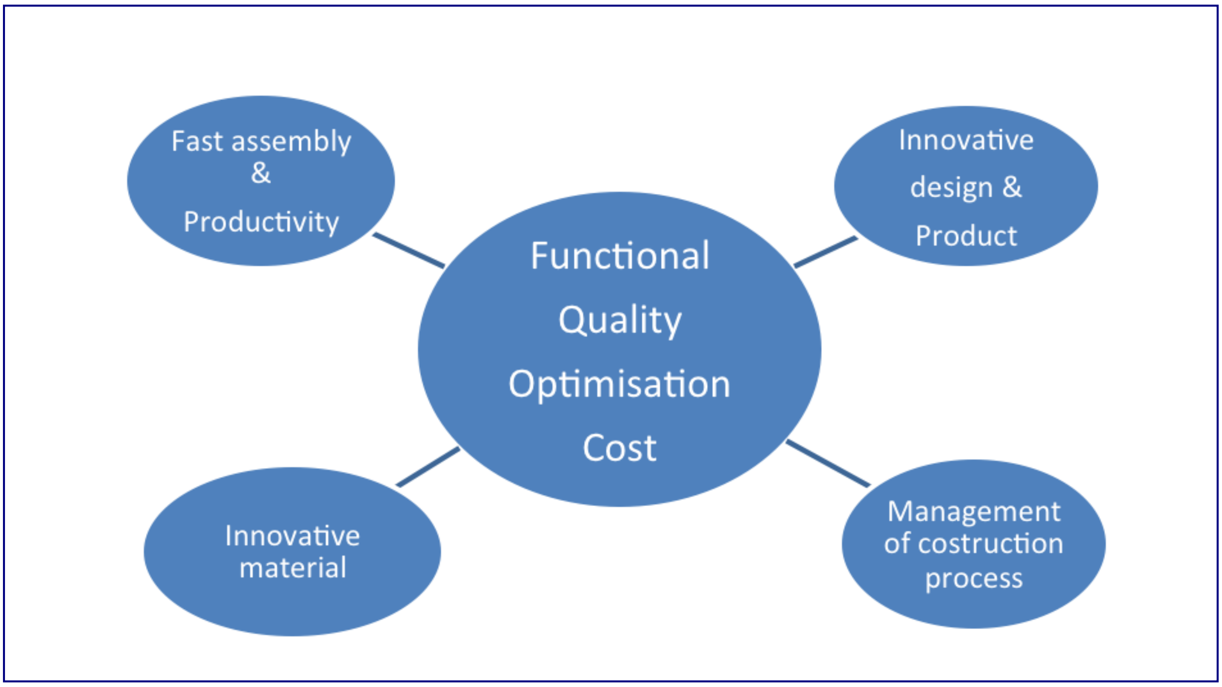

Critical success factors for efficient bridge construction

Meta-analysis of body of knowledge

Master of Science Thesis in the Master's Programme Structural Engineering and Building Technology

Fariba Kiamarsi

Gamaleldin Mahmoud Saeed Mohamed

Department of Civil and Environmental Engineering
Division of Structural Engineering
Concrete Structure
CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

Industry wise, success or failures of bridge construction have raised up questions about what were the critical success factors that lead to success or overcome failures. Many efforts were made to achieve the success factors for bridge construction.
This research assessed the stakeholder's goals definitions and how their goals were defined with critical success factors for an effective bridge construction. In order to achieve these aims two studies were conducted; quantitative study and qualitative study. Raw data were collected then reviewed with regards to several parameters to find the papers that create values to the research questions. From the quantitative analysis on effective bridge construction 10 aspects were found. Moreover from the reviewed papers, there were 10 aspects were considered by 5 stakeholders, Managers, Clients, Engineers, Contractors, and Designers. As results from the analysis of the general view, Functional, Quality, Cost and Optimisation were identified as 4 highest ranked main aspects for deeper analysis. In addition, from the more careful analysis of the literature, critical success factors were derived. These namely were: Management of construction process, Productivity and fast assembly, Innovative design and products and Innovative material.

Keyword: bridge construction, critical success factors, stakeholders, quantitative study, qualitative study, Innovative design, Innovative material

Kritiska framgångsfaktorer för effektiv brobyggnad
Meta-analysis av stomme av kunskap

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SAMMANFATTNING

Framgång eller misslyckanden av brobyggen har höjt upp frågor om vad som är kritiska framgångsfaktorer som leder till framgång av brobyggen. Detta projekt bedömer intressenternas måldefinitioner och hur deras mål definieras med kritiska framgångsfaktorer för ett effektivt brobygge. För att uppnå dessa mål har två studier utförs; kvantitativ studie och kvalitativ studie. Rådata, med avseende på flera parametrar, samlas för att hitta de bästa artiklarna som skapar värde för projektets frågor. Från den kvantitativa analysen på effektivt brobyggande har 10 aspekter upptäckts. Dessa aspekter beaktas av fem intressenter, projektledare, beställare, ingenjörer, entreprenörer och designers. Som resultat av analysen av litteraturstudien har fyra viktigaste aspekterna valts ut för djupare analys; funktionell, kvalitet, kostnad och optimering. Dessutom, från den mer noggranna analysen av litteraturen, har kritiska framgångsfaktorer härletts. Dessa är: ledning av byggprocessen, produktivitet och snabb montering, innovativ design och produkter, strukturhälsa, miljöpåverkan och innovativa material.

Nyckelord: brobyggen, kritiska framgångsfaktorer, aktörer, kvantitativ studie, kvalitativ studie, innovativ design, innovativa material

Contents

Preface

Critical success factors for efficient bridge construction have been studied in this master thesis. This study was carried out at the request of Rasmus Rempling, at the Division of Structural Engineering, Concrete Structures, at Chalmers University of Technology, Sweden during the spring 2014. This master thesis has been written for the Department of Civil and Environmental Engineering at Chalmers University of Technology.

We would like to express our special appreciation and thanks to our supervisors Rasmus Rempling (Assistant Professor, Structural Engineering) from Chalmers and Daniel Ekström (Industrial PhD, MSc in Structural Engineering) from WSP. The analyses have been performed at Chalmers. We would especially like to thank Rasmus Rempling for his support during this project, help and sharing of knowledge.

Göteborg June 2015

Fariba Kiamarsi & Gamaleldin Mahmoud Saeed Mohamed

Abbreviations

The following abbreviations are used in the main text of the thesis:

ACI 440	American Concrete Institute Committee 440, Guide for the design and construction of structural concrete reinforced with FRP bars.
ADTV	Average Daily Traffic Volume
BIM	Building information modelling
BCP	Bridge Construction Plans
CBR	Case-based Reasoning
CFRP	Carbon Fibre Reinforced Polymer
CPLM	Construction Project Life Cycle Management
ERA	Eigen system Realization Algorithm
FE	Finite Element
FEA	Finite element analysis
FAA	Frame Accurate Animation
FRP	Fibre Reinforced Polymer
GA	Genetic Algorithm
GFRP	Glass Fibre Reinforced Polymer
HPC	High performance concrete
HSC	High-strength concrete
IBRC	Innovative Bridge Research and Construction Program
ITD	Ibrahim Time Domain
LCC	Life - Cycle Cost
NC	North Carolina
NExT	Natural Excitation Technique
PE	Preliminary Engineering
PPC	Precast Prestressed Concrete
PBS	Product breakdown structure
PMIS	Project Management Information System
RHC	Rapid hardening concrete
RC	Reinforced concrete
SCC	Self-compacting concrete
SIP	Stay-In-Place (FRP pultruded deck)
USN	Ubiquitous Sensor Network
VR	Virtual Reality

WBS	Work breakdown Structure
AASHTO	American Association of State Highway and Transportation Officials
PBSME	Prefabricated Bridges Structural Members and Systems

1 Introduction

This chapter is covering the research background, objective, limitation and method.

1.1 Background

The fast growth of populations has created new needs for mobility and increased the demands for constructing efficient bridges. The growth in bridge construction has been very progressive in many countries around the world over the last decades. Many great bridges have been built successfully while other has not. Actors 'i.e. Engineers, Designers, Architects, Contractors and Clients" strive for finding very useful, cost efficient and sustainable ways of moving people across cities. Thus, building on an extensive knowledge to design, plan, construct and manage efficient bridge construction will contribute to mobility that is safe and reliable with a minimum impact on the environment. In spite the fact that bridge construction has experienced positive development trends compared to the past years. Though, from a holistic view, there are still some questions that need to be answered regarding the efficiency of bridge construction. In contrast, looking into the assumptions that kept arising from an early age, if a particular project is accomplished within the agreed time frame, cost and required quality "i.e. project management triangle", then the project is considered to be successful. Moreover, with implementing these assumptions, many construction projects were not meeting their strategic goals. Therefore, defining these goals beforehand is needed instead of just relaying on the assumptions from the project management triangle.

1.2 Research Objectives

The construction processes consists of many stakeholders that have different and common strategic goals for bridge construction. Thus, the aim of this project is to define these goals in order to find which ones create value for efficient bridge construction.

The specific objectives are:

- Define the strategic goals of the actors involved in bridge construction from different aspects.
- Drive the critical success factors for an efficient bridge construction.

1.3 Limitations

The research is limited to bridge construction in general view. The research questions are answered from the examined articles and conferences. The strategic gaols are limited to 5 actors' perspectives "i.e. Engineers, Designers, Architects, Contractors and Clients".

1.4 Method

To accomplish the stated objectives, a meta-analysis was conducted. To collect the raw data a quantitative study on effective bridge construction was conducted then followed by a qualitative study.

2 Research Methodology

The research method is divided into two sections: quantitative and qualitative studies. The following diagram shows the methodology in more details.

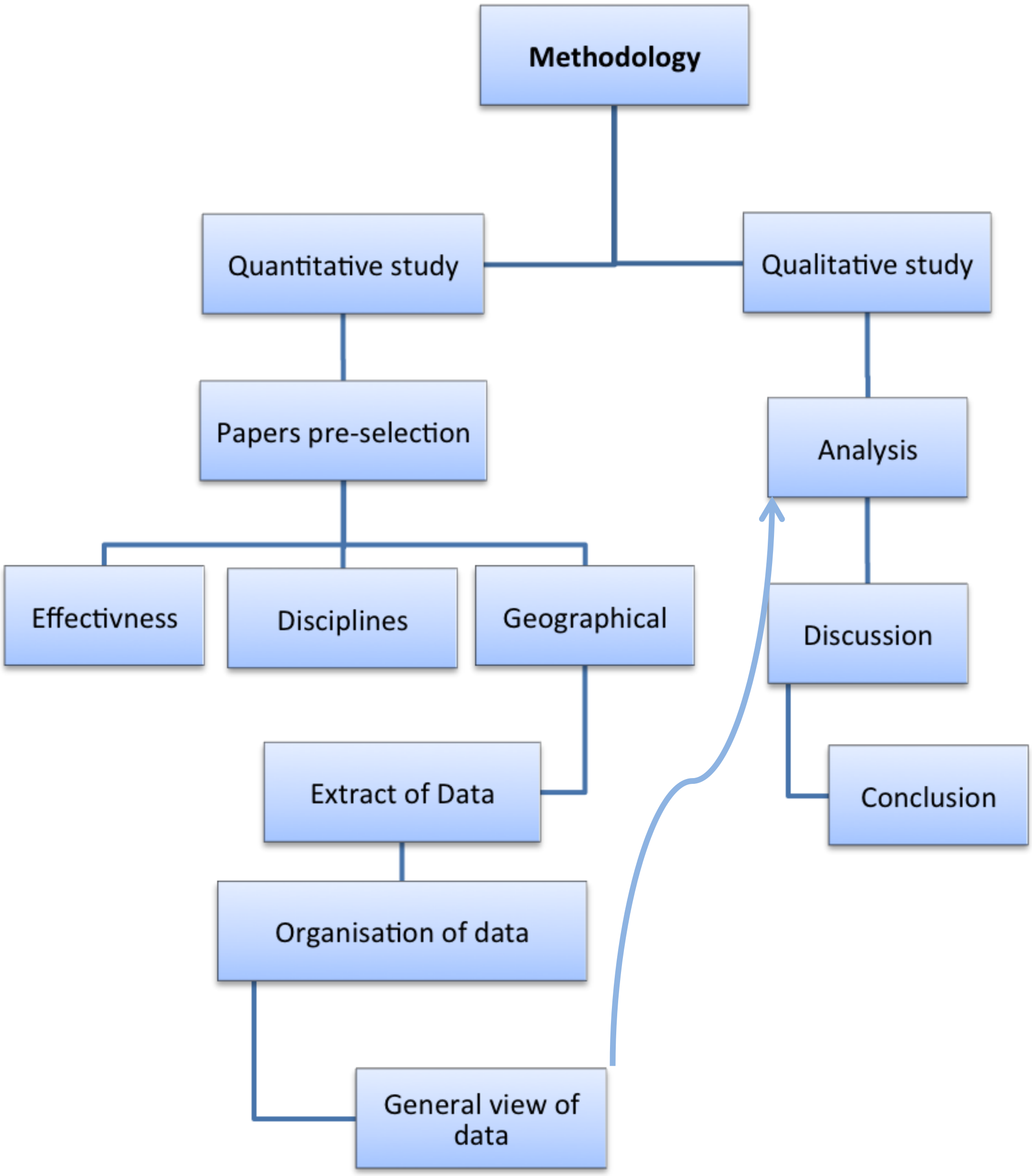

Figure 1: Research methodology

2.1 Quantitative study

In this part, the research methodology will be emphasised more critically.

Within the quantitative study, raw data about effective bridge construction were collected. For the raw data collection, the following search terms were formed: “efficient bridge” or “effective bridge construction” and searched for in the title.

The search on an efficient bridge construction was performed in order to collect raw data from 1960th to “February 1st, 2014”. The table below shows the results of the raw data collection with the corresponding databases:

Table 1: Raw data, databases and No. Of hits

No.	Databases	Title	Results
1	WEB OF SCIENCE	TI=(effective bridge AND construction)	5
2	WEB OF SCIENCE	TI=(efficient bridge AND construction)	1
3	Engineering village	efficient bridge AND construction) AND (({English}) WN LA))) AND (Civil Engineering))	46
4	Engineering village	effective bridge AND construction + Civil Engineering AND ({English}) WN LA)	97
5	Civil Engineering database	effective bridge AND construction Journal of bridge engineering	16
6	Civil Engineering database	effective bridge AND construction/ Journal of construction engineering and management	8
7	Science direct	effective bridge construction	75
8	Google scholar	effective bridge construction	430
9	Science direct	efficient bridge AND construction	37
10	Chalmers Library	efficient bridge construction	315

Throughout the review of the quantitative study several indicators were considered. Moreover, three computer aids were used in order to ease the work, manage all the reviews of papers and analyse the results. These aids were Mendeley, Python and Microsoft Excel.

Since there exists a possibility to have the same papers in other databases, all papers were reviewed as a first coarse filter.

Subsequently, to ensure the quality of the findings it was important to check the details, for instance, make sure the author(s) name(s) are correct, year of publishing, volume and issue of each paper or conference etc. Once the papers were correctly added to the database of papers, each paper was inspected and the following details were concluded in the database:

- Type of structure
- In which geographical area the research were conducted, i.e. "Africa, Asia, Europe, USA etc".
- Disciplines addressed in the research.
- Finding the main aspects or effectiveness.

2.2 The definition of parameters and terms

While reviewing the papers and extracting several parameters, there were some parameters that were duplicated. For instance, construction time, production time, etc. so this can results in duplications of our finding and it can cause difficulty to evaluate the overall effectiveness ranking. Hence, for a wider understanding and clarification of these parameters within the current practice of bridge construction, some definitions are described in the following section.

The main aspects were grouped into ten (10) as shown below:

1. Time

From the extracted papers, time was found to be mentioned in different perspectives, for instance "construction time, design time, planning time, maintenance time, project modification time, time efficiency, saving time etc". However, all of these terms were regarded as time in general.

2. Cost

The term cost covers all of construction cost, design cost, maintenance cost, etc as cost. However, life cycle cost "LCC" is treated separately.

3. Quality

The term quality covers all of: material quality level, overall construction quality level, material durability and bridge service life performance etc.

4. Life cycle cost (LCC)

Life cycle cost (LCC) is the total cost during all the project phases. Within some papers life cycle cost "LCC" is represented as "initial construction cost, repair, rehabilitation and maintenance costs". LCC was found to overlap with general cost in some papers. For the analysis of the data, both terms must be treated as separate.

5. Functional

To facilitate the analysis of data, the terms “production process, maintenance, accessibility of the bridge, simple erection, accessibility for passage and other monitoring activities etc.” were grouped as “Functional”.

6. Safety

Throughout the review of papers, the term safety was considered as “the condition of being protected against consequences of failure, damage, error, accidents, harm or any other event which could be considered undesirable such as design delay, construction delay, production delay etc”. In addition, risk assessment, risk analyse and other risk factors were grouped to this aspect.

7. Aesthetic

From the examined papers aesthetic has been mentioned for some extend. Aesthetic is mainly look after the bridge's spatial point of view and contextual aspects. For instance the design intensions of the bridge must be unique, tourist attraction, resemble other structure in the neighbourhood, elegant etc. Also during the construction of bridges aesthetic must be considered by keeping the surroundings area as it is (i.e. it should not make a huge influence on the surrounding).

Aesthetic can be important in this study because, considering aesthetic during the construction and design phase can influences the time and cost of the whole project, location, choice of material texture, appearance, and so forth.

8. Optimisation

The aspect optimisation incorporates maximizing or minimizing a real function by systematically choosing input values from within an allowed set and computing the value of that function. In some papers, the term optimisation is referred to as the process of selecting a specific structural system with regard to some design criteria.

9. Sustainability

Sustainability is a very wide topic, however, sustainable bridge design and construction gets increasing importance while looking into the future. On the other hand, the choices of sustainable materials play an important role to decrease carbon emissions and increase the use of bridge structure without creating an impact in our environment.

Nonetheless, choosing the right materials the rehabilitation, demolition and replacement of any bridge in the future will be more environmental friendly. All of these points of views are highlighted and discussed by different actors’ within the collected papers.

10. Collaboration

The aspect collaboration was used as a group of shared activities between different actors that were involved in tasks and that were willing to reach shared goals. Collaboration was found to be very important and it governs much project success. However, it requires leadership and communication between all disciplines in any project. Throughout the papers the term collaboration was used in direct and indirect way but all were grouped as collaboration.

Moreover, in this research the disciplines were grouped into five (5) as shown below:

1. Designers

Designers are entitled to architects and disciplines working in the conceptual design process. In most cases, designers are working closely with clients at early design phase, keeping close collaborations with structural engineers and contractors.

2. Contractors

Contractors are the constructors that build the facility or infrastructure. Most of their work is carried out at the construction site.

3. Engineers

Engineers include all of the structural, mechanicals, electrical and plumping (MEP) engineers. Structural engineers handle structural Design while MEP engineers follow the additional work.

4. Clients

Clients are referred to as the juridical person that has ordered the project.

5. Managers

Managers play a very important role in order to achieve the project success. In this project, managers can be either a project manager, designer, engineer or contractor except the client.

3 General view of data

A summary of the quantitative study is presented in Table 3.1 in appendix A. In total, there are 95 cite-keys from different geographical areas and time-span (years). In addition, there are ten effectiveness parameters and five disciplines that were extracted from the papers. However, after extracting the data, it was found that all ninety-five papers were actually published between the years 1990-2014.

In this section, the interrelation of effectiveness parameters, geographical areas, time-span and disciplines are presented. Figure 2 shows the specific number of cite-keys related to one of the ten effectiveness parameters. In the graph it can be seen that the function parameter has the greatest number of cite-keys, while quality is the second and life cycle cost (LCC) is the lowest among the ten effectiveness parameters. In a way, this does not say more than that time, optimisation and quality is getting the most attention in research.

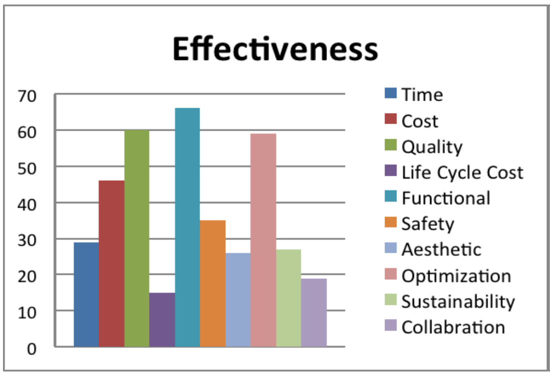

Figure 2: Effectiveness

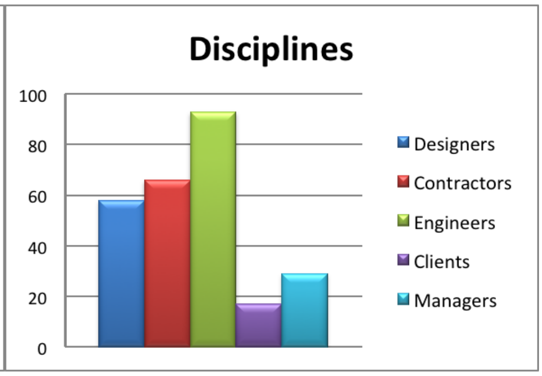

Figure 3: Disciplines

Figure 3 shows the number of cite-keys that are related to specific disciplines. Throughout the cite-keys, apparently engineering aspects play the biggest role and contractors are the second, while clients are having the lowest attention.

In Figure 4, 5, 6, 7 and 8, the highest ranked effectiveness parameters are broken down with regard to the identified disciplines.

First, when it comes to functional effectiveness, engineering aspects gets the highest attention. While client aspects gets the smallest attention, Figure 4.

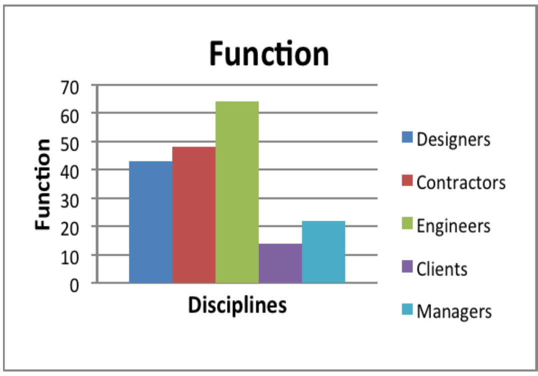

Figure 4: function

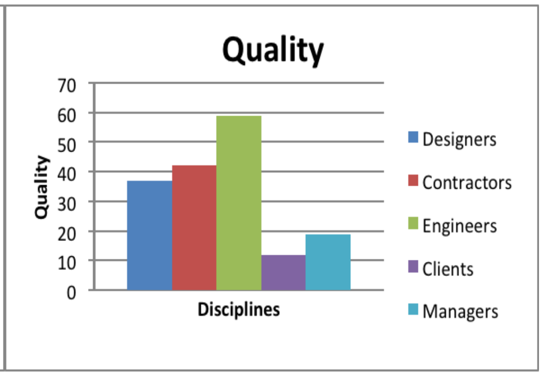

Figure 5: quality

Secondly, regarding quality effectiveness, again engineering aspects gets considerable attention and the clients are of least interest, Figure 5.

Thirdly, the same pattern repeats when the parameter optimisation effectiveness was studied. The only significant change is that contractor and designer aspects gets more or less the same attention from the research community.

Furthermore, the main interest of engineering aspects is confirmed by the study of cost effectiveness. Finally figure 8, summarises how the other effectiveness and parameters varies with regards to disciplines aspects.

In conclusion, the highest 4 ranked effectiveness (functional, quality, cost and optimisation) are considered for deeper analysis.

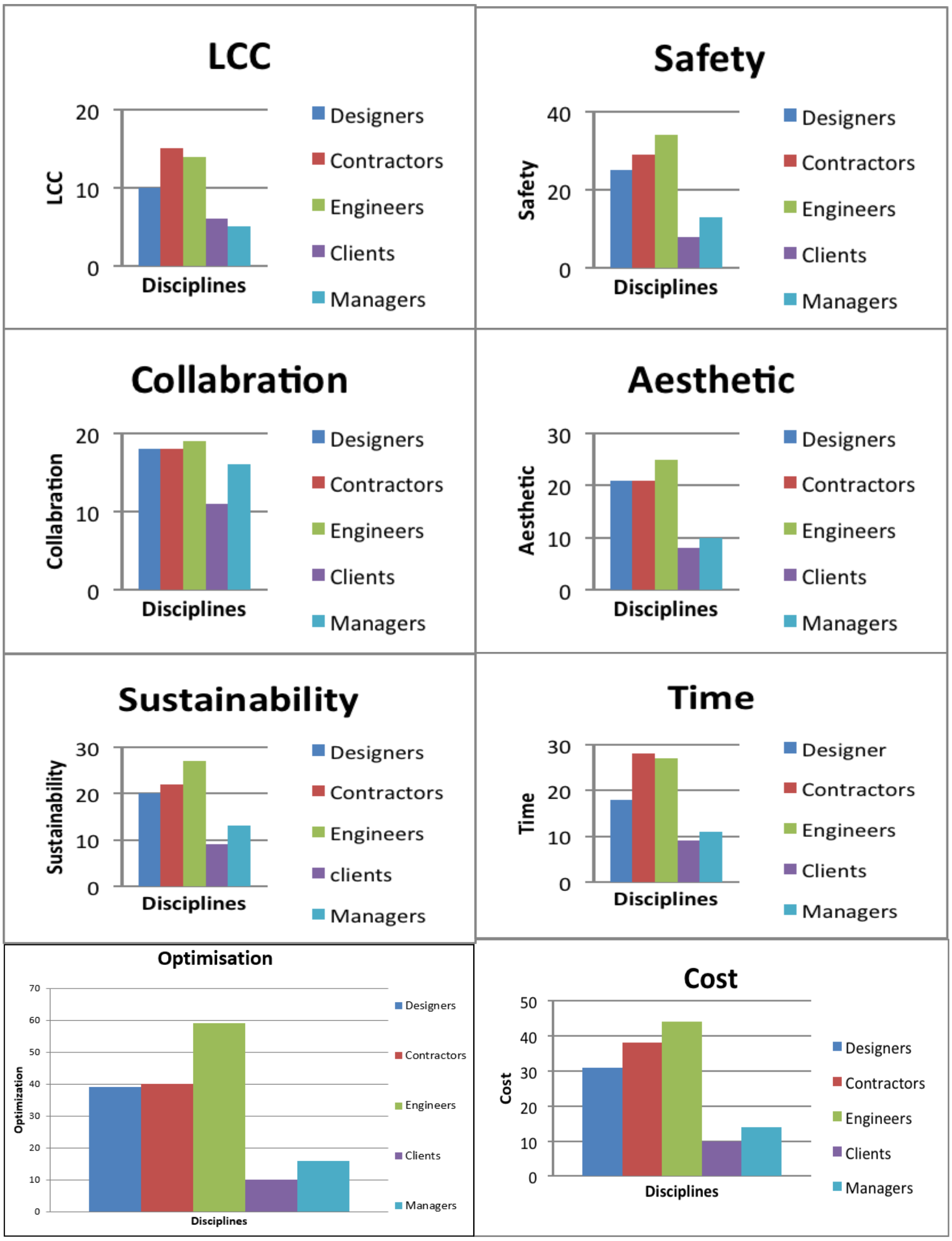

Figure 6: Relationship between disciplines and effectiveness

4 Zoomed in view of research on effective bridge construction

As it has been mentioned within the previous chapters, several actors that represent different disciplines are involved in the bridge construction processes. Also there are several effectiveness were considered by these actors. It is found interesting to see if this has any influence on the success of bridge construction. On the other hand, in order to draw a holistic view on that, it is important to analyse these parameters more critically with regard to their geographical differences and time.

Figure 9, shows the highest four effectiveness. Looking at figure 9, it can be seen that there is a rapid increase in the number of published papers. Also as it is shown below there are no much increase to be noticed between the years 1990 - 1996, then followed by small increase between the years 1996 - 2001 and ending up by almost the double of it between the years 2005 – 2014.

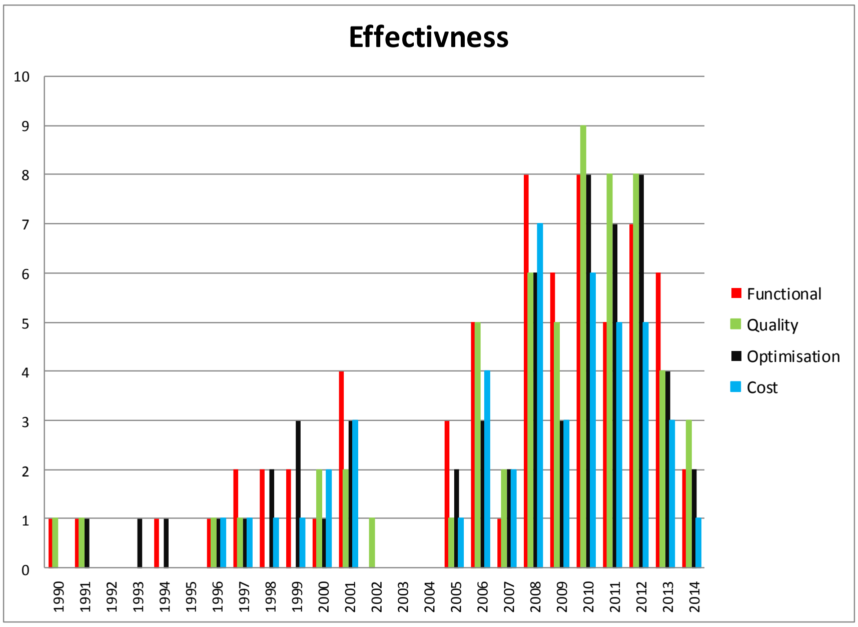

Figure 7: The variation of publications with regard to most common effectiveness parameters of the time-span.

4.1 Evaluation of effectiveness

In this section the evaluation of the highest four effectiveness (functional, quality, cost and optimisation) are investigated and the results presented were obtained from the reviews of the most citied papers within the total (95) cite-keys.

4.1.1 Effectiveness and geographical differences

As shown in figure 10, functionality of bridge construction is varying between 1990 and 2014, it has increased from 2006-2014. Also it varies with regards to different geographical areas as shown in figure 11.

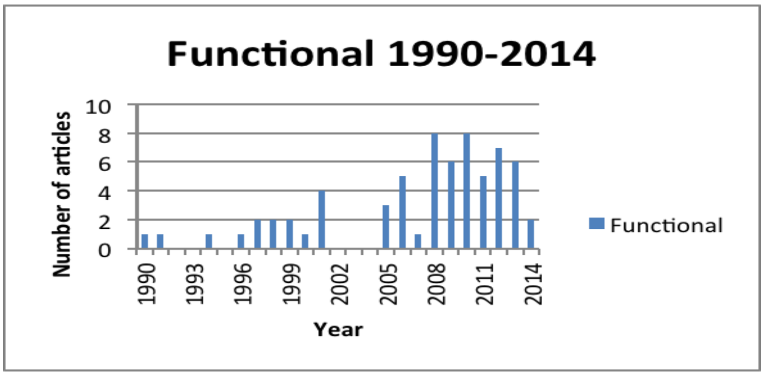

Figure 8: The number of published papers about functional with respect to time

According to figure 11, it is possible to see that functionality of bridge construction varies from one country to another; Asia has the highest published papers, while Europe and USA are having almost the same number of published papers.

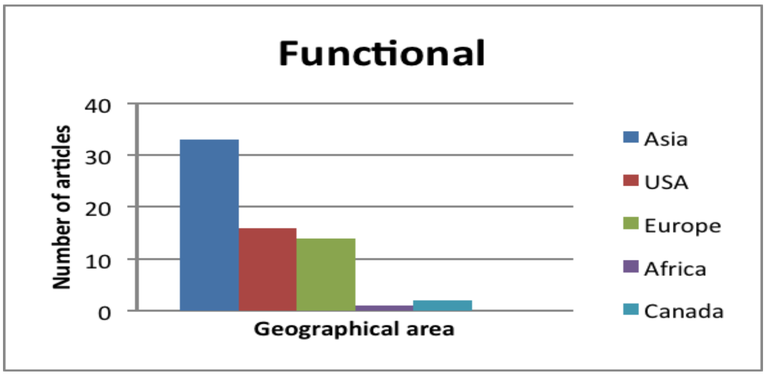

Figure 9: The number of published papers about Functionality with respect to geographical area

According to figure 12, quality has a rapid increase between the years 2006-2014. Regarding the geographical differences, Asia still has higher number of published papers about quality compared to the other geographical areas.

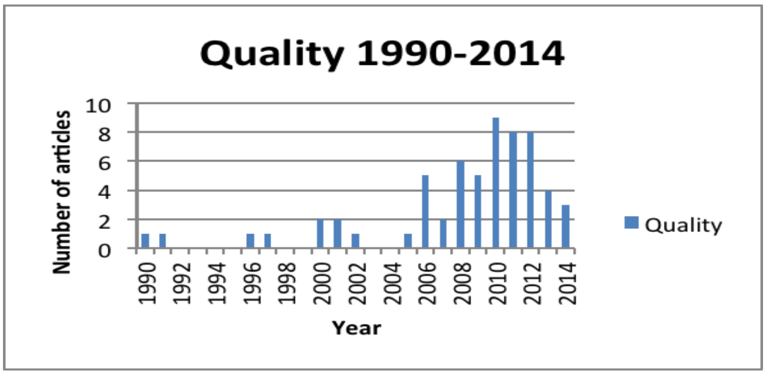

Figure 10: The number of published papers about quality with respect to time

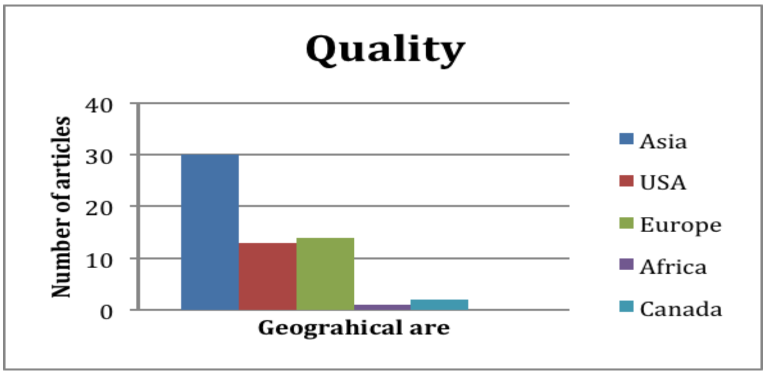

Figure 11: The number of published papers about quality with respect to geographical area

As shown in figure 14, through all the examined papers the number of papers that has been published about cost is growing between the years 2006 -2014.

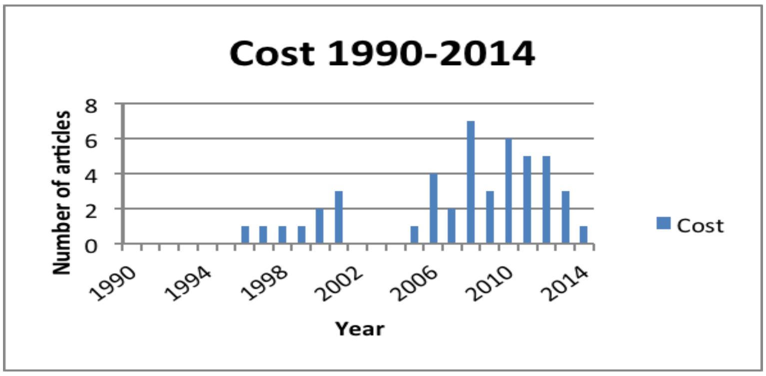

Figure 12: The number of published papers about cost with respect to time

Concerning the geographical differences, Asia, USA, and Europe respectively published more papers about the cost compared to rest geographical areas as shown in figure 15.

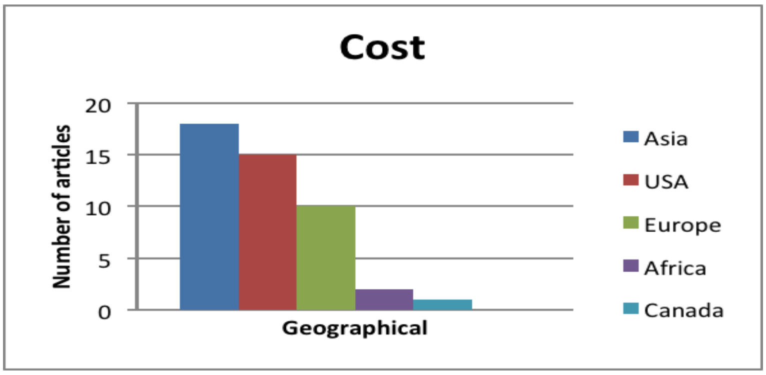

Figure 13: The number of published papers about cost with respect to geographical area

Through all the articles that studied the number of articles so produced about the optimisation is growing between the years 2006 -2014 and in geographic areas such as Asia, Europe and USA respectively.

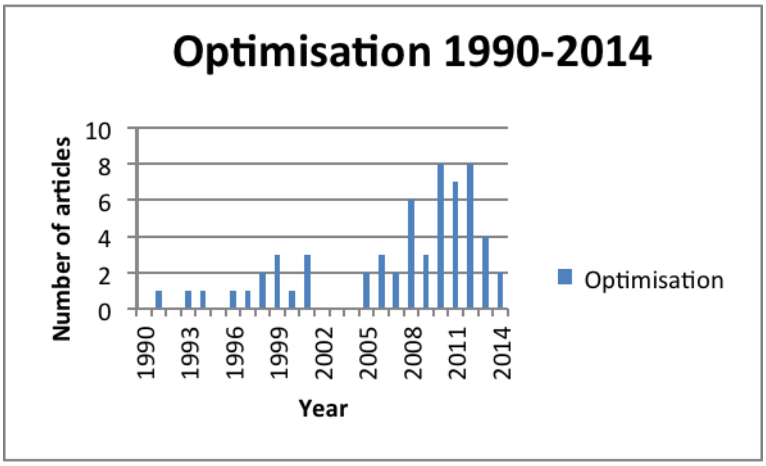

Figure 14:The number of published papers about optimisation with respect to time

Figure 16, show that there are more published papers discussing about optimisation between the years 2006 -2014 than 1990-2006.

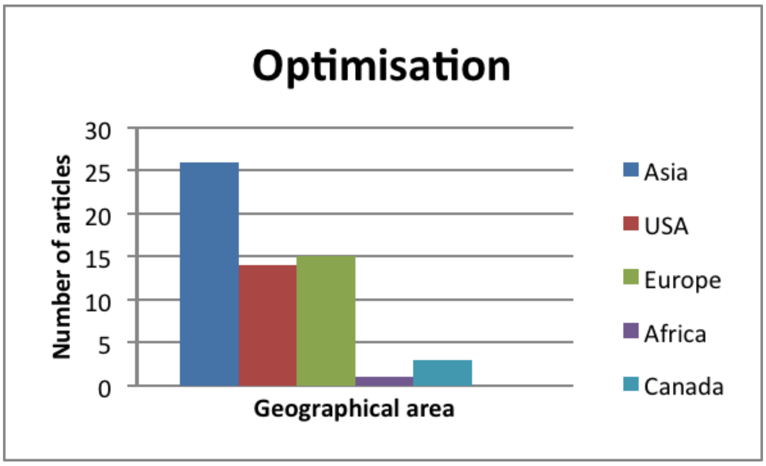

Figure 15: The number of the published papers about optimisation with respect to geographical area

Figure 17 indicates that there are more published papers in Asia, USA and Europe than in Africa and Canada.

4.2 Summary of research on effective bridge construction

In this section the main conclusion from the literature is presented.

Researchers at University West Lafayette, USA, made a study of an advanced tool that can assess the onsite productivity. They assess the tool by 2 bridges as case studies. The results showed that the time estimation by the tool was very accurate and they concludes that these tools are valuable for predicting the actual construction time and realistic production levels, as well as work duration and resources, Dulcy et al. (1998)

Islam et al (2011) conducted a research with purpose of assessing the structural health of urban bridges by instrumenting the structure with acceleration sensors, wireless networks, internet web services etc. The result showed that the wireless mesh network provides lower cost and high dependability procedure for real-time group of acceleration data. They conclude that this is a very promising methodology for lowering the costs of maintenance and accurate knowledge of structural health of bridges, but there is lack of research that gives evidence for these conclusions.

In order to optimise the design solution, Ohkubo, (1998) made a study based on an own developed design method for structural systems. The methodology takes into account economics, safety and aesthetics, etc. And is verified by the design of a pre-stressed concrete bridge. The study concludes that the method was successful. (Cost, Optimisation, Functional)

He et al (2012) state a special model of hybrid Glass Fibre Reinforced Polymer (GFRP) plate and concrete concept is preferable alternative for beam-and-slab bridges. The concrete deck consisting of pultrusion corrugated GFRP plate with T-up stands for the tension part and for the compression part used concrete with reinforcing bars. The results showed American Concrete Institute Committee 440 (ACI 440) bending and shear equation can efficiently forecast the final capacity for the hybrid deck. Usage of hybrid GFRP bridge deck will reduce the construction costs and saving construction time and it's a better alternative for beam-and-slab bridges. (Cost, optimisation)

A practical case of using rapid hardening concrete (RHC) is offered by Cangiano et al (2009). They constructed a deck of a small span bridge situated in a heavy traffic, by applying a concrete characterized by early age strength. The result of this paper shows RHC has excellent durability properties and the elastic behaviour of the bridge under service loads. The observation showed that one day after casting operations and final inspection of the bridge was opened to public traffic. (Cost, Quality, Functional)

Hollar et al (2013) addressed the cost of doing preliminary engineering (PE) is one of the costs of new bridge projects. They reviewed 461 projects between 2001 and 2009 from the North Carolina (NC) bridge projects. As a result, they found that, the bridge projects showed an average preliminary engineering PE cost ratio of 28%. In conclusion, this study on bridge PE costs takes up one part of infrastructure financing. (Cost, optimisation)

The sustainability of Fibre Reinforced Polymer (FRP) solutions in comparison with traditional bridge concepts is investigated by Mara et al (2014). The results of the study are reducing negative effect on users and improving the public sustainability. Also easy to transport and installed without traffic demands because of the light weight of FRP decks. Furthermore bridge construction with FRP decks has fewer carbon emissions and energy intake than ordinary concrete decks. Moreover FRP decks suggest a maintainable result for the rehabilitation of functionally outdated bridges. They achieved FRP decks help to possible cost investments over the life cycle of bridges and a less environmental effect. (Cost, Quality, Functional)

Fukuchi et al (1999) presented an important tool for the construction management, which is called the application of Frame Accurate Animation (FAA). The authors made an effort to support construction management process by reproducing the construction site and performing construction activities on the computer by suggesting Collaborative Supported FAA. They conclude that it's important for the project's actors or contributors "i.e. clients, engineers, workers, and local community" to understand the whole process of the project in the earlier stage of the construction. Also they mentioned that it is possible to use FAA for the working description and for pointing out the unsafe part in education for inexpert employees. Moreover they cited that it’s important for inhabitants, what kind of structure is going to build and how the vision variations rather than the way of construction. (Cost, Optimisation, Functional)

Virtual reality (VR) technology was useful for development of two models associated to the activity of bridge construction according to Sampaio et al (2012&2014). These models are the cantilever method and the incremental launching method of bridge deck construction. The educational respects and the technical facts conducted by the models are obvious in the selection of the quantity and type of elements to present in each virtual model. The main role of VR was to provide more natural interface to the data being manipulated by the computer program. On the other hand they believe that these advanced models bring new view to coaching in the form of support when debating new curricular issues or complex arrangement construction, both students and teachers cooperating with the VR models. (Optimisation, Quality, Functional)

El-Diraby et al (2001) offered a model for evaluating bridge construction plans (BCP) during the design phase. The model contains five factors and 22 sub-factors, all were developed to support in evaluating these factors. The promising model easy to apply and could have a positive effect on BCP development. Moreover that is suitable to most bridge projects and it cover the majority of unfavourable issues related to bridge projects. (Cost, Optimisation, Functional)

To increase the efficiency of construction a new method was presented for the construction of bridge's piers. Nasir et al (2001) suggested that applying precast pre-stressed concrete (PPC) panels as formwork for the construction of bridge piers. Some tests have been done to check the possibility of this promising method. They conclude that using PPC panel as formwork is a possible concept. (Optimisation, Quality, Functional)

Kitada (2006) presented that steel bridge construction has a bright future in Japan throughout the study of latest developments. He mentioned that it could be valuable for the other countries specifically with active earthquake affect as their bridge infrastructure development is in various stages. (Cost, Quality, Functional)

The aerodynamic optimization of the Messina Bridge and a discussion of associated suspension bridge evolutionary aspects, has offered by Brancaleoni et al (1993). They considered the evaluation of the bridge with respect to wind load has been made by means of tower, deck sections aerodynamic optimization and bridge finite element aero-elastic model. They mentioned that dead loads and static wind drag should be kept to a minimum and suitable aerodynamic stability must be ready. They summarised that one of the most important things that have influence in behaviour of long and slender bridges is wind effects. Aerodynamic optimization is necessary, to study the behaviour of long and slender bridges. (Optimisation)

Kang et al (2010) presented model that assess the durability of bridges. The model based on analytic hierarchy process and variable weight synthesising to evaluate the durability condition. They mentioned that real bridge uses the synthesis evaluation model and the calculating result shows the stability and efficiency of the evaluation model. Consequently the model can offer theoretical source for the management. (Optimisation, Quality, Functional)

A case study presents by Said et al (2009), show that how computer simulation is used to support bridge deck construction. El-Warrak Bridge in Cairo, Egypt, studied to show the capability of computer simulation in modelling construction of bridge deck. They used cast-in-place on false-work and cantilever carriage construction approaches. One important outcome from the study that is required to make a comprehensive documentation system to help the simulation parameters during design stage. This methodology helps contractors to estimate the time and costs of the repetitive process of bridge deck construction. (Cost, Functional)

Adanur et al (2012) offer that construction phases of suspension bridges with regard to geometric nonlinearity and time dependent material properties like creep, shrinkage and compressive strength for concrete and relaxation for steel. Finite element model of the bridge is created with help of SAP2000 program using project drawings. Two types of finite element analyses assumed with and without construction phases and the outcomes were compared with each other. The analysis with the construction phases can give the reliable results. With using second order effect large displacement criterion, geometric nonlinearities are derived to regard in the analysis. (Optimisation, Quality, Functional)

Wuzhong Yellow River Highway Bridge chose as a case study by Dong et al (2011). They discussed surveys of geometric control in the process of actual cantilever construction. Construction process has been simulated. The primary curves of pre-camber for various span are found, and pre-elevations are prepared in which a long-term in case of shrinkage and creep effect of concrete on the structure and other errors in other large-span bridges are measured. The results of study determine the theoretical simulation and associated program are dependable. All these surveys offered a basis for the bridge of linear control and a reference about geometric control. Also it would provide the essential reference points for construction of the other similar large-span bridge. (Optimisation, Quality)

Ailland et al (2010) suggested that to appraise applications and limits of the presented concept to apply grid points and how the estimated data can be applied in a simulation tool. This gives information about significance of accuracy, velocity, automation, redundancy, and importance of data gathering throughout construction processes. These simulation experiments results and application limits can be regulated for different construction situations. In addition, there is the possibility that missing data and how the simulation will respond in the case of doubt. They mentioned if the model implies complete control of the construction process, the reader should be conscious that the design is too complex to trust on mechanisation. The promising model is a method to progress the information on current construction places. Furthermore it is possible for construction managers to further concentrate on the actual barriers so have not encountered in improvement, and to get suitable information about routine processes governed. In this manner reaction time will be reduced. (Cost, Optimisation, Functional)

The cost approximation model which uses Case-based Reasoning (CBR) and makes the database reflected the character of the railroad bridge offered by Kim et al (2011). To find this effective CBR model, this paper observed blends of aspects, criteria of likenesses, recovery levels and used Genetic Algorithm (GA) for an optimization of feature weights during learning procedure. The result of this paper, CBR should apply a five- property combination, recover six like cases and apply the likeness criteria by using a method in which ten points are removed for each 10% variance to get the lowest inaccuracy. They conclude, despite the efficiency of the CBR model, there is restriction in the precision and dependability of the CBR model progressed as the case database has not been produced fully reflecting different superstructures of the railroad bridges. Moreover they determine ongoing update of database is rather necessary in the future for the railroad bridges. (Optimisation, Cost)

A case of study offered by Kim et al (2012) that a modified Case-based reasoning (CBR) model based on the regression analysis model was expanded. A design model capable of approximating the construction cost in the planning stage was progressed with an attention on railroad-bridge construction. Five case studies were chosen to control the modified CBR model. The outcome showed that the construction cost error rate of the planned CBR model reduced by 16.2%. They conclude that the modified CBR model will be valuable between the recovered case and the cases stored in the database. (Cost)

A practical and realistic Life Cycle Cost (LCC) methodology presented by Lee et al (2006) for the LCC-effective optimum construct of steel bridges with regards to the time influence of bridge dependability under some surrounding impacts, like corrosion and heavy truck traffic. For the valuation of the life-cycle reintegration costs, they calculated the annual possibility of error which depends on the previous and efficient load and resistance histories. Moreover they used the Nowak live load model and corrosion spread model regarding corrosion beginning, corrosion rate and repainting effect. The result of study showed that the local corrosion environment also impacts the optimum LCC design of steel bridges particularly in large Average Daily Traffic Volume (ADTV) areas. They conclude the promising methodology can be successfully applied for the LCC-effective optimum construction of steel bridges. (Cost, Optimisation, Quality, Functional)

The dynamic behaviour of long-span cable-stayed bridges studied by Lee et al (2011) with regards to different wind effects. The innovation of this paper is the attention of a primary static equilibrium state exposed only to the self-weight of the bridge at several construction steps under storm. They applied a new advanced finite element program for the dynamic response of a bridge to study the main and side spans before closing of the superstructure. The results achieved for a present three-span cable-stayed bridge model are compared to laboratory scale. They considered the different effects of wind velocity on the dynamic behaviour when the primary static equilibrium states at various construction steps. The outcome of this paper is that a geometrical nonlinear method is necessary to deal with such effects, and should be useful to analyse cable-stayed bridges to achieve better precision and effectiveness. (Optimisation)

Berg et al (2006) explain the usage of FRP materials as formwork and reinforcements for a concrete bridge deck, the construction steps and offers a cost analysis of the project. For reinforcing concrete deck three forms of the FRP reinforcement combined: The SIP (stay-in-place) FRP pul truded deck, FRP reinforcing bars and FRP reinforcing grid. They offered optimization of FRP stay-in-place formwork to reduce the cost of the FRP reinforcing system. (Cost, Quality, Functional)

The development of construction techniques for long span cable-stayed bridges offered by Kim et al (2013) to provide faster design and cost savings to secure international competitiveness. They expanded two equipment AS and PPWS for erection of cables. They expected to reach some effects as follows: There is a lack of cable erection equipment in the world, which means a complete dependence on foreign technology in this area. Their target achievement will provide a foreign import substitution and this is a permission of securing a purposeful or competitive position while they are taking apart in foreign projects through self – relying technology. In the subject of tower erection, solving the difficult technical problem of erecting towers 400 m high and promoting an efficient erection of concrete tower can happen by localizing of automated slip form system. As well as, an important reduction of the construction expenses will be found through accelerated and operational construction which owned to sharp decision making of the calibration of construction failure. In the subject of foundation erection, technological level superior will protect results of R&D or as of progressive countries, reach effective design of foundation structures as cost-saving construction and they will be suitable to the erection of the foundations of large scale sea-crossing bridges and particular structures. Results from the study that, in foundation are, remote instrumentation and analysis systems for water depths of 100 m and 50 m depth, forecasting and assessing technology for optimal load-bearing capacity and settlement that meets international standards, high-efficiency hybrid foundation construction technology appropriate for ground acceleration of 0.5 g and deep soft soil currently developed. (Cost, Optimisation, Quality, Functional)

A finite element (FE) analysis process presented by Kim et al (2006), which uses elastic catenary cable element formulation for controlling the length of the cable members, to develop a hanger installation design, especially for self-anchored Yong Jong Bridge. Initial surveys showed that jacking forces for some hangers reach nearly twice the dead load tension. In the situation of the actual construction, the available capacity of a string socket for installation hanger wires settled is 981 kN. This will take a total of 80 strand jacks to be used simultaneously, e.g. synchronized tensioning for installation quickly. They suggested two methods for limiting the maximum jacking force to below the jack capacity: one of them is jacking the whole stiffening trusses up and down; and the other one is the split tensioning of a few high stressed hangers. Since the split tensioning process was measured to be more economical and workable, a 6-stage construction plan was planned using synchronized and separated tensioning work through several tries by a construction stage analysis. They conclude the promising plan was successfully to the construction of the Yongjong Bridge in Korea. (Optimisation, Functional)

Kim et al (2008) described the measurement factors in phase of construction and maintenance of bridges and tunnels, as it is to provide a measurement design based on Ubiquitous Sensor Network (USN) technology. USN technology helps to monitor road structures like bridges from a fixed location, measure them to make sure security, and offer real time information to users in an emergency to avoid an accident. During the project phases related to PMIS (Project Management Information System), the required information is shared with joining stakeholders. Moreover, by setting and managing basic direction for the planning, design, construction and maintenance of a project, the whole project becomes easier. The technology allowed easier and cheaper maintenance, accident prevention and integrated management of a site. To analyse, gathering and storing data provided an efficient and economical reference for the construction and maintenance of other similar structures. They expected better safety of users through primary finding of danger in structure by using the design of construction. (Cost, Quality, Functional)

As part of the continues research program at the University of Wisconsin-Madison and the support of the Innovative Bridge Research and Construction Program (IBRC), the use of fibre reinforced polymers FRB materials as reinforcement and framework for a concrete highway deck has been described throughout describing the construction process and the project's cost analysis. The Support from IBRC has led to construct two span highway overpass the US highway 151 in Wisconsin. As results of the study, FRP might be cost effective, in spite of their current high costs. This finding is supported by the analysis made on the short term material and labour costs, which show that saving in the construction of FRP, their long term durability and maintenance. However in order to decrease the cost of FRP reinforcing system in the future, the optimization of FRP as onsite formwork is recommended. Berg et al (2006) (Cost, Quality, Functional)

Brozzetti (2000) presented in his research the recent technical trends in the design of composite bridges in France. He supported his finding by conducting two case studies, first by reviewing the market share of composite bridges then he compared that with other available solutions. In spite his results showed that composite bridges with span length between (40 m – 100 m) are more competitive compared to pre-stressed concrete bridges, material durability and maintainability appeared to a constrain while controlling the crack of structural members. He concluded that further development is needed, pre-stressing was one possible solution to do so, and on the other hand, the cost of composite bridges are cheaper compared to pre-stressed. (Cost, Quality, Functional).

With regards to the structural materials quality and innovations, Aref et al (2000) described the use of fibre reinforced plastics as a sole structural material including how are designed and how can it improve the efficiency of bridge design. The study is based on a conceptual design, by comparing the design and performances of bridges where reinforced plastics as incorporated in the structural member with other composite bridges. This comparison is done with help of finite element analysis (FEA). As results, they found that this new innovative materials are very promising solution to many problems that decreasing the durability of bridge construction with regards to materials and it will help to utilises material quality of bridges. They concluded that further research to address the performance of this new system depends upon the construction of the bridge plus carrying out all necessary tests. In addition the cost was not clearly addressed at this stage, therefore further knowledge is needed before building final conclusions about it. (Quality, cost, optimisation)

In order to improve the productivity, design and fabrication of cable stayed bridges, Choi et al (2013) made a theoretical study of anchor system design and simultaneously they reviewed the existing design process guides in South Korea of fixing the pipe. As results they suggested formulas to determine the thickness of the fixing pipe, and compensation of the design process was conducted to compare with the existing bridge designs. They concluded that by using the suggested equation for the thickness of the fixing pipe in the guide pipe anchor system; compensation design and safety can be secured in a convenient and reasonable way. As closing remark they added a comparison with the results of finite element analysis (FEM) might be necessary in the future, to confirm the validity of the anchor system. (Functional, safety, optimisation)

To establish an efficient repairing and maintenance program of bridge structure Furuta et al (1990), made an attempt to develop a knowledge-based expert system for assessing the durability of bridge decks. In order to assess the durability and to support the study a fuzzy system is constructed. As results the technique of neural network for generating several fuzzy production rules were found to be useful in the durability assessment of RC bridge deck. As concluding, introducing this current technique into the expert system enables us to acquire the expertise with ease. Even though it gives better reliability of the damage assessment, the technique of neural network is useful in generating production rules automatically. However it is still considered to be not practical approach. (Quality, Functional)

To simplify the assembly and to improve the productivity of bridge construction, Greig et al (2001) proposed the SPACES system as an alternative structural system for long span bridges construction. In their article they described the development of a lightweight automated welding system for the joining of tubular members with the help of computer advanced tool. This work was done as collaboration between companies and from the UK industry and universities. As results, tubular spaces frames are found to be costly due to the complexity of fabrications and complex welds, nevertheless are structurally efficient structures for bridges. However with the help of using this advanced tool to analyse the whole design of automated welds, the cost can be saved, safety, productivity and consistent results. In closing they concluded that this system still under progress and it would be implemented in the space frame bridge scheduled to start construction in 2000. (Cost, Quality, Functional, Optimisation)

Gutkowski et al (2008) made a study to assess the implementation of an innovative timber bridge technology developed for secondary road applications in rural Colorado, USA. The study supported by running field-testing on a constructed pilot bridge. The test involved through-girder primary system with transverse floor beams and longitudinal wood deck secondary system. As results, the pilot bridge was found to be structurally effective. As a conclusion, the experimental bridge proved to be very stiff under test loads that approached the AASHTO code requirements, however to improve the accuracy of the analytical results the knowledge of the material properties of the wood floor beam and deck elements is required. (Functional)

In order to estimate the quality and life time of bridge structure Pipinato et al (2012), made a research to show the analysis of coupled environmental and fatigue assessment of a representative cable stay bridge. The research is based on an analytical case study of one bridge, mainly focused on the damage estimation, and environmental induced damage coupled in deterministic terms. As results, seeking the most efficient construction details and optimising the design of the suspension system in order to minimise live load stress ranges and lifetime detrimental effects can improve the fatigue life of a cable-stayed bridge. However they concluded that the aims of the study was only to represents a first approach to the issue, further analysis and knowledge are needed to different cases. (Quality, Cost)

As part of the ongoing research, to understand the seismic behaviour of cable-stayed bridges Praveen et al (1999), presented a general methodology for construction sequence simulation of cable-stayed bridges. They simulated the stage-by-stage construction of an actual bridge with the help of the advanced computer tool BRIDGES and nonlinear finite-element method. As results, showed that to determine and analyse the behaviour of any structures, the simulation of the actual construction sequence is required. They conclude that with help of the described advanced tool and FE simulation many benefits can be achieved. Also this study will serve as the initial condition for further investigations of the dynamic and seismic behaviour of the cable-stayed bridges. (Functional, Optimisation)

Ruiz et al (2008) made a research about the application of under-deck cable-staying systems and combined cable-staying systems to pre-stressed concrete road bridges with multiple spans of medium length. The research method is based on a complete and systematic parametric study of multi-span continuous bridges with two innovative structural types. The results showed that uses of under-deck cable-staying systems are not suitable for continuous bridges since they are not efficient under traffic live load and only allow for the compensation of permanent load. Though, to enable the efficient design of continuous bridges with very slender deck, the combined cable-staying systems were found very efficient compared to the conventional schemes without stay cables. Their conclusions showed that combined cable-staying systems for continuous bridges have many substantial advantages such as high structural efficiency, varied construction possibilities, both economic and aesthetic benefits, and landscape integration. In addition they included design criteria for it. (Cost, Quality)

To provide a collaborative environment for design, construction and maintainability of bridges, Shim et al (2012) made a study of an advance tool represented in the form of three-dimensional (3D) bridge information models for bridge projects. The results of the research showed that emerging technologies Building Information Modelling (BIM) capable during the construction phase from the construction management perspective. Also by considering the work breakdown Structure WBS and product breakdown structure (PBS) to enhance the design and enable the digital mock-up, the 3D bridge models were realised. In addition to that the Construction Project Life Cycle Management (CPLM) system was proposed in terms of 3D information model and their main concept were explained. They conclude that, solutions were identified and derived for problems that expected to happen during the practical work, via help of this advanced tool the construction time expected to be shorten, the cost will be reduce by minimising the trial and error. Furthermore, BIM technologies for bridge construction are considered to have significant application value in reducing risks for construction management etc.

With the partial support by the strategic grant POSDRU Romania and the European Social Fund. Silvia et al (2012) made a research with the purpose to exploit the existent structures and assess the structural health of these existent structures. The research method based on two cases studies for old steel bridges. The method included evaluation of the technical state of the bridges and evaluation criteria cost-benefit for both, also comparison between a new construction and rehabilitation regarding price. The results did not showed much in that regards, however the technical solutions for the rehabilitation of the structure are discussed and found that the rehabilitating cost of one span is approximately 20 % of the value of a new structure, that entitled for both bridges since are built as the same time. He concluded that since the authority have not enough budget to build new bridges and the rehabilitation of both cases are the same, both bridges were maintained to extend their service life for the next 10 years. In addition they added that the reason was not just because of cost, but it was to keep the emblematical construction in service life. (Quality, Functional)

In order to assess the structural health of suspension bridges Siringoringo et al (2008) made a research and evaluated the application of system identification to a suspension bridge by using ambient vibration response. The research nature was based on investigating the accuracy and efficiency of two-advance numerical methods "the Random Decrement Method, the Ibrahim Time Domain (ITD) method and the Natural Excitation Technique (NExT) combined with the Eigensystem Realisation Algorithm (ERA)" and comparing that with the results obtained from the finite element simulation tool. Results showed that using both methods could provide reliable information on dynamic characteristics of the bridge. Also the NExT-ERA methods found to be more efficient and practical. In addition to that the wind-velocity dependency of natural frequency and damping ratio particularly for low-order modes is indicated from three days of measurements. In conclusion, the effect of aerodynamic forces alongside the girder, and friction force from the bearing near the towers was found to be the sources of these dependencies. (Functional, Optimisation)

With regards to the construction assessment and long-term prediction, Sousa et al (2013) conducted a research to assess and calculate the long-term behaviour of the Lezíria Bridge over the Tagus River in Portugal. The study is verified with the help of finite element models analysis (FEA). To validate the design assumptions, to calibrate the structural model, etc. the data collection from long-term monitoring systems was needed to improve the quality the outcomes. After a full discussion concerning the real long-term behaviour is made, the results showed that there is a good agreement between the numerical and the experimental results. They conclude that with the help of the sensors measurements structural models are well optimized and this will also contribute to the future monitoring and maintenance of the structure. (Functional, Quality)

Taib et al (2009), discussed in their article the site constrains and the possible construction methods stages of building a new bridge. The article was based on a case study of building the new bridge perpendicular to fly over an existing bridge also across very busy junction in the middle of Kula Lumpur, Malaysia. The result showed that the original method of constructions was not successful due to the site constrains and incoordination between the project contractors to fulfil the handing-over dates. Nevertheless, a combination of in situ method on temporary staging and balanced cantilever form travellers was the alternative solutions. They conclude that this method was flexible, improve the aesthetic of the bridge and timely efficient while the ongoing constructions activities of other projects. They added in order to successfully implement the right method and process of construction, the project stakeholders need to be familiar with the site constrains, local procedures.

5 Discussion of critical success factors of effective bridge construction

From the review of papers there were seen patterns of success factors. These are: construction process, innovative design and materials, production and fast assembly, etc. In this chapter these critical success factors are presented more carefully and their relation to the derived main aspects is explored.

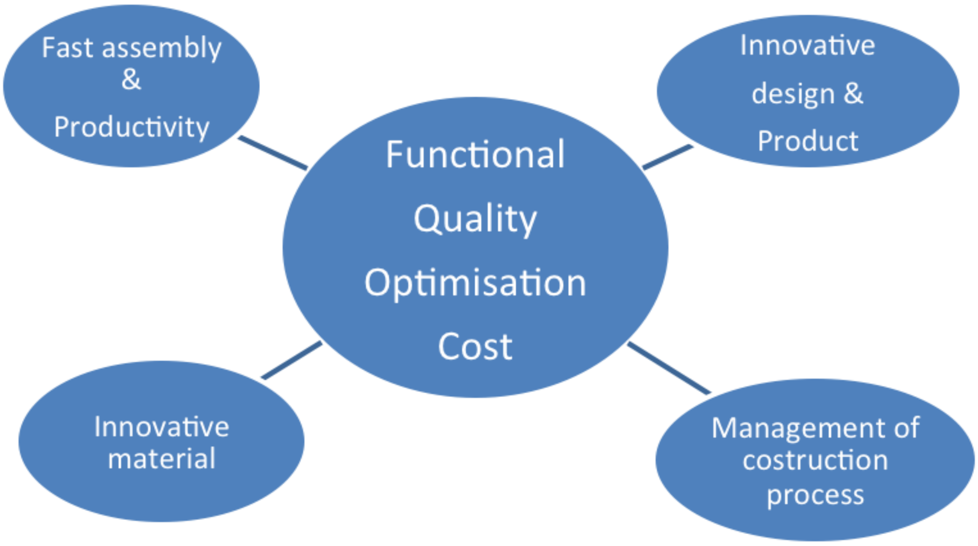

Figure 16: derived critical success factors

5.1 Derived success factors

The derived critical success factors from the reviewed literature are: Management of construction process, Productivity and fast assembly, Innovative design and products, Innovative material etc. these factors are shows in figure 18.

5.1.1 Management of construction process

To consider bridge construction is successful it must start with a clear justification and goal definitions; proceed according to specific strategic plan, and accomplish demonstrable construction process.

Generally, certain elements of construction process will differ from project to another, such as scope location and the size and so forth. But as management of construction processes there is an outcome oriented planning process for project completion with very specific aims. However, development of a construction process is very similar to the process of positive design concept. The project manager or planner must evaluate the total costs and reliability of different options and at the same time must insure technical feasibility of the entire project.

Bridge construction features many complex processes and hence improvement construction processes were found to be essential. Efforts from previous and current studies show that the construction industry understood the value of improving its construction processes towards achieving effective bridge construction. There are

several possible construction processes available for any given project. Although both current and past experiences are good guides for the planning of construction processes, nevertheless most projects are expected to have certain problems to overcome it.
The research made on construction process show several measures that create effective bridge construction processes. Some examples of measures that help to creates effective construction processes are highlights as follow:

- The research made on construction process show that advanced tools is used as measures to create an effective construction process. Structured Process Improvement for Constructions Enterprises (SPICE) model is one example of these advanced tools. The SPICE model provides a structured approach to help construction companies to improve their management process effectively. Basically the model work as step-by-step process improvement. Also it can point out the issue of competency directly by identifying current practice of constructions sectors. In addition the SPICE model can predicts the outcome of a process before it has been done. In contrast this can help with finding the balance focusing on production and focusing on process through the whole life cycles and possible productions methods are proposed.
- Buildings information modelling (BIM) is another advanced tool for creating an effective bridge construction process. 3D models is an extra feature of BIM technologies, it can support engineers with (3D) models that allow them to view and simulate the entire construction site. Hence the construction processes are rearranged and suitable production method is adopted. In addition, building these (3D) models for bridges can results in effective usage of construction materials and reduces both construction cost and risk.
- The application of Frame Accurate Animation (FAA) is another advanced tool that improves the bridge construction efficiency. The feature of FAA give an effective presentation of constrcution work. Hence the construciton process can progress relatively in smooth harmoney with the situation in the project site. It can help to visualise the sequences of the constuction process, simluate the changes during the excuation of the project and carrry them out smoothly before the constuction begin. In addtion, FAA provide mutual understanding among construction workers and to unify their ideas, the FAA it can work as a collaborative tools as well.

Since the measures to create effective construction processes are clearly pointed out and available for users. The stakeholders must consider the technical requirements for construction processes such as technology choices (i.e. computer aids or advanced tools, machinery). As in the development of appropriate alternatives for bridge construction, choices of appropriate technology and methods for construction processes are often unclear and, hence methods for accomplishing the aims of projects cannot be found. For instance, taking a decision whether to use precast bridge members or cast in-situ concrete will directly affect the cost and the construction processes time. All of cost, consistencies and ability to transport will control the decision has to be made by stakeholders. Unfortunately, given that direct guidance to

form good construction processes in all circumstances it is quite difficult. The reason is that different methods depend on various considerations for which information may be shallow during the construction-planning phase. Such as workers' experience and particular underground conditions at a site and other constrains.
Management of construction process is more complex in some point since the process is dynamic i.e. as the construction site condition and aesthetic constrains that change over time as the construction processes proceeds. On the other hand, construction processes tend to be rather standardised process from one case to another.
On the whole, studies have shown good potential in forming an effective construction process. For instance; to it is simulating the construction process with the help of an advanced tool (computer based or simulation technique). Also deciding to use a particular machine for one activity or task immediately leads to the question of is there enough space for that machine. 3D models mentioned above, maybe helpful in simulating the space requirements for the task and further investigation for any obstruction. On the contrary, obstacles concerning the resource allocations and availability indicated during simulating the construction process can be predicted by adding extra resources but as part of the construction process.
Moreover, collaboration between project stakeholders is another useful approach to form a construction process that is less complex and improves the overall construction efficiency. In contrast, collaboration between projects stakeholders allow experienced workers to share their long-term experiences. This helps in making the decision in what construction process is possible to follow, which is considered more beneficial instead of just relying on the project planner imagination to plan the construction process. One way enhance the collaboration between stakeholders is using the effective presentation features for construction work such as FAA or BIM communication and collaboration tools. Both tools are user-friendly and can bring together all the project stakeholders by creating a collaborative and communicative environment. In closing, by defining some input parameters from the construction site, construction process can progress relatively in smooth harmony with the situation of the Project site.

5.1.2 Productivity and Fast assembly

Productivity and fast assembly are continuously fascinating issues. Many definitions are used to describe productivity in the construction industry such as production ratio, labour/ hour rate, percentage of work done/time and so forth. However to put it in a simple term, productivity of bridge construction, is the physical progress accomplished throughout the construction processes. Productivity and fast assembly are related terms and mostly go together in the construction industry. Both terms plays as function of the adopted construction method.

The bridge construction method itself plays significant role in measuring the productivity and fast assembly, therefore construction method must be considered during the preliminary design phase. In order to create an effective bridge construction we must be able to measure the productivity and find a fast way to assemble the entire bridge structure.

Bridges in particular has distinctive necessities and challenges during production phase (fabrication or assembly). It is possible to experience that due to site restrictions and accessibility, the same bridge design may demand entirely different construction methods. One construction site may have free areas to allow storing materials, equipment production, and traffic control bypasses, while another construction site may have limited access and require unrestricted traffic routes meanwhile the construction is ongoing.

Studies made on productivity and fast assembly show several measures that create an effective productivity and fast assembly during the bridge construction. The following section highlights some examples of measures that create effective productivity and fast assembly:

- Simulation tools are measures for assessing the onsite productivity during the on-going construction. An example is the MicroCyclone simulation tool that provides approaches to model elements that a designer can use to represent the construction production. For instance specifying the durations and resources needed, activities, and the logical relationship between all of them. These tools are valuable for estimating the actual construction time and the hourly production levels, as well as the number of equipment and so forth.

  Simulation can be a very effective tool to plan both productivity and fast assembly. Moreover, simulation studies have been conducted for better understanding of various factors that effect on the overall production level and the choice of construction methods. For example the case of El-Warrak Bridge in Cairo, Egypt, demonstrates a concrete example of the capability of computer simulation in modelling the bridge construction. Two alternatives were analysed in this case study: cast in-situ and cantilever carriage construction methods. Varieties of benefits were achieved; for instance estimation of execution time together with the cost, additionally both contractors and project planner were able to evaluate different scenarios of construction possibilities that emphasis different type of construction production sequences, assembly and the number of assigned work forces. Furthermore, some studies argued that, as long stakeholders are able simulate the productivity and how to assemble the bridge structural components, similarly they can analyse the effect of other construction delay factors. For instance support claims due to loss of productivity from bad weather and other unexpected reasons to which might delay the production phase.
- The research made on productivity and fast assembly show that progressive construction method is one measure that help to create an effective productivity and fast bridge assembly. Progressive construction method with temporary cable staying is simple, straightforward method and currently used in the construction industry. It consists of arranging precast segments of the bridge deck in a continuous order, starting from the first layer. Also the method is known by enhancing the bridge deck stability by maintaining a set of stays towards the end of Construction. Notwithstanding progressive methods are currently one measure to create effective productivity and fast bridge assemblies. However the pre-stressing methods are found to be more economical than those used in progressive methods. Simply because the pre-stressing methods allows an extra storage area, bypasses or canals or rivers, better way to allocate construction equipment and most adaptable for the

aesthetic demands. For instance some curves and extra detailing on the bridge structure takes extra time to be assembled and hard to be produced onsite. In addition the pre-stressing methods will provide an essential enhancement in the production and assembly of large bridge with longer spans.

- Furthermore, a few studies arguing that the current practices need to be improved. These studies show strong support towards the use of new technologies in construction as measures to create an effective productivity and fast bridge assembly. The prefabricated bridges structural members and systems (PBSME) are illustrative examples from the demanded new technologies. PBSME are structural components of bridges that are built off-site. A prefabricated structural system can be as a single structural component of the bridge or the entire substructure elements. Some common examples of PBSME are: Fiber reinforced polymer (FRP), bridge with prefabricated pre-tensioned concrete beams and prefabricated concrete slab, box girder and prefabricated deck. The features of PBSME are brought forward to support the argumentation of implementing the new technologies to improve the productivity and fast assembly. Constructing more prefabricated bridges using PBSME can provide a reduction in work site, saving cost of traffic monitoring, easy inspection and indeed it reduces the risk due to weather delays. Furthermore, using PBSME can reduce the need for bypass that often is needed in the construction site to accommodate the equipment and machinery traffic. Inventing or implementing new technologies such as PBSME may require an early consideration during the preliminary design phase and that will add an additional cost for the project. However PBSME's shorter construction time result into savings the cost through reducing in traffic congestions and the overall road closures. The lightweight features of prefabricated structure allow the assembly of large members and in some critical circumstances the assembly can be carried out during the night. Additionally, stakeholders may realise more saving in cost by having the ability to move forward from the project planning phase. Additionally, PBSME provides architectural alternatives design possibilities, the PBSME can be light or heavy weight also can be suitable for different shapes that fit with the aesthetics requirements, in case there is any.

  Notwithstanding using PBSME allow high productivity, fast assembly and it will continue to be competitive. However one obstacle is that developing new prefabricated materials instead of using the ones existing in the market will be more costly. Thus, it is important that the concept design should be made while considering the construction possibilities and the availability of the prefabricated members. For instance, some structural systems tend to be complex and very demanding in terms of time, fabrication. Nevertheless, it can be structurally efficient structures.

In the case of measuring productivity and fast assembly, it is necessary to know where the projects stand in order to achieve effective bridge construction. The construction sector should make better use of both simulation tools and the new technologies such as the prefabricated structure. These improve the productivity and fast assembly of bridge structure in a way that construction processes are easily controlled and carried out in the right order.

5.1.3 Innovative design and products

The review of papers dealing with innovative design and products indicates that advanced design methods and products are one measure in order to achieve an effective bridge construction. For instance FRP products is one of innovative product that gain from the review of papers. FRP applications are useful for maintenance purposes and make it easy to replace decks. This is important in order to accommodate an increased traffic demand. FRP has several advantageous properties in comparison with traditional materials. These advantages include high strength-to-weight and stiffness-to-weight ratios and free formability. In addition, other properties worth mentioning are: good thermal and electromagnetic insulation properties, improved durability under tough environments, higher energy intake and low maintenance requirements. The main concern with the use of FRP decks on bridges is the initial higher price of an FRP deck compared to concrete decks. In the long run, the higher cost of FRP is justified by considering the life cycle costs; the extra durability and corrosion resistance will improve the deck performance and reduce the necessity for deck replacements. Furthermore, production quantities and advancement of manufacturing processes will help to reduce these costs. Besides the high initial costs, there are some technical weaknesses of pultruded bridge decks. The disadvantages are the low rigidity of the main girder direction, the absence of material-adapted forms, the brittle behaviour and the sensitivity to instability in comparison with concrete deck. To overcome such disadvantages the hybrid FRP and concrete structures have been developed. Several advantages are related to the hybrid FRP, such as the increase of bending stiffness, which reduces the deformability, and the increased strength, which gives a better use of the FRP profiles. The increasing amount of applications confirms the high potential of structural performance, manufacturing and sustainability.

A newly developed type of FRP deck, hybrid GFRP plate and concrete concept, consists of pultrusion corrugated GFRP plate with T-upstands for the tension part and concrete with reinforcing bars for the compression part. The concrete used for covering the corrugated pultruded GFRP plates not only decreases the risk for local buckling failure of the plate, it also increases the overall stiffness.

In reviewed research, the FE procedures have been successfully employed on studies of the performance of FRP bridge decks. 3-D nonlinear FE models, with shell elements, have been used in order to analyse the mechanical properties of the GFRP plate during construction stage. The FEA results showed good agreement with the experimental ones in terms of strength, deformation, and stiffness.

Moreover, the overall investigation showed that the pultruded GFRP plate is lightweight and has a high strength when used as formwork for concrete, as well as replacing reinforcing bars in hybrid GFRP and concrete bridge decks. Due to the several advantages mentioned above, hybrid FRP can reduce the construction time, cost and it’s a better alternative for beam-and-slab bridges than traditional on-site casted concrete.

An example of advanced tools is the Virtual reality (VR) technology. In one study it was used in order to assess the activities related to bridge construction. Two models were used in the study. One model described the construction by cantilever and the other model considered the incremental launching. VR make it possible to view the physical development of construction work, the monitoring of the strategic construction sequence, and visualization of details in the shape of each element of each construction. The combination of software used in the implementation of the VR model is shown in Figure 19. The main role of VR was to provide a more natural interface to the data being manipulated by the computer program. There are many potential of VR model. For instance, the ability to visualise the state of a construction at different times during the construction programme would be invaluable to planners concerned with the problems associated with coordinating the labour, machinery and materials resources on site at any time. Moreover, the evaluation of various structural systems can be a good application for a VR system. Finally, the use of a network VR system allowed the ability to have a conference with people who are geographically remote from each other. These changes to current work practices promise improved productivity and can lead to more knowledge- intensive design, and scheduling methods which technology becomes more accepted by the industry.

On the other hand, VR model could be useful for distance learning based on e-learning platform technology and could also help in the training of professionals. The learners could interact with the VR models in such a way that they could set in motion the construction classification required by real construction work. Furthermore, there are many other opportunities to create computational models mostly when the subject matter is appropriate for explanation along its sequential stages of development. The applications of these features make the benefits of using technologies for virtual reality more obvious, particularly when compared to the simplicity of complete models that cannot be broken down. Therefore, it was clear that the benefits of introducing new technologies appropriate for university students and technical education should be made known and applied.

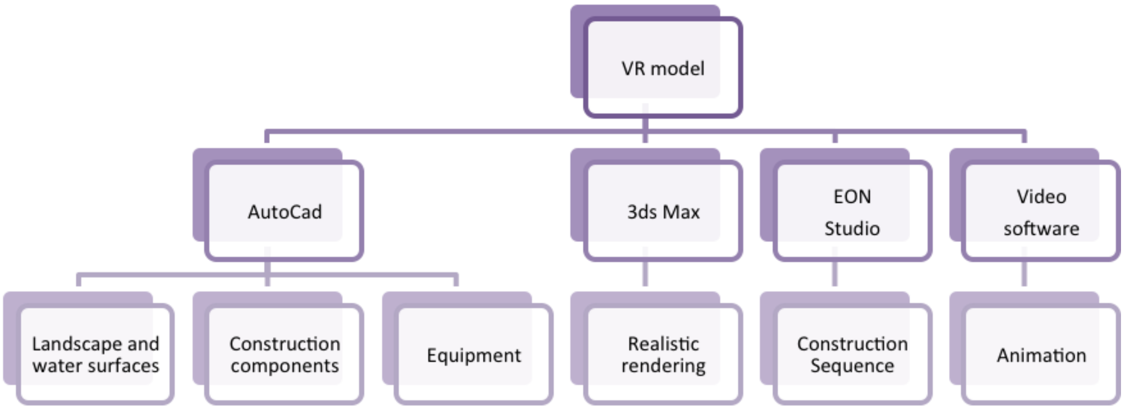

Figure 17: Software used on the implementation of VR model

Case-Based Reasoning (CBR) is an advanced method that applies a cost approximation model in the planning phase for the planning of the construction. Many researchers have proposed various methodologies for predicting the cost in the initial phase with the use of limited information. Toward this end, an improved CBR model that uses the Multiple Regression Analysis (MRA) technique in the revision phase of the CBR technique was developed. A case study was conducted on 41 business facilities and 99 multifamily housing projects to verify the prediction performance of the proposed model. Prediction performance of the existing CBR model (i.e., the non-revised CBR model) and that of the proposed model (i.e., the revised CBR model) were compared. It was determined that the proposed model is particularly effective when the similarity of retrieved case is low, because the number of cases stored in the case base is small. As the results of the two case studies showed, the error rate of the revised construction cost was higher than that of the non-revised construction cost.

In another study the CBR method was modified by introduction of regression analysis model. Thus the CBR method became more beneficial for construction of railway bridges. Therefore, a design model capable of approximating the construction cost in the planning stage was proposed. The influence factor affecting the construction was used a factor for estimating the similarity between the cases kept in the database and the recovered cases. The structure of the CBR consisted of four-cycle processes. The circulation process of CBR is presented in Figure 20. Moreover, the researcher applied the GA to optimize the weighted value of the influence factor and then used the MRA in order to review the construction cost error assessed by the suggested CBR model. Eventually, the effectiveness of the reviewed CBR model was proved by using five verification cases. The outcome of the reconsidered CBR model verification reduced the construction cost error rate by 16.2% in comparison with the suggested CBR model. Furthermore, the accuracy of the construction cost approximation improved by over 35% on average and standard deviation decreased by 11.55%.

Finally, CBR model will be valuable between the recovered case and the cases stored in the database. Besides, modified CBR model showed better result than the CBR model in the accuracy of the construction cost. Moreover, on-going update of database is necessary in the future of the railway bridges.

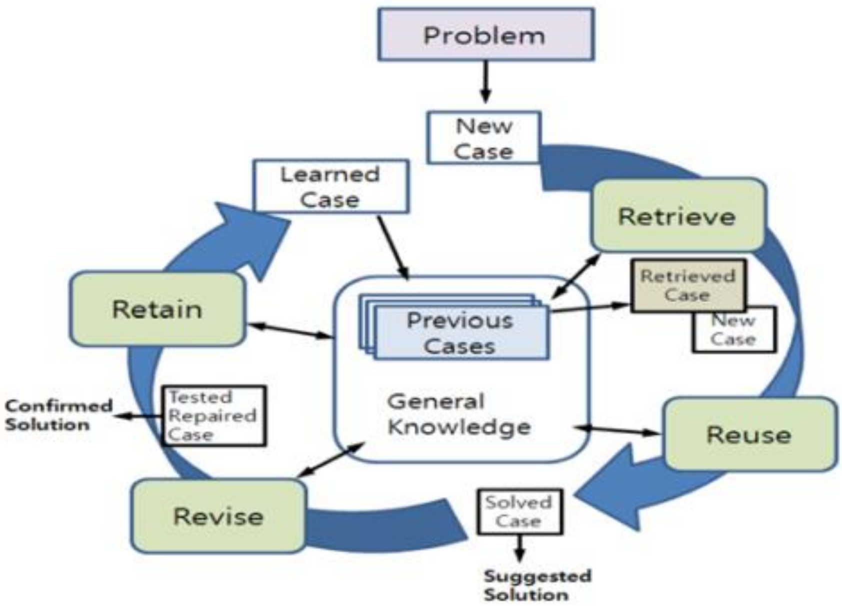

Figure 18: Process of CBR [Kim et al 2011]

In the end, advanced tools and products are a way to achieve more effective bridge construction. The actors involved in the construction could have better accuracy prediction of all bridge construction stages with the use of these new products, tools and equipment. Based on the reviewed articles, advanced products or models could be beneficial in different perspectives. As mentioned above a kind of innovative product could be having benefit for the productivity of the construction like FRP bridge deck. On the other hand, hybrid FRP bridge deck has better effect in the quality of the bridge and both of them reduced the construction cost, time and had better impact on users. Another advanced tools increased understanding and imagination of the construction phases by visualising construction activities. An illustrative example is the CBR model and the modified CBR model. Both were very beneficial for estimating the construction cost in the planning phase.

There are many advantages of innovative design and products in bridge construction. These methods and tools that mentioned above, which it help to estimate the risks of construction, reduce construction cost and time, visualisation of construction, increase quality of the work, and make the construction process efficiently.

5.1.4 Innovative materials

From the studied papers, innovative materials are one of the underlined aspects. The majority of the ‘’new’’ materials are related to fibre-reinforced polymers (FRP) of different kind. There are several benefits with the usage of FRP, like long-term durability under tough environments, high ratios of strength-weight and stiffness-weight, high thermal and electromagnetic insulation properties, free formability, higher energy absorption, competitive cost, and low maintenance cost. Additionally because of the lightweight of FRP decks, it is easy to transport, replace and install to accommodate. The use of FRP bridge deck will reduce the construction costs and saving construction time due to fast assembly. In addition, in comparison to steel rebar reinforced desk, FRP bridge deck lead to 57% savings in construction labour cost.

However FRP bridge deck has a higher initial material cost, around 60% higher than the conventional concrete deck and steel rebar reinforced deck. Bridge constructions with GFRP decks have less carbon emissions and energy consumption in comparison with the other various materials such as carbon fibre (CFRP), concrete and steel bridge. On the other hand, throughout production stage FRP materials produce more carbon emissions than the traditional material like steel and concrete. Nonetheless, usage of FRP makes better public sustainability and has fewer impacts on users.

A range of products of High performance concrete (HPC) designed to satisfy the performance requirements for various specific applications. Rapid hardening concrete (RHC) has excellent durability properties and the elastic behaviour of the bridge under service loads. RHC produced with standard raw materials is characterized by the complete lack of silica fume, or other addition of pozzolanic materials or accelerators. With the use of RHC bridge deck it is possible to open the bridge to public traffic one day after casting operations and final inspection. More attention has been paid to the compressive strength and improved concrete known of high-strength concrete (HSC). At HSC the concrete strength is increased by reducing the water-cement ratio to a lower limit of 0.4 below, but the loss of workability was no longer acceptable for practice. As a consequence, the new generations of super plasticizers and of admixtures has brought the introduction of self-compacting concrete (SCC); this new production of concrete is strategic to reduce working time, especially when a limited free distance between rebars is present. The higher compactness of HSC helps the structure to have a longer service life and lower maintenance costs. A concrete with an early age strength development is interest in the precast industry, because of the opportunity of speeding-up the production procedure without the use of costly heat curing. Using early age strength of concrete can increase the daily production of precast element by using materials that under normal circumstances develop the strength required for demoulding elements (or drop the preload if applicable). The rheological behaviour of RHC is very similar to that of self-compacting concrete. RHC also shows superb durability properties in terms of freeze-thaw resistance with and without de-icing salts, oxygen permeability and lack of carbonation after one year. RHC has excellent durability properties and the elastic behaviour of the bridge under service loads.

Steel-concrete composite bridges with span length between (40 m – 100 m) are more competitive and economical than pre-stressed concrete bridges. One of the problems comes to be the control of the cracking of the concrete slab in order to ensure durability and maintainability. Cracking in concrete bridge decks happens at the early age. One possible solution, but not the best to avoid these problems is the pre-stressing of the concrete slab that contributes to the economic competitiveness of the composite bridge.

Bridge construction with FRP decks has less carbon emissions and energy intake than regular concrete decks. On the other hand, throughout the production stage, FRP materials produce more carbon emissions than the traditional material. Moreover, usage of FRP makes better public sustainability and has fewer impacts on users.

In addition, new materials result in less environmental effects, increase material efficiency, increase time efficiency, reduces the construction cost and many other advantages.

5.2 Relation between success factors and the main aspects of effective bridge construction

The four (4) derived success factors can be linked to the derived aspects presented in Chapter 3. The main aspects derived were: functional, cost, quality and optimisation. Several success factors relates to more than one main aspect. Here, the main aspects and the relation to the success factors are explored.

5.2.1 Functional

From the extracted raw data, functional is the highest ranked main aspect and most important factor in bridge construction. Similarly functional is regarded as part of the construction requirements shown in figure no. 2, and includes several factors. Two of these factors are:

- Flexibility during the production process: that refers to ability to produce, transport and construct the bridge’s structural elements easily.
- Accessibility and comfort criteria: that refers to easy access to the construction site by everyone, ability to carry out maintenance activities, erection and other monitoring activities.

These factors are termed as functional to simplify the extraction of data. However to put it in the simplest possible term, bridge’s functionality means making the most optimum use of construction technique during the planning of an onsite construction operation and processes to meet the overall project objectives. This can vary within different construction site conditions and will require large integration of recourses and accurate use of technologies starting from the planning stage throughout the execution of construction work.

Generally, the construction site constrains and it is surrounding nature requires more alternative solutions for bridge's construction. Therefore differential construction techniques are put into focus. Similarly each bridge construction can be site specific. For instance while the construction process is influenced by the social and site constrains such as traffic system, closing other roads and intersections nearby the project site would be necessary due to safety, maintenance, etc. Therefore aiming towards constructing functional bridges is very essential solution that all stakeholders should strive for in order to overcome most of these various factors.

According to the related studies, there is good potential for improving efficiency in constructing functional bridges. However the stakeholders are needed to consider the functional requirements. In a way most of the obstacles "i.e. site constraints and surrounding nature" are possibly tackled with the help of the derived success factors. The project actors need to pay serious attention to all of these difficulties or constrains by critically plan and manage the construction processes with regards to the problem at theirs hand. With referring to management of construction process, stakeholders are able to improve the bridge construction efficiency by implementing several measures that lead to constructing functional bridges. The support from management of construction process allows stakeholders to recognise the close relationship between design and construction by reproducing the construction site and performing construction activities on the computer's aid software. The computer aid allows transferring the envisioned design into numerous construction tasks and identifies activities and the resources required to transfer the envisioned design into physically real. These can minimise the risk of production delay and allow faster erection time. In contrast, the use of Bridge_Sim allows designers and contractors with the ability of evaluating various scenarios of construction plans that represent different combinations of construction methods, crew formations, and construction sequencing. Similarly, using the SPICE model provides a structured approach to help construction companies to improve their management process effectively. The model is step-by-step process improvement and it can point out the issue of competency directly by identifying current practice of constructions sectors. In addition the SPICE model can predicts the outcome of a process before it has been done. In contrast this can help with finding the balance focusing on production and on processes throughout the whole life bridge's cycles and possible productions methods are can be proposed. With the help of this model collaborative subcontractors are able to preliminary estimate the time and costs for repetitive construction process from the beginning of the design phase.

Productivity and Fast assembly as derived success factor also influences the functionality of bridge construction. Several measures such as advanced tools are found accurate and provide better possibilities to select the optimum structural system that are safe, cheaper and easily produced and assembled. Advanced tools such as MicroCyclone simulation tools, It provides several approaches to model elements that designers can use to represent the construction production, "i.e. specifying the durations and resources, activities, and the logical relationship between all of them". These tools are valuable for estimating the actual construction time and the hourly production levels, number of equipment that needed, how to carry out the fabrication sequences, monitoring activities and so forth. Simulation tools are very effective to plan both productivity and fast assembly. Moreover, simulation studies have been conducted to understand better effect of various factors on the overall production level and the choice of construction methods, i.e., the case of El-Warrak Bridge in Cairo, Egypt, demonstrate a concrete example of the capability of computer simulation. Implementing the new technologies such the prefabricated bridges structural members and systems (PBSME) not only benefits measures of productivity and fast assembly but simplify several design issues connected with the constraints of production, transportation, erection and assembly. Constructing in more prefabricated bridges method using PBSME can provide a huge work force reduction onsite, saving cost of traffic monitoring, easy inspection and reduce the risk of weather delays.

Notwithstanding the use PBSME allow high productivity, fast assembly and it will continue to be competitive. However one obstacle is that developing prefabricated materials instead of the ones that existing today in the market will be more costly for some specific reasons "i.e if the site constrains are possibly tackled with machinery onsite with the help of small work force, in case of implementing straight forwards design, simple connections between the bridge's structural members and so forth". Thus, it is important that the concept design should be made while considering all the construction possibilities in addition to the availability of the prefabricated members. For instance, some structural systems tend to be complex and very demanding in terms of construction time nevertheless; it can be structurally efficient structures.

Altogether, efforts from research clearly show that productivity and fast assembly, constructions process and innovative design influence functionality of the bridge, "i.e safety and aesthetics, comfort, and other problems such as minimising disturbances to traffic while maintenance activates are performed. In addition all these efforts it steer the project activities towards it is success. However to achieve maximum benefits all the stakeholders must participate by sharing their knowledge and experiences from the early time of project and must remain actively involve.

5.2.2 Quality

As traditionally known the project triangle model consists of three key models, "Cost, Time and Quality". These three main aspects construct the success triangle as geometric proportions for project management. However in this project, the term quality covers all of "material quality level, overall construction quality level, material durability and service life performance of the bridge structure" as Shown in section

2.2. Also quality is the second highest main aspects according to the general view of data analysis. Based on the derived critical success factors, which have been discussed earlier, quality is discussed from several points of view. With respect to innovative design and products some advanced tools improve the bridge construction efficiency. Throughout the support of Innovative design and products it is possible reproduce the construction site and perform construction activities on the computer instead. And this can help to verify the materials performance with regard to their quality level. Also several researches agreed that computer simulations are very beneficial and supportive for analysing the lifetime durability of the bridge structure in terms of material performance with respect to quality level. For instance, using nonlinear finite-element method, the step-by-step construction of an actual bridge can be reviewed, additionally to the real behaviour of the bridge structure in terms of long-term assessments "i.e. fatigue analysis, structural member cracks and share".

As another use, advanced tools are considered to have significant application value in reducing production risks, time i.e. erections time for productivity and management of construction processes. It helps to plan an effective construction process, in a way that solutions are identified and derived for problems that expected to happen during the execution. Moreover, with the help of this advanced tool the maintenance activities of the structural members can be planned and optimised in advance and optimum use of material can be proposed in an early phase of the planning process.

Furthermore, studies made on both innovative design and products and innovative materials show that, the use of prefabricated structural members such as FRP, GFRP, and CFRP will not only improve productivity, fast assembly time and less cost but will also result in better quality of bridge construction. The prefabricated structural members have long-term durability under tough environments, high ratios of strength-weight and stiffness-weight, high thermal and electromagnetic insulation properties, free formability and higher energy absorption. It is easy to transport, replace and install the deck to accommodate because of the lightweight of FRP decks. Usage of FRP bridge deck will reduce the construction costs and save construction time without disturbing the materials quality due to their fast assembly. This is the opposite case scenario when it comes to on-site construction methods.

In addition, using FRP applications are useful for maintenance purposes and make it easy to replace decks. This is important in order to accommodate an increased traffic demand. FRP has several advantageous properties in comparison with traditional materials. Similarly using the products of High performance concrete (HPC) make it possible to open up the bridge for public traffic a day after casting operations began and final inspection without influencing the material quality. Also rapid hardening concrete (RHC) is another alternative product that has an excellent durability properties and good elastic behaviour of the bridge under service loads.

On the other hand, during the production stage FRP materials produce better carbon emissions than the traditional material such as steel and concrete. These materials make better public sustainability and have fewer impacts on users. The main obstacle with the use of the FRP decks on bridges is the initial high cost of an FRP deck compared to concrete decks. However studies show that in the long run, the extra durability and corrosion resistance will improve the FRP deck performance and reduce the necessity for deck replacements.

Besides this main concern, there are some technical weaknesses of FRP bridge decks. The disadvantages are the low rigidity of the main girder direction, the absence of material-adapted forms, the brittle behaviour and the sensitivity to instability in comparison with concrete deck. To overcome such obstacles, the hybrid FRP and concrete structures have been developed. Hybrid FRP have several advantages such as the increase of bending stiffness, which reduces the deformability, and the increased strength, which gives a better use of the FRP profiles. To validate the benefits of prefabricated structure, the FE procedures and simulation tools have been successfully employed on studies of the performance of FRP bridge decks. 3D nonlinear FE models, with shell elements, have been used in order to analyse the mechanical properties of the GFRP plate during construction stage. The FEA results showed good agreement with the experimental ones in terms of strength, deformation, and stiffness. In closing, the increasing amount of FRP applications confirms the high potential of structural performance in terms of quality, manufacturing and sustainability. Also the design methods are crucial when employing advance alternative solutions such as FRP in order to control the quality. More information is needed when it comes to combining several materials with composite action.

5.2.3 Optimisation

Optimisation is the third highest main aspects; according to the general view of data analysis is presented in chapter three. Based on the derived critical success factors in the previous part, optimisation is discussed from several points of view. With respect to management of construction process some advanced tools improve the bridge construction efficiency, throughout the support of construction management process by reproducing the construction site and performing construction activities on the computer. Many researchers agree that computer simulations are very beneficial and supportive for optimisation of design and construction process. For instance, by using nonlinear finite-element method, the step-by-step construction of an actual bridge can be reviewed. The other use of advanced tool is considered to have significant application value in reducing risks for construction management. It help to plan an effective construction process, in a way that solutions are identified and derived for problems that expected to happen during the practical work, with help of this advanced tool the construction time will be optimised. As an illustrative example optimisation of FRP products reduces the cost of the FRP reinforcing system and also reduces environmental impact due to less carbon emissions and energy intake. By optimisation FRP Bridge deck, confirmed their high potential at structural performance, manufacturing and sustainability. Moreover, a simulation model permits predicting the actual construction time and realistic production levels, as well as work duration and resources. Advanced tools are another measure for assessing the onsite productivity during the on-going construction. The estimation of construction time, cost and fewer work forces could be achieved throughout the advancement of computer simulation. As a final point, there are many advantages with optimisation, for example, reduce the construction cost and time, achieve effective construction process, efficiency of material, reduces the construction risk, to get a better quality and productivity, predicting the construction cost and time and many other benefits.

5.2.4 Cost

One of the most important factors in bridge construction is cost, which plays a very important role in governing the success of most projects. In most of the papers that have been examined, the authors attempted to reduce the cost of construction from different perspectives. Cost is the fourth highest main aspects according to the general view that presented in chapter three. The effort is to explain the cost based on the derived critical success factors. One of the derived critical success factors is innovative material, with the purpose of reducing the construction cost and environmental impacts based on these materials' properties. Durable materials like different kind of FRP are environmentally friendly and have less impact on users and also have low maintenance cost. Another durable material is a range of HPC product that has an excellent durability properties and elastic behaviour of the bridge under service loads and also low maintenance costs. HPC products reduce working time, especially when there is limited free distance between the re-bars. With help of effective management of construction process improves the bridge construction efficiency, throughout the support of construction management process by reproducing the construction site and performing construction activities on the computer. It reduces risks for construction management and save construction time; cost will be reduced by minimising trial and error. Moreover, computer simulations have very beneficial for modelling of bridge construction. As illustrative example Bridge_Sim offered designers and contractors with the ability of evaluating various scenarios of construction plans that represent different combinations of construction methods, crew formations, and construction sequencing. With the help of these simulation tools contractors are able to estimate the time and costs for repetitive construction process from the beginning of the design phase. Some advanced tools are proven to be accurate and provide better possibilities to select the optimum structural system that are safe, cheaper and easily produced and assembled. In addition, instrumenting the structure is a measure in order to create an effective structural health that can reduce maintenance cost. Some innovative design and products have reduced construction cost for instance with using of an FRP reinforced concrete bridge deck could be 57% in savings in construction labour and also save the constructions time. The modified CBR model based on the regression analysis showed that the construction cost error rate of the planned CBR model reduced by 16.2%.

6 Conclusions

The specific objective of this master thesis was to present the critical success factors for an efficient bridge construction. From the quantitative analysis on effective bridge construction, 10 aspects were found: Functional, Quality, Cost, Optimisation, Collaboration, Sustainability, Aesthetic, Safety, Life cycle cost (LCC), and Time. Moreover, from the review of the papers, 5 stakeholders were defined: Managers, Clients, Engineers, Contractors, and Designers. From the analysis on the general level Functional, Quality, Cost and Optimisation identified as the 4 highest ranked main aspects in relation to the stakeholders. (See appendix A).

From the more careful analysis of the literature, the following critical success factors were identified: Management of construction process, Productivity and fast assembly, Innovative design and products and Innovative material.

Then, these critical success factors were related to the most important main aspects. The key-points of these relationships are concluded below.

Functional, the highest ranked aspect, is related to production and fast assembly, Management of construction process and innovative design and products. These success factors influence functionality of the bridge construction. For instance implementing PBSME can provide flexibility at the work site, saving cost of traffic monitoring, easy inspection and reduce the risk of weather delays. Furthermore, using PBSME can reduce the need for bypass that often needed in the construction site to accommodate the equipment and machinery. In addition, setting-up well planned management of construction processes will also result in constructing a functional bridge “i.e. Building information modelling (BIM) technologies for bridge construction help to create an effective construction process, in a way that solutions were identified and derived for problems that expected to happen during the production process.

Quality is the second ranked aspect in bridge construction, it is related to management of construction process, innovative design and products and innovative material. With management of construction process, stakeholders can pre-plan and schedule the assessment of bridge’s structural health. This is one possible way to insure the material durability and plan the future maintenance that cost less throughout the service life of the bridge structure. Moreover, innovative design and products and advanced tools improve the bridge construction efficiency. Throughout the support of Innovative design and products by reproducing the construction site and performing construction activities on the computer in order to verify the materials performance with regard to their quality level. Also several researchers agreed that computer simulations are very beneficial and supportive for analysing the lifetime and durability of the bridge structure in terms of material performance with respect to quality level. For instance, using nonlinear finite-element method, the step-by-step construction of an actual bridge can be reviewed, additionally to the real behaviour of the bridge structure in terms of long-term assessments “i.e. fatigue analysis, structural member cracks and share”. Furthermore, studies made on both innovative materials and innovative design and products shown that, the use of prefabricated structural members such as “i.e. FRP, GFRP, CFRP etc” will not only improve productivity, assembly time and reduce the cost but will also result in better quality of bridge construction. The prefabricated members have long-term durability under tough environments, high ratios of strength-weight and stiffness-weight, high thermal and electromagnetic insulation properties, free formability, higher energy absorption. It is easy to transport, replacement and installation the deck to accommodate because of the lightweight of FRP decks. Usage of FRP bridge deck will reduce the construction costs and saving construction time without disturbing the materials quality due to their fast assembly.

The derived critical success factors related to the construction cost can be viewed in different perspectives. Durable materials such as various types of FRP and HPC reduce construction costs due to their low maintenance cost. Usage of hybrid GFRP bridge deck will reduce the construction costs and save construction time and it's a better alternative for beam-and-slab bridges. Advanced tools reduce risks for construction management and saving construction time; cost will be reduced by minimising trial and error. With the help of simulation tools, contractors are able to estimate the time and costs for a repetitive construction process, from the planning phase of the design. Productivity and Fast assembly also have impact on cost; advanced tools are proven to be accurate and provide better possibilities to select the optimum structural system that is safe, cheaper, easily produced and assembled.

The critical success factors related to optimisation have been discussed from several points of view. Throughout the construction, from the beginning to the finished building, optimisation help the stakeholders to get a better view of activities involved in any project. Computer simulations are very beneficial and supportive for optimisation of bridge construction. From the critical review of the papers, some advantages of optimisation have been found: effective construction management process, reducing risks for construction, estimating the construction time and cost, reduce environmental impact, predicting the actual construction time and realistic production levels as well as work duration and resources, efficiency of material, better quality, accuracy of prefabricated element, effective productivity and fast assembly and so on.

The main conclusion of this project is that Innovative material, construction process, Productivity and Fast assembly and Innovative design and products are all critical success factors for an efficient bridge construction. In addition, project stakeholders need to strive towards these success factors in order to accomplish effective bridge construction in the future.

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Appendix A

Citation	Geographical	Type of structure	Effectiveness										Disciplines					Year	Journal
			Time	Cost	Quality	Life Cycle Cost	Functional	Safety	Aesthetic	Optimization	Sustainability	Collaboration	Designers	Contractors	Engineers	Clients	Managers		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]