991). The inclusion of other items to evaluate performance means that in the near future, projects may be measured based on different criteria according to the construction industry evolution such as Building Information Modelling (BIM) government's plans, carbon emissions reduction plans and how these impact on the evaluation of performance.

2.2 KPIs to measure project performance

The construction industry has established itself as a highly competitive environment in which organisations have established measures to evaluate their performance in both company and project level; being benchmarking a common practice within the industry (Ankrah and Proverbs, 2005; Haponava and Al-Jibouri, 2009). The construction industry uses as benchmarking method key performance indicators (KPIs) which are measures used to monitor and control both, project and organisational performance (Radujković et al., 2010). In order to measure performance, organisations need to sort out their priorities and set up appropriate KPIs that will give a snapshot of their current success levels and also can give an idea on future trends to be assessed. Furthermore, KPIs can provide indication on future issues, so that early actions can be taken to avoid problems becoming more complex. There is a difference between process and project KPIs. The process KPIs are focused on a company level and includes planning, monitoring and control of process performance such as processing time, complaints among others. (Blasini and Leist, 2013). Key performance indicators are an important part for improving efficiency and effectiveness in construction projects because they give support on the decision making process and also they are helpful in achieving organisation's goals by evaluating activities performance (Ibrahim et al., 2010). Since KPIs were first published in 1999, they have been extensively used in the construction industry to measure performance and promote improvement (Swan and Kyng, 2004). It is important to mention that a set of KPIs has been established to measure project success; these address time, cost, quality, client satisfaction, client changes, business performance and health and safety (Cheung et al., 2004; Enshassi et al., 2010). However, performance criteria may differ from organisation to organisation, making it difficult to find a consensus on what a successful project is under performance parameters given the number of different stakeholders present in the industry and the fragmented nature of it. There is a need of measuring performance in the construction industry, therefore KPIs have been implemented to analyse different stages in projects. In this scenario, KPIs have their own issues, especially the Iron Triangle, but it is possible to improve their usefulness by incorporating other factors, for example the KPI "quality" can be improved by measuring the quality of relationship among project agents which will positively affect achievement of project goals (Haponava and Al-Jibouri, 2009). Despite the importance of KPIs to measure performance in projects, they are also subject to criticism since during the execution phase performance is not monitored, focusing on measuring final outcomes; therefore, problems cannot be found and tackled. The focus is on the final outcome rather than the processes to obtain those results, not covering the way they were obtained. The way KPIs have been used in the industry is one of the reasons performance systems fail to deliver appropriate results. Most of the times, KPIs are used as post events indicators, lagging measures that do not promote opportunities for changes to be made. Their effects are not validated and are therefore, open to interpretations (Beatham et al., 2004). For these reasons, it is critical to assess 'what' current construction performance is in order to establish a foundation to future models/frameworks that could be proposed to improve construction industry's performance.

The method of analysing performance in the construction industry will be based on key performance indicators through literature review since as it was previously stated, the industry uses them as a benchmarking method to monitor and control both, project and organisational performance (Iyer and Banerjee, 2016; Radujković et al., 2010).

3. Research methodology

A comprehensive review approach has been carried out to assess the existent literature to determine what the studied authors have established as performance. The reason for using mixed methods of qualitative and quantitative research is because different opinions about a subject are collected from the literature which are later analysed by using statistical methods to determine a response.

3.1 Literature search

A Prisma methodology was used for this part in the sense of following the steps proposed by this framework such as identifying, screening, assessing eligibility and inclusion of the resulting papers (Liberati et al., 2009). The method used to carry out this review is explained in Table 1 and figure 1

Method:	*Journal papers, conference papers and industry reports focused on construction industry performance. Text books were excluded from the literature search*
Period:	*1998 – 2018*
Journals reviewed	*Journal of Civil Engineering and Management (2)* *Journal of Management in Engineering ASCE (3)* *Alexandria Engineering Journal (1)* *Journal of King Saud University – Engineering Sciences (1)* *International Journal of Project Management (6)* *Automation in Construction (2)* *Building Research and Information (1)* *Revista de la Construcción (1)*

	Canadian Journal of Civil Engineering (1) *Journal of Construction and Management ASCE (3)* *Computers in Industry (1)* *Journal of Construction Engineering and Management (3)* *International Journal of Productivity and Performance Management (1)* *International Journal of Construction Engineering and Management (1)* *International Journal of Construction Management (2)* *Benchmarking: An International Journal (2)* *Journal of Civil Engineering and Management (2)* *Construction Management and Economics (4)* *Australasian Journal of Construction Economics and Building (1)* *Architectural Science Review (1)* *Journal of Construction Engineering (1)*
Conference papers	*Procedia CIRP (1)* *Procedia Engineering (1)* *Construction Research Congress (1)* *Proc. 9th Conference of International Group for Lean Construction, Singapore (1)* *IOP Conference Series: Earth and Environmental Science (1)*
Reports	*The report of the Construction Task Force (1)* *The Construction Industry KPIs Handbook (1)*

Table 1: Summary of methodology used

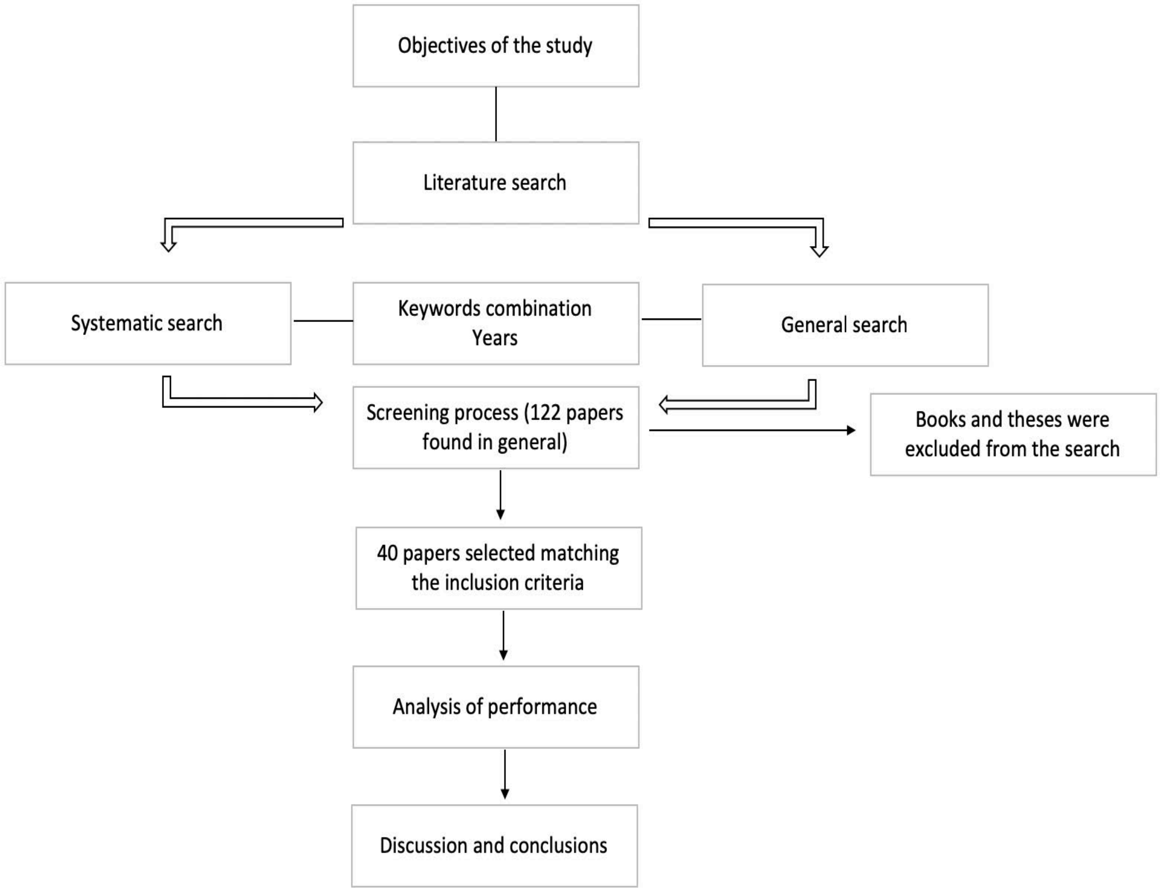


Figure 1: Outline of the study methodology

Search engines such as Scopus, ScienceDirect, Emerald Insight, Mendeley and ASCE were identified and used for searching relevant literature using specific keywords such as "performance", "KPIs", "project", "organisation", "Key performance indicators", "Construction industry", "built environment", "AEC", "iron triangle" and Boolean connectors "and" "or" were used and combined. A Google search was also conducted to widen the scope of the search to other journals j by applying the same keywords mentioned above. The period under study starts in 1998, which is where the Egan report was published, to 2018.

3.2 Papers screening

After identifying the papers that could potentially be included, a filtration process took place based on the screening of titles and abstracts which were read to assess if the journals met the inclusion and exclusion criteria. The inclusion criterion is regarding overall performance in the construction industry and a combination of at least two keywords were considered as appropriate. Exclusion criteria considered application in other areas and studies including only one keyword. Also, books were excluded from the review.

3.3 Paper classification

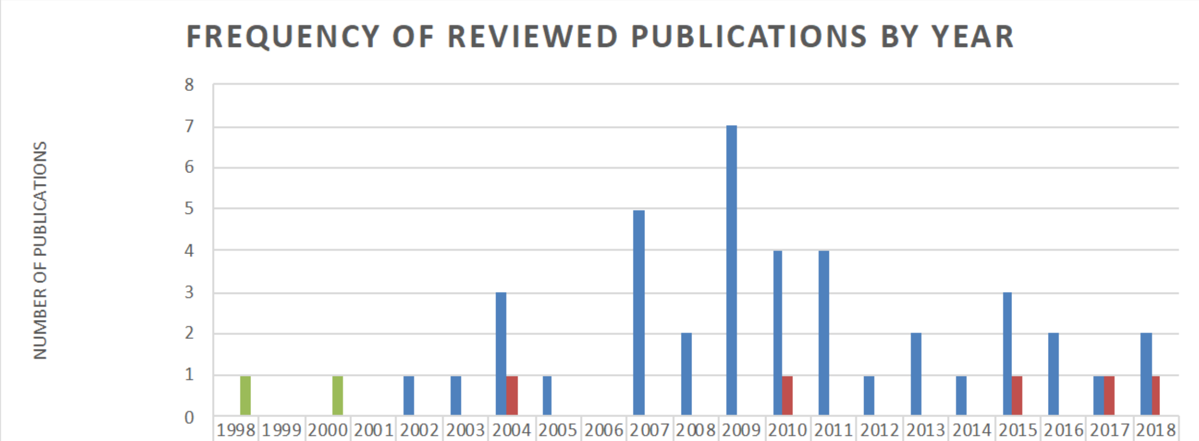
A total of 122 journal papers were identified meeting the mentioned criteria but only a total of 40 papers were related to the scope of this study. The analysed papers included case studies (12) where projects were analysed. Most of the studied papers considered surveys delivered to industry practitioners (23) to ask for their perceptions on performance indicators; review papers (3) and industry reports (2). In these articles, a vast number of KPIs were found which were ranked by the different authors. The paper selection was based on the criteria of explicitly mentioning or analysing overall performance at a project level. It is important to highlight that even though there are different ways of obtaining KPIs (Manually, semi-automatic or automatic), the focus on this research is synthesising performance to establish whether traditional views on performance are the preferred method to evaluate projects despite the disadvantages presented. Therefore, the focus is on the result and not the way they KPIs are constructed which in this case is not relevant.

3.4 Rank of KPIs

The best way of checking for a statistical significance among different authors who have ranked different responses is using the Kendall’s W test. The advantage of using Kendall´s W is that a coefficient of concordance can be obtained to establish agreement of different authors on certain subject based on ranks which they have determined (; Gearhart et al., 2013;; Kendall and Smith, 1939; Kvam and Vidakovic, 2007; Marozzi, 2014).
Kendall´s W (Kendall, 1938) is a non-parametric test similar to Friedman’s (Friedman, 1937). It is the normalization of the Friedman test with values between 0 and 1 (Kendall and Smith, 1939) and is used to evaluate differences between groups (Marozzi, 2014).. Kendall’s coefficient of concordance (W) was applied to observations from all observers.

4. Findings

From the review, it is found that most of the papers analysed are dated in 2009 and interest in the subject of overall project performance in the construction industry has decreased during the last years as shown in Figure 2). Different countries have also been identified in this review as shown in Figure 3) whose authors list KPIs in a different manner (Table 2 and 3) but with the Iron Triangle” as the main focus of attention.



	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Journal papers	0	0	0	0	1	1	3	1	0	5	2	7	4	4	1	2	1	3	2	1	2
Conference papers	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	1	1
Reports	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 2: Reviewed publications by year

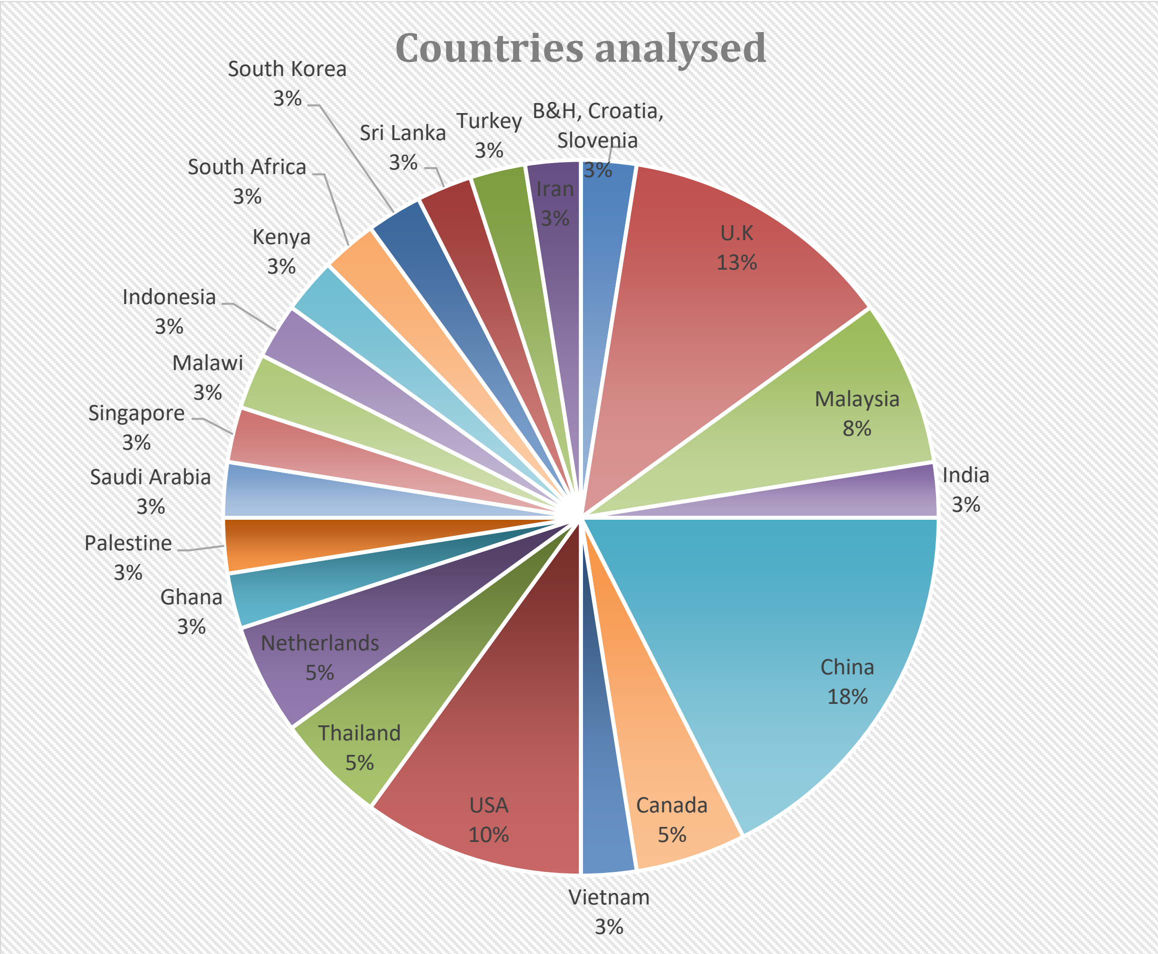


Figure 3: Analysed countries from the literature.

ID	KPI	ID	KPI
1	Quality	40	Material management
2	Cost	41	Efficiently
3	Number of investors	42	Disputes
4	Interferences	43	Problem definition
5	Changes in project	44	Management of design solution
6	Time	45	Management of design interactions
7	Client satisfaction	46	Management of project value
8	Employees’ satisfaction	47	Control management program
9	Innovation and learning	48	Information management
10	Client’s interest and requirements	49	Time variation
11	Predictability—cost	50	Net Present Value
12	Predictability—time	51	Functionality
13	Defects	52	End user's satisfaction
14	Planning	53	Design team's satisfaction
15	Meetings	54	Regular and community satisfaction
16	Record maintenance	55	Aesthetic purpose
17	Joint site visits	56	Expectations of project participants
18	Communication channels	57	Knowledge
19	Work integration	58	Professionalism
20	Cleared payments	59	$/Unit
21	Specifications	60	Top management commitment
22	Productivity	61	Trust and respect
23	Profitability	62	Facility management
24	Safety	63	Stress/conflict management
25	Business performance	64	Resource utilization
26	Benefit	65	Contract management
27	Risk	66	Technical management and skill
28	Project status	67	Tender responsiveness
29	Effectiveness	68	Tender estimation
30	Stakeholders	69	Product delivery
31	Project management	70	Air emission
32	People	71	Energy consumption
33	Environment	72	Fuel consumption
34	Variance cost	73	Labour relationship
35	Contractor satisfaction	74	Training and education
36	Social indicators	75	Labour dependency
37	Scope	76	Quality of coordination by the team
38	Sustainability	77	Contractor’s manpower capacity
39	Team performance	78	Construction flexibility

Table 2: Project level KPIs found on the literature

Author	***Year***	***Country***	***KPI ID***
Radujković et al.	*2010*	*B&H, Croatia, Slovenia*	*1,2,3,4,5,6,7,8,9,10*
Bassioni et al.	*2004*	*UK*	*2,6,11,12,13*
Egan	*1998*		*2,6,7,11,12,13,22,23,24*
DETR	*2000*		*1,2,5,6,7,24,25*

Roberts and Latorre *Sarhan and Fox*	*2009* *2013*		*2,6,7,11,12,13,22,23,24,34,35,36,49* *1,7,14,22,24,39,51*
Alaloul et al. *Chan* *Idrus et al.*	*2016* *2009* *2011*	*Malaysia*	*1,6,14,15,16,17,18,19,20,21* *1,9,22,32,33,38,57,58* *1,2,6,24,31,33,75,76,77,78*
Pillai et al.	*2002*	*India*	*2,7,22,26,27,28,29,30,31*
Cheung et al. *Chan and Chan* *Lam et al.* *Yeung et al.* *Ling et al.* *Yeung et al.* *Lai and Lam*	*2004* *2004* *2007* *2007* *2009* *2013* *2010*	*China*	*1,2,6,7,18,24,32,33* *1,2,6,7,22,24,33,34,35,49,50,51,52,53* *1,2,6,9,24,33,42,51,55,56* *1,2,6,9,18,60,61* *1,2,6,7,23,54* *1,2,6,7,14,18,24,33,51,52* 1,6,8,9,23,24,29,33,42
Rankin et al. *Omar and Fayek*	*2008* *2015*	*Canada*	*1,2,6,7,9,24,37,38* *1,2,5,6,7,22,24*
Luu et al.	*2008*	*Vietnam*	*1,2,5,6,7,24,39,40*
Skibniewski and Ghosh *Cox et al.* *Swarup et al.* *Yuan et al.*	*2009* *2003* *2011* *2009*	*USA*	*2,6,7,11,12,13* *1,2,6,22,24,59* *1,2,6,7* *1,24,27,33,62,63,64,65,66*
Toor and Ogunlana	*2010*	*Thailand*	*2,6,13,21,24,29,30,41,42*
Haponava and Jibour	*2009*	*Netherlands*	*1,2,6,10,30,31,43,44,45,46,47,48*
Ofori-Kuragu et al.	*2016*	*Ghana*	*1,2,6,7,22,24,25,32,33*
Enshassi et al.	*2009*	*Palestine*	*1,2,6,7,9,22,24,32,33,54*
Almahmoud et al.	*2011*	*Saudi Arabia*	*1,2,6,7,24,37*
Ling and Peh	*2005*	*Singapore*	*1,2,6,7,22,23,24,38*
Kulemeka et al.	*2015*	*Malawi*	*1,6,67,68*
Amrina and Vilsi	*2015*	*Indonesia*	*2,24,40,69,70,71,72,73,74*
Ngacho and Das	*2014*	*Kenya*	*1,2,6,24,33,42*
Sibiya et al.	*2015*	*South Africa*	*1,6,7,12,22,23,24,27,31,40*
Cha and Kim	*2011*	*South Korea*	*1,2,6,22,24,33*

Table 3: Authors and KPIs identified

Table 4 shows the authors and a description of the works carried out, their limitations and the stakeholders involved in obtaining the respective KPIs. The collected KPIs are the views from different construction stakeholders. Therefore, there is no surprise in the different priorities based on their perceptions.

Author	Year	Description	Limitations	CTC	CST	CLT
Radujković et al.	2010	Perception of KPIs from the management perspective.	The study did not consider the efficiency and effectiveness of these measures in overall management processes.	●	●	●
Bassioni et al.	2004	Review of performance measurement systems in construction	The application of a comprehensive frameworks is missing.	●	●	
Alaloul et al.	2016	Identification and prioritisation of coordination factors that influence the performance of building projects.	The coordination factors are established but there is no clarity on how they affect performance	●		●
Egan	1998	Report about the need to change current construction practices to achieve continuous improvement	The limitations of this report were not considered	-	-	-
DETR	2000	KPI report for the minister for construction UK	The limitations of this report were not considered	-	-	-
Pillai et al.	2002	Development of an Integrated Performance Index used to measure the overall performance of a R&D project during its life cycle.	Applicability is limited. More validation is needed.	-	-	-
Cheung et al.	2004	Development of a Project Performance Monitoring System aiming to help construction practitioners in monitoring and assessing project performance.	Constant monitoring and reliable databases are needed.	●		
Roberts and Latorre	2009	Critical analysis of the KPI measurement system in the construction industry	Validation is needed.	-	-	-
Rankin et al.	2008	Study to measure the performance of the Canadian construction industry.	There is a need of obtaining more information from owners, designers and contractors.			●

Luu et al.	2008	Application of key performance indicators (KPIs) to measure project performance.	Study limited to large contractors only.	●		
Skibniewski and Ghosh	2009	Development of a comprehensive KPI framework for application in the construction industry	A small segment of the industry was considered in this study, therefore more validation is needed.		●	
Toor and Ogunlana	2010	Exploration of KPIs in perspective of clients, consultants, and contractors in large construction projects	Study limited to large contractors only. CI is composed in its majority of SMEs.	●	●	●
Haponava and Jibouri	2009	Identification of process-based KPIs for use in control of the pre-project stage	Early project phases considered in the study. Impact on later stages is not considered.		●	●
Ofori-Kuragu et al.	2016	Identification of the most common KPIs for contractors in the construction industry of Ghana	Limited database from contractors in Ghana. The study is limited to large contractors.	●		
Chan and Chan	2004	Development of a framework for measuring success of construction projects based on KPIs	The analysed projects were hospitals, therefore the conclusions apply to these kinds of facilities whose processes are different and more specialised than traditional buildings.	-	-	-
Enshassi et al.	2009	Identification of factors affecting project performance in the local construction industry	The information on the type of projects is missing, so the applicability is also not clear.	●	●	●
Lam et al.	2007	Development of a project success index to benchmark the performance of design-build projects from KPIs.	Limited database of D&B project organisations.	●	●	●
Chan	2009	Development of a comprehensive set of performance measures for the construction industry to reach government goals	The application and updating of information depend on different stakeholders and a framework is still needed.	●	●	●

Cox et al.	2003	Collection of management perceptions of KPIs utilized in the construction industry in USA.	Limited sample size, therefore no conclusions could be reached about the mechanical and electrical construction sectors.	●		
Yeung et al.	2007	Measurement of the performance of partnering projects in Hong Kong based on a consolidated KPIs’ conceptual framework	The developed model is applied to project partnering only.	●		
Ling et al.	2009	Investigation on how foreign construction companies’ practices affect project performance in China	Low response rate which makes the study difficult to generalise.		●	
Swarup et al.	2011	Evaluation and verification of project delivery metrics for high-performance buildings.	Limited data cases and focused mainly on the private sector.	●		●
Almahmoud et al.	2011	Empirical study of the relationship between project health and project performance in the project delivery context.	The study did not consider the links that may exist among project health functions and project KPIs. Experimental studies are also suggested.	●		
Yeung et al.	2013	Formulation of a benchmarking model to assess project success in Hong Kong based on KPIs	The model allows performance prediction of a project, but it depends on the evaluator’s interpretation.	●		●
Sarhan and Fox	2013	Assessment of the importance of the use of appropriate performance measures and its role in supporting the application of Lean Construction	The sample includes large organisations, not considering SMEs which account for the majority of the construction industry.	●	●	●
Omar and Fayek	2015	Development of a systematic framework and methodology are to measure project competencies and project KPIs	More construction stakeholders need to be included to generalise the results.		●	

Ling and Peh	2005	Development of KPIs to measure contractors' performance in the Singapore construction industry.	Low response rate from industry practitioners. More data analysis is needed for validation purposes.	●		
Yuan et al.	2009	Identification of performance objectives and KPIs to improve public-private partnership projects	Quantification of performance objectives is needed, making the process difficult in practice.	●	●	●
Kulemeka et al.	2015	Study of inhibiting factors that influence the performance of small and medium scale contractors in the construction industry in Malawi	Empirical work is needed to validate the relationship between KPIs and inhibiting factors	●		
Amrina and Vilsi	2015	Proposition of KPIs for evaluating the manufacturing process in a cement industry.	The development of sustainable manufacturing evaluation tool is needed.	●		
Ngacho and Das	2014	Development of a multidimensional performance evaluation framework of development projects by considering performance measures.	Study limited to one region, therefore more research is needed to generalise the results. The causal relationships among the KPIs obtained of project performance were not considered.	●	●	●
Sibiya et al.	2015	Exploration of the most significant construction projects' KPIs in the construction industry in South Africa	Results limited to one region only, therefore more research is needed to generalise the results	●	●	●
Lai and Lam	2010	Examination of the importance of perceived performance criteria and their respective performance outcomes in a construction project.	The data was obtained mainly from the main contractors and clients. Not all the project participants were considered.	●	●	●
Idrus et al.	2011	Identification of actual criteria used by local clients to measure the performance of a construction project.	The data was obtained mainly from the main clients, not considering all the project participants.			●
Cha and Kim	2011	Definition of a quantitative performance measurement system	The metric system proposed should be considered during the whole project life.	●		

		and evaluation criteria by identifying KPIs				
Madushika et al.	2018	Investigation of Value management KPIs in the construction industry in Sri Lanka	There is a limited sample in this study due to a lack of experts in the area.	●	●	
Neval and Polat	2017	Development of a systematic performance measurement framework based on KPIs to measure subcontractors in Turkey	Subcontractors considered only in this study and limited to large construction companies	●		
Khanzadi et al.	2018	Identification and prioritization of BIM applications toward KPIs in the construction stage.	The model needs validation by using larger samples covering different sizes and various types of companies.	●	●	
Smits et al.	2017	Measurement of the impact of BIM on project performance	More metrics are necessary to measure actual project performance based on data and not perceptions.	●	●	●
Soewin and Chinda	2018	Development of a performance evaluation framework considering KPIs.	The study did not investigate the casual relationships among the factors affecting construction performance.	●		

*CTC=Contractor; CST=Consultant; CLT=Client

Table 4: Reviewed studies

For example, Radujkovic et al. (2010) compiled a total of 37 indicators applied to a large number of South-Eastern construction companies wherein low levels of awareness of KPI models and performance management systems were found, establishing a basis for developing KPI decision making platforms. Similarly, Bassioni et al. (2004) highlights the need of developing more integrated performance frameworks due to the lack of implementation efforts. Alaloul et al. (2016) determined the coordination factors affecting building performance and their relationship with KPIs. A similar approach was taken by Enshassi et al. (2009), concluding that coordination and communication need to be addressed throughout the project life cycle in order to promote improvements. Clearly, coordination is an important factor to consider which can be enhanced by adopting current modelling practices; for example, Ofori-Kuragu et al. (2016) identified the critical KPIs for project success, due to the lack of existent benchmarking methods and the low level of awareness among construction participants. Sibiya et al. (2015), Toor and Ogunlana (2010), Yuan et al. (2009), Rankin et al. (2008), Ling and Peh (2005), Cox et al. (2003) carried out similar studies in their respective countries about finding the most common KPIs applied to the local construction industries, finding different set of KPIs. Other papers, for example Luu et al. (2008) proposed benchmarking models or frameworks to evaluate and improve certain aspects of project performance.

The discussion of what the term project performance actually means is complex because the industry is wide and with different needs. Therefore, it is difficult to assess whether a project is a success or a failure. In this sense Lam et al. (2007) proposed a project success index to quantify the outcome of a project. However, it is challenging to apply this index because there are no databases to compare it against.

ID	*Project KPIs found on literature*	Author 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		16		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
		Rank																																				
1	Quality	1	0	2	0	3	0	4	0	3	4	0	0	3	4	1	2	1	3	3	2	1	5	3	3	3	4	3	5	3	1	1	0	5	6	4	1	3
2	Cost	2	1	0	2	2	6	2	4	1	1	1	2	2	2	4	8	5	7	2	0	3	2	1	2	2	2	0	1	1	0	0	1	2	0	0	2	1
3	Number of investor	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	interferences	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Changes in project	5	0	0	0	5	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
6	Time	6	2	1	3	1	0	3	4	2	2	2	1	2	3	1	4	3	5	1	0	2	1	2	1	1	3	0	2	2	0	2	0	1	1	1	3	2
7	Client satisfaction	7	6	0	8	4	7	6	1	8	3	5	0	0	1	4	6	4	4	0	0	0	0	4	4	6	5	2	7	4	0	0	0	0	7	0	0	0
8	Employees' satisfaction	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0
9	Innovation and learning	9	0	0	0	0	0	0	0	6	0	0	0	0	0	0	1	4	2	9	5	0	7	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0
10	Client's interest and requirements	10	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Predictability—cost	0	3	0	1	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Predictability—time	0	4	0	1	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0
13	Defects	0	5	0	7	0	0	0	2	0	0	4	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Planning	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	7	0	0	0	0	0	0	0	0	0	0
15	Meetings	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Record maintenance	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Joint site visits	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Communication channels	0	0	7	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0
19	Work integration	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Cleared payments	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Specifications	0	0	10	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	Productivity	0	0	0	4	0	5	0	8	0	0	0	0	0	7	2	5	6	6	0	1	6	0	0	0	0	0	5	6	7	0	0	0	0	10	0	0	5
23	Profitability	0	0	0	5	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	6	0	0	0	0	2	2	0	0
24	Safety	0	0	0	6	7	0	5	9	4	8	0	6	0	5	7	7	8	8	5	0	4	0	0	0	4	1	1	4	8	2	0	1	6	8	5	4	4
25	Business performance	0	0	0	0	6	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

26	Benefit	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	Risk	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	5	0	0	0
28	Project status	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	Effectiveness	0	0	0	0	0	4	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
30	Stakeholders	0	0	0	0	0	8	0	0	0	0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	Project management	0	0	0	0	0	9	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	6	0
32	People	0	0	0	0	0	0	1	0	0	0	0	0	0	8	0	3	7	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	Environment	0	0	0	0	0	0	8	0	0	0	0	0	0	9	8	10	10	9	7	6	0	0	0	0	0	10	0	0	0	4	0	0	4	0	3	10	6
34	Variance cost	0	0	0	0	0	0	0	5	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	Contractor satisfaction	0	0	0	0	0	0	0	6	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	Social indicators	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Scope	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
38	Sustainability	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
39	Team performance	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
40	Material management	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0	0	0
41	Efficiently	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	Disputes	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7	0	0
43	Problem definition	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	Management of design solution	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	Management of design interactions	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	Management of project value	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	Control management program	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	Information management	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	Time variation	0	0	0	0	0	0	0	5	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	Net Present Value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	Functionality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	4	0	0	0	0	0	0	9	6	0	0	0	0	0	0	0	0	0	0
52	End user's satisfaction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
53	Design team's satisfaction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

54	Regular and community satisfaction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	10	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	Aesthetic purpose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	Expectations of project participants	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	Knowledge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	Professionalism	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	$/Unit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	Top management commitment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	Trust and respect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	Facility management	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
63	Stress/conflict management	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0
64	Resource utilization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0
65	Contract management	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
66	Technical management and skill	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0
67	Tender responsiveness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
68	Tender estimation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
69	Product delivery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
70	Air emission	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
71	Energy consumption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
72	Fuel consumption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
73	Labour relationship	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
74	Training and education	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
75	Labour dependency	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
76	Quality of coordination by the construction team	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0

77	Contractor’s manpower capacity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0
78	Construction flexibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
	Number of items	**10**	**6**	**10**	**9**	**7**	**9**	**8**	**13**	**8**	**8**	**6**	**9**	**12**	**9**	**14**	**10**	**10**	**10**	**10**	**8**	**6**	**7**	**6**	**4**	**6**	**10**	**7**	**7**	**8**	**9**	**4**	**9**	**6**	**10**	**9**	**10**	**6**

T*able 5: Rank of Project level KPIs*

Statistical analyses were carried out using the SPSS software. The Kendall's coefficient of concordance indicates whether different respondents agree about a certain topic and if they respond in a consistent manner (Kvam and Vidakovic, 2007). In this case, there are different authors who have ranked different set of KPIs shown in Table 5. The list shows a number of 78 different performance indicators that are ordered considering the number 1 as the highest rank. The figure shows that not all of the 78 KPIs were considered by the different authors. Therefore, a value of zero was assigned to the KPIs not considered or not measured.

The reason for taking this approach to analyse the data collected from the literature review is that a final rank can be obtained which will establish what are the most important factors considered when analysing performance at a project level (Table 6). At first glance, it is shown that the authors rank the same KPIs in a different way but there are some performance indicators that are repeated which in the first instance mean those are the most important measures of performance by industry practitioners.

Ranks							
ID	***KPI***	***Mean Rank***	***Overall rank***	***ID***	***KPI***	***Mean Rank***	***Overall rank***
1	Quality	*65.69*	*2*	**41**	Efficiently	*36.34*	*68*
2	Cost	*65.39*	*3*	**42**	Disputes	*39.69*	*16*
3	Number of investors	*36.30*	*74*	**43**	Problem definition	*36.24*	*77*
4	interferences	*36.32*	*71*	**44**	Management of design solution	*36.43*	*47*
5	Changes in project	*39.55*	*17*	**45**	Management of design interactions	*36.24*	*77*
6	Time	*67.03*	*1*	**46**	Management of project value	*36.34*	*68*
7	Client satisfaction	*59.80*	*5*	**47**	Control management program	*36.43*	*47*
8	Employees’ satisfaction	*37.57*	*27*	**48**	Information management	*36.50*	*37*
9	Innovation and learning	*44.96*	*8*	**49**	Time variation	*37.38*	*35*
10	Client’s interest and requirements	*37.51*	*28*	**50**	Net Present Value	*36.47*	*39*
11	Predictability—cost	*39.32*	*19*	**51**	Functionality	*39.53*	*18*
12	Predictability—time	*40.50*	*12*	**52**	End user's satisfaction	*37.41*	*34*
13	Defects	*40.66*	*11*	**53**	Design team's satisfaction	*36.42*	*52*
14	Planning	*38.55*	*22*	**54**	Regular and community satisfaction	*39.91*	*13*
15	Meetings	*36.32*	*71*	**55**	Aesthetic purpose	*36.43*	*47*
16	Record maintenance	*36.36*	*60*	**56**	Expectations of project participants	*36.49*	*38*
17	Joint site visits	*36.36*	*60*	**57**	Knowledge	*36.35*	*64*
18	Communication channels	*39.70*	*15*	**58**	Professionalism	*36.46*	*41*
19	Work integration	*36.43*	*47*	**59**	$/Unit	*36.41*	*54*
20	Cleared payments	*36.46*	*41*	**60**	Top management commitment	*36.34*	*68*
21	Specifications	*37.49*	*30*	**61**	Trust and respect	*36.36*	*60*
22	Productivity	*51.47*	*6*	**62**	Facility management	*36.36*	*60*
23	Profitability	*41.65*	*9*	**63**	Stress/conflict management	*36.39*	*57*
24	Safety	*63.28*	*4*	**64**	Resource utilization	*36.42*	*52*

25	Business performance	*37.50*	*29*	**65**	Contract management	*36.45*	*44*
26	Benefit	*36.26*	*76*	**66**	Technical management and skill	*36.47*	*39*
27	Risk	*38.35*	*25*	**67**	Tender responsiveness	*36.38*	*59*
28	Project status	*36.31*	*73*	**68**	Tender estimation	*36.41*	*54*
29	Effectiveness	*38.47*	*24*	**69**	Product delivery	*36.45*	*44*
30	Stakeholders	*38.51*	*23*	**70**	Air emission	*36.28*	*75*
31	Project management	*39.72*	*14*	**71**	Energy consumption	*36.35*	*64*
32	People	*41.43*	*10*	**72**	Fuel consumption	*36.39*	*57*
33	Environment	*51.08*	*7*	**73**	Labour relationship	*36.35*	*64*
34	Variance cost	*37.49*	*30*	**74**	Training and education	*36.45*	*44*
35	Contractor satisfaction	*37.58*	*26*	**75**	Labour dependency	*36.35*	*64*
36	Social indicators	*36.53*	*36*	**76**	Quality of coordination by the construction team	*36.41*	*54*
37	Scope	*37.47*	*32*	**77**	Contractor’s manpower capacity	*36.43*	*47*
38	Sustainability	*38.62*	*20*	**78**	Construction flexibility	*36.46*	*41*
39	Team performance	*37.43*	*33*				
40	Material management	*38.58*	*21*				

Test Statistics	
N	37
Kendall's W[a]	0.342
Chi-Square	973.152
df	77
Asymp. Sig.	0.000
a. Kendall's Coefficient of Concordance	

Table 6: Statistical analysis results

The number of KPIs is high and therefore a selection criterion needs to take place in order to make the analysis simpler and more appropriate to project needs. It has been suggested that a number of 8-12 KPIs is an acceptable and manageable number to work with (Abd et al., 2013; Swan and Kyng, 2004). In this case, the top ten KPIs are shown.

Top ten KPIs	Rank
Time	1
Quality	2
Cost	3
Safety	4
Client Satisfaction	5
Productivity	6
Environment	7
Innovation and learning	8
Profitability	9
People	10

Table 7: Top ten KPIs

The results for the project performance analysis show that the Kendall's W value is 0.342. The W value ranges from 0 (Total disagreement) to 1 (Complete agreement). A significant W value means the null hypothesis that there is a complete lack of consensus among the respondents can be rejected (Chan et al., 2011). As it can be seen from the results, there is a lack of consensus on what project performance is according to the authors from the studied papers. This lack of consensus means that different countries have different perception of what performance really is and what it is measured (Bryde and Brown, 2004; Chan et al., 2004; Toor and Ogunlana, 2010). However, despite this difference there are indications that some KPIs repeatedly occur and therefore a common final ranking can be established.

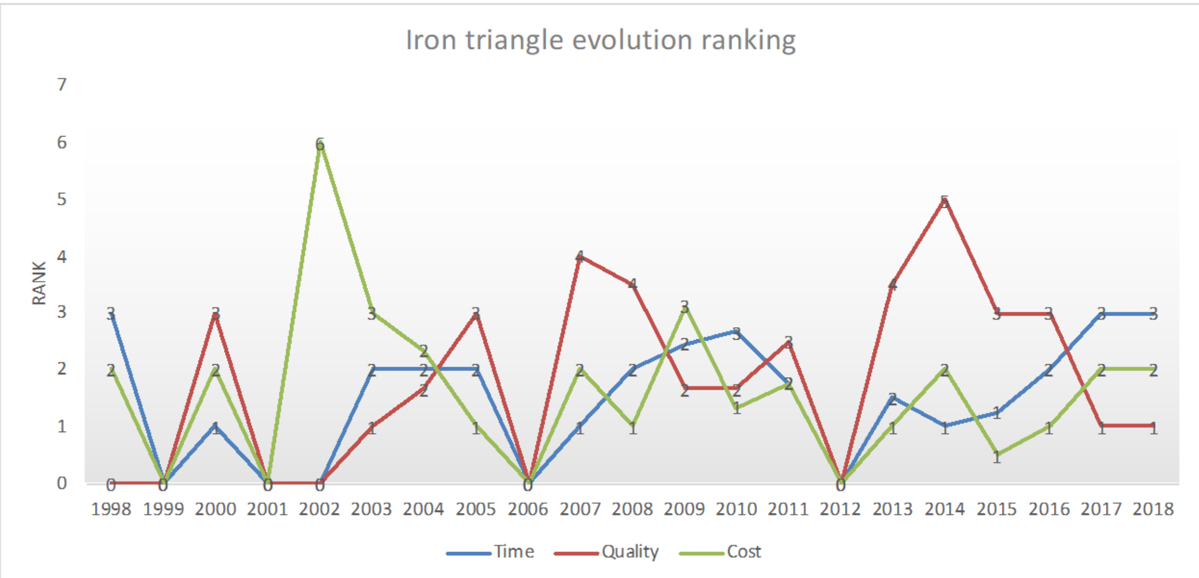


Figure 4: Iron triangle evolution ranking

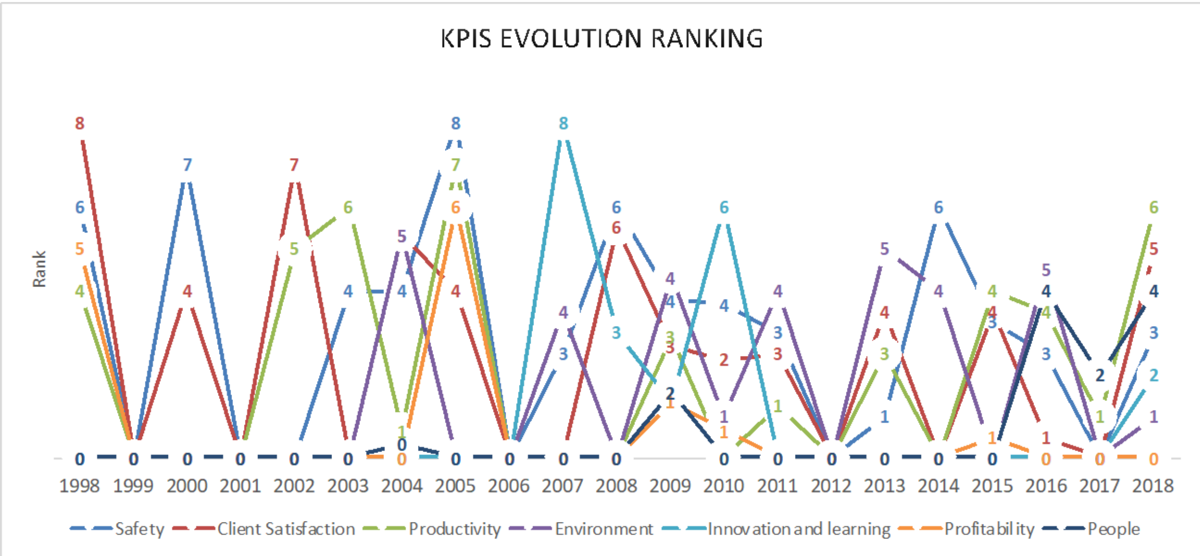


Figure 5: KPIs evolution ranking

The Iron Triangle remains the preferred measure to assess project performance in most of the years (Figure 4). Figure 5 shows how the top ten KPIs have evolved throughout the studied years. Meanwhile the rest of the top ten KPIs vary their position on the ranking. This is a clear indication of the lack of consensus among the authors on the meaning of project performance in the construction industry context. This is perhaps an unsurprising finding and is due to the different objectives that projects seek to deliver but there is still a need to identify a common set of performance indicators.

5. Discussion

The final KPIs project performance ranking shows the Iron Triangle is still the preferred method to measure project performance despite it being widely considered as an old measure with inherent weaknesses. It is argued that new approaches are needed when assessing performance outcomes (Haponava and Al-Jibouri, 2009; Pheng and Chuan, 2006; Toor and Ogunlana, 2010; Ward et al., 1991). KPIs promote opportunities for changes, however it is difficult to reach for improvements when the Iron Triangle is still is the most important aspect of performance in the construction industry. The top ten KPIs found from the analysis are listed as follows: (1) Time; (2) Quality; (3) Cost; (4) Safety; (5) Client satisfaction; (6) Productivity; (7) Environment; (8) Innovation and learning; (9) Profitability and (10) People.

Findings also show there are other major concerns in the construction industry. For example, sustainability and environment appear as important measures to be considered when analysing performance and one of the most important issues, but despite the importance of the triple constraint concept, changes would have to take place to adapt these constraints to the way projects are currently managed. For example, a project which is successful in terms of safety but is over budget would fall into a debatable category of successful performance. On the other hand, it would be illogical to assume that a project which is under budget but has raised safety issues could be consider as a well performed project. Therefore, even though aspects such as time, cost and quality are relevant, they are far from being the most important measures of performance. In this sense, "the iron triangle" alone is an outdated measure to assess performance in a project, however that does not mean it is not important because from the review analysis it can be said that others KPIs are "attached" to it. In order to achieve projects under quality, time and cost constraints, there must be an influence from other KPIs reflecting such factors as safety and environment, and others which will also influence the final outcome.

Many of the analysed papers propose frameworks including key performance indicators under different scenarios. This means the rapid evolving nature of the industry is making companies adopt different strategies to stay competitive, moving away from the operational focus. In terms of the productivity and client satisfaction KPIs, it is a common finding that productivity is low in a project due to poor scoping, lack of clarity, errors and omissions among others, impacting in the satisfaction of various stakeholders which may also lead to disputes and conflicts.

During the last decade, more integrated approaches to assess projects such as the use of modelling tools and systems have led to a reduction in the number of project inefficiencies by improving communication and coordination between project participants to enhance performance results. For example, the rise of BIM (Khanzadi et al., 2018; Smits et al., 2017), lean construction (Sarhan and Fox, 2013) and sustainability (Swarup et al., 2011) and their relationships with performance improvements has focused the research attention from academia and industry towards those topics. The existent performance frameworks and methodologies would have to change to include these trends because performance aspects would be measured differently according to the construction industry evolution. Understanding the concept of measuring success is vital because most of the decisions made are generally carried out based on the intuition of the project managers. Therefore, a general agreement on what constitutes "good project performance" would help take better decisions to achieve project goals.

The problem with how KPIs are used is they are focused on just a part of the project (Horta et al., 2010). The way these indicators are best used is when are combined with more integral and comprehensive performance evaluation methods including an analysis of different indicators to determine performance (Horta et al., 2010). Projects have different objectives so any proposed framework should be customizable depending on the needs of a specific project. On the other hand, a general framework could be used as a guideline to measure project aspects with KPIs as a way to assess the final outcome. It is believed that in the near future, projects will be assessed based on more parameters other than traditional methods including sustainability, functionality, energy efficiency, among others. Therefore, any proposed performance frameworks should include more comprehensive means of assessment, including both quantitative and qualitative standards.

6. Conclusions

The construction industry shows diversity in the way that KPIs are applied and analysed, however there are some patterns that are obtained from the analysis of this paper. A synthesis of performance in construction has been obtained. The analysis of 40 relevant papers focusing on project performance comprising a period from 1998-2018 applying Kendall´s W statistical test to determine concordance among authors and to determine final ranking data indicates that there is no agreement among authors on what performance is in construction, but a ranking of the most common indicators can be obtained. The top ten project performance ranking in the construction industry is in descending order: time, quality, cost, safety, client satisfaction, productivity, environment, innovation and learning, profitability and people. From the analysis, the Iron Triangle is still the preferred method to assess performance in projects. It is established by the literature that project performance determines overall companies' performance, therefore it is essential to pay attention to project performance to deliver better projects (Ankrah, 2007).

Even though projects are different, they have something in common, namely the way they are measured. Therefore, by integrating performance variables into a framework considering improvement initiatives such as modelling technologies and operational techniques focused on delivering efficient outcomes at different stages, there would be an expectation that projects would in general perform better. This framework is a work in process which will be presented in a future research.

Acknowledgements
This research is supported by BECAS Chile (Folio 72170109), National Commission for Scientific and Technological Research (CONICYT), Ministry of Education, Chile.

Conflicts of interest: None

References

Abd, H., Ibrahim A., Khalid S., 2013. Indicators for measuring performance of building construction companies in Kingdom of Saudi Arabia. Journal of King Saud University Engineering Sciences. 25(2), pp.125–134.

Ahuja, R., Sawhney, A. and Arif, M., 2016. Driving lean and green project outcomes using BIM: A qualitative comparative analysis. International Journal of Sustainable Built Environment. 6(1), pp. 69-80

Ajayi, S.O., Oyedele, L.O., Akinade, O.O., Bilal, M., Owolabi, H.A., Alaka, A., Kadiri, K.O., 2016. Reducing waste to landfill: A need for cultural change in the UK construction industry. J. Build. Eng. 5, pp. 185–193.

Alaloul, W., Liew, M., Zawawi, N., 2016. Identification of coordination factors affecting building projects performance. Alexandria Engineering Journal. 55(3), pp.2689–2698.

Al-Aomar, R., 2012. Analysis of lean construction practices at Abu Dhabi construction industry. Lean Construction Journal. pp. 105–121.

Allu, E., Ebohon, O., 2015. Assessing the knowledge and awareness of built professionals in Nigeria. International Journal of Contemporary Applied Sciences. 2(5), pp. 77-95.

Almahmoud, E., Doloi, H., Panuwatwanich, K., 2012. Linking project health to project performance indicators: Multiple case studies of construction projects in Saudi Arabia. International Journal of Project Management. 30(3), pp.296–307

Alreshidi, E., Mourshed, M., Rezgui, Y., 2017. Factors for effective BIM governance. J. Build. Eng. 10, 89–101

Alwaer, H., Clements-Croome, D., 2010. Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings. Building and Environment. 45(4), pp.799–807.

Amrina, E., Vilsi, A., 2015. Key Performance Indicators for Sustainable Manufacturing Evaluation in Cement Industry. Procedia CIRP. 26, pp.19–23.

Ankrah, N., Proverbs, D., 2005. A Framework for measuring construction project performance: Overcoming key challenges of performance measurement. Proceedings of the 21st Annual ARCOM Conference. London, 2(September), pp.959–69.

Ankrah, N., 2007. An investigation into the impact of culture on construction project performance. unpublished PhD thesis, University of Wolverhampton, Wolverhampton, UK.

Atkinson, R., 1999. Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. International Journal of Project Management. 17(6), pp. 337–342.

Bassioni, H., Price, A., Hassan, T., 2004. Performance Measurement in Construction. Journal of Management in Engineering. 20(2), pp.42–50.

Beatham, S., Anumba, C., Thorpe, T., Hedges, I., 2004. KPIs: a critical appraisal of their use in construction. Benchmarking: An International Journal. 11(1), pp.93–117.

Belassi, W., Tukel, O., 1996. A new framework for determining critical success/failure factors in projects. International Journal of Project Management. 14(3), pp. 141–151.

Blasini, J., Leist, S., 2013. "Success factors in process performance management", Business Process Management Journal, 19(3), pp.477-495

Bryde, D., Broquetas, M., Volm, J., 2013. The project benefits of building information modelling (BIM). International Journal of Project Management. 31(7), pp. 971–980.

Bryde, D., Brown, D., 2004. The Influence of a Project Performance Measurement System on the Success of a Contract for Maintaining Motorways and Trunk Roads. Project Management Journal. 35(4), pp. 57–65.

Cha, H., Kim, C., 2011. Quantitative approach for project performance measurement on building construction in South Korea. KSCE Journal of Civil Engineering. 15(8), pp.1319–1328.

Chan, A.P.C., Chan, A.P.L., 2004. Key performance indicators for measuring construction success. Benchmarking: An International Journal. 11(6), pp.203–221.

Chan, A., Scott, D., Chan, A., 2004. Factors Affecting the Success of a Construction Project. Journal of Construction Engineering and Management. 130, pp. 153–155.

Chan D., Chan, A., Lam, P., Yeung, J., Chan, J., 2011. Risk ranking and analysis in target cost contracts: Empirical evidence from the construction industry. International Journal of Project Management. 29(6), pp. 751-763.

Chan, T.K., 2009. Measuring performance of the Malaysian construction industry. Construction Management and Economics. 27(12), pp.1231–1244.

Cheung, S., Suen, H., Cheung, K., 2004. PPMS: A Web-based construction Project Performance Monitoring System. Automation in Construction. 13(3), pp. 361–376.

Cox, R., Issa, R., Ahrens, D., 2003. Management's Perception of Key Performance Indicators for Construction. Journal of Construction Engineering and Management. 129(2), pp. 142–151.

Demirkesen, S., Ozorhon, B., 2017. Impact of integration management on construction project management performance. International Journal of Project Management. 35(8), pp. 1639–1654.

Díaz, H., Alarcon, L., Mourgues, C., Garcia, S., 2017. Multidisciplinary Design Optimization through process integration in the AEC industry: Strategies and challenges. Automation in Construction. 73, pp. 102-119.

Egan, J., 1998. Rethinking construction. HMSO, London.

El-Mashaleh, M.S., Jr., Minchin, R., Brien, W., 2007. Management of Construction Firm Performance Using Benchmarking. Journal of Management in Engineering. 23(January), pp.10–17.

Elmualim, A., Gilder, J., 2014. BIM: Innovation in design management, influence and challenges of implementation. Architectural Engineering and Design Management. 10(3–4), pp. 183–199.

Enache-Pommer, E., Horman, M., Messner, J., Riley, D., 2010. A unified process approach to healthcare project delivery: Synergies between greening strategies, lean principles and BIM. In Proceedings of Construction Research Congress 2010: Innovation for Reshaping Construction Practice. pp. 1376–1385.

Enshassi, A., Mohamed, S., Abushaban, S., 2010. Factors affecting the performance of construction projects in the Gaza strip. Journal of Civil Engineering and Management. 15(3), pp. 269–280.

Field, A., 2005. Kendall's Coefficient of Concordance, in Encyclopedia of Statistics and Behavioral Science, pp. 1010–1011.

Formoso, C., Soibelman, L., De Cesare, C., Isatto, E., 2002. Material Waste in Building Industry: Main Causes and Prevention. Journal of Construction Engineering and Management, 128(4), pp.316–325.

Friedman, M., 1937. The Use of Ranks to Avoid the Assumption of Normality Implicit in the Analysis of Variance. Journal of the American Statistical Association. 32(200), pp. 675–701.

Gearhart, A., Booth, D., Sedivec, K., Schauer, C., 2013. Use of Kendall's coefficient of concordance to assess agreement among observers of very high-resolution imagery. Geocarto International. 28(6), pp.517–526.

Haponava, T., Al-Jibouri, S., 2009. Identifying key performance indicators for use in control of pre-project stage process in construction. International Journal of Productivity and Performance Management. 58(2), pp. 160–173.

Hongling, G., Yantao, Y., Weisheng, Z., Yan, L., 2016. BIM and Safety Rules Based Automated Identification of Unsafe Design Factors in Construction. Procedia Engineering. 164, pp.467–472.

Horta, I., Camanho, A., Da Costa, J., 2010. Performance Assessment of Construction Companies Integrating Key Performance Indicators and Data Envelopment Analysis. Journal of Construction Engineering and Management. 136(5), pp. 581–594.

Hu, X., Liu, C., 2017. Slacks-based data envelopment analysis for eco-efficiency assessment in the Australian construction industry. Construction Management and Economics. 35(11–12), pp. 693–706.

Humaidi, N., Said, N., 2011. The Influence of Project Life Cycle and Key Performance Indicators in Project Management Performance: Comparison between ICT and Construction Project. International Conference on Construction and Project Management IPEDR, Singapore. 15, pp. 26–31.

Ibrahim, A., Jing, W., Wenge, D., 2010. Key performance indicators supporting decision-making affecting Malaysian enterprise' project performance in China. American Journal of Applied Sciences. 7(2), pp. 241–247.

Idrus, A., Sodangi, M., Husin, M., 2011. Prioritizing project performance criteria within client perspective. Research Journal of Applied Sciences, Engineering and Technology. 3(10), pp.1142–1151.

Iyer, K., Banerjee, P., 2016. Measuring and benchmarking managerial efficiency of project execution schedule performance. International Journal of Project Management. 34(2), pp. 219–236.

Kagioglou, M., Cooper, R., Aouad, G., 2001. Performance management in construction a conceptual framework. Construction Management and Economics. 19(1), pp. 85–95.

Kendall, M., 1938. Biometrika Trust A New Measure of Rank Correlation. Biometrika, 30(12), pp. 81–93.

Kendall, M., Smith, B., 1939. The Problem of m Rankings. The Annals of Mathematical Statistics. 10, pp. 275-287.

Khalfan, M., Anumba, C., Carrillo, P., 2001. Development of a readiness assessment model for concurrent engineering in construction. Benchmarking: An International Journal. 8(3), pp.223–239.

Khatatbeh, A., 2015. The Effects of Building Information Modeling on Construction (Productivity and Cost). Journal of Information Engineering and Applications. 5(7), p. 8.

Koskela, L., Owen, B., Dave, B., 2010. Lean Construction, Building Information Modelling and Sustainability. Eracobuild Workshop on BIM and Lean. April 15-16, 2010, Malmö, Sweden

Kulemeka, P., Kululanga, G., Morton, D., 2015. Critical Factors Inhibiting Performance of Small and Medium Scale Contractors in Sub-Saharan Region: A Case for Malawi. Journal of Construction Engineering. 2015, pp.1–17.

Kvam, P., Vidakovic, B., 2007. Nonparametric statistics with applications to science and engineering. Wiley series in probability and statistics. p. xiv, 420.

Lai, I., Lam, F., 2010. Perception of various performance criteria by stakeholders in the construction sector in Hong Kong. Construction Management and Economics. 28(4), pp.377–391.

Lam, E., Chan, A.P.C., Chan, D., 2007. Benchmarking the performance of design-build projects: Development of project success index. Benchmarking: An International Journal. 14 (5), pp.624-638

Latham, M., 1994. Constructing the Team. HMSO London Department of the Environment, pp. 129.

Lauras, M., Marques, G., Gourc, D., 2010. Towards a multi-dimensional project Performance Measurement System. Decision Support Systems. 48(2), pp. 342–353.

Liberati, A., Altman, D.G., Tetzlaff, J., Mulrow C., Gøtzsche P.C., IoannidisJohn P.A., 2009. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ 339:b2700

Lin, G., Shen, Q., 2007. Measuring the Performance of Value Management Studies in Construction: Critical Review. Journal of Management in Engineering. 23, pp. 2–10.

Ling, F.Y.Y., Peh, S., 2005. Key performance indicators for measuring contractors' performance. Architectural Science Review. 48(4), pp.357–365.

Ling, F.Y.Y., Low, S.P., Qing Wang, S., Hua Lim, H., 2009. Key project management practices affecting Singaporean firms' project performance in China. International Journal of Project Management. 27(1), pp.59–71

Love, P., Holt, G., 2000. Construction business performance measurement: the SPM alternative Business Process Management Journal, 6(5), pp. 408–416.

Luu, T., Kim, S., Huynh, T., 2008. Improving project management performance of large contractors using benchmarking approach. International Journal of Project Management. 26(7), pp. 758–769.

Malekitabar, H., Ardeshir, A., Sebt, M., Stouffs, R., 2016. Construction safety risk drivers: A BIM approach. Safety Science, 82, pp.445–455.

Marozzi, M., 2014. Testing for concordance between several criteria. Journal of Statistical Computation and Simulation. 84(9), 1843-1850.

Misiurek, K., Misiurek, B., 2017. Methodology of improving occupational safety in the construction industry on the basis of the TWI program. Safety Science. 92, pp. 225–231.

Neely, A., Gregory, M., Platts, K., 1995. Performance measurement system design: A Literature Review and Research Agenda. International Journal of Operation Management & Production Management. 15(4), pp. 80–116.

Ngacho, C., Das, D., 2014. A performance evaluation framework of development projects: An empirical study of Constituency Development Fund (CDF) construction projects in Kenya. International Journal of Project Management. 32(3), pp.492–507.

Nguyen, T., Chileshe, N., 2015. Revisiting the construction project failure factors in Vietnam. Built Environment Project and Asset Management. 5(4), pp. 398–416.

Nudurupati, S., Arshad, T., Turner, T., 2007. Performance measurement in the construction industry: An action case investigating manufacturing methodologies. Computers in Industry. 58(7), pp. 667–676.

Ofori-kuragu, J., Baiden, B., Badu, E., 2016. Key Performance Indicators for Project Success in Ghanaian Contractors. International Journal of Construction Engineering and Management. 5(1), pp.1–10.

Ohno, T., 1988. Toyota Production System: Beyond Large-Scale Production. Productivity Press, Portland, OR.

Omar, M., Fayek, A., 2016. Modeling and evaluating construction project competencies and their relationship to project performance. Automation in Construction. 69, pp.115–130.

Pheng, L., Chuan, Q., 2006. Environmental factors and work performance of project managers in the construction industry. International Journal of Project Management. 24(1), pp. 24–37.

Pillai, A., Joshi, A., Rao, K., 2002. Performance measurement of R&D projects in a multi-project, concurrent engineering environment. International Journal of Project Management. 20(2), pp.165–177.

Prange, C., Schlegelmilch, B., 2018. Managing innovation dilemmas: The cube solution, Business Horizons. Kelley School of Business, Indiana University. 61(2), pp. 309–322.

Radujković, M., Vukomanović, M., Dunović, I., 2010. Application of key performance indicators in South-Eastern European construction. Journal of Civil Engineering and Management. 16(4), pp. 521–530.

Ramirez, R., Alarcón, L., Knights, P., 2004. Benchmarking System for Evaluating Management Practices in the Construction Industry. Journal of Management in Engineering. 20(3), pp.110–117.

Rankin, J., Robinson, A., Meade, G., Haas, C., Manseau, A., 2008. Initial metrics and pilot program results for measuring the performance of the Canadian construction industry. Canadian Journal of Civil Engineering. 35(9), pp.894–907.

Roberts, M., Latorre, V., 2009. KPIs in the UK's Construction Industry: Using System Dynamics to Understand Underachievement. Revista De La Construccion. 8(1), pp.69–82.

Robinson, H., Carrillo, P., Anumba, C., A-Ghassani, A., 2005. Review and implementation of performance management models in construction engineering organizations. Construction Innovation Information Process Management. 5, pp.203–217.

Sacks, R., Koskela, L., Dave, B., Owen, R., 2010. Interaction of Lean and Building Information Modeling in Construction. Journal of Computing in Civil Engineering. 136, pp.968–980.

Sarhan, S., Fox, A., 2013. Performance measurement in the UK construction industry and its role in supporting the application of lean construction concepts. Australasian Journal of Construction Economics and Building. 13(1), pp.23–35.

Savolainen, J., Kähkönen, K., Niemi, O., Poutanen, J., Varis, E., 2015. Stirring the Construction Project Management with Co-creation and Continuous Improvement. Procedia Economics and Finance. 21(15), pp.64–71.

Sibiya, M., Aigbavboa, C., Thwala, W., 2015. Construction Projects' Key Performance Indicators: A Case of the South African Construction Industry. In ICCREM 2015 - Environment and the Sustainable Building - Proceedings of the 2015 International Conference on Construction and Real Estate Management. pp. 954–960.

Siegel, S. and Castellan, N., 1988. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill.

Skibniewski, M., Ghosh, S., 2009. Determination of Key Performance Indicators with Enterprise Resource Planning Systems in Engineering Construction Firms. Journal of Construction Engineering and Management. 135(10), pp.965–978.

Souza, J., Alves, J., 2018. Lean-integrated management system: A model for sustainability improvement. Journal of Cleaner Production. 172, pp. 2667–2682.

Suermann, P., Issa, R., 2009. Evaluating industry perceptions of building information modeling (BIM) impact on construction. Electronic Journal of Information Technology in Construction. 14, pp. 574–594.

Sullivan, K., Carey, B., 2008. Analysis of the Use of Performance Information in the Construction Industry. First International Conference on Construction in Developing Countries (ICCIDC–I) 'Advancing and Integrating Construction Education, Research & Practice', pp. 320–337.

Sun, W., Zhou, G., 2010. KPIs: Analyzing the impact of Building Information Modeling on construction industry in China. Industrial Engineering and Engineering Management (IE&EM), IEEE 17Th International Conference. pp. 354–356.

Swan, D., Kyng, E., 2004. An Introduction to Key Performance Indicators. Centre for Construction Innovation, UK.

Swarup, L., Korkmaz, S., Riley, D., 2011. Project Delivery Metrics for Sustainable, High-Performance Buildings. Journal of Construction Engineering and Management. 137, pp.1043–1051

Teo, E., Ofori, G., Tjandra, I., Kim, H., 2015. The Potential of Building Information Modelling (BIM) for Improving Productivity in Singapore Construction. 31st Annual ARCOM Conference, (September), pp.661–670.

Toor, S., Ogunlana, S., 2010. Beyond the "iron triangle": Stakeholder perception of key performance indicators (KPIs) for large-scale public sector development projects. International Journal of Project Management. 28(3), pp. 228–236.

Waggoner, D., Neely, A., Kennerley, M., 1999. The forces that shape organisational performance measurement systems. International Journal of Production Economics. 60–61, pp. 53–60.

Walker, D., 1995. An investigation into construction time performance. Construction Management and Economics. 13(3), pp. 263–274.

Wang, N., 2014. The role of the construction industry in China's sustainable urban development. Habitat International. 44, pp. 442–450.

Ward, S., Curtis, B., Chapman, C., 1991. Objectives and performance in construction projects. Construction Management and Economics. 9, pp. 343–353.

Wegelius-Lehtonen, T., 2001. Performance measurement in construction logistics. Int. J. Production Economics. 69, pp. 107–116.

Yang, H., Yeung, J., Chan, A., Chiang, Y., Chan, D., 2010. A critical review of performance measurement in construction. Journal of Facilities Management. 8(4), pp.269–284.

Yeung, J., Chan, A.P.C., Chan, D., Kwan Li, L., 2007. Development of a partnering performance index (PPI) for construction projects in Hong Kong: a Delphi study. Construction Management and Economics. 25(12), pp.1219–1237.

Yeung, J., Chan, A.P.C., Chan, D., Chiang, Y., 2013. Developing a Benchmarking Model for Construction Projects in Hong Kong. Journal of Construction Engineering and Management. 139(6), pp.705–716

Yu, A., Flett, P., Bowers, J., 2005. Developing a value-centred proposal for assessing project success. International Journal of Project Management. 23(6), pp. 428–436.

Yu, I., Kim, K., Jung, Y., Chin, S., 2007. Comparable Performance Measurement System for Construction Companies. Journal of Management in Engineering. 23(3), pp.131–139.

Yuan, J., Yahun Zeng, A., Skibniewski, M., Li, Q., 2009. Selection of performance objectives and key performance indicators in public–private partnership projects to achieve value for money. Construction Management and Economics. 27(3), pp.253–270.

Zhang, S., Teizer, J., Lee, J., Eastman, C., Venugopal, M., 2013. Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. Automation in Construction. 29, pp.183–195.

Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C., 2015. BIM-based fall hazard identification and prevention in construction safety planning. Safety Science. 72, pp.31–45.