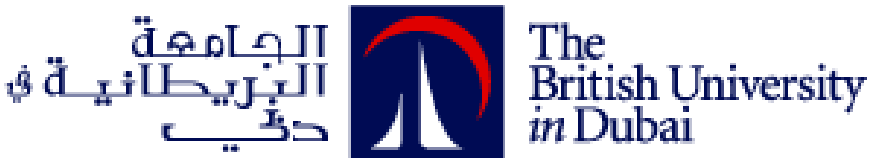

Innovation Strategies to Design and Deliver Resilient Critical Infrastructure Projects

استراتيجيات الابتكار لتصميم وتنفيذ مشاريع البنية التحتية الحيوية (الحرجة) المرنة

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Abstract

Critical infrastructure that considered the main artery of the economy and security for any country may get affected by different risks, challenges and threats, whether environmental (weather changes, earthquakes, volcanoes, etc.) or from human activity. In this sense, it is the duty of all parties involved in the design and construction of such facilities to cooperate in order to overcome these threats or in other words to deliver resilient CI , for this reason, many countries have developed a programs to secure the CI. It may come to mind that the CI are only complex projects like nuclear power stations or airports, but they include all the projects that damage or shutdown may cause paralysis of the state regardless of the size of the project.

The resilience starts from the design stage through anticipates the threats and risks that could affect the CI, these threats may be unexpected that is why innovation needed in the design and construction of these facilities is requirement for protecting and securing the CI.

The aim of this study is to examine the relationship between the innovation in the design, construction and operation of the project and the resilience of CI. To achieve this objective research included two sections, the first section includes the study of the CI definitions and the most important risks and threats related and the different definitions of the term and the various factors for resilience from previous studies. While the second section has included the study of previous research of innovation in the design and construction of critical infrastructure projects, focusing on the tools and strategies followed by the consultant and client. After collecting, the Information from both sections a conceptual model will be developing connected the Innovation tools and the resilience factors.

In order to collect the data, The method of qualitative research have been conducted by asking questions in interviews face-to-face with the design and construction engineers in three critical infrastructure, including transport and agriculture (water supply), in order to verify the conceptual model. After data collection and analysis founded that, the various tools and strategies followed by the owner and consultant have a direct impact on the reduction of the risks and threats to critical infrastructure projects and thus contribute largely in securing and resilience these projects. The different Innovative tools will be link to the resilience different factors

(*Recovery*, *Robustness*, and *Resourcefulness*) by analyzing and comparing three critical Infrastructures. It have been found that the technology is the most effective innovative tool to promote the resilience in the critical Infrastructure also conclusion come out of the importance of the trust, coordination and communication between the different teams to resist and adapt the risks and threats associated to the critical Infrastructure. The Innovation process (I) is a process that integrated different tools and strategies in order to design and deliver Resilient CI.

Keywords: Critical infrastructure, Secure, Innovation, Threats, Resilience, Recovery, Robustness, Resourcefulness

الملخص

البنية التحتية الحيوية (الحرجة) و التي تعتبر الشريان الرئيسي لاقتصاد و امن اي دولة في العالم قد تتعرض للاخطار , التحديات و التهديدات سواء البيئية (تغيرات الطقس والزلازل والبراكين وغيرها) أو عن النشاط البشري.و من هاذا المنطلق كان وجابا على جميع الاطراف المشتركة في تصميم و بناء هذه المنشئات التعاون فيما بينهم من اجل التغلب على هذه التحديات او بعبارة اخرى تنفيذ مشاريع بنية تحتية حيوية مرنة , حيث صممت كثير من الدول برامج تأمين لهذه المنشئات .قد يتبادر الى الذهن ان مشاريع البنية التحتية الحيوية تتعلق فقط بالمشاريع المعقدة كمحطات الطاقة النووية او المطارات و لكنها تشمل جميع المشاريع التي ان خدث فيها خلل او توقف قد تسبب شلل للدولة مهما كان حجم المشروع.

مرونة البنية التحتية الحيوية تبدأ من مرحلة التصميم من خلال توقع التهديدات والمخاطر التي يمكن أن تؤثر عليها، قد تكون هذه التهديدات غير متوقعة الحدوث و هنا تكمن الحاجة الى الابتكار اللازم في تصميم وبناء هذه المرافق كشرط لحماية وتأمين البنية التحتية الحيوية و الابتكار كعامل مساعد في مرونة البنية التحتية الحيوية .

ان الهدف من هذه الدراسة دراسة العلاقة ما بين الابتكار في تصميم و انشاء و تشغيل المشروع و مرونة البنية التحتية الحيوية و لتحقيق هاذا الهدف تضمن البحث قسمين القسم الاول شمل دراسة تعريفات البنية التحتية الحيوية و اهم الاخطار و التهديدات المتعلقة بها و التعريفات المختلفة لمصطلخ المرونة في مشاريع البنية التحتية الحيوية و العوامل المختلفة للمرونة من الدراسات السابقة بينما تضمن القسم الثاني دراسة للأبحاث السابقة المتعلقة بالابتكار في الانشاء و التصميم لمشاريع البنية التحتية الحيوية مع التركيز على الاستراتجيات والاداوات المتبعة من المالك و الاستشاري. و بعد تجميع البيانات من كلا القمسين تم التوصل الى اطار يربط مختلف ادوات الابداع مع عناصر المرونة لمشاريع البنية التحتية الحيوية .

من أجل جمع البيانات، وقد أجريت منهج البحث النوعي من خلال طرح أسئلة في مقابلات وجها لوجه مع مهندسي التصميم و من الانشاء في ثلاثة مشاريع بنية تحتية حيوية تشمل قطاع النقل و الزراعة(مشاريع تزويد مياه للمحاصيل) و ذلك للتحقق من اطار العمل المقترح .و بعد جمع البيانات و تحليلها تم التوصل الى ان مختلف ادوات و استراتجيات الابداع المتبعة من المالك و الاستشاري لها تأثير مباشر على الحد من الاخطار و التهديدات لمشاريع البنية التحتية الحيوية و بالتالي المساهمة الى حد كبير في تأمين و مرونة هذه المشاريع.

لقد تم عمل ربط ادوات الابتكار المتبعة في المشاريع الثلاث مع عوامل المرونة (*الاسترجاع* , *المتانة* و *سعة الحيلة*) و تبين ان استخدام التكنلوجيا و البرمجيات المختصة اكثر عوامل الابتكار فعالية لتعزيز المرونة لمشاريع البنية التحتية الحيوية و لقد اتى في المرتبة الثانية بناء الثقة عبر تعزيز قنوات الاتصال و التعاون بين مختلف فرق عملية الانشاء . و لقد تبين في النهاية ان الابتكار هي عملية تتكامل فيها ادوات و استراتجيات عدة تؤدي بالنتيجة الى تصميم و تنفيذ مشاريع البنية التحتية الحيوية .

الاسترجاع , , الكلمات الرئيسية : البنية التحتية الحيوية ,البنية لتحتية الحرجة , التأمين , الابتكار , التهديدات , المرونة *سعة الحيلة* ,*المتانة*

List of Abbreviations

BIM	Building Information Model
C	Client
CAD	Computer-Aided Design
CI	Critical Infrastructure
CIMS	Critical Infrastructure Modeling Simulation
CIMS	Critical Infrastructure Modeling Simulation
CITB	Construction Industry Training Board
CLDs	Causal Loop Diagrams
CO	consultant
CSR	Corporate social Responsibility
FOCP	Federal Office for Civil Protection
H&S	Health and safety
I	Innovation
IT	Innovation tool
NSF	The US National Science Foundation
QFD	Quality Function Deployment
R&D	Research and Development
R1	Recovery (Resilience factor number 1)
R2	Robustness (Resilience factor number 2)
R3	Resourcefulness (Resilience factor number 3)

RI Resilience Index

RO Role

S Strategy

T Tool

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Chapter One: Introduction

1.1 Overview

The life of the people is dependent on a lot of facilities and services defined as infrastructures. Infrastructure defined in The American Heritage Dictionary as the Services and facilities needed by the country for its functioning include the transportation sector, water, electricity or communications. Today, most countries consider many of the Infrastructures that are vital for the economy and security like transportation, communication network and energy and oil facilities, as critical, because their damage, destruction, or shutdown may affect the country stability. Dangers and threats to critical infrastructure projects greatly affect the security of the state and economy, the definition or the meaning of the critical term varying from narrow to wide depending on the government (country) or authorities' dictionary. A number of authors and authorities connect the critical infrastructure with the essential life functions. (Venables, 2009) considered that critical infrastructure is the main facilities for the new life; this is because the main elements of people's lives (water, energy, transport) are providing to them by these infrastructure.

In the United States the Executive Order 13010 focuses on the vital (importance) of some national infrastructure that, if defective or unsatisfactory, would affect the economy and the security of the country. According to the homeland security website, critical infrastructure has 16 divisions including the "Chemical, Commercial, Communications, Manufacturing, Dams, Defense Industrial Base, Emergency Services Sector, Energy, Financial Services Sector, Food and Agriculture Sector, Government Facilities Sector, Public Health Sector, Information Technology Sector, Nuclear Reactors, Transportation Systems Sector, Water and Wastewater Systems Sector" (Dhs.gov , 2016) . While comparing to Canada government, critical infrastructure include the technology facilities, networks, services, and assets that if any damage or stoppage may have a serious impact on the health, safety, security or economic well-being of the people or the effective functioning of governments in Canada. Canada's Government has 10 sectors regarding the critical infrastructure "Energy and utilities, Communications and

Information Technology, Finance, Health Care, Food, Water, Transportation, Safety, Government, and Manufacturing" (Publicsafety.gc.ca., 2015).

(Robles, 2015) in his study defined three categories of threats that face the critical infrastructure: natural threats, human-errors and accidental. Although most literature is concentrated on the natural disasters, (Jonkeren, 2014) argued that the resilience has an economic dimension along with the original engineering dimension, in his research he stated that recent studies focus on the economic failure for critical infrastructure, one famous example is the fluctuations in oil prices, which may affect the oil and gas projects . Because of the great importance of the critical infrastructure to the security and the national economy as well as the complexity and the difficulty in predicting events and threats that may that will occur these projects, governments set up various programs to protect critical infrastructure.

The Olive Group, which is a company that provides innovative and security solutions for resilience critical infrastructure, stated that in addition to the importance of the critical infrastructure nowadays, critical infrastructure is connected with each other by sub-categories of infrastructure with increasing demands on these sub-categorizes of the normal infrastructure. The risks will be more effective in the critical infrastructure if any risks, damages or threats infect the sub- categories of infrastructure. Although Resilience has many definitions and used in many fields some common Characteristics that can be applicable for the different fields, (Moteff, 2012) argued that most of the definitions for the resilience assume resilience to a change of the operations of a system, or a damage of the whole normal system.

In a conference about the disaster reduction, resilience defined as the ability of a system to *robust* or changes to keep the system function effective (Hyogo Framework for Action, 2005). The question come in mind is the resilience equivalent to the security.

(Canadellthe, 2002) refers in his research that according to the homeland security, security they differ from resilience in which security refers to eliminate the threat to the critical infrastructure caused by environmental and human risks, in the other hand resilience is the degree for preparation or the ability to change the circumstances, and to *robust* and *recover* quickly from damage. (Canadell, 2002) has defined resilience in two dimensions: firstly, the engineering

resilience is the time need to system to *recover* after damage; secondly, the ecological resilience is the quantity of damage a system can withstand before it come to its changing condition.

One example of the need for changes of the critical infrastructure protection (resilience) given in the literature are the reports coming from the disaster of Hurricane Katrina. One of the causes was the geodetic levels the investigation shows that engineers have two deferent reference points for the levee system. The disasters may occur because of weakness of the system an example is the protection systems for disaster (the hurricane in this case) that were an old systems without any update due to political and economic issues as was shown in the reports (Christian, 2007). Another famous example is the Northeast blackout of 2003. The brainstorming technique suggested for the resilience technique to create innovative ideas by two or more people argued ideas among each other (A Case Study of the 2003 North American Blackout with Exercises). Such threats and risks such as the disaster of Hurricane Katrina and the Northeast blackout of 2003 have increased the need for the innovation strategy especially in the design stage, as shown in the reports.

Countries and institutions have recently woken up to the importance of the innovation in various fields, one of these fields the field of the critical Infrastructure resilience. One of these examples that The US National Science Foundation (NSF) donates 17 million dollars for the Engineering and Computer and Information Science and Engineering, to find or create innovative techniques to increase the resilience level of the electrical projects, water supply and treatment and more critical infrastructure sections (National Science Foundation, 2014).

These disasters and risks to the critical Infrastructure require a system and tools to prepare or adapt them especially when start design the civil critical Infrastructure from the early phases by defining and predict these dangers to the critical Infrastructure , and due to the complexity and different threats innovation techniques need to evolve and penetrate the design strategy and management. Because Critical Infrastructure usually are complex projects like airports, energy , transportation and modern critical infrastructures consists of more infrastructures connected with each other design and deliver need new tools, strategies like technology, design soft wares

(O' Sullivan, 2009) argued the innovation should create new ideas which add a value for costumers. (DTI, 2007) agreed that innovation lead to new creation for ideas which benefit the businesses to have a completion in the global world.

From the construction side innovation has different definitions and meanings. (Dale, 2007) include in the definition in the Innovation in the construction industry the effective use of technology by using the research and development tool (R&D). An example given was of the green building that needed more R&D. In his study he examines 459 construction industry professionals; almost 100 % of respondents respond the R& D is important factor for the company and all also respondents that R&D are the important key in the construction future. He defined innovation as ideas, which are new, which create benefits usually in construction industry although he argued that these new ideas could lead to risks. The new idea may refer to new design, technology, material component or construction method deployed in a project'. In the innovation process, the different teams (contractor, client and consultant) each have roles in the innovation process. (Asad, 2016) in his research stated that the client is one of the drivers influencing innovation within the industry. (Kulatunga, 2011) in his book Construction Innovation stated that the client with his skills such as competition, value judgment, flexibility, and self-motivation can increase the efficiency of the work in the construction industry, which leads to innovative ideas from all the team (players) in the construction team, which leads to more effective overall innovation process. From the consultant side, the client views the consultant as their sources of knowledge, accelerator of the innovation process overall, analysis of the innovation strategies and the real player of innovation strategies.

1.2 Dissertation Aim

The aim of this dissertation is to investigate the innovation strategies followed by the client and the consultant in designing and delivering resilient critical infrastructure construction projects.

1.3 Dissertation Objectives

The objectives of this research are to:

1- Examine the uniqueness of critical infrastructure construction projects
2- Investigate the role the client and consultant can play in promoting the innovation process in the critical infrastructure.
3- Investigate the dynamics of the innovation process to design and construct a critical infrastructure project.

1.4 Dissertation Questions

1- What are threats, risks and challenges for the critical Infrastructure through the project life cycle?
2- How have the adopted innovation strategies and tools deployed improved the resilience of critical infrastructure projects?
3- What are the roles the client and the consultant can play to promote the innovation process in the critical infrastructures projects?

1.5 Research Structure

The research structure consists of six chapters, in which every chapter consists of different sections.

Chapter One: The introduction, this chapter starts with brief background about the critical infrastructure and the need for the protection (resilience) along with the innovation terms and definitions in the construction industry.

Chapter Two: Literature review focusing on the critical infrastructure definition and differences in the terms between the different authorities, while section two concerns interested in the issue of the protection of the critical infrastructure facilities, investigate the main dangers assigned to these projects, and move the reader to the concept of the resilience in the critical infrastructure projects. Section three clarifies the different meanings of innovation in the construction industry. Section four describes innovation as a process using two different frameworks, the Ozhorn and Nadia diagrams; section four also represents the roles of the client and the consultant in this process and the relationship between them. Section five focuses on the innovation of the design stage of the project life cycle by describing the tools (inputs), enablers /barriers, and the outcomes or the benefits of the innovation process. Section six gives a brief of the previous literature regarding the link or relationship between innovation, sustainability and resilience.

Chapter Three : Conceptual model , a framework use the Information and data from the Literature review to build a model connection the drivers, Inputs, tools and strategies with the resilience different factors.

Chapter Four: Research Method, this chapter discusses selecting method for the case studies, tools for collecting data and discuss In-depth the questions for the Interviews.

Chapter Five: Case studies, the chapter explains in details three critical infrastructure three case studies , Each case study starts with the project description, identifying the threats, risks and challenges associated to the critical Infrastructure, which draw lines for the Innovation strategies to overcome these threats and risks linking these strategies followed in each project with the different Innovative tools in the literature review and the role for the client and consultant in the project. After an Analysis will be done for the relationship between the Innovation tools and the

resilience factors to build a model for each case connecting the Innovation tools and the role for the consultant and client with the resilience factors

Chapter six: Discussion and conclusions, in the discussion section analyze of the data collected from the case studies and compare these data with the suggested conceptual model that will drive lastly the last section as the dissertation conclusion that will confirm the title of the dissertation which state that Innovation is synonymous the resilience in the critical Infrastructure.

Chapter Two: Literature Review

2.1 Critical Infrastructure Definition

Critical Infrastructure has different meanings and detentions and differs from one place to another , every country , government or authority have different sections for the critical Infrastructure, this come because of their understanding and the conditions in which Infrastructure can affect their functions like economy or safety.

List of the various definitions and meanings by governments and relevant institutions can be found in the Appendix C from the appendixes.

Through our understanding to the table, we can see that the vital infrastructure projects are the backbone of the economy and the security of any nation. According to the United States' Department of Homeland Security, risks that affect infrastructure divide to two parts: physical and virtual dangers.

The report Protecting Critical Infrastructure in the EU CEPS Task Force adds to the definition that vital infrastructure affects key government responsibilities, while the Framework for Meeting report adds that the various critical infrastructure areas are interconnected with each other physically to form urban communities.

From the different definitions of critical infrastructure, taking into consideration the various governments and institutions definitions, the following definition can come up:

Critical Infrastructure : Any infrastructure in a nation which can be a physical (facility, structure, assets…) or virtual (Network, process, system...) which are usually tie with other Infrastructure that any damage, destruction, shutdown or stoppage can affect the economic security public health safety societal key government responsibilities prosperity for the nation.

2.2 Critical Infrastructure Resilience

2.2.1 Risks and threats associated with the critical infrastructure.

(Katalinić, 2011) argues that in order to build an effective security plan it is necessary to undertake an appropriate and comprehensive risk assessment. (Robles and Bach, 2008) suggested three major causes for failure occurring to the critical infrastructure (risks, threats, damages and errors): natural threats, human threats and technical failure. (Robles, 2008) categorized the natural hazards for critical infrastructure to be Hazards related to the water change or atmosphere like flood and storms; or geological hazards like earthquakes. (Boin and McConnell, 2007) argue that the breakdown for any critical infrastructure will create from huge disasters (such as Hurricane Katrina) which are rare events the consequences of such disasters may be catastrophic. They added that due to the complexity of new critical infrastructure and coupling of the critical infrastructure multiple breakdowns may occur. (Bosher, 2007) have highlighted the greatest threats for critical infrastructure in the UK construction industry related to the natural and human-induced, including fluvial and pluvial flooding, coastal erosion, climate change and terrorist attacks. (Jonkeren, 2014) suggested that risks to the critical infrastructure can be on the economical side. (Fisher and Norman, 2010) have adopted the 'bowtie' representation that was used originally for the chemical process including the pre/post event elements as shown in figure 2.1. (Katalinić, 2011) divided the threats associated with the critical infrastructure into groups: human attacks which done purposed, technological failure, natural risks. After the definitions of threats to a project the calculating of vulnerability, (the weak spot of a system) which are the weakest points of a system.

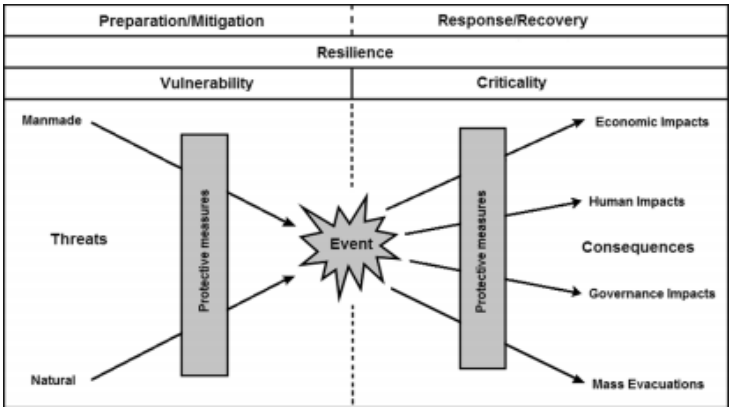


Figure 2.1 the bowtie representation adopted by Fisher and Norman to describe the events that have impacts on the CI

Risk Type	Source
1. Natural and environmental threats	(Robles ,2008) (Bosher, 2007) (Katalinić, 2010) (Bach, 2013)
1.1 Hazards related to water or atmosphere such as storms , flood	(Bach, 2013) (Bosher, 2007)
1.2 Geological hazards (e.g. earthquakes)	Bach (Bosher, 2007)
1.3 Climate change	(Bosher, 2007)
1.4 Coastal erosion	(Bosher, 2007)
2. Human threats	(Robles, 2008)
2.1 Human induced (e.g. terrorist attacks)	(Bosher, 2007) (Katalinić, 2010)
2.2 Human activity	(Katalinić, 2010)
3. Technical and/or accidental	(Robles, 2008) (Katalinić,2010)
4. Economical threats	(Jonkeren, 2014)

Table 2.1 Summary the risks associated with the critical infrastructure

2.2.2 Resilience

In the literature, there are different definitions and meanings for the term resilience. In the Department of Homeland Security, resilience defined as the ability for a system to absorb, adapt and *recover* from any accident, incident and threats. A system to be resilient it should have the ability to go back as the original state when a disaster occurs. (Longstaff, 2013) and (Claudio, 2015) concluded in their research that most definitions of resilience contain the idea of a system to come back (*recover*) from any threat or danger that system could not withstand them.

The general property for the resilience is to bounce (come back) and that can be a general property of the resilience in all fields possible to apply to. However some other aspects Could be clarified in the CI sector , recovery from disaster is not always the solution especially when happened to projects which are critical to the country. (Labaka, 2014) expanded the definition of resilience to include two characteristic one is the ability of system to withstand a disaster, in other worlds to increase the robustness of the system, along with the ability to bounce back to the original phase (*recovery*) of the system to be fast.

Resilience can have more aspects rather than the traditional engineering dimensions. (Jonkeren, 2004) argued that economic resilience as a resilience term to face the economic crisis, especially the fluctuation of the prices of different materials. (Moteff, 2012) mentioned that most of the definitions for resilience assume resilience to resist a change of the operations of a system, or even a damage to the complete system.

As discussed before the important factor of the resilience is to *recover* from a disaster to bounce back to the original state which require in result to resist any change in the operation of the system or a in a bigger picture as a damage for the whole system as has been suggested by the (Moteff, 2012). (Canadell, 2002) has defined resilience in two directions: firstly, the engineering resilience as the time needed the critical infrastructure to come back to its original state following a threat; secondly, the ecological resilience is the quantity of a damage that an infrastructure can handle before any change occurs due to the risk.

(Cutter, 2010) defines four types of resilience in terms of disaster resilience as social resilience, economic resilience, institutional resilience and infrastructural resilience. (Kallaos, 2014) defines resilience as a system characteristic in four types: absorption, adaptive function and response. (Ridley, 2011) in his research argues that the social side plays a vital role alongside the engineering, economical, and ecological (technical). By defining the scope of corporate social responsibility (CSR) he found in his research into the main criteria for the CSR (involvement of corporations and other stakeholders, corporation, competing ideas, using the argument system and communication) critical infrastructure connected with each other by sub-categories of infrastructure with increasing demands on these sub-categorizes of the normal infrastructure the risks will be more in the critical infrastructure if any risks, damages or threats have been done for these sub-categories' infrastructure (www.olivegroup.com). The need or importance of the

resilience is that if the facility or structure in an event or risk occurs the consequences will be on the smallest scale instead of large scale of damages if the resilience level is low. (Fisher, 2010) argues that resilience should be thought in steps through planning and design stages that will be more effective than in the construction or operation stages (Bosher and Price, 2007).

In the context of measuring the resilience, the Federal Office for Civil Protection (FOCP) adopts the Department of Homeland Security resilience index (RI) which is an indicator that helps in determining the efficiency of the developments done on the critical infrastructure which contains at level 1 the *robustness*, *recovery* and *resourcefulness*, while level 2 *robustness* (redundancy, prevention/mitigation, and maintaining key functions), *recovery* (restoration and coordination) *resourcefulness* (including training/exercises, awareness, protective measures, etc.) while level 3 these are the factors which are defined by the type of the critical infrastructure by which experts in the RI can determine. This RI can be used as a baseline for the research to determine the development done in order to deliver a resilient CI. (Kallaos, 2014) states three stages of resilience during the project life cycle as 1- before (anticipate, prevent, prepare) 2- during (resist, absorb), and 3- after (*recover*).

It observes that most of the literature and writers linking the resilience either engineering or environmental to the resistance to natural threats such as earthquakes and volcanoes, in particular, and it was due that these threats mostly caused catastrophic consequences on the CI, but some critics argued to other forms of the resilience related economic threats or social as reasons leading to system failure for the CI.

Table 2.2 summarizes the different definitions for the resilience in the critical infrastructure; the different definitions of resilience are summarized in table 2.2, while Table 2.3 summarizes the types of the resilience.

Definition	Source
Coming back (*recover*) from any threat or danger that system could not withstand them	(Longstaff, 2013) (Claudio, 2015)
The ability of the system withstands disaster.	(Labaka, 2014)

The resilience for the Change of the operations of a system, or even damage to the complete normal system.	(Moteff, 2012)
The characteristic that gives the system the following features: absorption, adaptive function and response.	(Kallaos, 2014)
the ability for a system to absorb, adapt and *recover* from any accident, incident and threats.	(Homeland Security 2015) Resilience, Available: - http://www.dhs.gov/topic/resilience.

Table 2.2 Resilience definitions

Type of Resilience	Definition	Source
Engineering resilience	The time need to system to *recover* after damage.	(Canadell, 2002)
Ecological resilience	The quantity of damage a system can withstand before it come to its changing condition	(Canadell, 2002)
Social resilience	The scope of corporate social responsibility (CSR) main criteria for the CSR (involvement of corporations and other stakeholders, corporation competing ideas, using the argue system and communication).	(Susan L., 2010)
Economic resilience	The resilience that measures the economic power of countries such as capital and	(Susan L, 2010)

	justice in the distribution of national product which indicate the strength state economy in one or more partitions	
Institutional resilience	Resilience concerning the characteristics of the pre-disaster like planning	(Susan L, 2010)
Infrastructural resilience	Index to measure the society's capacity for response and *recovery* from dangers	(Susan L, 2010)

Table 2.3 Summary of the different types of resilience

Resilience Index (RI) is explained by the Department of Homeland Security as a tool that can help for determining the effective strategies done for the development of the critical infrastructure. RI contains three levels in which level 1 and level two are shown in figure 2.2, while level three will be different from one CI to another.

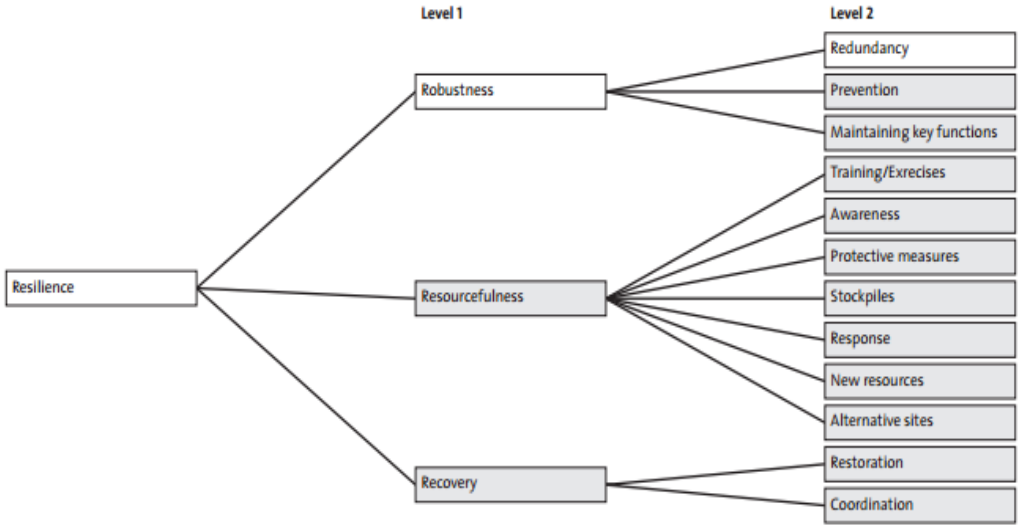
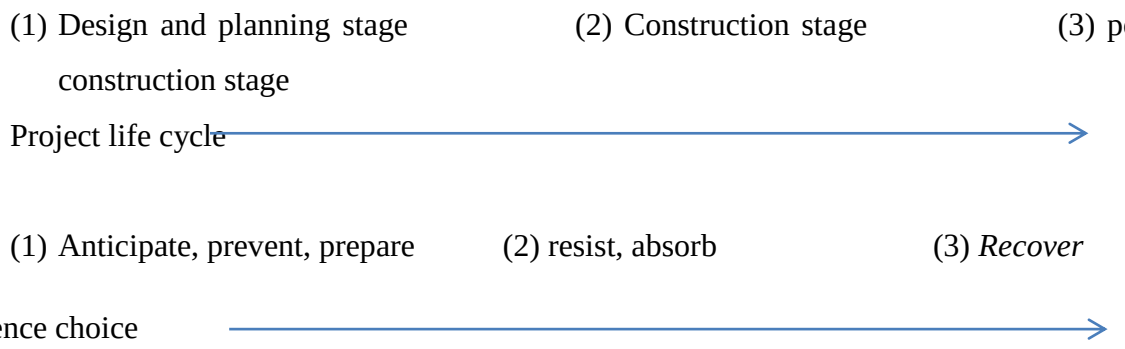


Figure 2.2 Resilience Index diagram: a diagram showed two stages to achieve the resilience

Figure 2.2 Resilience Index diagram: a diagram showed two stages to achieve the resilience.

Resilience stages through the project life cycle as discussed in the literature review are shown in the next diagram.



The main goal is to achieve the resilience in the critical infrastructure projects. From a construction point of view to achieve the resilience is different from what has been discussed as a general concept for the resilience.

Risks and threats associated to the critical Infrastructure need to be think about and to predict of the dangers early in the design phase in order to prepare for the risks producing a risk management plan to overcome these risks during the construction and operation and this can be achieved through different innovative approaches in the design and intelligent thinking in order to *recover* to the original state in the post-disaster including , other way is by including the safety in design will help to resist or to build sustainable and resilient infrastructure. Risk Management consists of planning the system to handle the different risks to the project, due to the complexity of the critical Infrastructure and increasing environmental risks in the recent years Innovative techniques and using of the advanced technology within the project can help the planning the system for the dangers Critical Infrastructure usually owned by the country, the government, which need to be a leader, innovative leader, to the project work effectively and efficiently. Even through disaster integration need to be at high level like communication, coordination that can lead to effectively respond and *recover* the system to the original state. Innovation and creativity can be a tool for the climate change as it considers unpredictable in some cases In other words Innovation in the critical Infrastructure leads to resilient critical

Infrastructure. The Innovation in the construction and critical Infrastructure will be discussed in the next sections.

2.3 The innovation in the construction industry

Many definitions for innovations are given in the literature. One question come to the mind connecting the Innovation and the creativity of something new which can add benefits to the organization , project or system , It does necessarily mean that the innovation to come up with something totally new ?

(Brandon, 2008) gives the definition of innovation clearly from the creation of something that is totally new to a current situation. (Crossan and Apaydin, 2010) define innovation as" the production or adoption, assimilation, and exploitation of a And that can provide the benefits of economic and social sector; renewal and enlargement of products, services, and markets; development of new methods of production; and establishment of new management systems, It is both a process and an outcome". Dr. Friday O. Okpara connected innovation with creativity, mentioning that all innovation starts with creativity (Okpara, 2007). (Dulaimi, 2002) defined the innovation process in the construction industry point of view as A new application that will be applied in a particular construction project in order to achieve the benefits this construct of this project effectively, but he also argues that this newness can lead to uncertainties. In the world of construction, this new idea (creativity) may be in the design stage with creative application designed to bring out innovative design or the construction phase through innovation in the way of construction or creativity in the construction materials science (Brandon, 2008) . On the other hand some authors argued that the Innovation not necessarily mean new in all cases . (Brandon, 2008) has argued that the Innovation as the newness of something in an existing situation is not necessary to be new to all situations but rather than development of the existing situation. the solution to this dilemma is that Innovation can be looked as creative of something which can add a value to the system and as discussed by CITB (CITB or Construction Industry Training Board, 2003) that Innovation in the construction can be looked by two ways : doing differently (uniqueness) or doing better (Better quality). (Asad, 2006) considered the innovation as a fourth

dimension for the performance of the construction organizations which can be added to the original factors of the Project Management Triangle (time, cost and quality).

In the context of the complex and critical infrastructure, Jennifer Whyte stated that innovation is one of three modern theories of systems integration along with the complex projects and engineering design (Whyte, 2016). For the risks associated with the climate, the Royal Academy of Engineering on behalf of Engineering the Future mentioned that engineers have a role for the resilience of the infrastructure by setting out new and innovative engineering strategies (Henley, 2011). According to Jennifer Whyte that the Innovation is modern theory for the delivery of the complex projects (CI) which require more design problems , errors and dangers , When it is addressed to modernity are we necessarily referring to the technology ?

A number of authors stated that technology is a vital factor for innovation in construction. (Dale, 2007) stated that technology has a vital role for construction innovation. In his extensive research the Research and Development (R&D) has taken the vast majority of the participants (the important factor for the construction innovation). (YAMAZAKI, 2004) argued that technological directions are construction innovation's future.). Added that environment take a big part in the modern construction which required more research and development. (Sørensen, 2004) and (Seaden and Manseau, 2001) mentioned that innovation nowadays is viewed as a solution that added to the company the value of the competition among the construction industry by applying the new ideas. (Whyte, 2016) mentioned that the using of 3-D digital in design and explore the Infrastructure to the teams (i.e. Building Information Modeling (BIM) and other technologies) help getting a digital picture which can identify the different risks and threats (Whyte, 2016). The Federal Ministry of Education and Research (BMBF) agree that 3D can be an IT-based platform to retain to it in any extreme emergency case to take the correct decisions (*recovery*) (Federal, 2012). The Royal Academy of Engineering argue that for climate change countries can take lessons from overseas countries where there is similarity but it can present an opportunity for innovative development of technology (*robustness*, *resourcefulness*) (Henley, 2011).

In the literature, the competitiveness of organizations is a result for their innovation strategies (Gambatese and Hall, 2011) argue that a link between the innovation and the competence in any industry is due to the open market of the industry. (Xue and Jason, 2014) also regard a link

between the competence being as result of innovation which leads to positive effects on the on the economic growth. They added that innovation in construction has an important role in the corporations and the update of the industry. (Yusof, 2015) links innovation in the construction firms and the engineering innovations as being related overall to the financial benefits, as the engineering and construction firms win the tenders and so improve the financial results of these projects. Innovation is highly beneficial to the construction industry. One benefit of innovation is its contribution to increase productivity. (S, F., D, T, 2014) researches the results coming from the project clients. In Hong Kong, he found benefits for innovation from a client perspective that technical difficulties risk can be overcome by using the communication and collaboration tools (Ling and Dulaimi, 2007) .(Hwang, Hwangb and Donga, 2007) have stated two type of innovation as a product and a process. Innovation can be classified in the view of the construction industry as organizational or technical. (Asad, Pan and Dainty, 2016) refer to organizational concerns about innovation within the enterprise itself and the technical concerns about the product or the process development.

The different definitions for the innovation are in table 2.5

Definition	Industry	Source
An approach that give benefits to the economic and social sections	General definition	(Crossan and Apaydin , 2010)
The newness of something in an existing situation	General definition	(Brandon, 2008)
Creation of new Idea that provide extra benefits to the construction site	Construction industry	(Dulaimi , 2002)
The successful commercial exploitation of new ideas	Construction industry	CITB or Construction Industry Training Board (2003) Innovation, Skills and Productivity
A process that provides the competitive position of a firm	General definition	(Seaden and Manseau, 2001)

A factor from three contemporary theories of systems	Critical infrastructure	(Whyte, 2006)
Innovation and new engineering approaches for the resilience the critical infrastructure	Critical infrastructure	

Table 2.4 Innovation definitions

The innovation types: Two sources in the literature review have been given for the types of innovation as shown in table 2.6

Types	Industry	Source
Product	General	(Hwang, Hwangb and Donga, 2007)
Process	General	(Hwang, Hwangb and Donga, 2007)
Organizational	Construction industry	(Asad, 2016)
Technical	Construction industry	(Asad, 2016)

Table 2.5 Types of Innovation

The Innovation benefits: The benefits derived by the literature review shown in table 2.7

Benefit	Source
Competitions	(Gambatese and Hall, 2011) / (Xiao Long and Jason, 2014)
The financial benefits	(Yusof, 2015) / (Ozorhon, 2013) / (Gambatese

	and Hall, 2011)
Increase productivity	(S.F. D.T, 2014) / (Gambatese and Hall, 2011)
Project duration	(Ozorhon, 2013)
creating safe and security	(Ozorhon, 2013)
Flexibility in design	(Ozorhon, 2013)
The better quality	(Gambatese and Hall, 2011)

Table 2.6 Innovation Benefits

2.4 The innovation process in the construction Industry

2.4.1 The innovation process

(Ozorhon, 2013) defined the steps for the innovation process on the project level. The Innovation framework derived by Ozorhon is three-dimensional input-output models: 1-Drivers, Inputs; 2-Barriers as a negative influence, Enablers as a positive influence and on the innovative activates; 3-Benefits, Impacts (Ozorhon, 2013). Another framework for the innovation process given by (Kilinc, Ozturkb and Yitmenc, 2015) is the three dimensional diagram related to the client. The three dimensions: 1- the role of the client in the innovation process; 2- Innovation Value chain 3- Innovation variables.

The innovation process framework: In the literature, two frameworks have been mentioned:

The Ozorhon framework as shown in figure 3.2 (all team players)

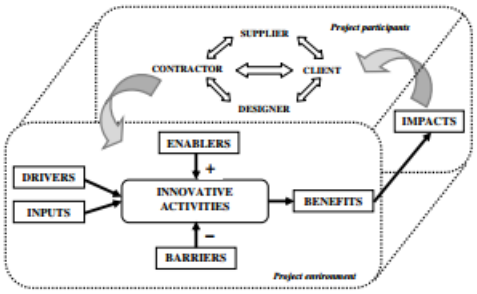


Figure 2.3 the Ozhoron framework

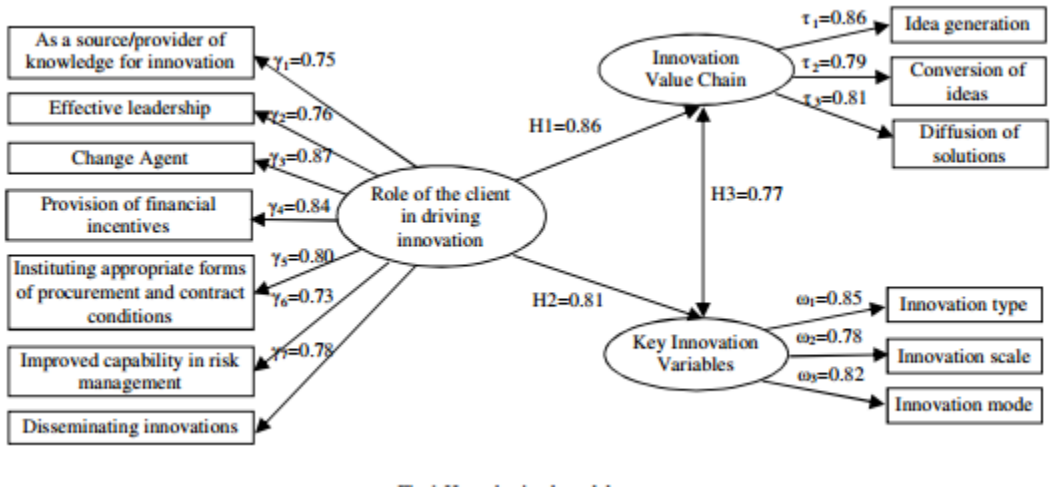


Figure 2.4 The NIDA framework (Kilinc, Ozturkb and Yitmenc, 2015)

The NIDA framework shows the role of the client on the innovation y by providing new strategies and taking leadership in the innovation process.

The role of the client and the various Innovative strategies will be discussed in the next section.

2.4.2 The role of client/consultant in the innovation process

(Kulatunga, Kulatunga and Haigh, 2011) in their study found that the client is the manager in the innovation process, especially in the design stage by building the trust and coordination that helps the consultant to transfer the ideas to the right design procedures and drawings. From the perspective of the critical infrastructure (Akintan and Morledge, 2013) refer to the Johansen and Porter article mentioning that failure to coordinate and to build trust between the different teams can result in incorrect and uncertain duration of critical activities which help in maintaining the key function of the project. (Brandon, 2008) in his book gives the leadership for the innovation management to the client as the client has the power and the force over the project life cycle. He assures that innovation based on knowledge transfer, which in some complex projects need cooperation between the different parties. His drawing of the complexity of the project and the knowledge transfer shows that a low degree of knowledge gained (individual or with coordination with other parties) results in a lower innovation level whether the project is

complex or simple, so suggests that the complexity of the project is still the knowledge transfer having influence in the innovation level. Similarly, Pathirage sees the link between knowledge transfer and the resilience level by prevention and increasing the training and awareness of the teams for critical projects. (Wood, 2008) suggested that the client plays a role by being encouraged to pay more attention to the innovation process. The client views the consultant as the sources of knowledge (The need for the consultant in any construction project) by means in giving advice and help regarding the engineering , planning,,, and the accelerator of the innovation process overall, analysis of the innovation strategies and the real player of the Innovation strategies. However, he argued that the consultant role must not be overstated; he assures, as other authors mentioned in the previous section regarding new technologies (by supporting the R&D networks), for the complexity for critical infrastructure, the consulting management needs a bigger consultancy firms than the traditional projects. According to (Dr. A.J. Briding, 2015) innovative approach during the design eliminate the threats and help in resilience and *recovery* and the factor that give the strength for the projects to withstand major disasters which result in *robust* and hardened against the physical attacks. Dr. A.J. Briding (2015) agreed that the role of the consultant in the traditional projects discussed by Fracy could be projected to the critical infrastructure in terms of the resilience linking the innovation with the resilience in the critical infrastructure by taking a major look at relationships and building in community resilience. (Dr. A.J. Briding 2015) give the importance of the consultant role in the design stage more than the construction and operation, there are many tools that help the consultant to promote the Innovation in the design stage especially in the CI. Number of ways suggested by the white paper of French Consultancy Company: Internal Innovation (through knowledge management). Innovation by the employers themselves, innovation in daily engineering (an example of a technique called reinforced soil which give new mechanical characteristics to the soil) and innovation in consultancy engineering and technology (R&D and CAD programs). In their study about the Turkish real estate companies (Kilinc, Ozturkb and Yitmenc, 2015) found that the client could have a big impact on the innovation process as the client has the dominant role for driving the innovation by forcing the procurement methods, polices, practices and project specifications. (Egbu, 2009) has defined seven keys for client innovation (as a source of knowledge, leadership, changing agent, financial incentives, providing the accurate procurement route).

2.5 Innovation strategies

The project life cycle consists of different phases; one of these phases is the design phase. The construction projects life can consist of specified stages or phases as suggested by

(Guo, Li and Skitmore, 2010): Planning, Design, Construction, Commissioning, Utilization, Maintenance and Decommissioning. These stages are traditionally separated, which leads to many problems due to miscommunication. Innovation in complex and hence critical projects that failure in communication and errors lead to the technical failure, so communication play significant role to overcome the risks, the communication are social in nature when the owner (c) creates the project design criteria which are transformed to drawings by the engineer and architects (co). In the construction industry, critical Infrastructure design need creative people when design the projects this required a well-managed organization to help in the communication , collaboration process and thus result in building the trust. (Erbil and Acarc, 2013).

The CTIB have different approaches for innovation in the design stage, such as: 1- computer-aided design, modeling and costing; 2- the use of electronic data interchange over public and private networks to share projects, materials and commercial information relating to a project; 3- plant and equipment – the use of conveyor and handling systems to speed up and ease the movement of materials onto and around a site; 4- timber, steel and concrete frames is not new technology but its application in lower cost, high volume markets is new. Factory manufactured units – the off-site manufacture of components for constructions, structural panels and volumetric units, for example, are now proven and applied in a number of construction sectors (CITB or Construction Industry Training Board, 2003).

2.5.1 Innovation tools followed by the consultant and client

Innovation tools or strategies in the design stage will be considered as drivers or inputs using Ozorhon. Three-dimensional input-output models of innovation should be applied during the entire project's life cycle to fulfill the required tasks. In this section, attention will be made to the innovation in the design stage of the construction project. As discussed in the innovation section, technology is a significant factor in the innovation process in the critical infrastructure. The BIM (building Information Model) has been increasing in the recent years as one strategy (tool) for

design management (innovation in the design) (Elmualim and Gilder, 2013). Erbil in his interviews for the turkey market finds that the consultant (engineer or architect) using technology and using the specialized software leads to more innovations (Erbil, 2013). The client has the leadership in driving the innovation process in all of the project life cycle. In considering the tools for the consultants to drive the innovation process in the design stage for the projects, in a review of the white paper (Engineering Consultancy and Innovation) produced by members of the French Engineering Consultancy Industry, consultants haven been shown as the representative for the owner of the project. Various tools and methods done in the design stage as suggested by the Engineering Consultancy and Innovation: the internal innovation by introducing knowledge management terms by steps, firstly arranging for the circulation of the documents, specifications and data, secondly by arranging the knowledge share between the team members through tutors, books and different groups, thirdly by assuring the correct promotion for the available skills and experience for the individuals and, lastly, by giving the free access to the information and knowledge for further updating on this knowledge (Bessiere, Bisch Geon and Ussegli, 2008). Another tool is the innovation produced by the employee either by the request of the employee by mutual understanding or by several employers through the collaboration between them, during using of the CAD software's) which accelerates the R&D improvement as discussed before that technology based on the R&D. (Bessiere, Bisch Geon and Ussegli, 2008). A. Hidalgo and J. Albors agreed with the previous opinions about the knowledge management and had define the knowledge-driven economy as the knowledge management discussed as a driver for the economic taking the part related to the design stage. Hidalgo gives CAD systems, rapid prototyping, usability approaches, Quality Function Deployment (QFD), value analysis (Hidalgo and Albors, 2008). In the context of the construction side, CAD systems, QFD, value analysis will be accountable, the QFD tool takes into consideration the improvements and design specifications. QFD also can be a tool that transfers the client ideas to information that can be designed from the consultants or designers by using a matrix as a suggested "House of Quality" (Gargione, 1999). (Dell'Isola, 2003) gives the meaning of the value analysis "as an explicit set of disciplined procedures designed to seek optimum monetary value for both early and long-term investment. Value analysis uses tools such as function analysis and risk analysis and relies on collaboration and creativity coupled with accurate cost estimating". He added that the design would be due to the quality within the budget producing

the term of “zero-based design”. The appropriate choice of the construction materials will be used in the project can lead to an innovative project, Klassen (Associate Professor, Ryerson University, Faculty of Communication and Design, School of Interior Design) uses the term material innovation in choosing the appropriate and innovative choice of the construction materials that will be used in the project and could help the structure to sustain the natural and the built environment along with achieving higher productivity of the construction materials in their built state. This effort will be early in the project, i.e. in the design stage, which will reflect the designer’s imagination on the state of the materials and their transformation and not only on the appearance of the materials. This requires more research on the chemistry and biology of the construction materials. In terms of resilience and critical infrastructure challenge for the resilience, critical infrastructure is the collaboration and communication between the stakeholders, public and authorities as suggested by Bach in his research when taking into the account the public referring to the social resilience, the integration of citizens into resilience building (Bach and Serre, 2013).

(Barroca and Serre, 2013) connect between the technical solution before and after or even within the crisis (*recovery* and *resourcefulness*) by introducing innovative technical system approaches that are qualitative, “socio-centered” and semi-quantitative. Technology and R&D result in benefits of critical infrastructure, observing that new technologies are needed to deal with the future vulnerabilities and have effects on the management of incidents as well as the *recovery* (Sunil, 2015). In terms of technology and resilience, the Chartered Institution of Civil Engineering mentioned that the BIM approach could build a better model for the critical infrastructure by identification of the best ways of improving energy efficiency and reducing the carbon emissions (The Chartered Institution of Civil Engineering Surveyors, 2013). Using specialized software leading to innovation in the traditional projects is one example of specialize software addressed by (Schneider.M, 2016). Software used in critical infrastructure named Critical Infrastructure Modeling Simulation (CIMS) is a tool that has been created after the Hurricane Katrina disaster. It provides a portrayal of the different infrastructure sectors that create a model for open source information. “Thus it is possible in cases of a destructive event to capture the dynamics of the cascading effects and the way this affects the operation of emergency teams.” According to the Homeland Security website the knowledge management by circulation of the documents and specifications as well as other information and knowledge share

results in better decision making, especially in the critical infrastructure which result in improving the resilience by increasing the awareness and the coordination and by risk management actions and strategic planning (Department of Homeland Security) (Information Sharing: A Vital Resource for Critical Infrastructure Security). These refer to the Resourcefulness, Redundancy, Coordination factors. In an analysis for Ernst and Young connected between the promotion of skills and leadership as critical matters that need non-routine skills for the organization, these skills lead to building business *recover*y and help the organization to respond to the severe impacts (Ernst and young, 2013). (Mattioli, 2014) recommended that communication and collaboration is essential for critical resilience. "Effective collaboration between public sectors (government and mandated agencies) and the private sector is fundamental in protecting CII assets and services. For the identification of CIIs in communication networks, the involvement of two categories of stakeholders should be pursued: 1- operators of critical infrastructures, 2- network operators, along with free access to the information that the collaboration and communication can be a tool for identifying the risks for the critical infrastructure (prevention, protective measures) and collaboration is a factor that builds the trust between the client and the consultant. The client and the consultant role in the Innovation process: the different roles for the client and the consultant in the innovation process in the construction industry are shown in table 2.8, which will be the drivers or inputs in the Ozhoron framework

Role	Client/consultant	Source
The manager in the innovation process	Client	(Kulatunga, 2011)
Trust	Client / consultant	(Kulatunga, 2011)
Coordination	Client / consultant	(Kulatunga, 2011)
Leadership for the innovation management	Client	(Brandon, 2008) (Egbu, 2009) (Ozorhon, 2013) (Loosemore and Holliday, 2012)
Knowledge transfer	Client / consultant	(Brandon, 2008)

Encouraging the client to play more attention to the innovation process	Consultant	(Wood, 2008)
Sources of knowledge	Consultant	(Wood, 2008)
Accelerator of the innovation process overall	Consultant	(Wood, 2008)
Analysis of the innovation strategies	Consultant	(Wood, 2008)
The real player of the innovation strategies	Consultant	(Wood, 2008)
Internal innovation	Consultant	(Bessiere, Bisch, Geon and Ussegli, 2008)
Innovation by the employers themselves	Consultant	(Bessiere, Bisch, Geon and Ussegli, 2008)
Innovation in daily engineering	Consultant	(Bessiere, Bisch, Geon and Ussegli, 2008)
Innovation in consultancy engineering and technology (R&D and CAD programs	Consultant	(Bessiere, Bisch, Geon and Ussegli, 2008)
Forcing the procurement	Client	(Egbu, 2009)
Provide the accurate procurement route	Client	(Egbu, 2009)
Change agent	Client	(Egbu, 2009)
Financial incentives	Client	(Egbu, 2009)

Table 2.7 Roles of the client and the consultant in the Innovation process

Approaches, strategies and tools (enablers and inputs) followed by the consultant and the client are represents in table 2.9. Focus will be on the design stage rather than other stages.

Tools	Source
1- Technology and R&D (research and	CITB or Construction Industry Training

development)	Board (2003) Innovation, Skills and Productivity
1.1 Computer-aided design (CAD), modeling and costing	CITB or Construction Industry Training Board (2003) Innovation, Skills and Productivity (Hidalgo and Albors, 2008)
1.2 An electronic knowledge transfer for design, materials, procurement private and public	CITB or Construction Industry Training Board (2003) Innovation, Skills and Productivity
1.3 BIM (building information model) (tool) for design management	(Elmualim and Gilder, 2013)
1.4 Using of the specialized soft wares	(Erbil, 2013)
2- Knowledge management	(Bessiere, Bisch, Geon and Ussegli, 2008)
2.1 The circulation of the documents, specifications and data	(Bessiere, Bisch, Geon and Ussegli, 2008)
2.2 Arrange the knowledge share between the team members through tutors, books and different groups	(Bessiere, Bisch, Geon and Ussegli, 2008)
2.3 The correct promotion for the available skills and experience for the individuals	(Bessiere, Bisch, Geon and Ussegli, 2008)
2.4 Give free access to the information and knowledge for further updating on this knowledge	(Bessiere, Bisch, Geon and Ussegli, 2008)
2.5 The knowledge-driven economy (the knowledge management discussed as a driver for the economy)	(Hidalgo and Albors, 2008)
3. The mutual understanding between the client and the consultant	(Bessiere, Bisch, Geon and Ussegli, 2008)
3.1 Trust	(Kulatunga, 2011)
3.2 Coordination	(Kulatunga, 2011)

3.3 Collaboration	(Bessiere, Bisch, Geon and Ussegli, 2008) (Loosemore and Holliday, 2012)
3.3.1 BIM also raised as a way for the innovation by means of collaboration as the drawings will give better view for the whole structure by the stakeholders	(Loosemore and Holliday, 2012)
4. Understanding the client	Different sources during the literature review
4.1 Quality Function Deployment (QFD), translating the client demands into information	(Hidalgo and Albors, 2008) (Gargione, 1999)
4.2 Value analysis (determine the zero-based design)	(Hidalgo and Albors, 2008)
5. The appropriate choice of the construction materials	Filiz Klassen
6. Integration	(Ozorhon, 2013).
7. Communication	(Gambatese and Hall, 2011)
8. Organizational Culture	(Gambatese and Hall, 2011)
9. Regulation by the client	(Loosemore and Holliday, 2012)

Table 2.8 Innovation strategies

2.5.2 Enablers and barriers for the innovation in the design stage

(Ozorhon, 2013) has mentioned that leadership and integration are enablers for innovation in the construction industry. Leadership by the client is the power the client has on the different players in the project to push them to the innovation process early in the design stage as the client can drive the regulations and policies and has the power to force or push. (Loosemore and Holliday, 2012) argued that although regulation and polices are essential for the innovation process as enablers, it could present barriers with the risk of overregulation which can be obstruction for the Innovative ideas by the other teams, so the need for regulation must be balanced. (Loosemore and Holliday, 2012) in their research, Technical Innovation Solutions found that the upper

management like client support, achieving the highest rate (82% of respondents which are the respondents who completed the questionnaire, having had an average of 23 years in the profession) as enablers for the innovation process as well as communication and the organization culture while the barriers are the fears of the change and the miscommunication. (Suprun, 2015) studied the enablers and barriers for the Russian Federation, resulting in finding the ranked barriers, regarding the design context agreed with John in the fear of the innovation process application as becoming significant in the construction industry for the high responsibility of all teams in the construction process, an example given that design errors by using inappropriate technology could result in deaths If the structure collapsed. The Government's role can be as a barrier or enabler for the innovation by providing institutes that help the organizations in the innovation process along with hostile attitude of designers and builders to contracts with fixed prices and lack of technological solutions. In the research (Suprun, 2015) argues that the client by lack of support and resistance to the innovation ideas suggested by the different parties could be a barrier to the innovation process. (Gambatese and Hall, 2011) define four main enablers for the innovation process: collaboration, regulation, skills, education and research and, with regard to leadership for the collaboration, suggested that to drive innovation, a new approaches techniques to be expanded than the traditional strategies that used in the construction industry. BIM also raised as a way for the innovation by the means of collaboration as the drawings will give a better view for the whole structure by the stakeholders

The barriers to the innovation process are in table 2.10

Barrier	Source
1. The fear of the change	(Gambatese and Hall, 2011)
1.1 Fear of taking full responsibility in the construction like the design errors by using inappropriate technology	(Stewart, 2015)
2. Miscommunication	(Gambatese and Hall, 2011)
3. Client by lack of the support and resistance to the innovation ideas suggested by the different parties	(Stewart, 2015)

Table 2.9 Innovation barriers

2.5.3 Impacts, benefits for the Innovation in the design stage

The outputs for Innovation in the construction industry as suggested by (Ozhoron, 2013) related to the project duration, and the economic cost of the project, creating safe and security, give flexibility in design. (Gambatese and Hall, 2011) agreed about the cost and added the better quality and productivity as an outcome of the innovation process.

2.6 Innovation, safety, sustainable and resilience

(Sterling, 2015) in his research about the risk management, put a connection between the innovative strategies in design and safety by introducing the Safety In Design (SID) which predicts the elements of the hazards in the project. It is the process of making deliberate design choices that enhance safety during every project stage. (Schneider, 2016) Many programs for resilience haven been created. Schneider Matt Montgomery introduce new systems: the Halcrow Sustainability Toolkit and Rating System HalSTAR systems which are based on complex adaptive systems which make for transport infrastructure resilience which consists a part of the Causal Loop Diagrams (CLDs) which are used in group model building processes with project stakeholders and industry experts. These group models consist of communication and knowledge share between the parties (Montgomery, 2012). Sustainability and resilience are matching together as per (Rees, 2016). “Resilience and sustainability are not the same. The pursuit of sustainability assumes that we (a) know what can be sustained and (b) have the capacity to maintain stationary (i.e., keep the system operating within an unchanging envelope of variability). In contrast, resilience thinking acknowledges disequilibrium and nonlinear, continual change - often as a result of crossing a “tipping point” or threshold - and offers a tool for assessing the dynamic relationships between systems…” so the resilience is not a substitute to the sustainability but a complement. The use of the new materials and construction technologies incorporate sustainable solutions so that increasing the profit, decreasing construction duration and has positive effects on the environment. (Madingley, 2011)

As discussed in the Resilience section, resilience must be thought of in the planning and design stage instead of doing it at the later phases of the project life cycle (Bosher, 2007). (Bosher, 2007) mentioned from his different step in the agenda for integration of the different team

players that the innovation solutions done by professionals like the engineers and consultant to the developments in areas which have possible hazards (Bosher, 2007). James Kallaos connected between the innovation in the design and the resilience in his research when it come to the operation stage a resilient design and well managed Infrastructure will lead to a resilient Infrastructure in the operation stage , he suggested two steps for achieving resilience design by 2 steps:

1. Connecting the *robustness* of building or the Infrastructure to handle the environmental threats by using modern design and materials methods by reviewing the standards and the specifications and the critical requirements and taking into account the safety factors for building and infrastructure to resist the natural and environmental risks and threats like extreme weather conditions.
2. Including the Risk management and Business Continuity Management standards into the design especially in the early stage to be combined with the specification and requirements to assure an acceptable level of resilience in the design to overcome and withstand the different disasters and human threats in the operation and construction stage (Kallaos, 2014).

Through understanding from the previous definitions for the security and the resilience (from the homeland security), resilience is an element of the security as the ability to eliminate the risks. If these risks could not be eliminated, the ability of the system to *recover* (bounce) to the original state, when the sysem come back to the original effectively after a disaster or risk result of the security of the system.

Chapter Three: Conceptual Model

In this chapter framework will be adopted from the literature review:

1- The Framework is a framework for the innovation process in the critical infrastructure consists of two parts:

1.1 The innovation process in the critical infrastructure using the Ozhoron framework using the different elements:

- Drivers and inputs
- Benefits which here will mainly be the resilience
- Enablers

Framework

In the literature review some of the factors of innovation in the critical infrastructure (tools and role of the client and the consultant) have been linked to the resilience factor (level 1 and level 2); Recall from the literature review the criteria in which the critical infrastructure differs from the traditional infrastructure, while the main issues regarding the critical infrastructure in they which differ from the ordinary infrastructure are the risks and threats for the critical infrastructure which need innovation in the design, construction and operation from both the client and consultant in the project life cycle, as will be shown in the framework.

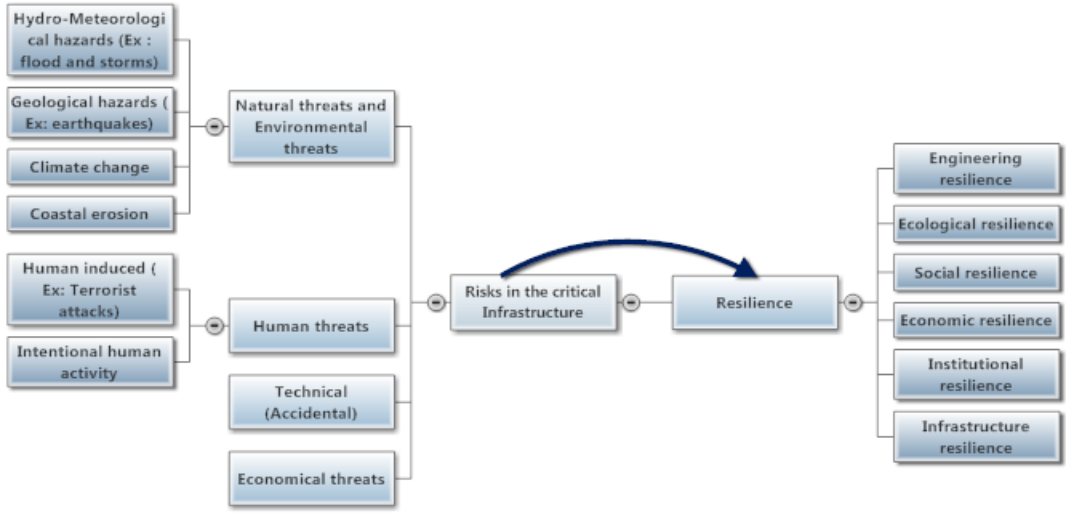


Figure 3.1 Risks for the CI and resilience different types

Framework (will be adopted using the Ozhoron framework for the innovation process as discussed in the literature review).Diagram and figures will be shown to expand the framework on the resilience showing relationship between the tools and strategies between the Innovation tools and strategies by both client and consultant and the different factors of the resilience in the critical Infrastructure.

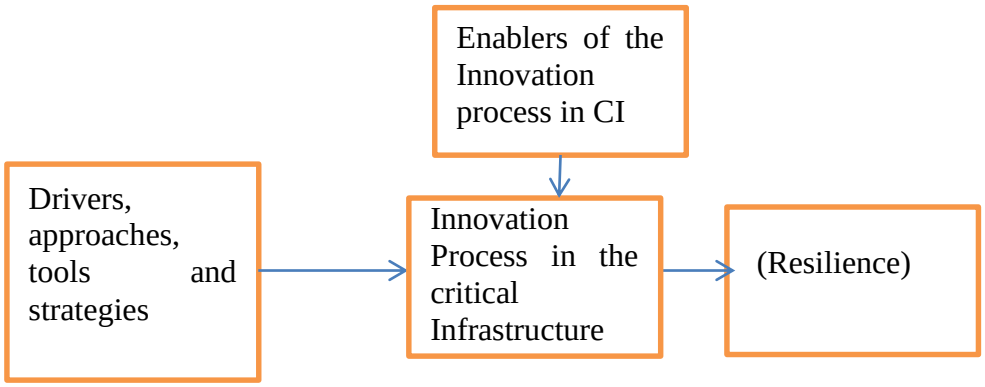


Figure 3.2 Framework

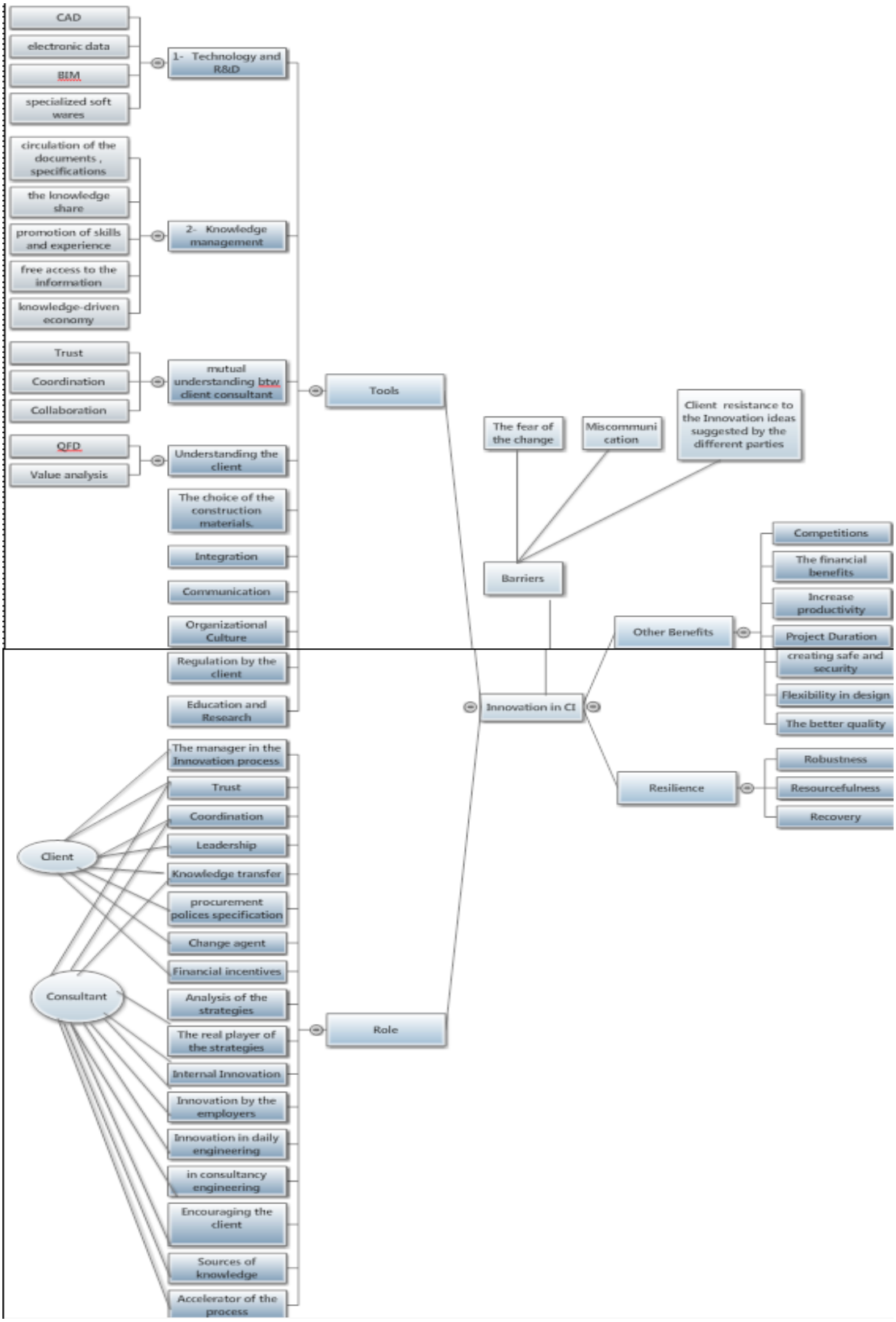


Figure 3.3 Expansion of the framework

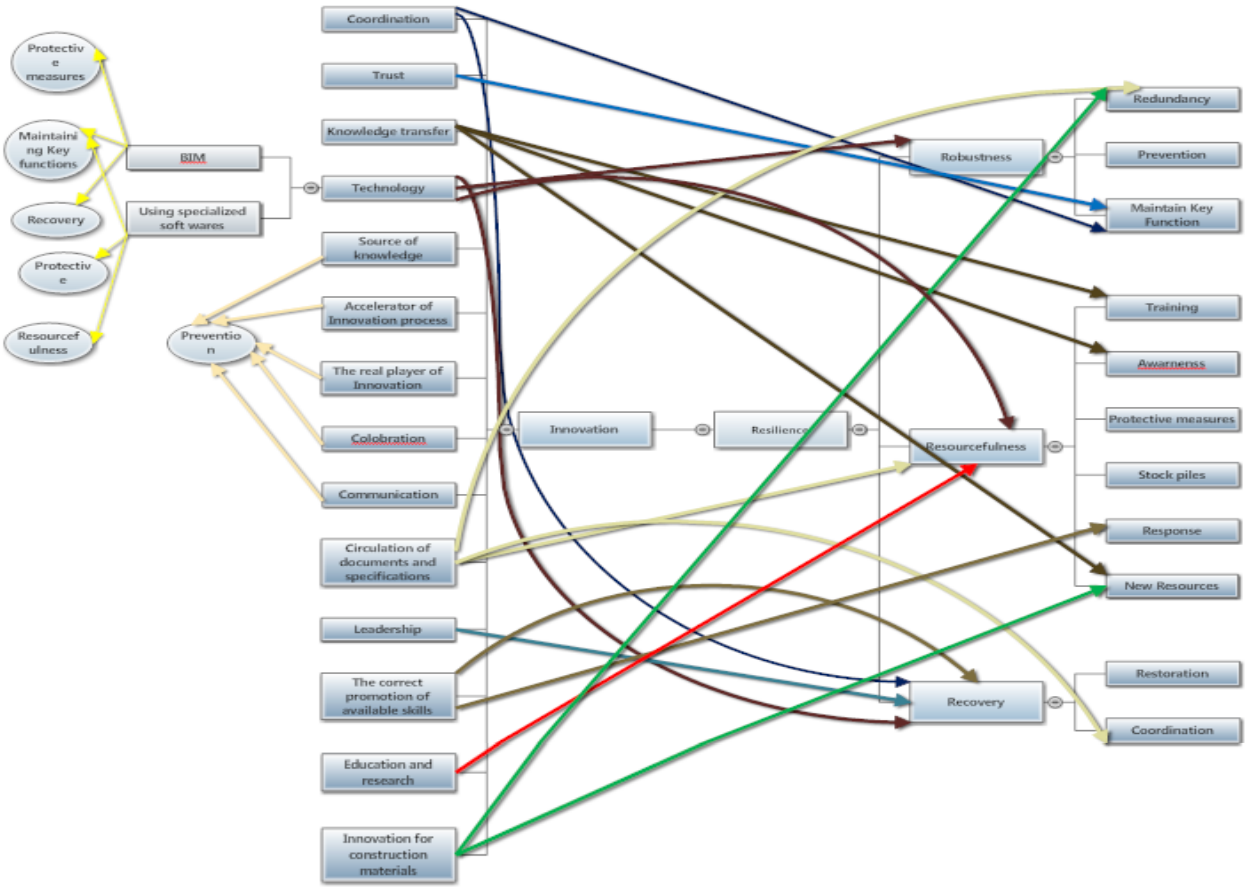


Figure 3.4 Relationship between Innovation factors and resilience factors in the critical Infrastructure

To simplify the relationship between the different factors, see below Table:

Innovation tool/strategy	Resilience factor level 2	Resilience factor level 1
Coordination	_____	Recovery
Coordination	Maintain key function	Robustness
Trust	Maintain key function	Robustness
Knowledge transfer	Training, awareness, new resources	Resourcefulness
Knowledge transfer	Prevention	Robustness
Technology	_____	Recovery, resourcefulness
Source of knowledge	Prevention	Robustness
Accelerator of innovation process	Prevention	Robustness
BIM	Protective measure	Resourcefulness
BIM	Maintain key function	Robustness
BIM	_____	Recovery
Using specialized software	Protective measures	Resourcefulness
Using specialized software	Maintain key function	Robustness
Using specialized software	_____	Recovery
Circulation of documents and specifications	Coordination	Recovery
Circulation of documents and specifications	_____	Resourcefulness
Circulation of documents and specifications	Redundancy	Robustness
Leadership	_____	Recovery
The correct promotion of the available skills	_____	Recovery
The correct promotion of the available skills	Response	Resourcefulness
Educational and research	Training, Awareness	Resourcefulness

Collaboration	Prevention	Robustness
Collaboration	Coordination	Recovery
Collaboration _____trust	_____	Robustness (as a result to trust)
Communication	Prevention	Robustness
Communication	Coordination	Recovery
Communication _____trust	_____	Robustness (as a result to trust)
Innovation of using the construction materials	Redundancy	Robustness
Innovation of using the construction materials	New resources	Resourcefulness

Table 3.1 the relationship between innovation tools and resilience factors

Notes on the framework:

1- Collaboration and communication is a result of the trust between the team members so as a result collaboration and communication will lead to the same result in the resilience factors as trust.
2- From the literature review, extra notes for innovation and resilience have been found that (collaboration, communication and technology) as innovation tools result in improving the social resilience.

Chapter Four: Research Method

4.1 Introduction

A qualitative approach has been used to study the resilience of three critical infrastructure by explaining the innovation process in the critical infrastructure and the role of the client and consultant in this innovation process by tools and strategies and the benefits highlighting the resilience for the critical infrastructure.

The approach highlights and clarifies in detail the source of data, the selection method and the data analysis. The source of data for this approach is highlighted by the client (owner) and the consultant.

A lot of literature examines the innovation process for the traditional projects due to the facts of the benefits for innovation in the construction Industry. Moreover, innovation in the project lifecycle starts in the design phase early in the project. However, not so much of the literature investigates the innovation process related to the critical infrastructure and the link or connection between the innovation and the resilience.

The conceptual model will be examined through observations, documents review and interviews relating to critical infrastructure projects.

The questions in the interview will address the dissertation questions and objectives. The questions and the instruments for data collections will be discussed in the following sections.

The findings from the different interviews will be used to examine the conceptual frameworks one and two and in additions to expand the conceptual framework number two that links the innovation strategies and tools with the resilience of different factors.

4.2 Selecting

In the context of the critical infrastructure, three major critical infrastructure projects have been selected in the Agriculture / water supply and Transportation sectors.

4.3 Analysis tool

The research adopts a conceptual framework for analyzing the projects. Framework explains the innovation process in the critical infrastructure and the relationship between the tools and strategies for the innovation and the different resilience factors; the strategies are mainly for the client and consultant, however some strategies are also applicable for the contractor team.

4.4 Instruments for data collection

Collecting data for the case studies through conducting face-to-face interviews with the client and the consultant team collecting answers for the questions related to the model derived from the literature review. In addition, investigating the organization and project innovation environment as well as investigating the projects documents. The interviews were done to address all project life cycle stages from the client and the consultant side responsible for the critical infrastructure. The interview questions were designed to identify the influence of each factor in the concluded conceptual model of innovation process on the selected projects. The interview questions were as follows:

The Interview start by explaining the term of the critical Infrastructure to the Interviewers

1- Describe the project and explain the aspects that can consider the project as a critical Infrastructure project.
2- Describe the main challenges, risks and threats that were considered for the project at the design and later experienced at the operation stage.
3- What were the tools, practices and strategies adopted to overcome these challenges?
4- Explain the role of client and the consultant in supporting and enabling the realization of innovation in support of this project

Chapter Five: Case studies

This chapter investigates three CI projects. Each project starts with describing the project and identifies the threats, risks and challenges for the design, construct and operate the project. An analysis will be conducted for the strategies, approaches and tools by the client and the consultant in order to draw a model by linking the Innovation tools (IT) with the Resilience factors (*Recovery*, *Robustness*, and *Resourcefulness)*

5.1 Case study one

5.1.1 Project Description

The project is a water supply project for a main Agricultural Land , which supply the needs of the food in the country and hence it consider a key factor in the food security for the country , the concept behind the project is to transfer the water from a low level dam to a higher dam through pump stations and pipes connected with the tanks and after that to transfer the water from the high dam tank to the Agricultural areas , the pump head (the difference between the two levels is around 300m) . The Agricultural Land covers the most of the Agricultural Lands in the country, It is a key sector in the gross domestic product of the country and a part in the exporting sector which affects the economy of the country.

The project have some risks, threats and challenges in the design and the construction as well as the operation. These risks and threats if they occurred they would have an impact of the availability of the water or the quality of the water delivered to the agricultural crops also any contamination of the water supply to the agricultural crops may affect the people health and this make a risk for the country safety.

Agricultural crops provides the essential support for economic for the country, so any destruction or damage will affect the whole country economy , from this side the project consider as a critical Infrastructure project to the country.

5.1.2 Threats, challenges and risks

From the Interviews questions for the design and contractor teams, threats can be divided to three main categorizes.

1- Natural and environmental threats:

A- Forecast methodology of the rainfall, the problem may occur in the design or the operation stage, which can lead to flood in the tank and have impact on the pipes or the pump stations.
B- Seismic hazardous, which leads to the cracks on the concrete of the tanks, or the pump stations, which can affect the availability of the water, deliver to the crops.
C- Climate change (The temperature change) has an impact on the concrete by the contraction and expansion this lead to a challenge in the design stage and risk in the construction and operation stage.

2- Human threats:

A- Local residence threat from stealing the water from the pipes connecting between the two dam tanks (Threat in the construction and operation stage).
B- Threats through delivery of the pump station from their factory countries (turkey and Germany)

3- Technical and/or accidental:

A- Durability of the pump station (risk and challenge on the project life cycle)
B- Electricity shutdown (threat in the operation stage)
C- Conflict between Local codes and International codes
D- Contamination of the water
E- Obstructions for the new pipelines (The existing Infrastructure)
F- Excavation for the pipelines (In the construction stage)

From the previous threats, table 5.1.1 summarizes the threats and the risks.

Threat	Risk
1- Forecast methodology of the rainfall	Flood in the tank and have impact on the pipes or the pump stations which can result in a damage in the pump stations and/or water overflow
2- Seismic hazardous	Cracks on the concrete of the tanks or the pump stations and thus water leakage or shutdown of the project
3- Climate change (The temperature change)	contraction and expansion of the concrete which can lead to cracks and thus water leakage or shutdown of the project
4- Stealing the water from the pipes by local residence	Water loss and leakage in the pipes
5- Delivery of the pump station from their factory countries	Project delay / pump station damage
6- Durability of the pump station	Shutdown of the pump stations which can lead to the risk of water cutting for the Agricultural land
7- Electricity shutdown	Stoppage/disconnect of the project in the construction which can lead to delay or shut down of the pump station and other works during the operation.
8- Conflict between Local codes and International codes	Errors in the design / conflict between the design drawings and the site conditions during the construction
9- Contamination of the water	Contamination of the crops
10- Obstructions for the new pipelines	Stoppage of the project / delay of the project
11- Excavation for the pipelines	Construction errors, safety issues

Table 5.1.1 Threats and risks for case study one

5.1.3 Innovation process of the critical Infrastructure

The previous risks, threats and challenges concluded from the interviews questions require solutions in a way that Innovation need to be included when addressing them. Each risk or threat have a strategy followed by the client and the consultant to overcome these dangers. The diffrent strategies refers to different Innovation tools (from the Innovation tools described in the Table 2.10 in the literature review). The strategies, tools and role of the client and the consultant are described in the table 5.1.2.

In this section, we will conclude strategies followed by the client and the consultant and the synonym Innovation tools, where Innovation will be donated as (I), Strategy will be donated as (S) and tool (T), Role (RO), client (C), consultant (CO).

Strategy (S)	Tools (T)	Role (RO)
1- Using the records from the satellite (IS1.1)	• Technology (IT1.1)	• The real player of the strategy (CO)
2- Check the different authorities and different database to take close records for the rainfall and climate change which required Integration tools	• Communication (IT1.2) • Collaboration (IT1.3) • Trust(IT1.4)	• Building trust (C, CO). • Coordination (C, CO).
3- Take the most critical situation in design to overcome the conflict and difference between International and local codes	• Circulation of documents and specifications (IT1.5). • The correct promotion of the available skills (IT1.6). • Educational and research (IT1.7).	• Internal Innovation (CO). • Innovation in the daily engineering (CO). • Innovation by the employees (CO). • Analysis of the strategies (CO).

4- Design the concrete and the pump station including the safety in the design to protect the concrete and the pump station from cracks and damage due to the seismic hazardous	• Educational and research (IT1.7) • Technology (IT1.1).	• Internal Innovation (CO). • Innovation in the daily engineering (CO). • Innovation by the employees (CO). • Analysis of the strategies (CO).
5- Client to appoint Insurance on the transportation of the pump station. And to appoint the correct transporter for the pump station and consultant to help the client of the right choice of the insurance company accelerate the project and have a safety in the transportation process	• Leadership (IT1.8). • Accelerator of the Innovation process (IT1.9).	• The manager in the Innovation process (C). • Leadership (C). • Change agent (C). • Financial Incentives (C).
6- Training the local residence about the importance of the project.	• Knowledge transfer (IT1.10)	• Knowledge transfer (C).
7- Sensors and cameras to	Technology (IT1.1)	• Analysis of the

monitor any water stolen and control programs to check the quantity of the water passing through the pipes	Using specialized soft wares (IT1.11)	strategies (CO). • The real player of the strategy (CO).
8- Using civil 3D program to give full picture in three dimensions to the all parties in the construction a program used for redesign and *recover*y easily and effectively.	Using specialized soft wares(IT1.11)	• Analysis of the strategies (CO). • The real player of the strategy (CO). • Internal Innovation (CO). • Innovation in the daily engineering (CO). • Innovation by the employees (CO). • Source of the knowledge (CO). • Encouraging the client (CO).
9- Have a trust through the communication and collaboration between the client and the pump station factories	Trust(IT1.4)	• The manager in the Innovation process (C). • Leadership (C). • Building trust (C).
10- Using telemetry technology which are	Innovation of using the construction materials	• Analysis of the strategies (CO).

fiber optics that connect long pipes together	(IT1.12)	• The real player of the strategy (CO). • Internal Innovation (CO). • Innovation in the daily engineering (CO). • Innovation by the employees (CO). • Source of the knowledge (CO). • Encouraging the client (CO). • Financial Incentives (C).

Table 5.1.2 Strategies, tools and role for client and consultant (case study One)

5.1.4 Resilience and Innovation

Twelve tools have been mentioned in the first case study as an Innovation during the design, construct and operate the project to adapt, prevent the risks and threats.

The resilience in the literature review consist of two level factors, the first level consists of three factor, *Recovery* (R1), *Robustness* (R2), *Resourcefulness* (R3)

Firstly the *Technology* (IT1.1) using the records from the satellite for the forecast for the rainfall will build a strong background for the designers (consultants) to design the project based on these Information recorded from the images and past forecasting data to have a measure of the quantity of the rain during the years the dangers of the flood in the dams/tanks and overflow which can damage the pump station so the designers can design a protective system for the pump station for the critical case for the rain , thus the technology in this case lead to a resilience by

protective measures *Resourcefulness* (R3). Similarly when design the concrete for the seismic hazardous will lead to *Resourcefulness* (R3) factor. Using technology by providing cameras and sensors to monitor the stolen (Human threats) during the operation of the water supply help in identifying the location of the water leakage in the system (pipes) exactly that the correct valve in that area can be shut down only whiteout cutting all the water of the project which accelerate the *recover*y process, hence the *Technology* (IT1.1) support the resilience by the *recovery* factor (R1).

Second, the effective *Communication* (IT1.2) tool between the client and consultant with different authorities and database for the records of the rainfall will lead to a strong coordination between the construction, design and the authorities and hence effectively coordination among them with the correct Information; the *coordination* is a level two factor from the *recovery* factor of resilience (R1).

Similarly effective *Collaboration* (IT1.3) with the authorities leads to effective coordination and though effective *recovery* (R1) plans.

Trust (IT1.4) is the result of the effective *communication* (IT1.2) and *collaboration* (IT1.3) when build trust between the client and the factories of the pump stations this can maintain the key function which result *Robustness* (R2) to the for the project during the construction of the pump stations for the tanks. In the same way when build the trust between the client and the consultant with the authorities and data center for the forecasting information.

Tool five is *the circulation of the documents and the specifications* (IT1.5) through the design team and the client requirements as when take the most critical situation for the different building codes so by comparing the different codes locally an internationally design team can be creative to take the most critical case with respect to the budget and client requirement so the project will have some kind of *Resourcefulness* (R3).

In the same context of taking the critical situation from both local and international codes tools IT1.6 and IT1.7 (*The correct promotion of the available skills, Educational and research)* respectively promotion for the correct and effective staff with the correct skills in the design team, these members will *response* to the challenge of design the critical situation for the different codes , response is important factor for the *Resourcefulness* (R3) with the correct

educational and research for these skills of the design issues will increase the training and awareness and so the *Resourcefulness* (R3) of the project, In the same way when design the pump station for the different risks than can be happened.

When the client appointed Insurance company on the transportation of the pump stations this *Leadership* (IT1.8) in this process help the *Recovery* (R1) of these pump station with regards to the time and budget of the project , the strategy of appoint the correct transporter and the insurance company from the client consider as an *Accelerator for the innovation process* (IT1.9) which strength the transportation process and hence the overall construction process for the project and prevent the factory from dismiss or play with the transportation path , any delay or dismiss of the pump station can result in the delay in the project and when client help the contractor in choosing and providing regulations for the contractor to choose the right insurance by helping from the consultant team , the previous knowledge from both client and consultant help the contractor to choose the right company for the insurance of the equipment (pump stations in this case study) and by providing the insurance company by the deadline these equipment need to be present at site so the project will run smoothly and effectively without delay and help contractor from wasting the time in searching for the right insurance company this which accelerator the Innovation process that can provide a protective measures for the transportation process *Resourcefulness* (R3). Prevention local residence from water stealing from the path of the pipeline through transfer the Information and knowledge of the importance of the project to the country (knowledge awareness) which is the tenth tool for innovation used in this project *Knowledge transfer* (IT1.10) that can help in some extent in the *Robustness* (R2) The next tool is *using specialized software* (IT1.11) link to the *Recovery* (R1) by the control programs for measuring the water flow in the pipe and the redesign (*recover*y) using three-dimensional programs like civil 3D. The last tool is the *Innovation in using the construction materials* (IT1.12) like the telemetry which are fiber optics that connect between the long pipes a new resources to give the project strength that the pipes will have the redundancy which can be linked to the two factors of the resilience *Robustness* (R2) , *Resourcefulness* (R3) respectively.

5.1.5 Case study (1) Model

From the previous discussion a link have been done between the Innovation strategies, tools and the resilience factor in the critical project of the water supply for the wide large agricultural areas

with different risk different strategy have been followed which will design and deliver resilient project, the following relations have been derived from the analysis as shown in table 5.1.3.

Innovation Tools (IT)	Resilience Factor (R)
IT1.1	R3 , R1
IT1.2	R1
IT1.3	R1
IT1.4 (as a result of IT1.2 and IT1.3)	R2
IT1.5	R3
IT1.6	R3
IT1.7	R3
IT1.8	R1,R3
IT1.9	R3
IT1.10	R2
IT1.11	R1
IT1.12	R2,R3

Table 5.1.3 Relationship between Innovation tools and resilience factors for case study one

The following diagram have derived from the previous table and the information in the discussion

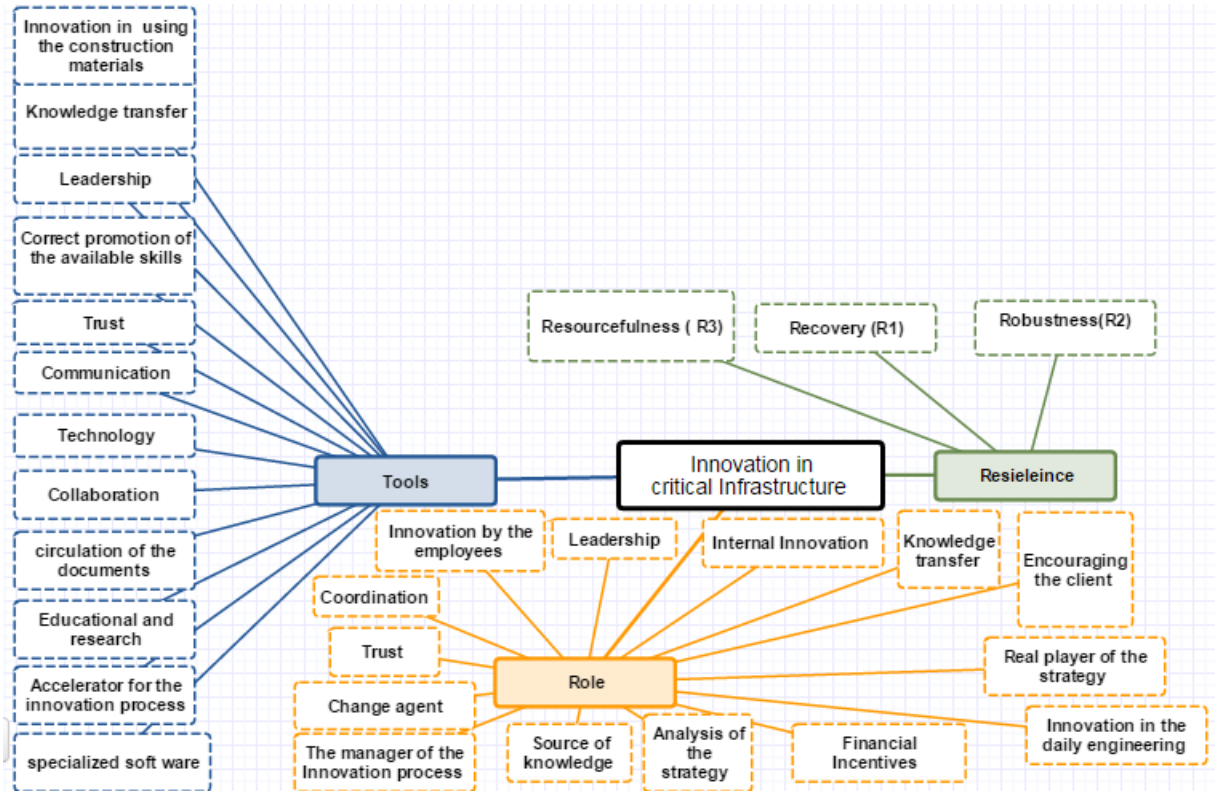


Figure 5.1.1 Cast study (1) model

5.1.6 Summary

The project was a water supply for a large and main agricultural land that covers most of the agricultural output for the country, the risks and threats to the project can affect the economy, and any contamination for the water can affect the health of the residence.

The Interviews with the construction and design teams show up some of the risks during the design, construction and operate the project, with the risks associated the different Innovation strategies have been addressed through the interviews

From the above analysis it shows that most effective innovation tool used is the technology where it was mentioned in three strategies in the project, followed by the use of specialized software using in two different strategies and this indicates the importance of the technology and specialized soft wares especially in the critical Infrastructure projects, this has discussed in the literature come from the complexity and unpredictable risk for the critical Infrastructure.

Trust , Educational and research and learning rank in the second place, and in fact the trust include the communication and collaboration and also turns out that communication and cooperation are common tool between the consultant and the client in the field of Innovation. While Educational and research is a tool for the consultant especially in the design phase

5.2 Case study Two

5.2.1 Project Description

Airport project is the aviation transportation gate for people and goods, any shutdown or damage in the airport and the aviation transportation can lead to economic losses for the country. The project is expansion the existing Airport by one more concourse. The new Concourse will handle around 90 million passengers, and will be connected to terminal one.

5.2.2 Threats, challenges and ris**k**s

From the Interviews questions for the design and contractor teams, threats and risks can be divided to three main categorizes

1- Natural and environmental threats:

Climate change for the planes (wind and storms) which can affect the plane path and the operation for the airport (risks during operation and risk during the design stage)

High temperature can affect the Apron slab concrete that can lead to cracks and so plane landing can lead to a crash.

2- Human threats:

Terrorist attacks (during the operation stage).

Workers and staff errors even small errors can lead to disasters in the aviation industry (during the operation stage and the construction stage).

Construction materials which can be flammable or damage the planes left after the project finish or while the operation is partially started and the construction not finished yet, by the contractor team members , recall from the literature review that human threats divided to two sectors the first section is the Human induced which relate for example to the terrorist attacks while the second section the human activities , also from the high level engineers in the contractors can miss some small materials which affect in real in the landing of the planes on the airport.

3- Technical and/or accidental:

Plane accidents.

Plane and aviation operation risks (shutdown and failure) (during the operation stage).

Design errors or construction risks in the road markings that can pose risks on the plane and vehicles inside the airport (during design and construction).

From the previous threats, table 5.2.1 summarizes the threats and the risks.

Threat	Risk
1- Climate change for the planes (wind and storms)	Plane accidents
2- High temperature	Apron slab concrete cracks / plane crash because of these cracks
3- Terrorist attacks.	Damages / explosions and any other risks coming from the attacks
4- Workers and staff errors (small errors)	Construction faults that can lead to shutdown of the airport or damages to the operation
5- The flammable construction materials that left in the construction site in the construction and operation stages	Plane accidents, shutdown of the operations
6- Errors in the Plane and aviation operation	Plane and aviation operation risks
7- Design errors or construction risks in the road markings that can pose risks on the plane and vehicles inside the airport.	Plane and airport vehicles accidents

Table 5.2.1 Threats and risks for case study Two

5.2.3 Innovation process of the critical Infrastructure

As case study one the following table will link the strategies followed in the airport project to overcome the threats and risks associated with the project with the Innovation tools determined in the literature review and the role of each the client and the consultant as will be shown in table 5.2.2 .

Strategy (S)	Tools (T)	Role (RO)
1- Integration with different department through the disaster to find the effective way for the *recover*y	• Collaboration (IT2.1) • Trust (IT2.2) • Leadership (IT2.3)	• Leadership (CO,C) • Coordination CO,C) • Trust CO,C)
2- Control Systems which can recognize the passengers ID and the possible attacks by using the Z backscatter technology to check the luggage	• Technology (IT2.4) • Using specialized software(IT2.5)	• Encouraging the client (CO). • The manager of the Innovation process (C).
3- Using creative sewerage and drainage system through the slabs to resist the flood that can happen from the rainfall	• Source of knowledge(IT2.6) • The correct promotion of the available skills (IT2.7)	• Source of knowledge CO) • Analysis of the strategy (RO6)(CO) • The real player of the strategy (CO) • Innovation in the consultancy engineering CO)
4- Introduce innovative	• Source of knowledge	• Source of knowledge

construction materials that mitigate the thermal challenges, e.g. Using special concrete with special admixture for the thermal change	(IT2.6). • Circulation of the documents and specifications (IT2.8) • The correct promotion of the available skills (IT2.7) • Educational and research (IT2.9) • Innovation in using of construction materials.(IT2.10)	(CO) • Analysis of the strategy (CO) • The real player of the strategy (CO) • Innovation in the consultancy engineering (CO)
5- Enhance H&S capabilities on site by Training the staff and the contractor workers about the safety of the airport.	• Knowledge transfer (IT2.11)	• Knowledge transfer (C)
6- Assign the creative and suitable staff for the design team	• The correct promotion of the available skills (IT2.7) • Educational and research (IT2.9)	• Innovation by the employee (CO) • Innovation in the consultancy engineering (CO)

Table 5.2.2 Strategies, tools and role for client and consultant (case study Two)

5.2.4 Resilience and Innovation

Eleven Tools associated to the strategies from the airport project have been addressed. These tools have been used in the project in order to resist, adapt or prepare the threats and dangers.

The resilience in the literature review consist of two level factors, the first level consists of three factor, *Recovery* (R1), *Robustness* (R2), *Resourcefulness* (R3)

The first tool the *Collaboration* (IT2.1) between the different departments through the disaster which means coordination between the different departments assist in find a suitable and effective plan for the *recover*y of the airport to the original phase to go back to effective operational stage , the coordination as discussed in the literature review lead to increase the *Recovery* (R1)factor. The collaboration between these departments is not easy task as the authorities for the forecast information need an authority or government to pass the Information and thus the collaboration between the client which in the critical Infrastructure are government authority help in build trust between firstly the authorities and the client and hence the trust between the authorities and the other teams like the consultant and the contractor Hence the second tool the *Trust* (IT2.2) which is result for the Collaboration will lead to effective *Recovery* (R1) .

In the same context of the Integration between the different departments client need to be featured in the *Leadership* (IT2.3) when the disaster occurs to make effective communication between the departments to *recover* effectively *Recovery* (R1).

Technology (IT2.4) using system that can recognize the passengers and the luggage to overcome any threat and attacks that lead to have new resources for checking the passengers before a disaster from attack can happen this is the core of the *Resourcefulness* (R3) factor. The fifth tool is connected in somehow with technology is *The using of specialized software* (IT2.5) as the technology used in checking the passengers and luggage need a control system by special software to control so this tool also assist in the *Resourcefulness* (R3) factor.

Source of knowledge (IT2.6) from the consultant/designer in using creative sewerage system to resist the floods and determine the special concrete to resist the thermal change that lead to cracks in the concrete and thus to the accidents all of these strategies prevent the accident from

happen that means it make the system/the project more stronger which increase the *Robustness* (R2) factor.

The following tool is *The correct promotions of the available skills* (IT2.7) which can be connected to the previous tool the source of knowledge because when promotion of the design teams skills help the knowledge of the whole team to be stronger source that response to the challenges will increase and thus the *Resourcefulness* (R3) will also increase. The tool number eight is the *Circulation of the documents and specifications* (IT2.8) help in choosing the correct materials like the concrete design to resist the thermal change and the concrete will resist this thermal change to overcome the cracks problem increasing the *Robustness* (R2) factor.

Educational and research (IT2.9) another tool in choosing the correct concrete by training and increase the awareness *Resourcefulness* (R3) as will the *Robustness* (R2) factor

Innovation in using the construction material (IT2.10) is the result of tools 2.7, 2.8, 2.9 in choosing the concrete to resist the thermal change that means new resource and thus the *Resourcefulness* (R3) will increase and the redundancy of the concrete will increase also and the cracks will be eliminated and this increase the *Robustness* (R2) of the airport.

The last tool was *Knowledge transfer* (IT2.11) about the safety of the airport and plane path especially to overcome the danger of the construction materials during the construction and operation stages these include training to increase the contractor awareness and thus prevent any plane accidents or shutdown of the airport operations, these refer to the *Robustness* (R2), *Resourcefulness* (R3).

5.2.5 Case study (2) Model

From the previous discussion a link have been done between the Innovation strategies, tools and the resilience factor in the critical project of the Airport with different risk different strategy have been followed which will design and deliver resilient project, the following relations have been derived from the analysis as shown in Table 5.2.3

Innovation Tools (IT)	Resilience Factor (R)
IT2.1	R1
IT2.2	R1
IT2.3	R1
IT2.4	R3
IT2.5	R3
IT2.6	R2
IT2.7	R3,R2
IT2.8	R3, R2
IT2.9	R3, R2
IT2.10	R3, R2
IT2.11	R3, R2

Table 5.2.3 Relationship between Innovation tools and resilience factors for case study Two

The following diagram have derived from the previous table and the information in the discussion

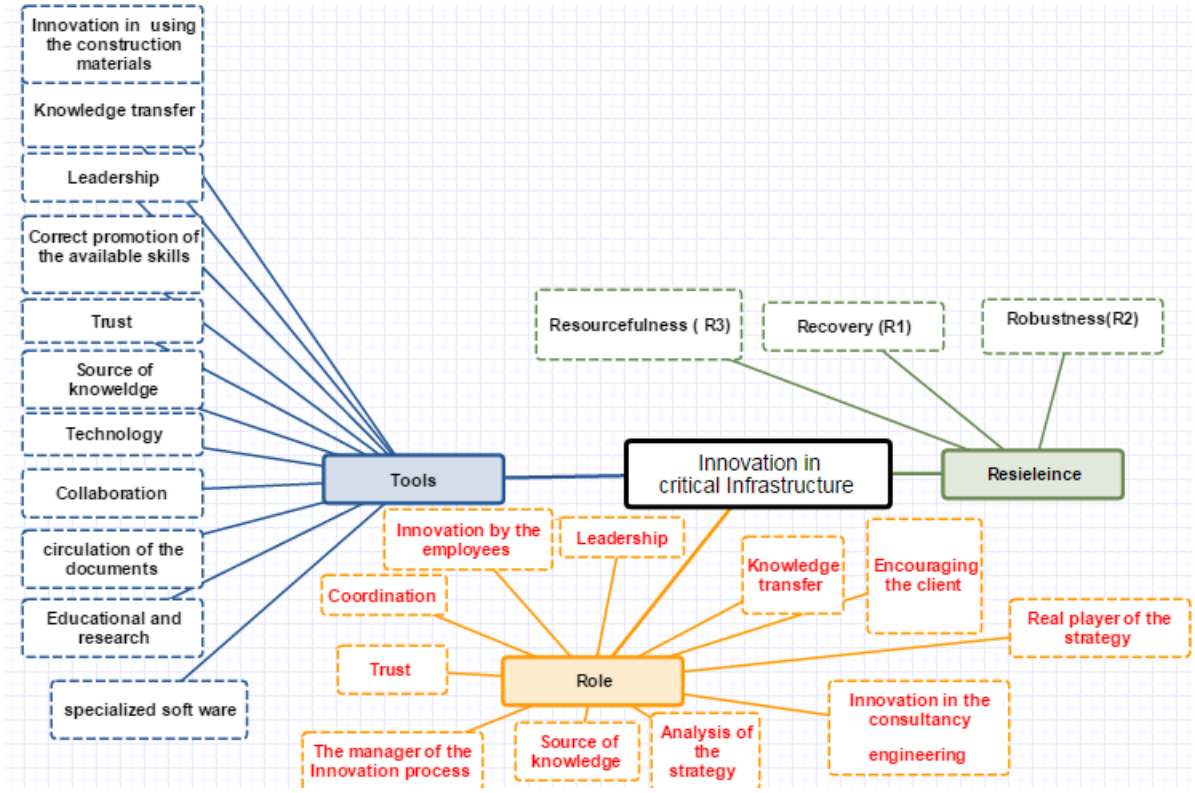


Figure 5.2.1 Case study (2) model

5.2.6 Summary

Airport is a an important critical Infrastructure because it consider as the aviation gate for any country, the natural risks is important and the sensitive threat to the planes and from the different hazardous on the airport ground.

In the analysis it is clear that using of special concrete for the Apron slab construction of the airport can help to resist the cracks that could been happen in the slab, this innovation of the using of this construction material has to be integrated with other Innovation tools like the correct promotion for skills in the design team , and the freedom for the specification and document to pass through other and educational and research which can be concluded that the Innovation is an integrated process which require combined and integrated tools and strategies.

The analysis shows that the Information especially safety concern should pass to the workers an example of the materials left on the ground that could affect the plane and lead to the crashes and accidents this can achieve by the knowledge transfer management.

Other conclusion from the analysis that Innovation needed not only in the pre-disaster process also even through the disaster that the essential tools like communication , collaboration and trust help in plan an effective *recover*y plan.

5.3 Case study Three

5.3.1 Project Description

A highway which connect major parts of the capital , this highway use to transport the people and goods through the city , any damage or obstructions on the Road can lead to decrease the efficiency of the transportation on this highway and by decreasing the resilience of the highway the safety and economy for the country will get affected.

5.3.2 Threats, challenges and risks

In this project Natural risks will be discussed , flood on the highway caused by the rainfall especially that Dubai drainage system are not designed to handle lot of rainfall which can lead to flood , the Flood on the highway reduce the efficiency of the highway and lead to traffic jam that can paralyze the country in the different sectors. (Threat during operation and construction) High temperature can affect the Asphalt and cracks, a challenge in the design stage.

From the previous threats, table 5.3.1 summarizes the threats and the risks.

Threat	Risk
1- Heavy rainfall	Flood which can lead to stoppage of the vehicles transportation on the road , and or accidents / traffic jam which can interfere with other main activities for the country
2- High temperature can affect the Asphalt and cracks	Vehicles accidents

Table 5.3.1 Threats and risks for case study Three

5.3.3 Innovation process of the critical Infrastructure

The following table will link the strategies followed by the client and the consultant in the highway project to overcome the threats and risks associated with the project with the Innovation

tools determined in the literature review and the role of each the client and the consultant as will be shown in table 5.3.2 .

Strategy (S)	Tools (T)	Role (RO)
1- Including some safety by using safety factor to design a sewerage system resist a rainfall more than the predictable	• Source of knowledge (IT3.1) • Circulation of documents and specification (IT3.2) • Educational and research(IT3.3) • Promotion of the available skills (IT3.6)	• Source of knowledge (CO) • The real player of the strategy (CO) • Analysis of the strategy (CO) • Innovation in the consultancy engineering (CO)
2- Coordination with forecast authorities to get accurate forecast for the rain	• Coordination (IT3.4) • Circulation of documents and specification (IT3.2) • Communication (IT3.5)	• The manager in the Innovation process (C) • Trust (RO6)(C, CO) • Coordination (RO7)(C, CO)
3- Asphalt design including the high temperature factor of safety.	• Source of knowledge (IT3.1) • Circulation of documents and specification (IT3.2) • Educational and research(IT3.3)	• Source of knowledge (RO1) (CO) • The real player of the strategy (CO) • Analysis of the strategy (CO) • Innovation in the consultancy engineering (CO)

Table 5.3.2 Strategies, tools and role for client and consultant (case study Three)

5.3.4 Resilience and Innovation

Six tools have been concluded from the different strategies followed in design the highway project.

The resilience in the literature review consist of two level factors, the first level consists of three factor, *Recover*y (R1), *Robustness* (R2), *Resourcefulness* (R3)

Source of knowledge (IT3.1) by the design team help in design a sewerage system that handle more than the expected quantity of the rain . The source of knowledge can be strengthen by the *Educational and research* (IT3.3) . *Circulation of documents and specification* (IT3.2) assist the design process these three strategies make the system (the highway) more strong to resist any future flood can be caused by the rainfall , these three tools so increase the *Robustness* (R2) factor.

Promotion of the available skills (IT3.6) help in building a strong team for the design challanges and this help in increasing the *resourcefulness* factor (R3) in the design which result to the *Robustness* (R2) of the system,

The forecast information need to be coordinated and communication between the client and the concerned authorities (*Coordination* (IT3.4), *Communication* (IT3.5)) and these information will be used in design a strong drainage system in order to resist the flood *Robustness* (R2).Comparing this point with the case study One “”The collaboration between these departments is not easy task as the authorities for the forecast information need an authority or government to pass the Information and thus the collaboration between the client which in the critical Infrastructure are government authority help in build trust between firstly the authorities and the client and hence the trust between the authorities and the other teams like the consultant and the contractor Hence the second tool the *Trust* (IT2.2) which is result of the Collaboration will lead to effective *Recovery* (R1) .”” communication and coordination are also tools to help the teams in the construction and design process like the contractor and the consultant to get the correct and predictable Information and forecast mythology about the rain.

5.3.5 Case study (3) Model

Innovation Tools (IT)	Resilience Factor (R)
IT3.1	R2
IT3.2	R2
IT3.3	R2
IT3.4	R2
IT3.5	R2
IT3.6	R2,R3

Table 5.3.3 Relationship between Innovation tools and resilience factors for case study Three

The following diagram has derived from the previous table and the information in the analyses of this case study.

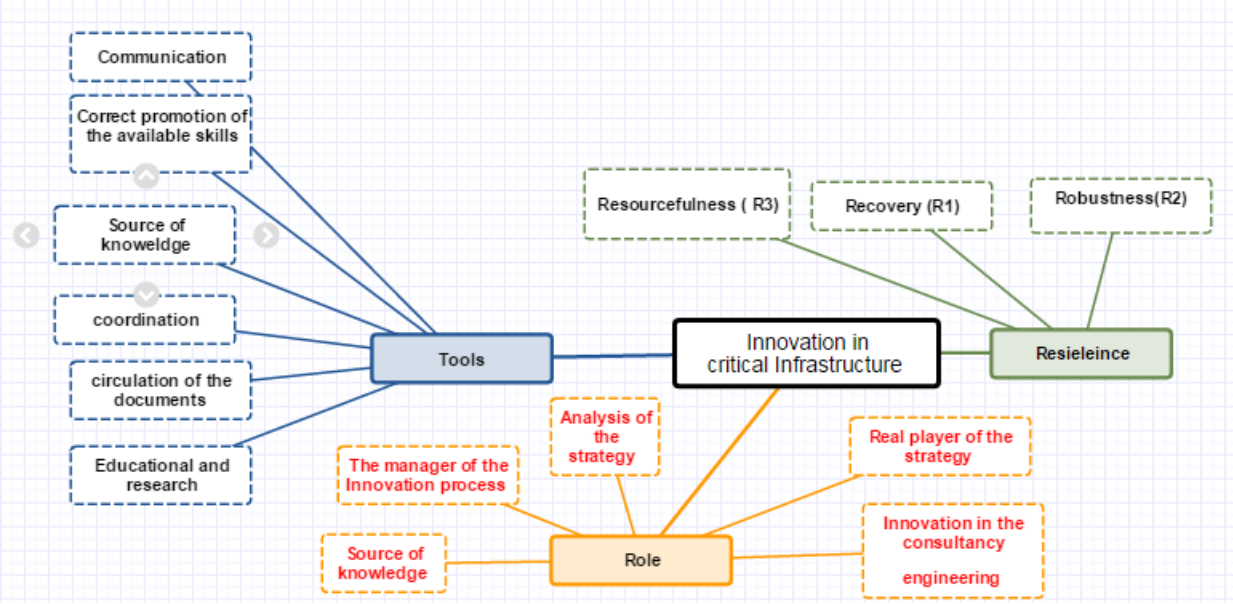


Figure 5.3.1 Case study (3) model

5.3.6 Summary

In this case study the project that have been discussed was in the transportation sector a highway that connects the main parts of the capital city .Any damage or shutdown of this project can lead to problems to the city in the economical and safety issues , the main risk discussed was related to the environmental threats mainly the rainfall which can lead to the flood which can lead to stoppage of the transportation path on this highway , accidents and traffic jam which can affect other sectors in the country.

To overcome the flood(Environmental threat) is to build a strong system especially in the design of the drainage system within the highway this mainly concentration on the *robustness* factor.

Designing the effective drainage system require an Integrated Innovation process using different source like educational and research and the correct circulation of documents and specification through the design team , for all the reasons Integration in the organization with correct promotion of the correct skills in the design team.

In the collecting of the Forecasting information the role of client to coordinate and communicate integrated in the design stage help design a resilient project.

Chapter six: Discussion , Conclusion and Recommendations

6.1 Discussion

In the three Case studies natural and environmental risks have the major impacts on the critical infrastructure that come from that these risks and threats lead mostly for disaster which can shut down or disconnect the system of the critical infrastructure, these risks affect the project usually in the operation stage although it can happen through the construction phase of the project life cycle , these threats pose challenges for the designer to design the Infrastructure to resist the risks like thermal, seismic, flood ,,,etc. All the projects that have been discussed have been shown that the effective Innovation tools lead to design and deliver a resilient critical Infrastructure. Although, each project, different innovative strategies have been developed due to the nature of the project, the risks associated with the particular critical Infrastructure. In the water supply project, the *Technology* was the most effective tools that best describe the strategies followed in the project. The second project, Airport is a famous sector for the critical Infrastructure one tool was the knowledge transfer, though the complexity and critically of the project require the normal Innovation and creativity in the design, but small errors and mistakes from the construction staff can lead to catastrophic accidents for the plane like the construction materials that left on the site of the work. In the last case study, the focus was to ensure the effective design for the sewerage system by correct skills of the consultant/design team and the continuous development by increasing the educational and research. Some common tools have been concluded in the all case studies are building trust in the whole life cycle of the project (design , construction and operation) Technology as discussed in the literature review have been considered as the most effective tool for Innovation especially for the critical infrastructure this been clearly shown in case one as the most effective tool used , and in the case of the airport technology integrate with using of specialized software help to overcome the risks from the human threats like the attacks. In the other hand the third case related to the highway project show no tool for the Innovation, but the correct educational and research for the design team / the consultant to design effective and to associated the creative skills in the right positions for the design of the sewerage system for the highway.

From the different case studies one important note have been shown up , in case study one and case study three for the forecast information role the client need to use the tools (communication , collaboration , coordination) with the authorities to get the correct Information about the rainfall and the yearly predictable rainfall quantity. While using the technology e.g. satellite records was the consultant role as the consultant is the real player for choosing the best technology for the satellite images and records, in the context of using technology using special soft wares like civil 3D as case study One for the water supply project is a consultant role he is the analyzer of the strategy by using the special software also the consultants role (Internal Innovation, source of knowledge, Innovation in the daily engineering, Innovation in the consultancy and educational and research) are shown clearly in design stage (design the materials (concrete and asphalt) , equipment (pump station) ,system (drainage and sewerage system) to handle the various risks especially the environmental risks (thermal change , rainfall , seismic hazardous). Accordingly Human threats like terrorist attacks was the client role as the manager of the innovation process by providing technology which identify the passenger ID and luggage and this need to be integrate with the role of consultant by encouraging the client for the new and innovative technology, however in case study one the solution for the water steal from the local residence was training them about the importance of the project to the country which is the role of the client by transferring the knowledge also this role (knowledge transfer) shown in airport case study as the threat can be accidental by the contractor staff as the plane may be affected by any construction materials on the airport ground and the client in this case need to enhance the H&S in the project and transfer of the safety of the plane in the operation stage. In some cases client have role by change the agent and provide the financial incentives like appointing correct insurance company for transporting the pump station from the original factory countries. In all cases the client need to have the leadership in the Innovation process as he act the manager of the Innovation process.

Although critical Infrastructure face less challenges, barriers in implementing Innovation due to many reasons (The size and complexity of the project , government (country authorities) involving as the client , The bigger size of the consultant and contractor firms) There were some challenges to implement such Innovation in the critical Infrastructure projects in case one and three the main challenge was collecting the Information of the forecast from the authorities and

data base , In the second case the consultant challenge to change the client in the airport regarding the safety issues or the client resistance to change the technology use

6.2 Conclusion

Critical Infrastructure is the main root for the country economy and safety, CI can be affected by different risks, threats and challenges through the project lifecycle that require designing and delivering a resilient critical Infrastructure which can be achieved through emerging the different Innovation tools from the different teams in the design, construct and operate. In the research, three critical Infrastructures have been analyzed through detailed Interviews , the Information gathered from the interviews it was concluded that that different tools of Innovation can help overcome, prepare, adapt or *recover* these risks.

In order to increase the resilience level in the critical Infrastructure , Innovation in design, construction and operation have been emerged by different tools followed by the client and the consultant . In the research an investigation have been done of the relationship between the Innovation tools and the resilience factors by examining the tools for client and consultant .The client takes the leadership in the Innovation process and as accelerator of the process .In the other hand the consultant is the real player of the Innovation process and the client encouraging agent for the Innovation process by using different tools, one of the most important tool is the technology and the using of the special software the technology also . Innovation in using the construction materials can play significant role to overcome the natural threats like thermal change. Communication , collaboration and building trust are important tools that required for all teams in the construction of the critical Infrastructure during the project life cycle even when disaster occurs(post-disaster) , these tools can increase resilience by the three resilience factors (*Recover*y, *Robustness* and *Resourcefulness*). Educational and research is an important strategy for critical Infrastructure in the design stage for the consultant to expect the risks for the critical Infrastructure. Knowledge transfer from the client and consultant to the other can have impact on the resilience especially in the human threats.

Although Innovation is important to build resilient Critical Infrastructure some barriers still obstruct the process like the fear of change and the client resistance to the Innovative ideas.

To sum up the research Innovation (with all tools, approaches and strategies) is equivalent to the resilience with respect to all the factors (*Recover*y, *Robustness* and *Resourcefulness*)

6.3 Limitation of the research

The Research has a number of limitations:

1. The Research have focused on the role of consultant and client (including the strategies, approaches and tools) in the Innovation process in the critical infrastructure projects, and that is because the client and consultant is the main engine for the Innovation in the critical Infrastructure, however contractor can promote the Innovation process and have his own tools to overcome the threats associated with the CI in conjunction with the consultant.
2. The number of the participants in the interviews was limited due to the nature of the research topic as well as the sensitivity of the critical infrastructure projects as most of these projects managers and engineers involve in them have some kind of reservation in giving some of the information related to these kind of projects.

6.4 Recommendations

1- To add specialized modulus to the postgraduate level concern about the critical infrastructure resilience due to the sensitivity of infrastructure projects and their importance to the security and economy of the country, and the difference from the regular infrastructure projects , one important note regarding the United Arab Emirates that UAE still have continuous working on the airport which consider one of the important CI.

2- Further studies should be conducted on the barriers that obstruct the process of the Innovation in the CI. few research in the literature about the barriers regarding the critical Infrastructure academic research required for the barriers for the Innovation process in the critical Infrastructure more research should be conducted in the barriers of the Innovation process in the critical Infrastructure

3- To give the opportunity for the contractor to participate in the Innovation process from the early phases of the project.

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Appendix

Appendix A: Interviews

Case Study One / Design team member

1- Describe the project and explain the aspects, which can consider the project as a critical Infrastructure project.

The project is a water supply project to supply a main agriculture are with the required water for the crops, the project consists of two dams each one with tank connected between each other with pump stations and pipes, the level difference between the two dams is 300 m .The first dam collecting the rain water, and the transfer to the upper dam while the upper tank supply the crops with the necessarily water through, the tanks consists of concrete structure the pump stations have been imported from factories from Germany and turkey. The project duration is three years. The agriculture areas contain the main supply of crops for the local residence and for International exporting; therefore any damage or shutdown of the water tank can affect the economy of the country.

2- Describe the main challenges, risks and threats for this critical Infrastructure in the operation stage.

(1) Shutdown of the pump station
(2) Shutdown of the electricity

3- Describe main challenges, threats and risks for the project in the design and construction stage which can lead to shut down, disconnect the system.

(1) Forecast mythology of the rainfall.
(2) Conflict between the local and the International codes.
(3) Challenge to design the concrete to handle the thermal change

4- How the organization try to ensure to deliver an effective critical Infrastructure, what are the tools and strategies to overcome these challenges.

(1) Check the different authorities/Database for the forecast analysis from International and local sources.

(2) Check the satellite records for the forecast analysis

(3) Take most critical requirements in each codes in a way to meet overall risks of the project

(4) To design the pump station to resist expecting seismic loads based on the time history of the area and considering safety factors recommended by the codes.

(5) Using special software like Civil 3D for redesign / recovery for the pipeline routes , telemetry technology which are fiber optics that connect long pipelines which connected to pump stations)

5- Explain the role of the client

The client needs to have leadership when the project needs to be designed against the natural risk and to coordinate and communicate with the authorities to have the correct data for the forecast analysis.

6- Explain the role of the consultant

Consultant need to help the contractor overcome the risks one example is that the contractor needs to provide external generator to ensure the electricity if any shut down occurred during the operation.

Case Study One / Construction team member

1- Describe the project and explain the aspects which can consider the project as a critical Infrastructure project.

The project consists of constructing two different level tanks with pump station and different pipes connecting them (Irritation) which one tank will be the dam that collecting the water from rain and transfer the water by pump station to upper Dam in which tank connected to this Dam will provide the agriculture areas through different pipes , the duration of the project last for three years.

The project consider critical infrastructure because it affect the country by the economy from the crops, and affect the country safety and security because contaminated water may affect the people health.

2- Describe the main challenges, risks and threats for this critical Infrastructure in the operation stage.

(3) Shutdown of the pump station
(4) Water contamination
(5) Tank overflow due to the rainfall
(6) Pipe lines which transfer the water may get affected by local resident to steal the water from.

3- Describe main challenges, threats and risks for the project in the design and construction stage which can lead to shut down, disconnect the system.

(1) Cracks of the concrete structure due to high temperature or thermal change due to expansion and contraction.
(2) Durability of the pumping station machines epically that the pump station will be stored in their factories for duration of 6-8 months, other risk will by during importing the machines.
(3) Excavation for pipeline during construction
(4) Risk of obstructions for the pipeline during construction

4- How the organization try to ensure to deliver an effective critical Infrastructure, what are the tools and strategies to overcome these challenges.

(1) To agree with professional transporter for the pump station machine and assure all required safety measures during the transportation of the pump station.

(2) Provide Insurance for the transportation

(3) To protect the pipelines from water stealing through sensors, cameras that show any waste of water through pipelines.

(4) To build trust and have coordination with the factories

5- Explain the role of the client

The Coordination between the different authorities, which require the client need to build trust between them and the supplier of the factories.

Coordination with police, using cameras to protect the pipeline from stealing and attacks

6- Explain the role of the consultant

Agree with 3rd party Inspection with conjunction with the client

Case Study Two / Design team member

1- Describe the project and explain the aspects which can consider the project as a critical Infrastructure project.

The project is upgrading of main airport with new concourse, Airport consider as the aviation gate for the country where people, cargo and goods transport internationally or locally, Airport shutdown or damage can affect the safety of the country what is why airport need to be monitored because people and materials transfer from outside the country to inside moreover any damage can cost the country economical losses.

2- Describe the main challenges, risks and threats for this critical Infrastructure in the operation stage.

(1) Climate change like wind can lead to disaster for planes way and the airport system.
(2) Terrorist attacks.
(3) Flood because of the heavy rainfall can lead to stoppage of the motion of the planes on the airport.

3- Describe main challenges, threats and risks for the project in the design and construction stage which can lead to shut down, disconnect the system.

(1) Risks in design errors like road markings can lead to disasters in the airport.
(2) Challenge to design the airport to have high security with regard to the passenger's flexibility, to design more areas for security check and emergency.

4- How the organization try to ensure to deliver an effective critical Infrastructure, what are the tools and strategies to overcome these challenges.

(1) Communication and collaboration between different departments and authorities can reduce the effects of a disaster if happened in the airport and to have easy way to recover and the airport operation to come to normal.
(2) Design a control system that can identify passengers ID to help eliminate the terrorist attacks and using Z Backscatter technology to check the luggage.
(3) Design sewerage system and drainage system through the airport apron slabs to overcome the flood risk.
(4) Assign the correct design team in the design stage to design the airport with regars to the safety issues that can lead to the accidents

5- Explain the role of the client

Client is government type that concern about using the innovation process and ideas and the ability of implementing BIM in the projects.

6- Explain the role of the consultant

The role of the consultant is the implementing the value engineering and contract management concepts in high levels.

Case Study Two / Construction team member

1- Describe the project and explain the aspects, which can consider the project as a critical Infrastructure project.
The project is upgrading of main airport with new concourse, Airport consider as the aviation gate for the country where people, cargo and goods transport internationally or locally, Airport shutdown or damage can affect the safety of the country what is why airport need to be monitored because people and materials transfer from outside the country to inside moreover any damage can cost the country economical losses.

2- Describe the main challenges, risks and threats for this critical Infrastructure in the operation stage.
(1) Construction materials, which some of them can be flammable or may cause harm for the plane may be left after contractor finish his work and operation start or while operation start partially before the contractor finish his work.

3- Describe main challenges, threats and risks for the project in the design and construction stage, which can lead to shut down, disconnect the system.
(1) Contractor staff and workers errors even small errors can lead to shut down one example is the fuel tank for the airport a rope which handle the float of tank removed by contractor team worker, he was cleaning the tank and think the rope is nothing so he remove from its place and this lead to stoppage in the tank and therefore to shut down the fuel for the airplane.
(2) Apron Concrete damage and cracks due to thermal change

4- How the organization try to ensure to deliver an effective critical Infrastructure, what are the tools and strategies to overcome these challenges.
(1) Using special concrete with special admixture for handling the thermal change.
(2) Train the staff and worker about the safety of the airport and the danger of the different materials

5- Explain the role of the client

6- Explain the role of the consultant
Supervise the work done and give the required Information to the contractor.

Case Study Three / Design team member

1- Describe the project and explain the aspects which can consider the project as a critical Infrastructure project.

Main Highway road connected between the capital city, the highway consider a main road for people, goods to transfer whit in the capital any damage of the road can affect negatively the economy of the country because the residence and people will late on their work, the goods will get late and may be damaged also the safety of the country will be affected because of the people using the road if any disaster happened whit that time.

2- Describe the main challenges, risks and threats for this critical Infrastructure in the operation stage.

I will speak about the risk of the rain , heavy rain in Dubai may occurred with the year and the roads doesn't have capacity to handle the heavy rain which can lead to the flood on the road and can cause traffic jam , accidents , delays for people for their duties.

Other risk is high temperature effect on the asphalt leading to cracks

3- Describe main challenges, threats and risks for the project in the design and construction stage which can lead to shut down, disconnect the system.

I will speak about the risk of the rain , heavy rain in Dubai may occurred with the year and the roads doesn't have capacity to handle the heavy rain which can lead to the flood on the road and can cause traffic jam , accidents , delays for people for their duties.

Other risk is high temperature effect on the asphalt leading to cracks

4- How the organization try to ensure to deliver an effective critical Infrastructure, what are the tools and strategies to overcome these challenges.

(1) Design of the drainage system which can handle the heavy rain.

(2) Coordination with forecast authorities through UAE to predict the rainfall during an acceptable period of time.

(3) Asphalt design including the high temperature factor of safety.

5- Explain the role of the client

Client (municipality and RTA) must put the regulations and polices to check the drainage system as per the specification to handle the heavy rain.

6- Explain the role of the consultant

Appendix B: Critical Infrastructure Definitions

Definition	Authority, government, literature	Year of publication/source
Infrastructures that their destruction impact on the defense or economic security.	Executive Order 13010 establishing the President's Commission on Critical Infrastructure Protection (PCCIP)	1996
There are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof.	The Department of Homeland Security	https://www.dhs.gov/topic/critical-infrastructure-security
Processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic.	Government of Canada	http://www.publicsafety.gc.ca/cnt/ntnl-scrt/crtcl-nfrstrctr/index-en.aspx
Asset or system which is essential for the maintenance of vital societal functions.	European Commission	http://ec.europa.eu/dgs/home-affairs/what-we-do/policies/crisis-and-terrorism/critical-infrastructure/index_en.htm

Infrastructure that provides an essential support for economic and social well-being, for public safety and for the functioning of key government responsibilities, such that disruption or destruction of the infrastructure would result in catastrophic and far-reaching damage.	Protecting Critical Infrastructure in the EU CEPS Task Force Report	2010
"lifeline systems" that physically tie together metropolitan areas, communities, and neighborhoods, and facilitate the growth of local, regional, and National economies	Sustainable Critical Infrastructure Systems: A Framework for Meeting 21st Century Imperatives: Report of a Workshop • Author: National Research Council (U.S.)	2009
Specific assets which if destroyed or seriously disrupted would cause major disruption to the service being provided.	The Centre for the Protection of National Infrastructure (CPNI)	http://www.cpni.gov.uk/
Systems, assets, facilities and networks that provide essential services and are necessary for the national security, economic security, prosperity, and health and safety of their respective nations	Forging a Common Understanding for Critical Infrastructure (Shared Narrative)	2014