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Structured approach to measure performance in Construction Research and Development: Performance Measurement System Development

Abstract

Research and development (R&D) activities are identified as vital to address the challenges faced by the construction industry. Despite the importance, there are number of issues that hinder the success of construction R&D activities such as lack of accountability of the R&D resources, inadequate mechanisms to evaluate the success, output not addressing the requirements of the stakeholders, lack of communication and coordination between the parties involved in the R&D process etc. These issues have resulted in producing research results with low applicability and have discouraged the investment towards construction R&D. It has been revealed that the cause of a majority of the issues in construction R&D is directly or indirectly rooted with the lack of evaluation mechanisms implying the need for performance measurement (PM). Therefore this study addresses this eminent need by exploring PM applications and by developing a structured approach to measure the performance of collaborative construction R&D during its lifecycle from initiation, conceptualising, development and launch stages and at the project management.

During the exploratory phase of the study, semi-structured interviews and a questionnaire survey were carried out to develop the performance measurement system (PMS). During the explanatory phase, the developed PMS was refined with a series of semi-structured interviews. The data was gathered from principal investigators, researchers and industrial partners involved in collaborative construction R&D work. The study contributes to knowledge by developing a PMS to measure the performance of construction R&D. The

PMS consists of critical success factors, performance indicators and performance measures during the lifecycle of a R&D project.

Key words: Construction industry, research and development, critical success factors, performance measurement

Introduction

Research and development (R&D) has been identified as a driving force for the success of the construction industry (Barrett, 2007; Fox and Skitmore, 2007). Similarly, Hampson and Brandon, (2004) view R&D as an overarching strategy for the construction industry in addressing its goals. Prioritising R&D activities, creating longer term R&D programmes and increasing investment on R&D activities are therefore recognised as vital factors for the growth of the construction industry (Hampson and Brandon, 2004; Fairclough, 2002). Dulaimi et al (2002) assert that lack of R&D within the construction industry as one of the main reasons for its underperformance. Due to the cost and resources involved for R&D activities, the notion "imposing financial constraints could negatively affect the freedom and creativity of R&D activities" (Roussel et al, 1991) has been challenged. With this challenge, much attention is given on identifying the actual contribution from R&D activities towards the development and towards the competitive advantage of the organisation (Chiesa and Frattini, 2007; Germeraad, 2003). Managers are therefore, under pressure to monitor and improve the performance of R&D activities (Kerssens-van Drongelen et al, 2000).

To gain the maximum outcome of the processes and factors which influence R&D activities, continuous evaluation in the form of Performance Measurement (PM) is well articulated (Bremser and Barsky, 2004; Karlsson et al (2004). Yawson et al (2006) claim that PM for R&D activities provide the basis to assess whether the organisation is progressing towards its

goals, identifies the strengths and weaknesses, decides on the future actions needed for improvements and provides data to request additional resources. PM in R&D could also identify the proper resource allocation within organisations (Bremser and Barsky, 2004; Pearson et al., 2000; Kerssen-van Drongelen and Bilderbeek, 1999) whilst improving the communication and coordination of the R&D activities (Bremser and Barsky, 2004; Loch and Tapper, 2002). Research carried out in various industries indicates that long term competitive advantage depends on commitment to ongoing R&D work and the use of PM applications to evaluate its success (Osawa and Yamasaki, 2005; Pearson et al, 2000; Kerssens-van Drongelen et al, 2000; Kerssens-van Drongelen and Bilderbeek, 1999; Werner and Souder, 1997; Tipping et al, 1995; Brown and Svenson, 1988).

Within construction, lack of investments for R&D activities is evident (Department for Business Enterprise and Regulatory Reform, 2007; Institute of Civil Engineers, 2006; DTI, 2006; DTI, 2005; DTI, 2004; Dulaimi et al, 2002; Fairclough, 2002; Seaden and Manseau, 2001; Laing, 2001; Egan, 1998) due to "improper reporting of R&D expenses" (Seaden and Manseau, 2001, p: 186). The value of R&D is being questioned, when clear links between its benefits and the financial commitments are not established (Guerrera and Waters, 2006). Inappropriate reporting of R&D expenditure (Seaden and Manseau, 2001; Lorch, 2000; Hodkinson, 1999) and inadequate mechanisms to evaluate the effectiveness of R&D activities (Lorch, 2000) have negatively affected construction R&D activities. Moreover, construction R&D activities lack effective communication, feedback and validation procedures, and coordination between the parties involved in the process (Gann, 2001; Lorch, 2000). Flanagan and Jewel (2006) argue that construction R&D does not properly address the target audience. These issues within construction R&D show the need of effective monitoring, controlling and validating mechanisms. The study carried out by Lorch (2000) ascertains the

non-existence of effective validation/feedback and evaluation mechanisms within construction research as a "fundamental missing link". This was further proven by Kulatunga et al's (2007) theoretical investigation on to current PM literature and issues within construction R&D. Even though a number of studies are carried out in R&D performance measurement in other disciplines, a paucity of literature was evident within construction R&D and its PM applications. To address this research gap the study investigates the PM applications within construction R&D and develops a performance measurement system (PMS) to evaluate the performance of construction R&D.

The paper first discusses the existing PM applications in research and development. This is followed by the research method adopted for the study. Data analysis and results are presented next. The paper presents a discussion by evaluating the strengths of the PMS developed through the empirical investigation and draws up contribution to knowledge and further research from the conclusion.

Research and development performance measurement systems and measures

Since few decades back, companies were adapting various mechanisms, mainly output and outcome based performance measures to measure certain aspects of R&D (Kerssens-van Drongelen et al, 2000; Robert, 1994). The performance measures related to R&D used during earlier days (1970s) focused mainly on three indicators (Robert, 1994): strictly technical products (patents, technical publications or citations to technical publications); financial benefits that emerge from R&D (profits, sales); and judgments about the success of individual R&D projects. These measures were developed based on the output and outcome of R&D activities. Further, the use of objective measures dominated the R&D PM during earlier stages (Keller and Holland, 1982).

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PM in R&D has undergone major changes over the last few decades. Technological advances and customer and profit-oriented markets have demanded R&D to facilitate broad areas of activities such as differentiations, time to market, value for money, service and economic production (Cooper, 1998; Smith and Reinertsen, 1998). The need to go beyond financial measures and consider customer and shareholder value, business processes, organisational learning and growth are therefore identified and emphasised (Pearson et al, 2000). Further, the use of financial measures as the only criterion of R&D PM has been challenged as they are lagging indicators and not connected with the operational activities (Loch and Tapper, 2002). As a result, multiple and integrated performance measures that combine qualitative, quantitative, objective and subjective measures are identified as more effective ways to measure the performance of R&D work. Bremser and Barsky (2004) view that for the successful attainment of management strategies and aims and objectives, integrated PMSs are required as they capture the changes in financial and non-financial aspects of organisational performance. However, Cooper and Kleinschmidt (2007) assert that having multiple performance measure on R&D activities could confuse and make the implementation of PM more complex.

Werner and Souder (1997) divide R&D performance measures into macro and micro measures where macro level approaches concentrate on the impact of R&D on society as a whole whilst micro level approaches concentrate on the impact of R&D on the organisational level. One of the earlier developed R&D PMS was by Brown's (1996) framework. This framework was developed by considering the R&D laboratory as a system and considering input (people, ideas, and equipment), output (patents, products, publications) and outcome (cost reductions, sales improvements) based performance measures. In 1985, Moser carried

out a survey and identified 14 categories of R&D performance measures. Most of the measures identified from this categorisation, are output based. Griffin and Page (1993) classify the measures into four groups: customer acceptance; financial; product level; and organisation level. The categorisation of R&D performance measures according to Kaplan and Norton's (1992) Balanced scorecard (BSC) i.e. according to financial, customer, internal business process and learning and growth perspectives can be identified in number of instances (Yawson et al, 2006; Bremser and Barsky, 2004; Kerssens-van Drongelen et al, 2000; Kerssens-van Drongelen, 1999; Kerssens-van Drongelen and Cook, 1997). The use of BSC provides an integrated PMS to implement the strategy while comprehensively and appropriately covering the vital areas of PM in the R&D environment (Yawson et al, 2006; Bremser and Barsky, 2004; Kerssens-van Drongelen et al, 2000). Godener and Soderquist (2004) identify three more classifications to measure performance, in addition to the four perspectives used in the BSC. They are strategic (strategic goal satisfaction), technology management (generation of new competitive products) and knowledge management (return on investment in terms of knowledge creation, knowledge transfer and knowledge exploitation). Coccia (2004) measures the performance of public research institutes using five measures (training, finance, national publications, teaching, international publications). In another study, the application of the European Foundation for Quality Management (EFQM) model for a research organisation can be identified by assigning performance measures for customer, people, social and business attributes (Weggeman and Groeneveld, 2005).

Having discussed the existing PM applications in R&D, the following section discusses the research method used for the study.

Research method

Collaborative construction R&D activities initiated by universities were selected as the unit of analysis of the study whilst data was gathered from the parties involved in the research collaboration (Principal investigators, Researchers and Industrial Partners). The study was based around the lifecycle of a R&D project from initiation, conceptualisation, development and launch stages and at the project management. The study consisted of two main phases: exploratory phase to develop the PMS and explanatory phase to refine the PMS. The details of the interviews and questionnaire survey respondents are given in Table 1.

Insert Table 1

The approach to the development of PMS was based on the concept that "implementation of the key success criteria could improve performance" (Thakkar et al, 2007). Accordingly, the study evaluated CSFs of construction R&D and derived the performance indicators and measures (component parts of performance indicators) to align with the CSFs. The following section describes data collection in detail.

Exploratory phase of the study

Step1: Establishment of the need for PM in construction R&D

Having established the need for PM in construction R&D via literature, the first step of the study further investigated the need for PM in construction R&D with empirical evidence. In addition, the current practices and expectations of PM applications within construction R&D were investigated. This was done by using semi-structured interviews. The analysis of the semi-structured interviews was done by using content analysis technique.

Step 2: Derive critical success factors of construction R&D

The CSFs were derived by evaluating the success factors of construction R&D activities. To gather the success factors, respondents were questioned about "what they pursue as success factors in construction R&D" during initiation to launch phases and at the project management of R&D projects. This was done through a series of semi structured interviews and analysed by using content analysis.

In addition, a comprehensive literature review was carried out to investigate the success factors of R&D in general and with particular reference to R&D in construction. Having identified the success factors from semi-structured interviews and literature, a questionnaire was compiled. A five-scale Likert scale was used to capture the importance of the success factors (refer to Table 2). Table 2 shows the values assigned for the Likert scale used for this study.

Insert Table 2

The analysis of the questionnaire survey to derive the CSFs was done in two stages: firstly by considering the overall mean value and secondly based on the Asymptotic significance generated from the Wilcoxon signed rank test results. The Wilcoxon signed rank test is a non-parametric method to test the differences of two related variables when the subject (dependant category) is measured on two occasions or under different conditions (Hill and Lewicki, 2007; Pallant, 2001). During the first stage, the success factors with a mean value of less than 4 were excluded from further analysis as they were considered not to be critical to the success of the construction R&D project. This elimination was done as the factors with a mean value less than 4 belong to unimportant (value 1), of the little important (value 2) or

moderately important (value 3) based on the assigned values of the questionnaire survey analysis (refer to Table 2). Following this, during the second stage Wilcoxon signed rank test was used for the remaining success factors i.e. the factors that have an overall mean value above 4. By taking a consecutive pair of data, the Asymptotic significance was calculated. The Asymptotic significance shows an estimate of the significance of differences within attributes being tested (Pallant, 2001). Generally, Asymptotic significance less than 0.05 is considered as indicating a significant difference between the attributes being tested. Accordingly, the paired data which showed an Asymptotic significance < 0.05 was considered as responses having a significant difference regarding the importance of the success factors, hence such factors were considered as not critical for the success of construction R&D projects (Please note that in Table 3, Asymptotic significance was not calculated for the non-critical success factors).

Step 3: Derive performance indicators and measures

Having established the CSFs of construction R&D activities, the next step was to identify the performance indicators and measures related to CSFs. A section of the questionnaire survey was therefore, structured to capture the existing performance indicators and measures used by the respondents.

Step 4: Development of the PMS for construction R&D

During the final step of the exploratory phase, a PMS was drafted for construction R&D activities by using the CSFs, performance indicators and measures derived empirically and theoretically.

Explanatory phase of the study

Step 1: Refinement of the PMS

The main intention of this stage was to identify the impact of the developed PMS on the success of construction R&D activities. However, implementing the PMS within a construction R&D project within the scope of the study was limited due to the time span of R&D projects. To overcome this limitation, the authors sought to gather the views of experts involved in research projects regarding the impact that the developed PMS could have on the success of R&D work. In addition to identifying the impact, it was also intended to refine the developed PMS during the explanatory stage.

A series of semi structured interviews were carried out during this phase (refer Table 1 for details). The respondents were questioned about the completeness of the CSFs, performance indicators and performance measures; ease of understanding of the PMS; applicability of the PMS to construction R&D and the impact of the PMS.

Data analysis and results

Current status of performance measurement applications in construction research and development

The respondents showed interest in and acknowledged the use of performance measures during the construction R&D project. A variety of performance measures were being used ranging from financial to non financial, qualitative to quantitative. Lack of measures to evaluate the actual impact of R&D project for its beneficiaries was identified by the respondents as a shortcoming of the current PM applications. Thus, allocating funds for the evaluation of post delivery success within R&D PM applications was suggested. Another drawback of the current PM applications was evident as lack of feedback to the on-going

R&D process and lack of communication of the results to the people involved in. In supporting this view similar studies carried out in construction R&D revealed that lack of communication on the performance of the R&D project has weakened the interest of funding bodies and industrial partners resulting in low level of investment and contribution (Gann, 2001; Seaden and Manseau, 2001; Print, 1999; Hodkinson, 1999; CRISP consultancy commission, 1999). Moreover, feedback on the ongoing R&D process would enable further improvements to the future process. Thus, creating appropriate feedback loops, effective communication on the progress to the involved parties and obtaining the views of the beneficiaries towards the ongoing R&D activities can be highlighted as important.

Lack of clarity, structure and the use of informal methods to measure the performance of R&D project were also evident from the empirical investigation. Further, lack of quality parameters within PM applications is another drawback which can lead to substandard outcomes. Thus, incorporation of peer reviews and building up testing and validation for research results is emphasised. According to the study carried out by Parker (2000), PM enables managers to make decisions based on facts rather than on assumptions and faith, making PM an integral part of planning and control within organisations. This fact was reinforced by the empirical investigation of this study where one of the interviewees commented "… performance measurement should be part of the culture. It is partly the way we do things…So it should be about peer pressure, peer review that constantly monitoring your own performance and other people's performance in a positive organic way, not abstracting out so then becomes sort of external things which we work against".

Critical success factors of construction R&D

The study derived CSFs for construction R&D under the phases of initiation, conceptualisation, development, launch and for the project management. Table 3 shows the mean values and wilcoxon signed rank text results for the CSFs. As Table 3 indicates, at initiation and conceptualising phases, establishment of a clear research problem and ensuring clarity and focus of the research work were highlighted to provide a proper foundation for the research work. Skills, commitment and motivation of the team members and having adequate resources specially the human resource were being evident as critical during the conceptualising and development phases. Effective dissemination of work for the advantage of the beneficiaries was highlighted during the launch phase. Throughout the R&D project, the importance of project coordination and resource management were emphasised.

The CSFs identified from the empirical investigation have both similarities and differences with those identified in studies carried out in other disciplines. Some of the similarities can be listed as commitment of the principal investigator (Cooper and Kleinschmidt, 2007; Lester, 1998), proper up-front work (Cooper and Kleinschmidt, 2007), committed and skilled research teams (Fairclough, 2002), need for mechanisms to monitor and control the R&D projects (Lorch, 2000; Seaden and Manseau, 2001), well established operational procedure (Cooper and Kleinschmidt, 2007). The CSFs like satisfying the requirements of funding bodies and industrial partners, establishment of a dissemination plan and the effective dissemination of work were not disclosed from the studies carried out in other disciplines.

Insert Table 3

Performance indicators and measures for construction R&D

As explained in step 3 of the exploratory phase (refer research method section), the study evaluated the use of performance indicators and measures from the questionnaire survey. There were three questions on identifying the performance measures used by the researchers. When constructing the questionnaire, these questions were excluded from the industrial partners' questionnaire due to their irrelevance to them. Table 4 shows the percentage usage of performance measures during the construction R&D project and ranked them accordingly.

It was revealed that the performance measures which are required to satisfy the stakeholder requirements (funding bodies' and industrial partners') are being well implemented within R&D project. More than 70% of the respondents have identified the use of measures on project finance, time, and accomplishment of objectives, milestones and quality within the R&D project. Moreover, a higher usage of performance measures on the identification of stakeholder requirements from the project was also viewed as important by both industrialist and academic members. This proves the fact that during the R&D project as it moves from initiation to launch phases, more attention was paid to identifying and satisfying the stakeholders' (funding body and industrial partners) requirements through achieving the cost, time, quality targets and accomplishing the project objectives. This fact further coincides with the identification of CSFs of construction R&D as consideration and satisfaction of the funding bodies and industrial partners are being treated as CSFs during the R&D project (refer Table 3).

In opposition to the satisfaction of the stakeholders, researchers' satisfaction was not identified as critical for the R&D project. In most of the situations, it obtained an overall mean value less than 4 (refer Table 3). This fact was further proven in from the performance

indicators identified from the study as the measures on the learning and growth of the researchers, education and training of the researchers and identification of the satisfaction of the researchers were not given much emphasis by the respondents of the study (refer Table 4).

Insert Table 4

Development of PMS for construction R&D

Based on the empirical investigation and literature findings on CSFs, performance indicators and performance measures, the PMS for construction R&D was drafted. The CSFs obtained from the empirical investigation (refer Table 3) were categorised into main groups when developing the PMS (refer Figure 1). The performance measures were structured under the main groups of CSFs (refer Table 5). The draft PMS was refined through a series of semi-structured expert interviews during the explanatory stage of the study. In addition to the refinement of the PMS, the impact it could make towards the success of construction R&D project was assessed through the experience of the respondents.

The refined PMS, and the table representing performance measures are presented in Figure 1 and Table 5.

Insert Figure 1

Insert Table 5

Having developed the PMS, the below section evaluates the strengths of it.

Discussion

Strengths of the performance measurement system

The PMS has incorporated multiple performance indicators to identify the factors that influence the performance. Further, it presents a combination of leading (e.g.: resource allocation and utilisation, time commitment of the team members and absence ratio) and lagging indicators (e.g.: achievement of deliverables and milestones). The lagging indicators of the PMS demonstrate the impact or status that the performance has been achieved. Therefore, presence of lagging indicators inform the success of the activities carried out, initiatives taken and modifications made for the R&D project. Conversely, leading indicators demonstrate the performance of the team, processes and direction of resources thus, they help in taking corrective actions before the overall performance is affected. Therefore, having leading indicators within the R&D PMS would help taking initiatives and making modifications to keep the overall R&D project within the expected goals. Accordingly, the use of leading and lagging indicators within the PMS ensures the proper flow of R&D activities.

Furthermore, the PMS consists of quantitative measures (hard measures) i.e. measures which are straightforward and easy to quantify such as project meeting attendance, number of publications and number of training activities provided and qualitative measures (soft measures) i.e. the intangible attributes such as satisfaction of the stakeholders and deviations from the required quality standards. However, the PMS does not incorporate specific performance indicators for the CSFs "leadership of the principal investigator" and "flexibility and responsiveness to change". Yet, it is argued that there should be a proper awareness of those factors within the R&D project or in other words, recognising them as CSFs within the R&D project to influence the performance of R&D activities. Moreover, the PMS consists of

input measures (e.g.: resource requirement analysis), process measures (e.g.: comparison of allocation of duties and responsibilities with their achievement), output measures (e.g.: achievement of deliverables, milestones) and outcome measures (e.g.: number of subsequent projects acquired) as similar to Brown's (1996) framework.

Advantageous of the performance measurement system

Through the integration of CSFs, performance indicators and measures in the PMS a typical construction R&D project could achieve the following benefits:

- precise understanding of the targets and the work involved within each phase of the R&D project guides the team members in identifying their contributions in terms of achieving the overall goals of the research project. Further, allocation of roles and responsibilities to the correct personnel will ensure the right people are doing the right job thus enhancing the quality of work;

- one of the shortcoming of the construction R&D activities was evident as outcome not addressing the requirements of the stakeholders/ beneficiaries (Flanagan and Jewel, 2006; Barrett and Barrett, 2003; Print, 1999; Hodkinson, 1999). The developed PMS incorporates performance indicators and measures relates to satisfaction of the requirements of the stakeholders/beneficiaries thus this will provide benefits such as continuous funding, continuous engagement of work etc.;

- carrying out market analysis to establish the research problem clearly will increase the value of the research outcome. Furthermore, feasibility studies will identify any pitfalls the research could encounter, thus helping to determine the best research option from the beginning of the R&D project;

- improves the reporting of success, failures, deviations and resource utilisations to the team members providing proper awareness of the progress of the research work; This

addresses the shortcoming of lack of reporting mechanisms on funds utilisation of construction R&D (Cripps et al, 2004; Seaden and Manseau, 2001; Hodkinson, 1999), unaware of the progress of R&D work (Lorch, 2000).

- awareness of the motivation and behavioural issues of the team members and being, receptive to their contribution throughout the project ensures the smooth flow of work;

- being realistic about the entire research process and helping to identify alternative approaches if the activities deviate from the original plans;

- as identified by Print (1999) and Hodkinson (1999), lack of accountability of the utilisation of resources have negatively impact for funds generation within construction R&D. The presence of performance indicators on resources management of the developed PMS increases the accountability of resource utilisation.

- the presence of leading performance indicators to identify lagging areas which need attention before they impair the outcome of the R&D activities.

Conclusion

The main aim of this study was to address the knowledge gap of a comprehensive PMS for construction R&D activities. Within this scenario, this study developed a PMS that can be used to measure the performance of construction R&D work during its lifecycle from initiation, conceptualising, development, launch phases and at the project management. The study merged theories and concepts from different knowledge areas such as construction R&D, PM in general, PM in R&D in other disciplines, PM in construction R&D and CSFs to get the theoretical background. With the theoretical background, the study empirically investigated with a series of semi-structured interviews and a questionnaire survey and

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developed a PMS to evaluate the performance of construction R&D projects. The comprehensiveness and suitability of the PMS was further evaluated and refined with expert interviews.

The PMS was developed on the basis of implementation of the CSFs via performance measures. Accordingly, the first element of the PMS is the CSFs of construction R&D during its lifecycle. They include at the initiation: consider stakeholder satisfaction, solid upfront work, authority and commitment of the principal investigator; at the conceptualisation, team dynamics, consider stakeholder requirement, clarity and focus of work, adequate resources and capabilities; at the development, adequate resources and capabilities, team dynamics, stakeholder satisfaction; at the launch, adequate resources and capabilities, stakeholder satisfaction, effective dissemination of work and at the project management, project coordination and resource management. The second element of the PMS: performance indicators related to the aforementioned CSFs are also detailed out in the PMS whilst the performance measures (the component parts of performance indicators) are provided in the tabulated format. The PMS also shows the overarching role of project management during the lifecycle of R&D activities and highlights the importance of continuous reviews, feedback and feed-forward for effective monitoring and controlling.

As evident from literature, lack of effective monitoring and controlling mechanisms within construction R&D was identified as a shortcoming and was quoted as a fundamental missing link. Thus, the development of PMS from the study fills this gap and provides a comprehensive approach to evaluate the success of construction R&D activities. The study also contributes to knowledge by identifying CSFs, performance indicators and measure which are specific to construction R&D PM.

The PMS developed and subsequent research carried out provides research areas that can be further investigated. For this study, the unit of analysis was fixed at the collaborative construction R&D projects, and gathered the data from the stakeholders involved in. However, future studies can be carried out by fixing the unit of analysis on the organisations that carry out R&D work such as universities, construction organisations. Further, this study focused on collaborative construction R&D activities lead by the universities. In contrast, future studies can be carried out for collaborative research work lead by the construction organisations.

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Table 1: Details of the respondents

Category	Description	Exploratory stage			Explanatory stage
		Semi-structured interviews	**Questionnaire survey**		**Semi-structured interviews**
		No. of interviews	**No. of questionnaires sent**	**Response rate**	
Principal Investigators	Principal investigators represent the university and manage and lead the R&D project	5	55	62%	4
Researchers	Researchers represent the University and carries out the research work related to the project (e.g.: data collection, analysis etc.)	5			2
Industrial Partners	Industrial partners are the representatives from construction organisations who contributes to the R&D project	5	34	35%	

Table 2: Values assigned for the Likert scale

Scale	Unimportant	Of the little important	Moderately important	Important	Very important	No opinion/ N/A
Value	1	2	3	4	5	99

Table 3: Critical success factors of construction R&D

Success Factors	Academia	Industry Partners	Total		Asymp. Sig.
	Mean	Mean	Mean	Rank	
Initiation					
Establish the research problem clearly	4.74	4.85	4.79	1	N/A
Commitment of the principal investigator	4.59	4.52	4.56	2	0.06
Selecting a competent team	4.50	4.44	4.48	3	0.51
Leadership of the principal investigator	4.35	4.19	4.28	4	0.08
Consider industrial partners' requirements	4.03	4.56	4.27	5	0.99
Consider funding bodies' requirements	4.29	4.22	4.26	6	0.87
Understand the market and its dynamics	4.21	4.04	4.13	7	0.45
Consider researchers' requirements	*3.85*	*3.70*	*3.79*	*8*	
Conceptualising					
Check the feasibility of the project	4.68	4.85	4.75	1	N/A
Commitment of the principal investigator	4.62	4.52	4.57	2	0.07
Committed and cooperative team members	4.48	4.59	4.53	3	0.55
Establish clear and realistic goals/ deliverables/ milestones	4.41	4.63	4.51	4	0.99
Adequate resources/financial support	4.44	4.44	4.44	5	0.52
Allocation of responsibilities to team members inline with competencies	4.41	4.37	4.39	6	0.61
Establish a plan to disseminate research results	4.35	4.44	4.39	7	1.00

Leadership of the principal investigator	4.26	4.37	4.31	8	0.58
Having a skilled team	4.38	4.19	4.30	9	0.76
Establish clear method to measure success	4.18	4.44	4.30	10	1.00
Consider industrial partners' requirements	4.35	4.22	4.30	11	0.95
Consider funding bodies' requirement	4.35	4.19	4.28	12	0.97
Absence of lengthy bureaucracy	*3.91*	*4.11*	*4.00*	*13*	*0.03*
Early involvement of industrial partners	*3.76*	*4.30*	*4.00*	*14*	
Comprehensive briefing process	*3.88*	*4.11*	*3.98*	*15*	
Recognition for team members	*3.88*	*3.96*	*3.92*	*16*	
Consider researchers' requirements	*3.91*	*3.74*	*3.84*	*17*	
Fast decision making process	*3.59*	*3.88*	*3.72*	*18*	
Development					
Committed and cooperative team members	4.62	4.56	4.59	1	N/A
Commitment of the principal investigator	4.56	4.59	4.57	2	0.83
Adequate resources/financial support	4.53	4.59	4.56	3	0.91
Having a skilled team	4.53	4.48	4.51	4	0.55
Meet funding bodies' requirements	4.53	4.48	4.51	5	0.99
Share a common understanding about the work	4.38	4.44	4.41	6	0.29
Having a well establish operational procedure	4.50	4.26	4.39	7	0.91
Meet industrial partners' requirements	4.24	4.59	4.39	8	0.98
Secure momentum/ motivation of the team	4.41	4.33	4.38	9	0.91
Flexibility and responsiveness to change	4.38	4.37	4.38	10	1.00
Leadership of the principal investigator	4.38	4.37	4.38	11	0.94

Absence of lengthy bureaucracy	*4.03*	*4.22*	*4.11*	*12*	*0.02*
Meet researchers' requirements	*4.09*	*4.07*	*4.08*	*13*	
Recognition for team members	*4.00*	*4.04*	*4.02*	*14*	
Fast decision making process	*3.82*	*4.11*	*3.95*	*15*	
Having a risk mitigation strategy	*3.85*	*4.08*	*3.95*	*16*	
Testing the market	*3.79*	*4.07*	*3.92*	*17*	
Launch					
Effective dissemination of the results	4.56	4.48	4.52	1	N/A
Meet funding bodies' requirements	4.65	4.30	4.49	2	0.73
Having a well established dissemination/ marketing plan	4.47	4.48	4.48	3	0.88
Meet industrial partners' requirements	4.21	4.63	4.40	4	0.46
Launch the output within the planned time frame	4.35	4.37	4.36	5	0.93
Comprehensive project review and feedback	*3.91*	*4.22*	*4.05*	*6*	*0.03*
Meet researchers' requirements	*3.74*	*4.07*	*3.89*	*7*	
Refinement of the output after launch	*3.94*	*3.70*	*3.84*	*8*	
Project Management					
Effective communication	4.68	4.74	4.70	1	N/A
Effective collaboration	4.62	4.63	4.62	2	0.28
Effective planning, controlling, and organising of activities	4.41	4.67	4.52	3	0.29
Continuous reviews	4.35	4.63	4.48	4	0.53
Effective resource management	4.26	4.44	4.34	5	0.19
Effective management of the people	4.38	4.26	4.33	6	0.85

Having an external person to do reviews	*3.97*	*4.00*	*3.98*	*7*	
Evaluating post delivery success	*3.82*	*4.11*	*3.95*	*8*	
Having a separate project administrator	*3.41*	*3.44*	*3.43*	*9*	

Table 4: Use of performance measures by the respondents

	Industry % N=26	Rank	Academia % N= 34	Rank	Overall % N= 60	Rank	Performance measures
Measures on the project finance (requirement, allocation and utilisation)	84.00	1	96.77	1	91.07	1	Analysis of project budget; delays due to lack of finance
Measures on the project time	84.00	1	90.32	2	87.50	2	Achievement of milestones, deliverables; time deviations from the expected
Measures on the accomplishment of the project objectives	80.00	3	83.87	3	82.14	3	Achievement of milestones, deliverables
Measures to identify the stakeholder requirements/ expectations from the project	80.00	3	74.19	6	76.79	4	Stakeholder requirement analysis
Measures on the accomplishment of the milestones	72.00	5	80.65	4	76.79	4	Achievement of milestones, deliverables
Measures on the project quality	68.00	7	77.42	5	73.21	6	Achievement of deliverables to the required standards
Measures on the stakeholder involvement and commitment	64.00	9	70.97	7	67.86	7	Time commitment of stakeholders; project meeting attendance; absence ratio

	Industry % N=26	Rank	Academia % N= 34	Rank	Overall % N= 60	Rank	Performance measures
Measures on the feasibility of the project	52.00	12	70.97	7	62.50	8	Measures on cost and benefits analysis; achievement of project goals against the potential risks
Measures on the project team performance	68.00	7	58.06	9	62.50	8	Number of publications made by the team members; number of awards won; presentation at workshops/ conferences
Measures on identifying the satisfaction of the stakeholders	72.00	5	54.84	11	62.50	8	Achievement of milestones, deliverables; scores on the stakeholder satisfaction surveys
Measures to identify the market needs	64.00	9	58.06	9	60.71	11	Market analysis
Measures on the other resources (human, equipment etc)	64.00	9	48.39	12	55.36	12	Resource requirement and utilisation analysis; delays of work due to lack of resources
Measures on the post delivery success	44.00	13	48.39	12	46.43	13	Response from the industry on the utilisation of the research results
Measures to identify the researchers' requirements/ expectations from the project	-		45.16	15	45.16	14	Researchers' requirement analysis
Measures on the education and training of researchers	-		41.94	17	41.94	15	Qualifications and experience of the researchers; training activities provided
Measures on the comprehensiveness of the research proposal	32.00	14	45.16	15	39.29	16	A research justification plan
Measures on the development of new research directions	28.00	16	48.39	12	39.29	16	Acquisition of new research projects

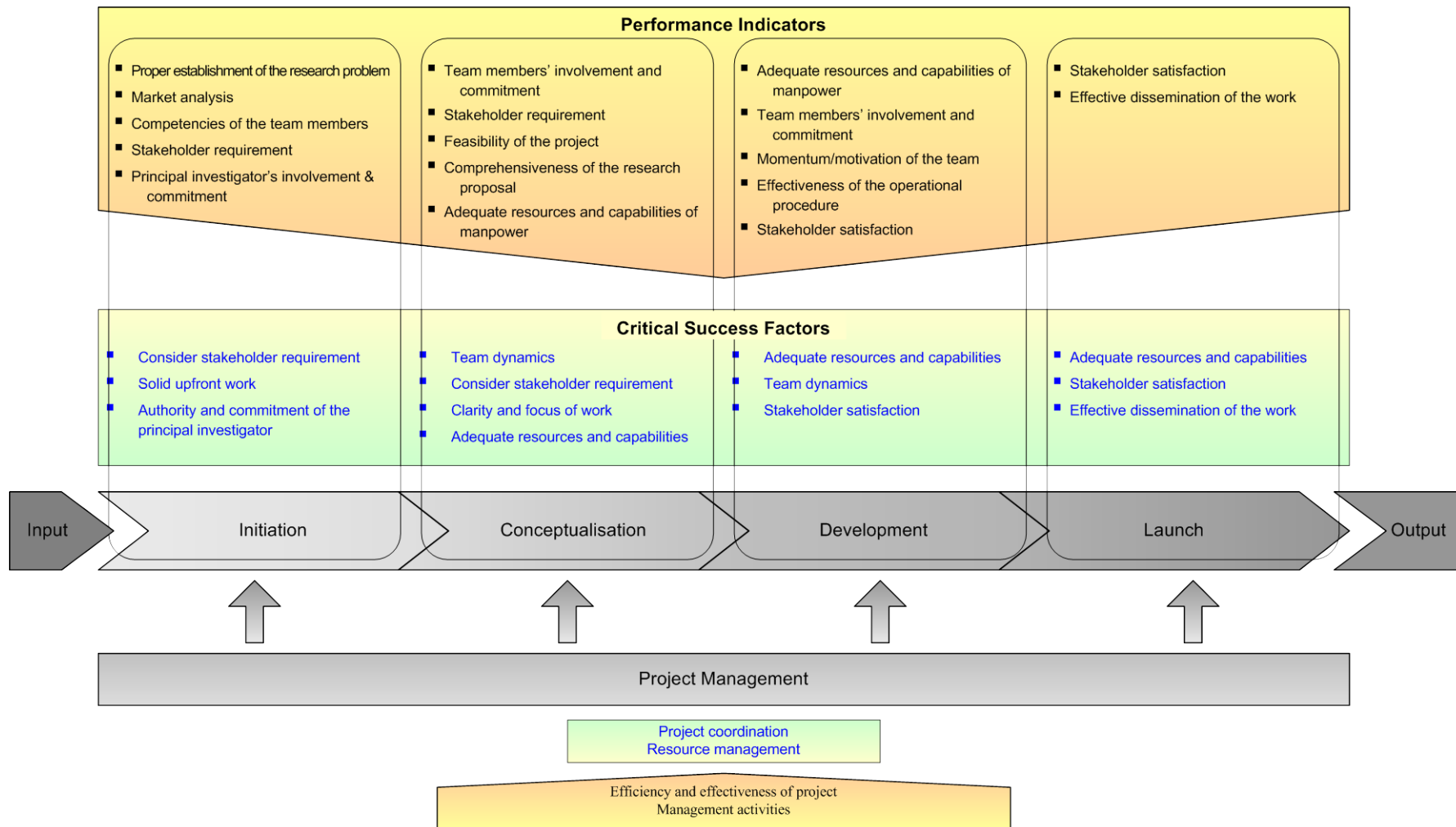|	Industry % N=26	Rank	Academia % N= 34	Rank	Overall % N= 60	Rank	Performance measures
Measures on the learning and growth of the stakeholders and researchers (knowledge gains/ knowledge creation, transfer and exploitation)	32.00	14	38.71	18	35.71	18	Completion of postgraduate degrees (PhDs); Number of publications by the team members; presentations at conferences
Measures on identifying the satisfaction of the researchers	-		35.48	19	35.48	19	Time commitment of researchers; project meeting attendance; absence ratio
Measures on the retention of the stakeholders	28.00	16	16.13	20	21.43	20	Follow on funding; continuous engagement/ partnership of stakeholders
Measures on the acquisition of new business relationships	28.00	16	16.13	20	21.43	20	Number of subsequent projects acquired and new opportunities derived from the project; follow on funding

Figure 1: Performance measurement system of construction R&D

Table 5: Performance indicators and measures of construction R&D

Critical success factors	Performance measures (component parts of performance indicator)
Initiation Phase	
Solid upfront work	
Understand the market and its dynamics	Existence of market analysis
Establish the research problem clearly	Existence of a research justification plan; completeness of the research proposal in terms of knowledge gap and importance of the research problem
Select a competent team	Existence of a skills evaluations; existence of recruitment plan; comparison of skills needed with the qualifications of the potential researchers, industrial partners
Consider stakeholder requirement	
Consider funding bodies' requirements	Existence of a requirement analysis of the stakeholders
Consider industrial partners' requirements	
Authority and commitment of the principal investigator	
Commitment of the principal investigator	Time commitment of the principal investigator
Leadership of the principal investigator	
Conceptualising Phase	
Team dynamics:	
Authority and commitment of the principal investigator	
Commitment of the principal investigator	Time commitment of the principal investigator
Leadership of the principal investigator	
Motivational and behavioural issues of the team members	

Committed and cooperative team members	Existence of performance evaluation methods of team members; comparison of allocation of duties and responsibilities against their achievement; project meeting attendance; time commitment of the team members; absence ratio
Consider stakeholder requirement Consider funding bodies' requirement Consider industrial partners' requirements	Existence of a requirement analysis of the stakeholders
Clarity and focus of work Check the feasibility of the project	Existence of a feasibility analysis; measures on cost, benefits analysis, achievement of project goals against the potential risks
Establish clear and realistic goals/ deliverables/ milestones	Comparing project expectation with available resources
Establish clear method to measure success	Existence of a procedure to establish project evaluation methods (e.g.: identification of time targets to evaluate performance/reporting, reporting mechanisms and reporting structure of project performance, identifications of people responsible to do the evaluations/reporting; timing of reporting)
Allocation of responsibilities to team members inline with competencies	Comparing the responsibilities with the competencies of the team members
Establish a plan to disseminate research results	Existence of a procedure to develop a project dissemination plan (e.g.: identification of the mode of dissemination of work, the target group/ beneficiaries, allocation of sufficient funds and personnel for launch events/ dissemination, identifying the timeframe for launch events/ dissemination)
Adequate resources and capabilities	

Having a skilled team	Number of publications and citations of the team members, generation of new ideas and findings, number of awards won, presentation at workshops/ conferences; number of training activities provided; evaluation of the skill level of the team members (e.g.: educational qualifications, experience)
Adequate resources/financial support	Existence of resource requirement analysis

Development Phase	
Adequate resources and capabilities	
Having a skilled team	Number of publications and citations of the team members, generation of new ideas and findings, number of awards won, presentation at workshops/ conferences; number of training activities provided; evaluation of the skill level of the team members (e.g.: educational qualifications, experience)
Adequate resources and financial support	Existence of resource requirement analysis
Having a well established operational procedure	Existence of a method to evaluate the operational procedure of the project (e.g.: identification of alternative approaches at cost, time, budget deviations)
Motivation and behaviour of the team members	
Committed and cooperative team members	Existence of performance evaluations of team members; comparison of allocation of duties and responsibilities against their achievement; project meeting attendance; time commitment of the team members; absence ratio
Secure momentum/ motivation of the team	Employee turnover
Share a common understanding about the work	Frequency of project meetings and comprehensiveness of the project briefing
Flexibility and responsiveness to change	

Authority and commitment of the principal investigator	
Commitment of the principal investigator	Time commitment of the principal investigator
Leadership of the principal investigator	
Stakeholder satisfaction	
Meet industrial partners' requirements	Existence of stakeholder satisfaction analysis; achievement of milestones, deliverables; scores on the stakeholder satisfaction surveys; number of subsequent projects acquired and new opportunities derived from the project; follow on funding or spin off effects; number of new stakeholders/contacts acquired; % of time, cost, quality deviation from planned
Meet funding bodies' requirements	
Launch Phase	
Adequate resources and capabilities	
Having a well established dissemination/ marketing plan	Existence of a dissemination of plan (e.g.: identification of project results and output reaching the target audience, beneficiaries; dissemination of the outcome within the planned time frame, obtaining feedback from the stakeholders)
Stakeholder satisfaction	
Meet funding bodies' requirements	Existence of stakeholder satisfaction analysis; achievement of milestones, deliverables; scores on the stakeholder satisfaction surveys; number of subsequent projects acquired and new opportunities derived from the project; follow on funding or spin off effects; number of new stakeholders/contacts acquired; % of time, cost, quality deviation from planned
Meet industrial partners' requirements	
Dissemination of work	
Launch the output within the planned time frame	% deviation from proposed timeframe
Effective dissemination of the results	Response rate from the industry on the utilisation of research results
Project Management	
Project coordination	

Continuous reviews Effective collaboration Effective communication Effective planning, controlling, and organising of activities	Frequency of project reviews/ meetings; number of cancellation of meetings; existence of communication and coordination plans (e.g. : identification of communication mode,); efficiency of communication, coordination; effectiveness of the communication of project deviations, achievement of milestones, deliverables to team members; effectiveness of the feedback (e.g. : getting the feedback from the required personnel, integrating the feedback within the system, taking correct actions based on the feedback received); evaluation of the project management procedure (e.g. : identification of communication channels, structure_ who should communicate with whom)
Resource management Effective resource management Effective management of the people	Existence of human and other resource utilisation analysis (comparing the resource requirement with the utilisation; procedure to revise and reallocate resources if needed; procedure act on resource constraints) budget deviations from planned, % of delays due to insufficient finance, human resource and other resources