AN ABSTRACT OF THE DISSERTATION OF

Fan Zhang for the degree of Doctor of Philosophy in Civil Engineering presented on June 10, 2016

Title: Introducing the Concept of Foundational Attributes and Project Metabolism to Assess Construction Project Similarity

Abstract approved: ____

John A. Gambatese

A construction project is considered to be unique due to the process of delivering a customer-designed product, diverse stakeholders involved, the unique location and timeframe of construction, and specific social, economic, and environmental constraints attached to it. The uniqueness of construction projects brought great challenges to the construction industry professionals as well as researchers and educators in the construction discipline. If a method or a model can be developed to assess the similarity between projects and make project comparison more science than art, we can increase the confidence level of researchers when they conduct analyses and make conclusions. We can help industry professionals make better decisions based by providing more accurate information.

This dissertation describes three attempts to try to create a new level of thinking and to solve the problem of project comparison. The first attempt is to adopt a concept created by a well-known researcher and to figure out if this is the solution to the problem. The second attempt is to review the history of construction to see what we can learn from the history. The third attempt is inspired by the findings of the first two approaches, and the author creates a new concept to understand construction projects through a new lens.

Manuscript 1 describes the definition and develops a framework for the concept of Foundational Attributes of construction projects. A literature review is conducted to create the framework, and case study projects are applied to the framework to demonstrate how this concept helps with project comparison. Manuscript 2 reviews the history of the construction industry, from the very first structure in the Stone Age to the construction industry we have now. A review of the history helps to see the trend and the development of the construction industry, and helps to understand the important things that do not change over time. Manuscript 3 introduces the concept of Project Metabolism which was inspired by the findings of the first two manuscripts. Concept mapping methods are used to help with defining the concept and a literature review is conducted to help with the concept development. A survey is carried out to gather opinions from industrial professionals and the responses are analyzed using statistics tools.

Introducing the Concept of Foundational Attributes and Project Metabolism to Assess Construction Project Similarity

by

Fan Zhang

A DISSERTATION

submitted to

Oregon State University

in partial fulfillment of

the requirements for the

degree of

Doctor of Philosophy

Presented June 10, 2016

Commencement June 2017

Doctor of Philosophy dissertation of Fan Zhang presented on June 10, 2016

APPROVED:

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Head of the School of Civil and Construction Engineering

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Fan Zhang, Author

ACKNOWLEDGEMENTS

The author would like to express sincere appreciation to my Ph.D. advisor Dr. John Gambatese for his everlasting and unconditional support and encouragement during my entire Ph.D. study. I would like to thank my committee members: Dr. David Sillars, Dr. Ingrid Arocho, Dr. Sarah Emerson, and Dr. Jimmy Yang, for their patience, guidance, and advice. I would also like to thank my former committee members: Dr. David Rogge who retired two years ago, and Dr. Chris Lee who left Oregon State University last year.

I received much help during my stay at Oregon State University. Kathy Westberg, Dana Ainsworth, Cindy Olson, Jordan Jones, Paul Montagne, Lauren Farmen-Schnoor, and Jan Strombeck from the School of Civil and Construction Engineering at OSU helped me in various ways. The members of Gambatese Research Group have always been helpful and supportive. I would like to thank Chuma Nnaji for his daily reminder to drag me to the office to work on my dissertation for the past month.

Other than within the School of Civil and Construction Engineering, Sheila Evans, Josh Norris, and Ty Atwater from Adventure Leadership Institute of OSU trusted me to work as a climbing instructor and an outdoor trip leader. Those must be the coolest jobs I will ever have. I also appreciate the opportunity provided by Dee Curwen and Caitlin Sullivan for me to volunteer at Corvallis Multicultural Literacy Center. They accepted and welcomed me when I was turned down by all construction companies that I applied.

Without my parents' support, I would not be able to come to the US for graduate study. They have always been my biggest supporters and influencers. I would also like to thank my MS advisor Dr. Oswald Chong who introduced me to the field of construction management. I would like to thank the University of Southern Mississippi who offered me my first professional job. I am looking forward to a new life chapter in Hattiesburg, MS.

The best thing happened to me during my stay in the US is to know and believe in God. It opened my gate of change. Without trusting in God, I would not be who I am today. Thank God for bringing the book "The 7 Habits of Highly Effective People" to my attention. The book changed my life dramatically at a critical moment, and it still influences me daily. I am grateful for all the friends I have in Corvallis, and I believe that God brings you to me. May God bless you all.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure Page

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure Page

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

Chapter 1 Introduction

1.1 Problem statement

1.1.1 The uniqueness of a construction project

It is widely agreed that almost every construction project is unique in its own way. This argument is supported by the fact that a construction project is usually the process of producing a custom-made structure which cannot be assembled on a factory production line. A construction project typically starts with an owner's desire to have a certain structure to serve a specific need. After that, designers and consultants are involved in the planning process to design a structure to meet the owner's goal. Then, contractors are hired to make the design a physical entity. Finally, after the construction of the structure is substantially completed, the owner or the end user occupy the structure and begin to use it. Construction projects end when the final physical structure is delivered to the owner, but it is not the end of the work on a structure. Usually during the lifetime of a structure, regular maintenance is necessary for the structure to continue to function. At the end, the structure is demolished and the land which the structure is located on is freed for other usages. This is a typical life cycle of a structure.

A construction project is unique due to the fact that the stakeholders involved in one project are usually different from those in another project. During the process of design and construction of a structure, many organizations are involved. The number of organization involved in a project usually depends on the magnitude and complexity of the project. A mega project could have hundreds of organizations working on it, and many of those organizations may have never worked together before or will never work together again. Considering that the interaction within and among different organizations involved in a project is an important part of the overall process, it is reasonable to conclude that construction projects are different when they have different stakeholders involved.

In addition, a construction project is considered to be one of a kind due to its unique location. The location of a construction project has a significant impact on the cost, schedule and many other aspects of a project. It affects the design of the job site, the sequence of the work, the time to get permits, the public impacted by the construction, material availability, material transportation, temporary structures, temporary fencing, nearby traffic, and the time allowing the work to take place. Therefore, the location of a project contributes a significant amount to the uniqueness of the project.

The time when the structure is constructed has a big impact on overall project performance as well. First of all, the price for materials, labor and equipment is changing frequently, so structures built at different time periods could result in very different project costs. Second, due to the fact that many places have distinct seasonal weather conditions, the time of the year when the construction work is being conducted has a large impact on the many aspects of a project. For example, some commercial projects may have a very specific time constraint due to the owner’s request to open the business on or before a specific date, so even if the time of the year is not fit for construction, the work needs to proceed. If the structure were to be built at a different time, many aspects of the project outcomes could be different.

Other than a time constraint, a project can have many other constraints, such as social, economic, and environmental constraints. These constraints are associated with the location of a project, the time when the project is built, the culture and preference of the local community, and local environmental regulations.

In summary, a construction project is considered to be unique due to the process of delivering a customer-designed product, the involvement of diverse stakeholders, the unique location and timeframe of construction, and specific social, economic, and environmental constraints attached to it. All those factors acting together make a construction project unique. The factors mentioned above are not independent, and they affect each other as well.

1.1.2 The problem associated with the uniqueness of a construction project

The uniqueness of construction projects has brought great challenges to construction industry professionals as well as researchers and educators in the construction discipline. This characteristic brings limitations to researchers when they try to compare multiple projects and make inferences, as well as to industry professionals when they try to make decisions based on previous projects. The current common practice is to ignore differences between projects and assume that they are similar enough so people can go on with their analysis and make conclusions. Sometimes people address this issue by only comparing projects that fit certain criteria. It is better than no standard at all, but the confidence level is low.

For example, consider a research study is being developed to evaluate the effectiveness of a new safety procedure. To figure out if the procedure enhances construction safety, the researchers probably implement the procedure on one or more projects, and use other similar projects which do not have the new safety procedure as controls. However, the projects may not be the same and the researchers assume that they are comparable. Even though the researchers can still analyze data and make conclusions, their conclusions are based on a seemingly false assumption that the projects are similar enough.

1.1.3 The significance of solving the problem

If a method or a model can be developed to assess the similarity between projects and make project comparisons more science than art, we can increase the confidence level of researchers when they conduct analyses and make conclusions, and we can help industry professionals to make better decisions based on better information. Considering the example of a research study to evaluate the effectiveness of a new safety procedure mentioned in the previous section, if some kind of tool can be used to justify the researchers' assumption and to prove that the projects are similar enough to be compared, it could significantly boost the confidence level, and it will be a big contribution to the construction research community.

1.2 Current studies about comparing projects

A thorough literature search was conducted to locate any past and current studies directly related to construction project comparison, and unfortunately, none have been found. As mentioned above, researchers compare projects in their research studies with or without acknowledging the fundamental differences between projects. One of the reasons for why there has been no effort on making a more justified comparison between projects is that the uniqueness of construction projects is a commonly accepted fact, and it is not possible to make an apples-to-apples comparison between projects. Another reason for the lack of research effort on this subject could be because the construction management research community is used to doing qualitative research, and this kind of research is more of an art than a science, so there is no need to address seemingly small differences between projects. Unlike doing research in a controlled lab, doing research on a construction project is too complicated and contains too many variables, so there is no need to know to what extent the projects being compared are similar.

As discussed in the previous section, solving this problem is worthwhile and will have a significant impact on both the research community and the construction industry. Therefore, the lack of previous research efforts presents a chance and a challenge. The author is determined to make the initial effort to work on this subject.

1.3 Proposed solution—a new level of thinking

This is a complicated problem, with no previous studies to learn from. The author wants to try something different to see if a solution can be found or not. Albert Einstein once said, "The significant problems we face cannot be solved at the same level of thinking we were at when we created them." Therefore, to solve the current problems in the construction industry, a new level of thinking could be a possible solution. However, what is this new level of thinking? How can we find it? How could it help to solve the problem brought by the uniqueness of construction projects? The author is going to try to answer these questions in this dissertation.

This dissertation describes three attempts to try to create a new level of thinking and to solve the problem of project comparison. The first attempt is to adopt a concept created by a well-known researcher and to figure out if this is the solution to the problem. The second attempt is to review the history of construction to see what we can learn from the history. The third attempt is inspired by the findings of the first two approaches, and the author creates a new concept to understand construction projects through a new lens.

1.4 Research plan

This dissertation is mainly composed of three manuscripts, and each of them explains one attempt to solve the problem as mentioned in the previous section. An introduction to explain the problem being researched is provided at the very beginning, and a general conclusion section to summarize all findings of the three manuscripts is provided at the end.

Manuscript 1 describes the definition and develops a framework for the concept of Foundational Attributes of construction projects. A literature review is conducted to create the framework, and case study projects are applied to the framework to demonstrate how this concept helps with project comparison.

Manuscript 2 reviews the history of the construction industry, from the very first structure in the Stone Age to the construction industry we have now. A review of the history helps to see the trend and the development of the construction industry, and helps to understand the important things that do not change over time.

Manuscript 3 introduces the concept of Project Metabolism which is inspired by the findings of the first two manuscripts. The concept mapping method is used to help with defining the concept and literature review is conducted to help with the concept development. A survey is conducted to gather opinions from industrial professionals and the responses are analyzed using statistics tools.

The three manuscripts are all about finding a method to solve the problem brought by the uniqueness of construction projects, and each of them can be viewed as a separate research study. As shown in the figure below (Figure 1.1), the manuscripts are parallel, but they are also inter-connected in many ways. For example, the third manuscript is inspired by the findings of the first two, and without the first two attempts, the third one would not be as what it is now.

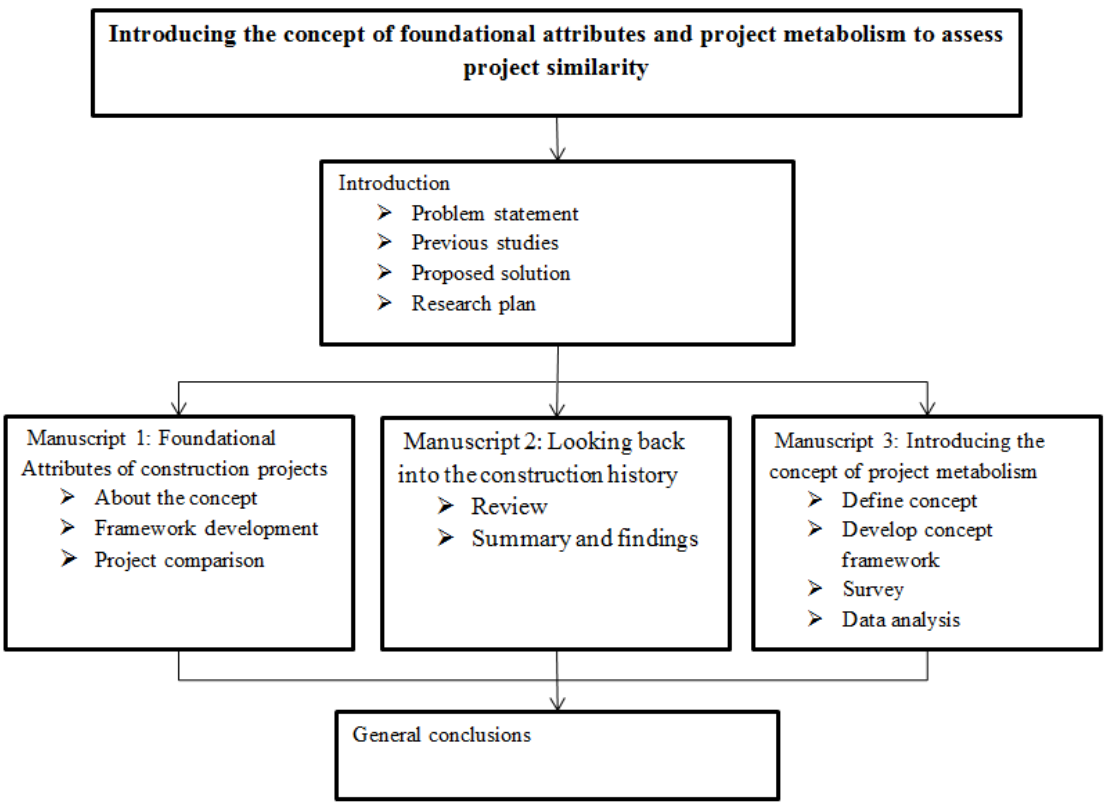

Figure 1.1 Research plan flowchart

Chapter 2 Foundational Attributes of construction projects (Manuscript 1)

2.1 An overview

Manuscript 1 describes the definition and develops a framework for the concept of Foundational Attributes of construction projects. A literature review is conducted to create the framework, and case study projects are applied to the framework to demonstrate how this concept helps with project comparison. A spider chart is chosen to host the concept of Foundational Attributes, and two case study projects are selected to demonstrate how to quantify project similarity using the concept of Foundational Attributes and a spider chart. Last but not least, lessons learned and future research directions are discussed at the end of this manuscript.

2.2 The concept of Foundational Attributes

The concept of Foundational Attributes of construction projects was initially mentioned in the keynote presentation given by Dr. John A. Gambatese during the CIB W099 Conference 2011 in Washington, D. C. The presentation was titled "A Look at Prevention through Design Based on Foundational Attributes of Construction Projects". In the presentation, Dr. Gambatese introduced the concept of foundational attributes of construction projects. The Foundational Attributes of construction projects are defined as *the fundamental elements of all projects that establish a project's nature and shape a project's outcomes, and the disposition of a project's foundational attributes must be known in order to understand and characterize a project, to compare one project to* *another, and to determine how to effectively impact a project's outcomes* (Gambatese 2011). Dr. Gambatese proposed five foundational attributes and described the scope and meanings of them as follows.

- Physical Form and Function
    - The physical properties of a project's design and the construction features and processes.
    - Shape, size, weight, texture, materials, stress, strain.
    - The nature and arrangement of construction activities undertaken to construct a project.
- Organizational and Project Structure
    - The formal relationships established between the project team members that define the interconnectivity and interactions between the parties.
    - The formal relationships within an organization which establish the roles and responsibilities of the employees, and the relationships between the employees on a project.
- Resources, Tools and Processes
    - The devices and resources utilized to design and construct a project and the means and timing in which they are implemented.
    - The materials, equipment, labor, money, and time needed and available to construct a project.

- Culture
  - The patterns of interacting elements and the accumulated learning of a group.
  - The ways of thinking, feeling and perceiving the world that has made the group successful and shape its interpretations and actions.
  - The shared beliefs in the minds of all employees.
- Risk
  - The potential that an action, activity, or condition will lead to a loss.
  - Probability, severity, exposure
  - Risk tolerance/threshold

Figure 2.1 is an illustration of the five foundational attributes and how they may work together to define a project. In the figure, the area enclosed by the solid lines represents one project and the area enclosed by the dash lines represents another project. The overlapping area represents the similarity between the two projects.

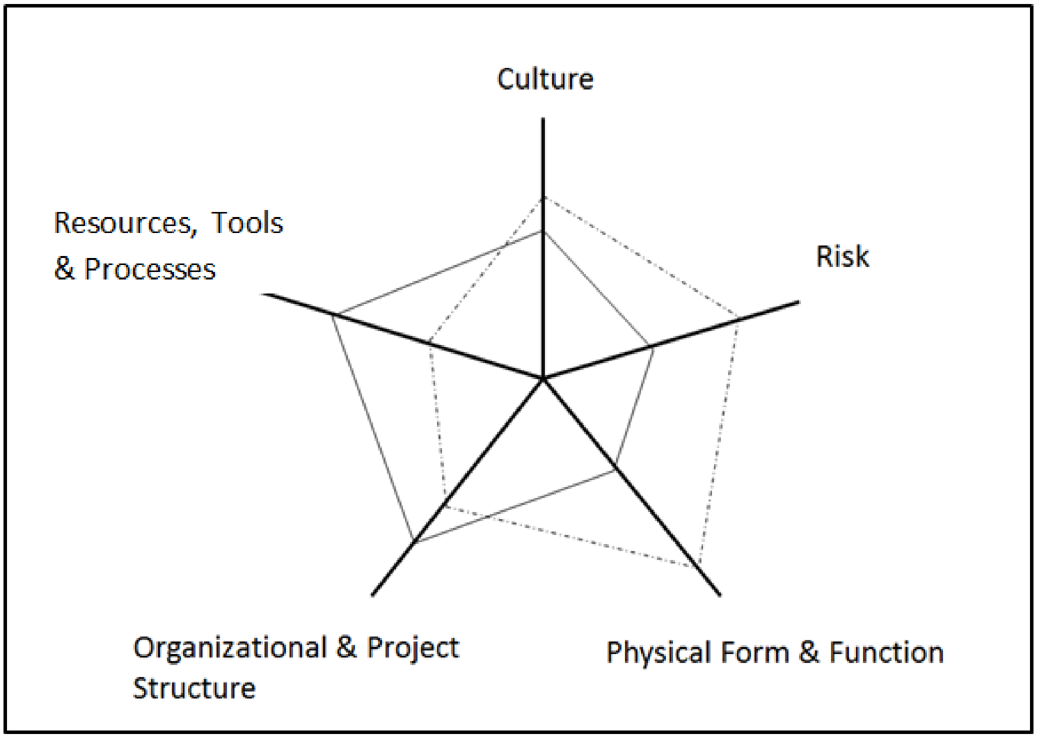

Figure 2.1 Illustration of the five foundational attributes

The illustration in Figure 2.1 is just one possible framework, and there has been no effort to quantify the five attributes. It is to be determined whether or not the overlapping area could represent the similarity between projects, and if so, what is the threshold used to conclude that two projects are similar enough to be considered comparable.

2.3 Research plan

2.3.1 Research objectives and questions

The primary objectives of this research study are 1) to develop the framework of Foundational Attributes of construction projects, and 2) to figure out how the concept helps with project comparison. To achieve these objectives, the following research questions need to be answered.

Research questions for Objective 1 – to develop the framework of Foundational Attributes:

- What are the elements of Physical Form and Function of a construction project?
- What are the elements of Organizational and Project Structure of a construction project?
- What are the elements of Resources, Tools and Processes of a construction project?
- What are the elements of Culture of a construction project?
- What are the elements of Risk of a construction project?
- How to quantify each attribute?

Research questions for Objective 2 – to determine how the concept helps with project comparison:

- Is the spider chart appropriate to illustrate the Foundational Attributes of a construction project?
- Does the overlapping area represent the similarity between projects? If so, how to benchmark the similarity?

2.3.2 Research methods

To answer the research questions and fulfill the research objectives, multiple research methods are used. To achieve the first research objective, the author conducts an intense literature review to populate each attribute and to try to quantify each attribute as well. The author evaluates the appropriateness of using a spider chart as the proposed host for the concept in order to compare projects after the framework of the concept is developed. The case study method is used to explain and demonstrate how it works.

2.4 Framework development

To develop the framework of Foundational Attributes, a literature review is conducted. Various sources are used to populate each attribute, and potential methods to quantify each attribute are discussed at the end of each section.

2.4.1 Physical Form and Function

The attribute of Physical Form and Function of a construction project refers to the physical properties and the function of the final product. In the construction industry, it is a common practice to put projects into two major categories: building construction and heavy civil construction. Building construction is also referred to as “vertical” construction, and heavy civil construction, also called “horizontal” construction, usually includes projects involving highways, airports, bridges, canals, harbors, dams, and other major public works (Nunnally 2001). Another popular way to categorize construction projects is based on the owner’s status. If the owner is a public entity, then the project is a public project, and if the owner is a private company or individual person, then it is a private project.

According to the U.S. Census Bureau, the construction industry can be divided into private residential, private nonresidential, public residential, and public nonresidential construction. The newest data about Value of Construction Put in Place is based on the information before the end of March 2016, and Figure 2.2 is a pie chart showing the distribution of the values (Bureau 2016). According to the data released by the U.S. Census Bureau, the total construction value for the year 2016 is estimated to be $1,137.5 billion, of which 38% is from the private residential sector and 36% is from the private nonresidential sector. Public residential projects only account for 1% and public nonresidential projects contribute 25% of the total value.

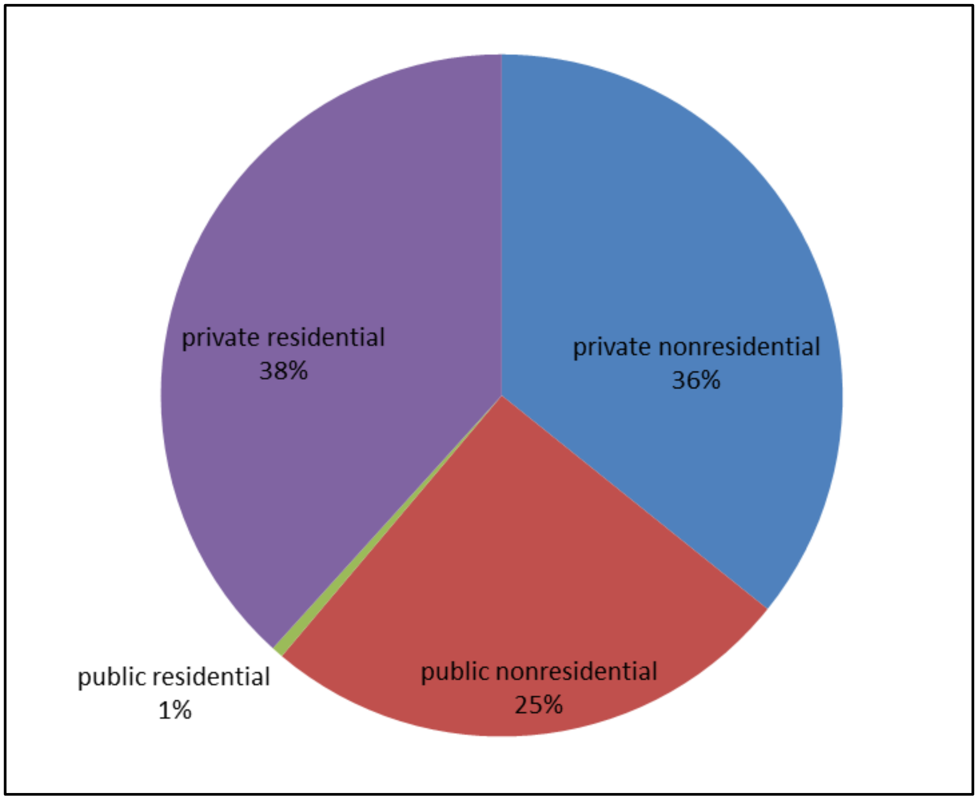

Figure 2.2 Value of Construction Put in Place, March 2016

The Value of Construction Put in Place is the monthly estimates of the total dollar value of construction work done in the U.S. and includes new structures and improvements to existing structures for private and public sectors. This survey has been conducted monthly since 1964, and the value estimated includes labor and material cost, architectural and engineering work cost, overhead cost, interest and taxes paid during construction, and contractor’s profit. Table 2.1 shows a detailed breakdown of the estimated annual value of construction (Bureau 2016).

Table 2.1 Estimated annual rate of Value of Construction Put in Place

Type of construction	**Value of Construction Put in Place, annual rate (unit: millions of dollars)**
Residential	441,774
Nonresidential	695,714
Lodging	23,660
Office	62,585
Commercial	73,773
Health care	40,918
Educational	88,734
Religious	3,360
Public safety	7,633
Amusement and recreation	21,037
Transportation	44,969
Communication	19,096
Power	86,938
Highway and street	97,615
Sewage and waste disposal	25,866
Water supply	12,187
Conservation and development	7,437
Manufacturing	79,905
Total Construction	1,137,488

The first column of Table 2.1 describes the type of construction, which is categorized based on the function of the structure. This also serves as the basis for the attribute of Physical Form and Function. A few more files on the website of U.S. Census Bureau give information on sub-categories of construction types. Together with the information in Table 2.1, the author develops the first three levels of categories for the attribute of Physical Form and Function, which is shown in Table 2.2.

Table 2.2 Level 1, 2 and 3 of Physical Form and Function

Level 1	**Level 2**	**Level 3**
Building construction	Residential	Single family; Multi-family.
	Lodging	--
	Office	--
	Commercial	Automotive – sales; Automotive – service/parts; Automotive – parking; Food; Dining/drinking; Multi-retail – general merchandise; Multi-retail – shopping center; Multi-retail – shopping mall; Warehouse – general commercial; Warehouse – mini-storage; Drug store; Building supply store; Other stores.
	Health care	Hospital; Medical building; Special care.
	Educational	Preschool; Primary/secondary Higher education – instructional; Higher education – dormitory; Higher education – sports/recreation; Library/archive; Gallery/museum.
	Religious	House of worship; Other religious.
	Amusement and recreation	Theme/amusement park; Sports; Fitness; Performance/meeting center; Social center; Park/camp; Movie theater/studio.
	Manufacturing	Food/beverage/tobacco; Chemical; Plastic/rubber; Nonmetallic mineral; Fabricated metal;

		Computer/electronic/electrical; Transportation equipment.
	Power	--
	Communication	--
	Public Safety	Correctional – detention; Correctional – police/sheriff; Fire/rescue.
Heavy civil construction	Transportation	Air – passenger terminal; Air – runway; Land – passenger terminal; Land – mass transit; Water – dock/marina.
	Highway and street	Pavement; Lighting; Bridge; Rest facility.
	Sewage and waste disposal	Sewage/dry waste – plant; Sewage/dry waste – line/pump station Waste water – plant; Waste water – line/drain.
	Water supply	Plant; Line; Pump station.
	Conservation and development	Dam/levee; Breakwater/jetty.

The first three levels only explain the basic types of projects. Usually, projects can be further distinguished by the major structural materials and the project size. For example, the pavement projects under the highway and street category of heavy civil construction can be further divided into new construction and preservation projects, as shown in Figure 2.3. According to the Federal Highway Administration, pavement preservation projects can be divided into minor rehabilitation, routine maintenance, and preventative maintenance (FHWA 2016), which consist of level 5 of the Physical Form and Function. Figure 2.3 describes an example of the level 4, 5 and 6 of Physical Form and Function, and it is clear that for each level 3 type of project listed in Table 2.2, a different sub-level can be developed.

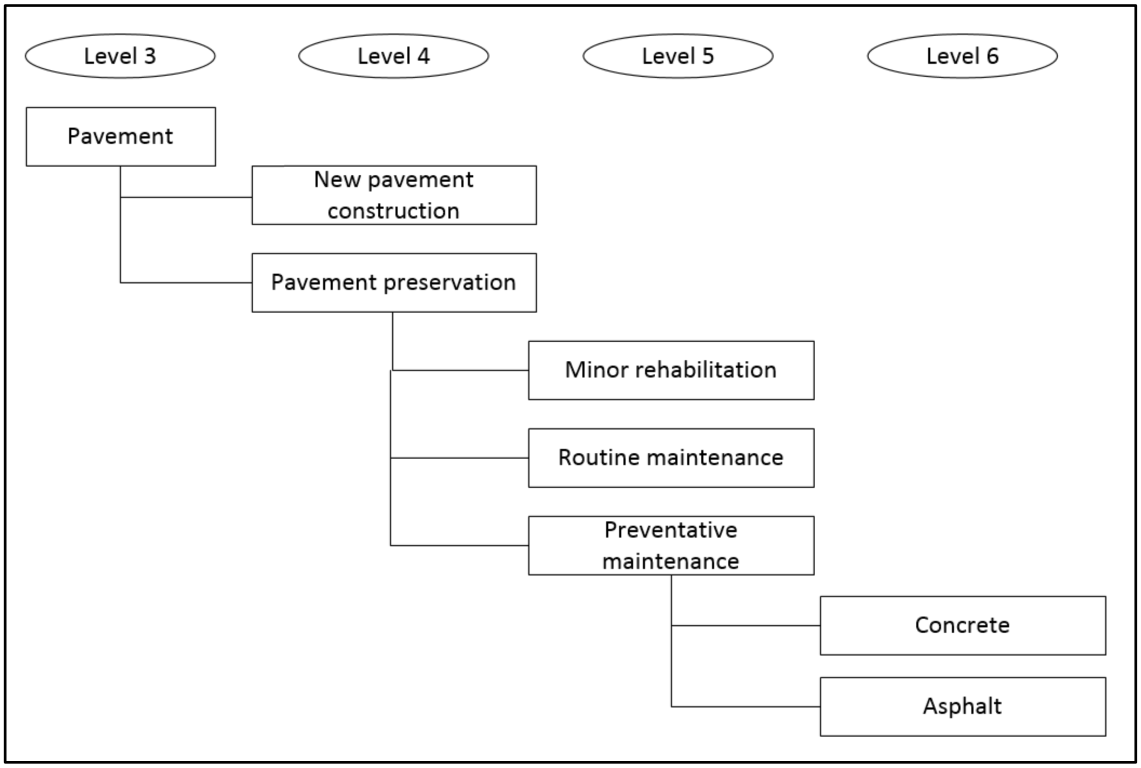

Figure 2.3 An example of level 4, 5 and 6 of Physical Form and Function

The attribute of Physical Form and Function is a categorical factor, and it is unlikely to be quantified. Comparison between projects which are not in the same category may not be wise, but this may become possible when comparing projects in certain aspects. Further discussion of quantification and project comparison will be provided in the next section of this manuscript.

2.4.2 Organizational and Project Structure

The attribute of Organizational and Project Structure refers to both the formal relationships established between the project team members and the formal relationships within an organization. There are two folds here, and they need to be dealt with separately.

2.4.2.1 Project Structure

Project Structure is often determined by the project delivery method or contracting method that is used to bond different organizations together in a project. Three major participants in most construction projects are the owner who wants the project, the designer who provides the service of designing the structure, and the contractor who is in charge of building the structure.

The traditional construction contracting method is called general contract method or Design-Bid-Build method, as shown in Figure 2.4. This method is commonly used in publicly funded projects when the owner is a government agency, who hires an architecture or engineering firm to complete the design of the project, and after that hires a general contractor through an open bidding process.

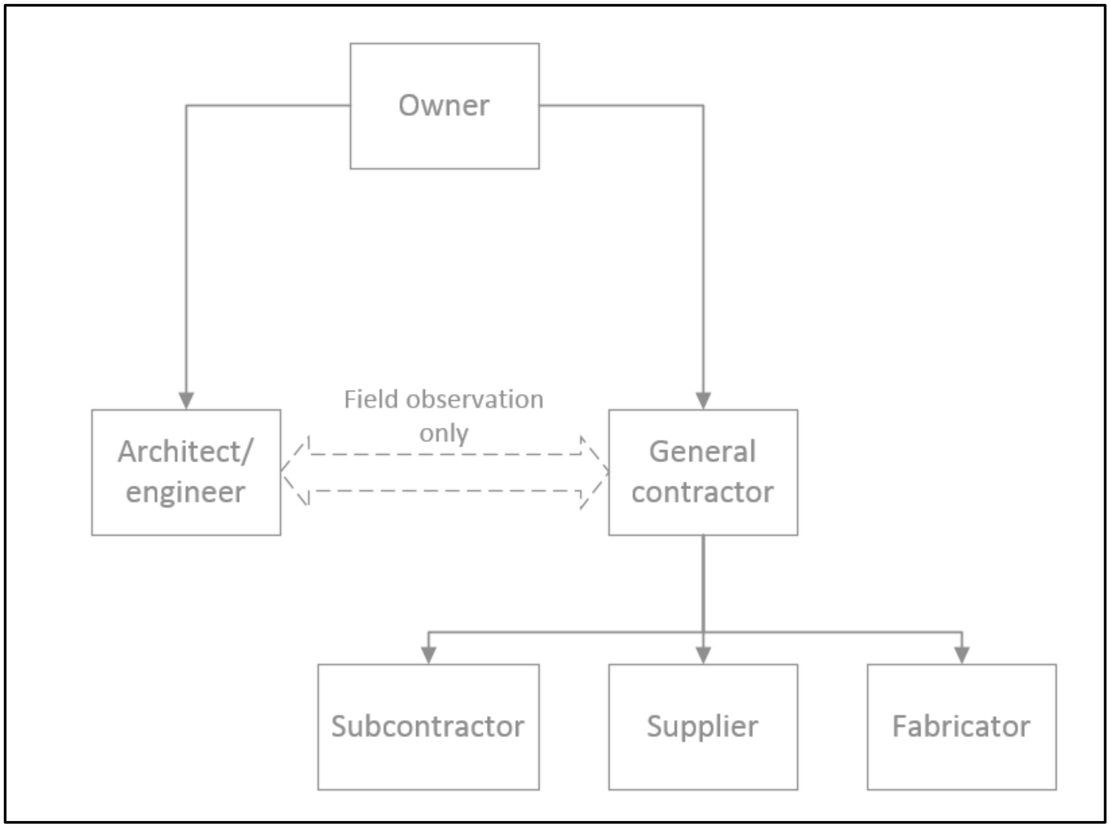

Figure 2.4 General contract relationships

For the general contract method, the designer acts as the owner's representative during the construction phase. However, construction is typically not one of the designer's areas of expertise, and the owner sometimes hires a professional construction manager to oversee the project and to act on the owner's behalf. This contracting method is usually called professional construction management method, as shown in Figure 2.5.

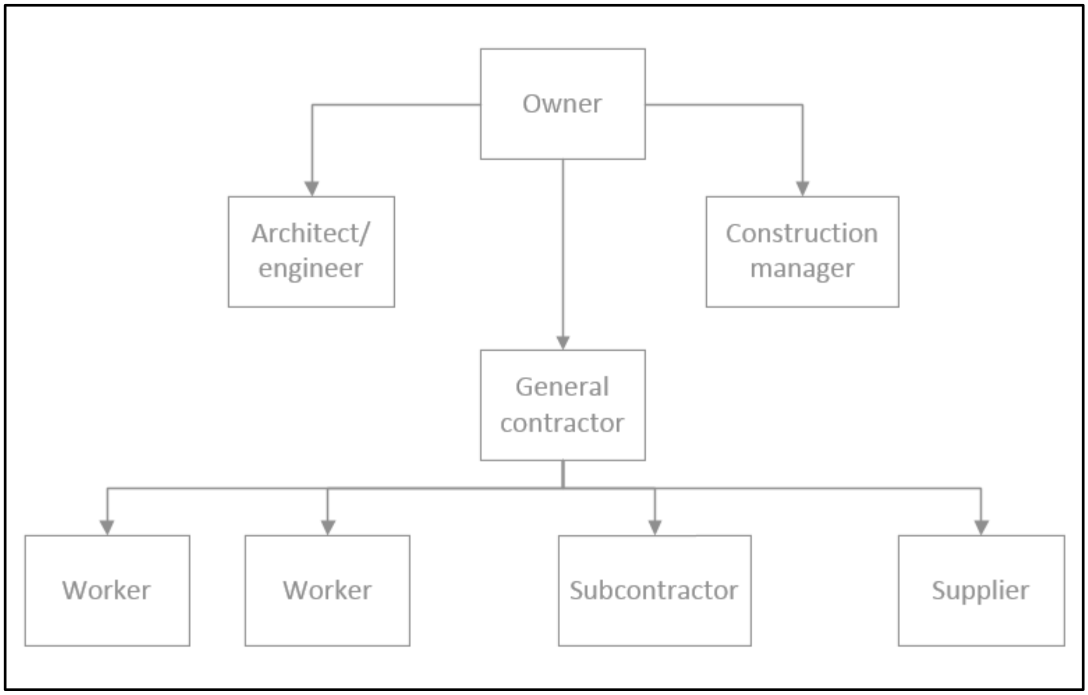

Figure 2.5 Professional construction management method

In the professional construction management method, the owner enters into separate contracts with the designer, the professional construction manager, and the general contractor. The professional construction management firm (CM) is usually hired before any substantial design work is done, and sometimes even before the designer is hired. The CM helps the owner to review the design and to inform the owner of the cost and schedule of the project according to the current design. During the construction phase, the CM is the owner’s agent and is not responsible for the means and methods of construction. It is still the general contractor’s responsibility to control the cost, schedule and quality of the product (Hinze 2011).

Another contracting method that is widely used today is the CM at risk or CM/GC method. In this contracting method, the general contractor (GC) also works as a professional construction manager and gets hired before the design is finished. As shown in Figure 2.6, the general contractor serves as both CM and GC.

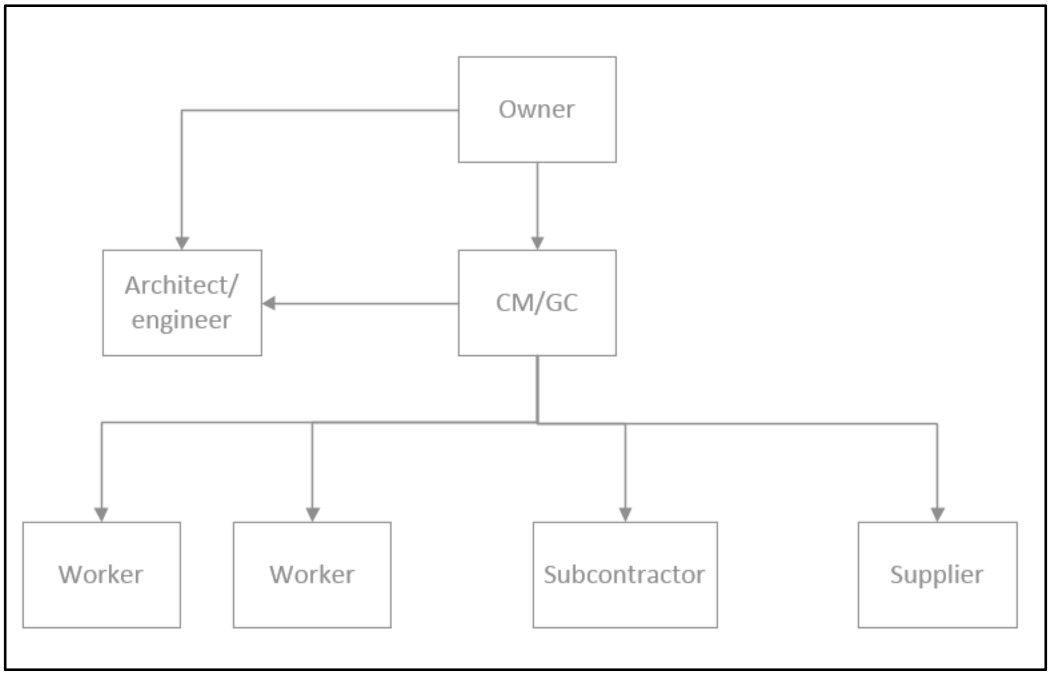

Figure 2.6 CM/GC contracting method

The above methods all involve the owner entering into separate contracts with the designer and the general contractor, and sometimes, it puts the designer and the general contractor into adversarial roles. The design-build contracting method is a solution to this problem. As shown in Figure 2.7, the owner enters a single contract with a design-build firm or a joint-venture entity formed by both the designer and the contractor.

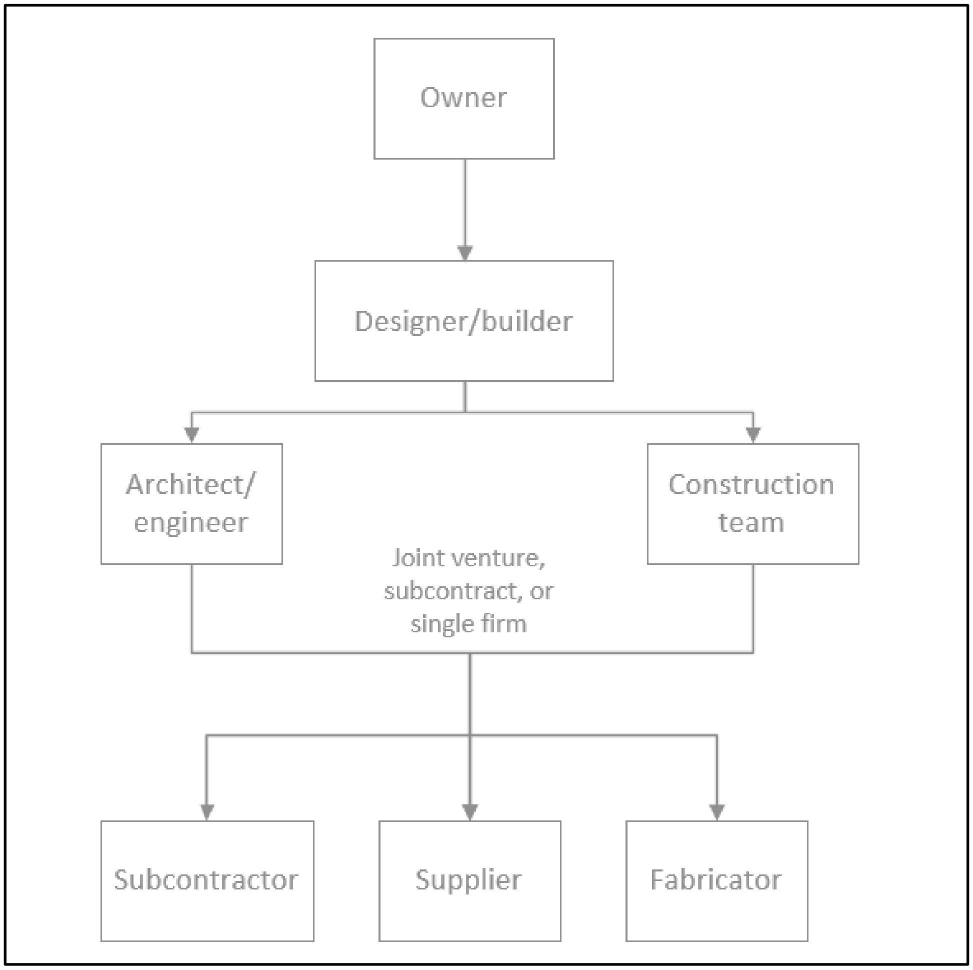

Figure 2.7 Design-build contracting method

When the owner is knowledgeable enough to perform as the general contractor's role, there will be no need to hire a general contractor. The owner will hire a designer to do the design work, and self-perform the construction work or hire subcontractors to perform the work. These are called self-performance method and separate contracts method (Hinze 2011).

The contracting method used in a project has a great impact on the relationships between different parties and many other aspects of the project (Tran et al. 2015, Korkmaz et al. 2010, Gaba 2013, Construction 2014). It likely also plays a very important role when doing project comparisons. Project Structure is also a categorical factor, similar to the attribute of Physical Form and Function. However, when comparing projects regarding some specific outcomes, the Project Structure can be quantified by how well the selected project structure facilitates the desired outcome.

2.4.2.2 Organizational Structure

Organizational structure refers to the hierarchical arrangement of lines of authority, communications, rights and duties of an organization (BusinessDictionary 2016). It is widely agreed that the organizational structure of a company can have a large impact on the ability to manage a project (Oberlender 2000, Elkassas et al. 2013). Construction companies usually have their own organizational structure which fits their needs. Figure 2.8 shows an example of an organizational structure for a large construction firm.

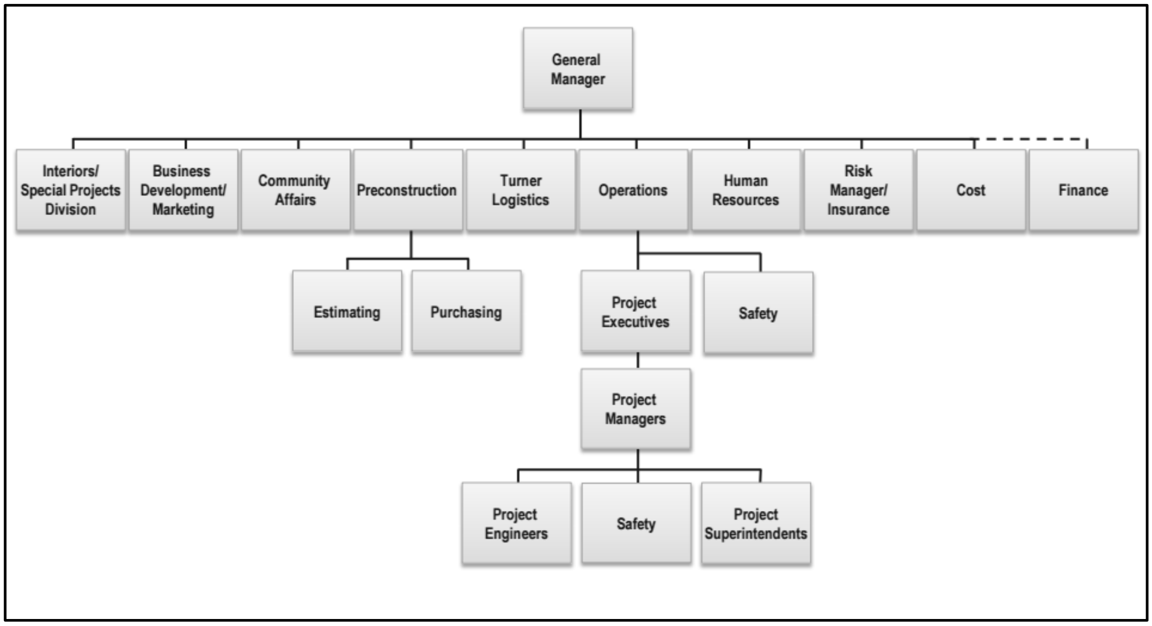

Figure 2.8 Typical business unit organizational structure (Turner 2016)

Small construction firms usually do not have many departments, and project managers play a key role in the management of the company as well as their projects. Project engineers for a small firm sometimes are entrusted to manage a whole project and act as the project manager for small and medium size projects. Therefore, the organizational structure of a company will impact the authority of project managers and the information flow and communication, the paperwork processing time, and many other factors. The organizational structure is also a categorical factor, and it may be quantified by how well the selected organizational structure facilitates the desired outcome.

2.4.3 Resources, Tools and Processes

The attribute of Resources, Tools and Processes refers to the devices and resources utilized to design and construct a project, and the means and timing in which they are implemented. The resources here include the materials, equipment, labor, money and time needed to construct a project. Therefore, the resources needed for one project are more than likely different from the resources needed for another project. However, the specific resources needed for a project may not be a big factor as long as there are adequate resources to conduct the work. When resources are limited and become constraints to the project, they must be taken seriously. Therefore, for the resources part of this attribute, it can be quantified according to the level of adequateness.

It is noted that there are many other ways to quantify resources depending on the research interest. For example, the quality of materials could be a major concern and it can be quantified by the degree to which the quality of materials meets the requirement.

The design of a project used to be recorded and communicated in hand-draw drawings. After computer aided design systems were developed in the 1970s, more and more companies started to use some kind of software to help with the design. It starts with providing 2D drawings and gradually moves to 3D design. As construction management software was developed, contractors become more and more dependent on technology as well. A variety of software can be used to help with document management, cost estimating, scheduling, risk analysis, and almost every aspect of a construction project management. It does not matter what specific software is used in a project, but using new technology can make the project management more effective. So the tools part of this attribute is also quantifiable by the level of utilization of new technologies.

It is noted that the tools part of this attribute is not only about software, but also about other tools. It can be quantified by not only the level of utilization of new technologies but also in many other ways.

The processes used to construct a project are choices made by the general contractor. The timing and sequence of the work is an important factor which affects project outcome. Similar to resources and tools, the processes may be an enabler or inhibitor for the project outcome of interest, depending on what kind of project outcome is being compared. So the processes can be quantified according to the level of fitness of the specific process to the project outcome of interest.

In summary, the attribute of Resources, Tools and Processes can be quantified by the level of appropriateness of using the specific tools and processes to the project outcome which is being compared. The Resources, Tools and Processes can be enablers when comparing project outcome A, and the same Resources, Tools and Processes can be inhibitors when comparing project outcome B.

2.4.4 Culture

Research on culture started in the field of anthropology and sociology, which gives a perspective on how groups of people develop a common sense of history, values, beliefs, and purpose through collective interpretations, and then act to produce the social institutions of their existence (Denison 1996, Schein 2004, Fellows and Liu 2013). In the construction industry, organizational culture can be defined as the shared beliefs in the minds of all employees. Many people believe that organizational culture conveys a sense of identity for organization members, facilitates the generation of commitment, and enhances the stability of the organization (Louis 1980, Peters and Waterman 2006, Cheung et al. 2011).

Schein (2004) described three levels of organizational culture as shown in Figure 2.9 (Schein 2004). Artifacts are the base level and include all the phenomena that can be seen, heard, and felt. Artifacts can be observed but they are difficult to decipher. The next level is espoused values which refer to strategies, goals, and philosophies. The third level is the basic underlying assumptions which refer to unconscious, taken-for-granted beliefs, perception, thoughts, and feelings.

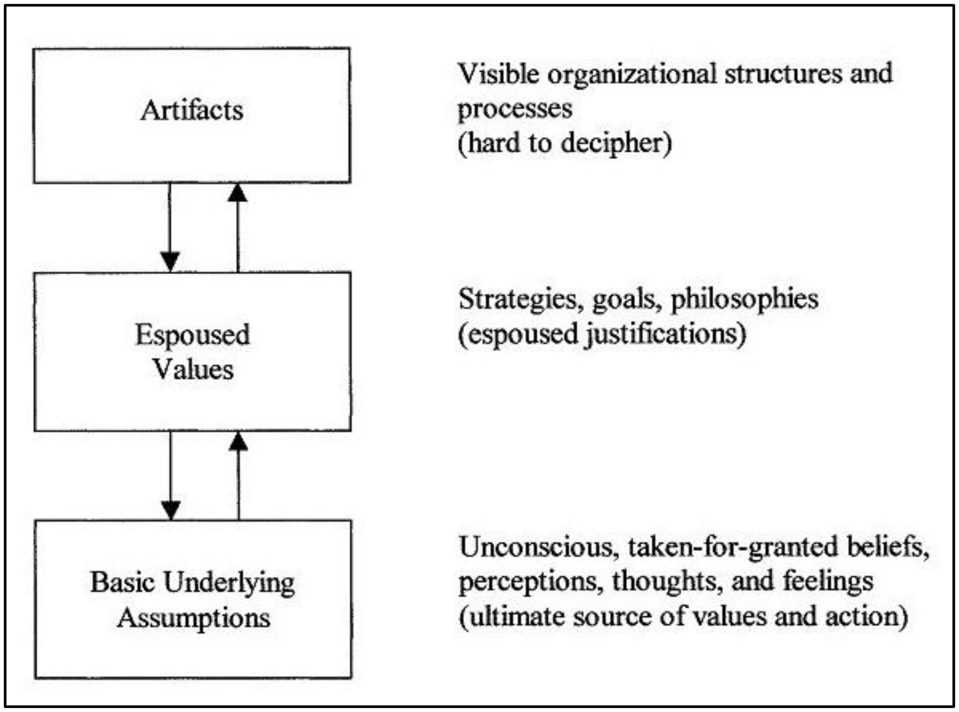

Figure 2.9 Three levels of organizational culture (Schein 2004)

The attribute of Culture here refers to the companies' cultures, not the project climate. The project team is a short-term temporary-formed group with team members holding different objectives, so it is not appropriate to use the word 'culture' to describe the shared beliefs of project participants. The attribute of Culture can be quantified by the degree to which major project participants' organizational cultures are aligned.

There are many other ways to quantify the attribute of Culture. For example, it can be quantified by the degree to which each organizational culture facilitates the project outcome of interest. It could be more important than whether or not the participants' organizational cultures are aligned.

2.4.5 Risk

Risk can be defined as a positive or negative deviation of a variable from its expected value (Schieg 2006). In practice, when people talk about risk, it usually refers to negative deviation and the potential for a loss. The construction industry is usually considered to be a high-risk industry, and the risk associated with a project is an important factor to the project outcome. Karim et al. (2012) put major risk factors related to a construction project into five categories from a contractor's viewpoint, and they are listed in Table 2.3.

Table 2.3 Construction project risk factors (Karim et al. 2012)

Risk Category	**Risk Factor**
Construction	Land acquisition
	Shortage of equipment
	Shortage of material
	Late deliveries of material
	Poor quality of workmanship
	Construction site safety
	Insolvency of subcontractors
	Inadequate planning
	Weather
	Insolvency of suppliers
Politics & Contract Provision	Change in law and regulation
	Delay in project approval and permit
	Inconsistencies in government policies
	Excessive contract variation
	Poor supervision
	Bureaucracy
Finance	Delay in payment for claim
	Cash flow difficulties
	Lack of financial resources
Design	Improper design
	Change of scope
Environmental	Pollution
	Ecological damage
	Compliance with law and regulation for environment issue

The owner and designer's perception of risks may be different from the contractor's, but the risk management processes are similar, as shown in Figure 2.10. After risks are identified, they will be accessed by using a risk matrix which usually include columns for the magnitude and possibility of risks.

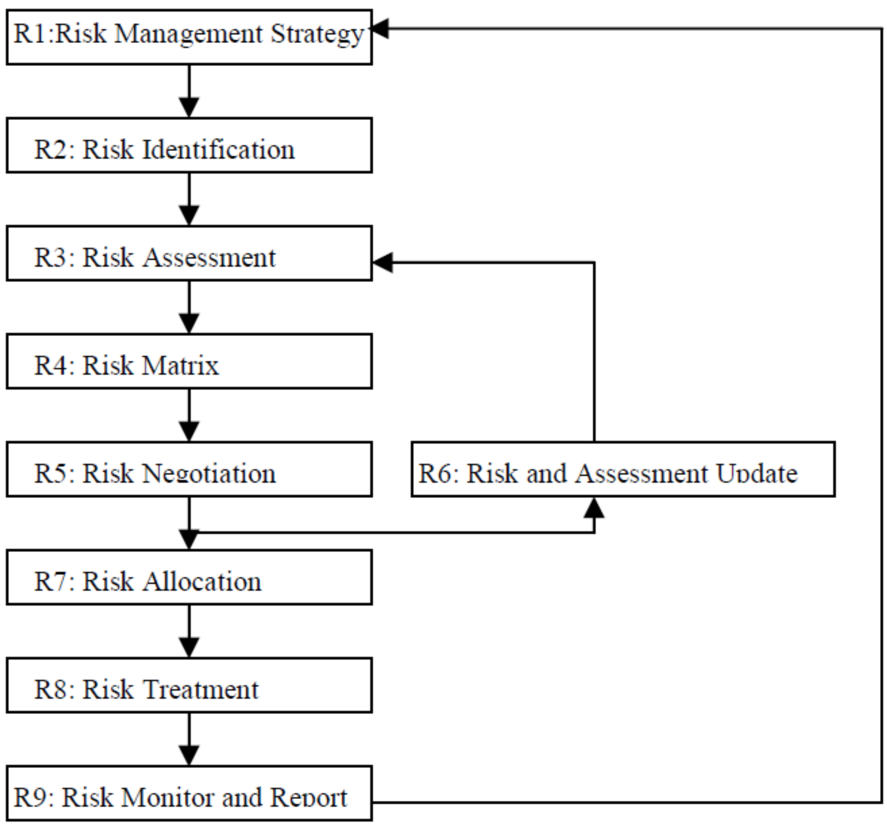

Figure 2.10 Risk management process (Li and Ren 2009)

The attribute of Risk is not the same as construction project risks mentioned above, and it has two folds. One of them is the risk associated with the project in different project participants' perspective, and the other one is the risk tolerance/threshold of major project participants. For each organization, the attribute of Risk can be quantified by the overall level of project risk, and the tolerance level of the organization.

2.4.6 A summary of Foundational Attributes

The five Foundational Attributes discussed in the previous section holistically represent all aspects of a project. However, they are not independent or mutually exclusive from each other. For example, the Organizational Structure of a company is a representation of part of the company Culture. The Resources, Tools and Processes can be influenced by the Physical Form and Function of the structure. Risk is associated with Project Structure and Culture as well. The definition of Foundational Attributes does not indicate that each attribute is independent of others, so the dependency between attributes is not a violation of the concept, and it just needs to be noted and dealt with.

The attribute of Physical Form and Function is a purely categorical factor. However, a cross-category comparison may be possible depending on the project outcome of interest. The other four attributes are categorical factors as well, but they may be quantified according to whether or not those attributes are enablers or inhibitors of a specific project outcome.

2.5 Project comparison

The five Foundational Attributes were developed and discussed in the previous section, and they will be used in this section to determine how they could help with project comparison. Two case study projects were selected and will be used to demonstrate the comparison.

2.5.1 About case study projects

The two case study projects were selected from five similar construction projects in which the author was previous involved. All five projects are highway preservation projects that took place in Oregon during the past few years. The projects are very similar in a common sense, and one of them is more complicated than the other four, so it becomes the author's first choice. For the second project, the author chose the most recent one.

2.5.1.1 Case study #1

The first case study project was located on Interstate 5 in Douglas County approximately 50 miles south of Roseburg and 20 miles north of Grants Pass, so it was located in a rural area. The limits of the project were between milepost 66.7 and milepost 81.4, including both southbound and northbound lanes. Figure 2.11 shows the location of the project. The overall scope of the project contained many pieces of work, including pavement resurfacing for both lanes in both directions within the project boundary and the construction of a new lane in the northbound direction for trucks to climb the steep grade without significantly slowing down normal traffic.

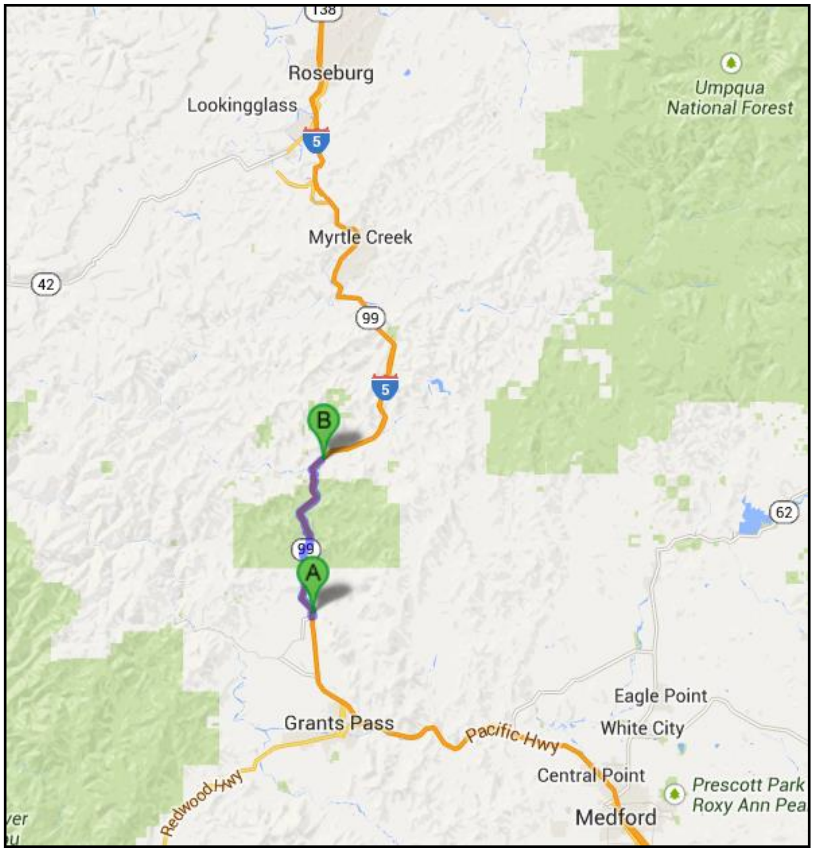

Figure 2.11 Location of case study #1

The project consisted of both base course and wearing course paving, and included not only paving in the fast and slow lanes but also shoulder paving. A large part of this project was located in a mountain area, with sharp curves and elevation changes. Figure 2.12 shows the approximate roadway elevation along the length of the work zone.

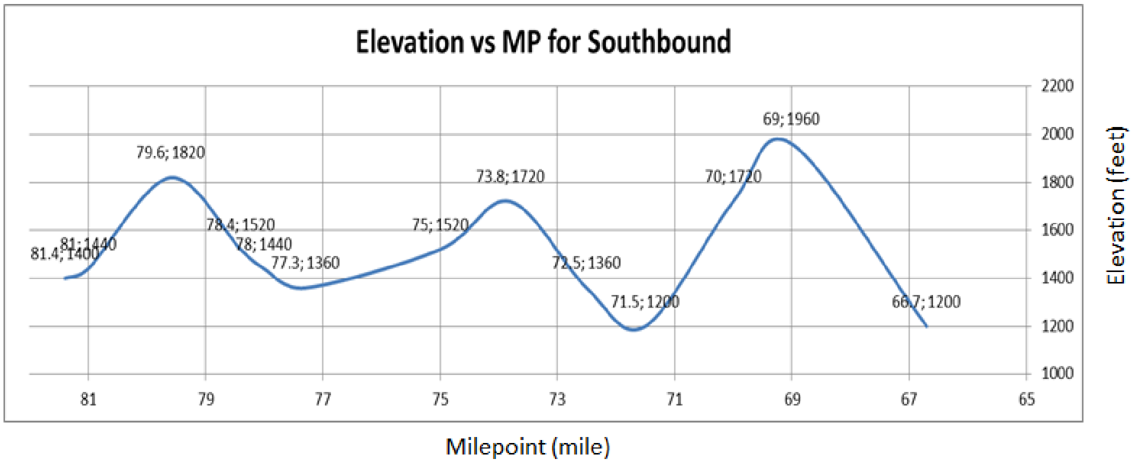

Figure 2.12 Roadway elevation for case study #1

2.5.1.2 Case study #2

Case study #2 is also a highway preservation project and located in a rural area on Interstate 84 along the Columbia River in Oregon, as shown in Figure 2.13. At this location, the roadway is mostly flat and straight, unlike case study #1.

Figure 2.13 Location of case study #2

The project extended for about 21 miles from milepost 138 to milepost 159, and the paving scope of work consisted of grinding 2 inches of existing highway surface and placing a new layer of asphalt in both the slow lane and fast lane. The similarity and differences between the two case study projects will be discussed in detail in later sections.

2.5.2 Spider charts

As mentioned previously and shown in Figure 2.1, a spider chart is initially chosen to host the concept of Foundational Attributes of construction projects. This section will apply the concept and the spider chart to the two case study projects to figure out if a spider chart is appropriate to use.

2.5.2.1 About spider charts

A spider chart, sometimes called a radar chart, star chart, or web chart, is a two-dimensional chart used to plot values for multiple quantitative variables by providing an axis for each variable. The axes are arranged radially as equal-angular spokes around a center point (ScottLogic 2016). Sometimes, the values for adjacent variables in a single series are connected by lines as shown in Figure 2.14. The values for other spokes could be in a different series, and if that is the case, no line will be used to connect adjacent spokes to represent the same value.

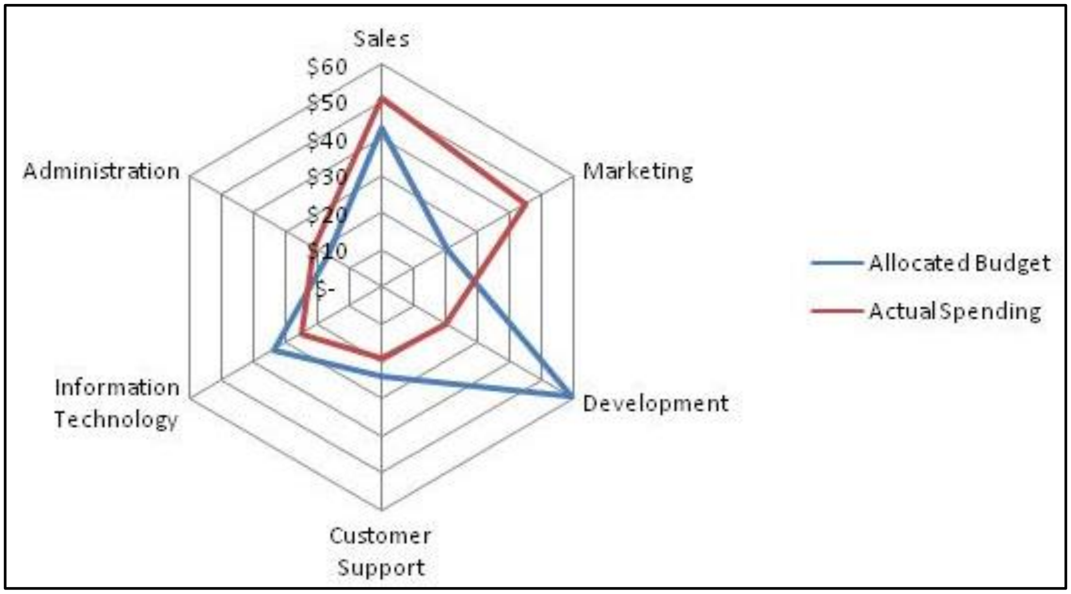

Figure 2.14 An example of single value spider chart (Clement 2006)

Spider charts are very helpful for comparing two entities regarding multiple variables. In Figure 2.14, the chart clearly shows the difference between the budget and spend in the departments of sales, marketing, development, customer support, information technology, and administration. The values for all spokes are money in dollar value, and $30 spent in the sales department is the same amount as the $30 spent in the marketing department. However, this is not always the case. Figure 2.15 shows another spider chart which is used to compare two employees' multiple skills.

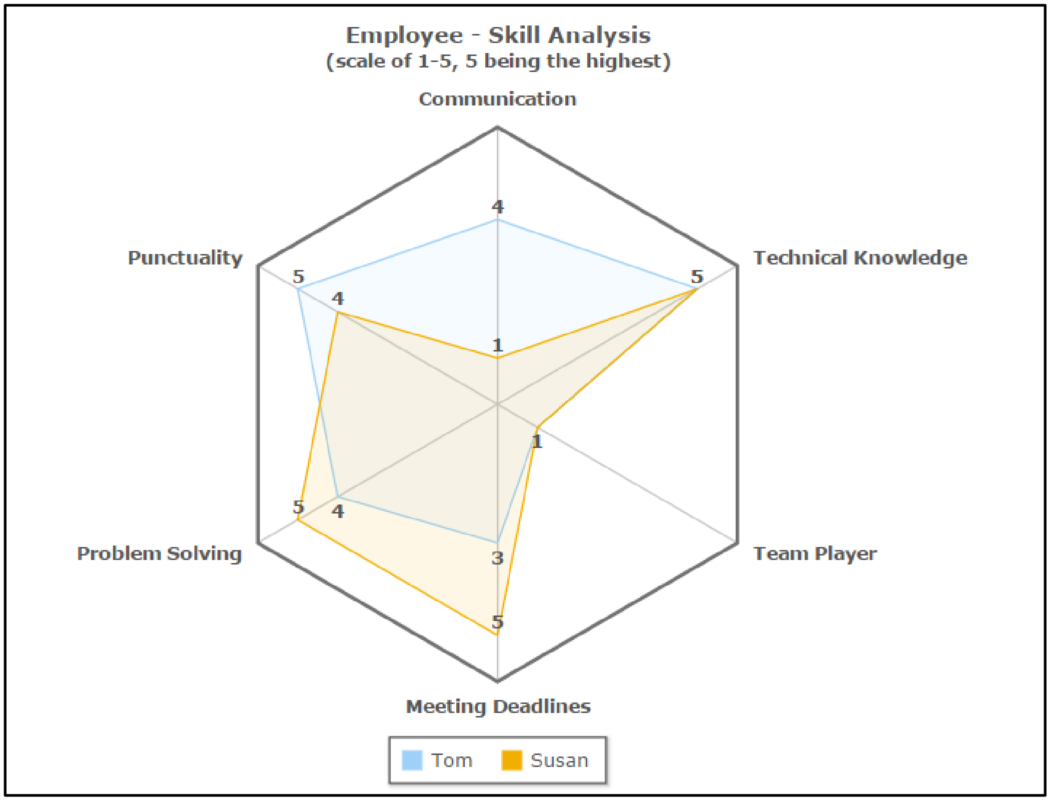

Figure 2.15 A spider chart for employee skill analysis (FusionCharts 2016)

Figure 2.15 shows an example of comparing employees' multiple skills in one chart. The employee performance data were based on the rankings given by their supervisors. So the values 1-5 represent the satisfaction level of their supervisors to their specific skills, with 5 being the highest level. However, level 4 satisfaction of communication skills does not equal to level 4 satisfaction of meeting deadlines, which is to say the same value in different spokes may not mean the values are comparable. This difference is something that needs to be considered when applying the spider chart to the concept of Foundational Attributes.

2.5.2.2 Using Spider Chart to host the concept of Foundational Attributes

A spider chart can represent multiple quantitative variables, and give a vivid view of the difference and similarity between two entities. As mentioned in previous sections, not all attributes are quantifiable. The attribute of Physical Form and Function is purely a categorical variable, so it is not appropriate to put this attribute in a spider chart. The other four variables are quantifiable depending on the project outcome being compared.

The attribute of Physical Form and Function can be considered as a super-attribute or a prerequisite before using a spider chart with the other four attributes to assess project similarity. If two projects have similar Physical Form and Function, for example, then they meet the prerequisite and can be compared further using the spider chart below (Figure 2.16).

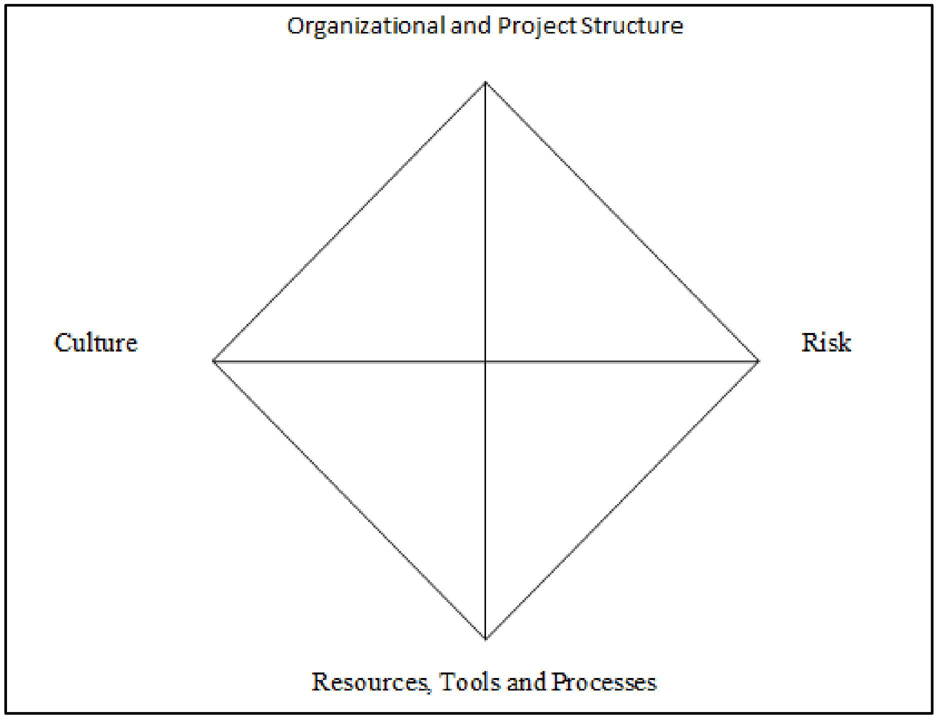

Figure 2.16 Updated spider chart for Foundational Attributes

2.5.3 Application to case study projects

To apply case study projects to figure out how to use the Foundational Attributes to compare projects, the subject of interest, which is the project outcome being compared, needs to be determined. Usually, the overall project cost, schedule, quality, and safety are subjects of interest. For example, if we want to implement a new safety procedure and to assess the effectiveness of this new procedure, two projects are chosen: one with the new procedure, the other one without. To confidently conclude that the new safety procedure makes a difference in safety performance, we need to eliminate confounding factors brought by the uniqueness of a construction project.

Case study #1 and #2 are both heavy civil construction projects. The second level of Physical Form and Function is Highway and street, and the third level of this attribute is pavement. Therefore, the first three levels of the Physical Form and Function are the same for both case study projects, as shown in Table 2.4. Starting with the fourth level, they become different because case study #1 includes not only the pavement preservation work, but also the new construction of a climbing lane for trucks, while case study #2 only involves pavement preservation work. With the same first three levels, they pass the prerequisite and can be compared further for the other four attributes.

Table 2.4 Physical Form and Function for both case study projects

Physical Form and Function	**Case study #1**	**Case study #2**
Level 1	Heavy civil construction	Heavy civil construction
Level 2	Highway and street	Highway and street
Level 3	Pavement	Pavement
Level 4	Pavement preservation and new pavement construction	Pavement preservation

When the project outcome of interest is the effectiveness of a new safety procedure, the attribute of Organizational and Project Structure can be quantified by the degree to which the project structure and organizational structures of major participants help to facilitate the implementation of a new safety procedure. For this evaluation, a scale from 1-5 can be used, with 5 equal the best. The ratings for the attribute of Organizational and Project Structure for both case study projects are listed in Table 2.5. The average rating of Organizational and Project Structure (AR-OPS) is calculated using Equation 2.1. In the equations, AR-OPS represents the average rating of Organizational and Project Structure. OOS stands for the owner's organizational structure. COS stands for the contractor's organizational structure. PDM stands for the project delivery method.

Table 2.5 Organizational and Project Structure for both case study projects

Organizational and Project Structure (OPS)	**Case study #1**	**Case study #2**
Owner's organizational structure (OOS)	2	2
Contractor's organizational structure (COS)	4	3
Project delivery method (PDM)	2	2
Average rating (AR)	2.67	2.33

$$\text{AR-OPS} = \frac{OOS + COS + PDM}{3} \qquad \text{(Eqn. 2.1)}$$

$$\text{AR-OPS}_{\#1} = \frac{2+4+2}{3} = 2.67$$

$$\text{AR-OPS}_{\#2} = \frac{2+3+2}{3} = 2.33$$

The ratings for both case studies in terms of the owner's organizational structure, the contractor's organizational structure, and the project delivery method are assigned based on the information from the case studies and the author's judgment. The owners for both case study projects are the same, the State Department of Transportation (DOT). The subject of the safety procedure mainly impacts the construction phase, so the role of the designer/engineer can be omitted. The general contractor for case study #1 is a large nation-wide heavy civil construction company with about 4,800 employees. The general contractor for case study #2 is a local heavy civil construction company with about 240 employees. The project delivery methods are the same for both case study projects, and because it is a government funded project, the project delivery methods is the Design-Bid-Build method.

The attribute of Resources, Tools and Processes can be quantified by the degree to which the resources, tools and processes of construction projects help to facilitate the implementation of a new safety procedure, and the rating for this attribute is shown in Table 2.6. The average rating of Resources, Tools and Processes (AR-RTP) is calculated using Equation 2.2. In the equations, AR-RTP represents the average rating of Resources, Tools and Processes. “Re” stands for resources. “To” stands for tools. “Pr” stands for processes. The ratings are assigned based on the information from the case studies and the author’s judgment.

Table 2.6 Resources, Tools and Processes for both case study projects

Resources, Tools and Processes (RTP)	**Case study #1**	**Case study #2**
Resources (Re)	4	4
Tools (To)	5	4
Processes (Pr)	4	4
Average rating (AR)	4.33	4

AR-RTP = $\frac{\text{Re} + To + \text{Pr}}{3}$ (Eqn. 2.2)

AR-RTP$_{\#1}$ = $\frac{4+5+4}{3} = 4.33$

AR-RTP$_{\#2}$ = $\frac{4+4+4}{3} = 4$

The attribute of Culture can be quantified by the degree to which the major project participants' company cultures facilitate the implementation of a new safety procedure. The rating for this attribute is shown in Table 2.7. The average rating of Culture (AR-Cu) is calculated using Equation 2.3.

Table 2.7 Culture for both case study projects

Culture (Cu)	**Case study #1**	**Case study #2**
Owner's company culture (OCC)	4	4
Contractor's company culture (CCC)	5	4
Average rating (AR)	4.5	4

AR-Cu = $\frac{OCC + CCC}{2}$ (Eqn. 2.3)

AR-Cu$_{\#1}$ = $\frac{4+5}{2} = 4.5$

AR-Cu$_{\#2}$ = $\frac{4+4}{2} = 4$

The attribute of Risk can be quantified by the overall project risk level and the tolerance level of the major project participants. This attribute is not affected by the subject of interested being compared. The rating for Risk is shown in Table 2.8. The average rating of Risk (AR-Ri) is calculated using Equation 2.3.

Table 2.8 Risk for both case study projects

Risk (Ri)	**Case study #1**	**Case study #2**
Overall project risk to the owner (PRO)	2	2
Overall project risk to the contractor (PRC)	4	2
Owner's risk tolerance (ORT)	2	2
Contractor's risk tolerance (CRT)	4	3
Average rating	3	2.25

$$\text{AR-Ri} = \frac{PRO + PRC + ORT + CRT}{4} \qquad \text{(Eqn. 2.4)}$$

$$\text{AR-Ri}_{\#1} = \frac{2+4+2+4}{4} = 3$$

$$\text{AR-Ri}_{\#2} = \frac{2+2+2+3}{4} = 2.25$$

Table 2.9 shows a summary of the average ratings for the four attributes discussed above for both case study projects. Figure 2.17 shows the spider chart which describes both case study projects. The solid green line represents case study #1, and the dashed orange line represents case study #2.

Table 2.9 Average ratings for the four attributes

Attribute	Case study #1	Case study #2
Organizational and Project Structure	2.67	2.33
Resources, Tools and Processes	4.33	4
Culture	4.5	4
Risk	3	2.25

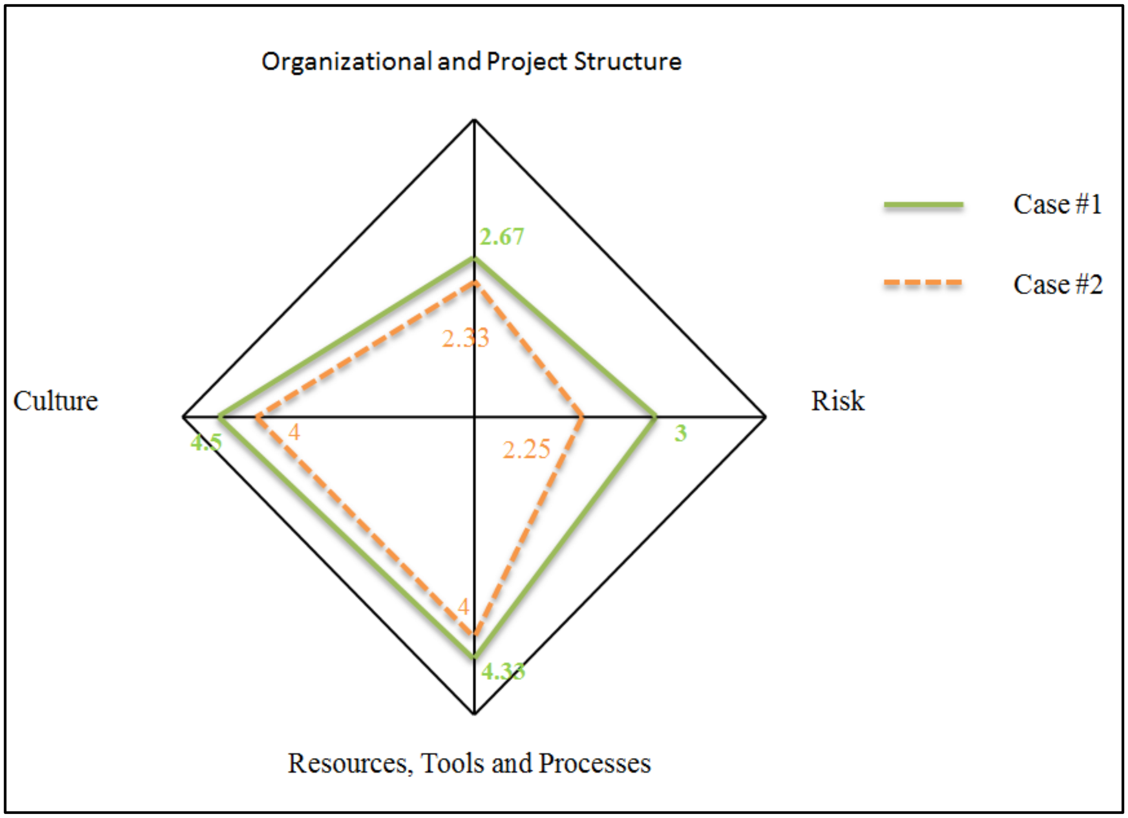

Figure 2.17 Spider chart for both case study projects

2.5.4 Quantification of the similarity between projects

The original assumption of similarity quantification is to use the common area enclosed by both projects to represent the similarity between them. Apparently, this assumption is not true according to the situation shown in Figure 2.17. The area enclosed by case study #2 is completely within the area enclosed by case study #1. A different method to quantify the similarity between projects is needed.

In Figure 2.18, the area enclosed by case study #1 is shadowed with a series of green lines, and the total area is separated into four sections for ease of calculation. The areas are calculated using Equations 2.5, 2.6, 2.7, 2.8, and 2.9.

$$Aa = \frac{Cu \times OPS}{2} \qquad \text{(Eqn. 2.5)}$$

$$Ab = \frac{Ri \times OPS}{2} \qquad \text{(Eqn. 2.6)}$$

$$Ac = \frac{Cu \times RTP}{2} \qquad \text{(Eqn. 2.7)}$$

$$Ad = \frac{Ri \times RTP}{2} \qquad \text{(Eqn. 2.8)}$$

$$A = Aa + Ab + Ac + Ad \qquad \text{(Eqn. 2.9)}$$

$$Aa_{\#1} = \frac{4.5 \times 2.67}{2} = 6$$

$$Ab_{\#1} = \frac{3 \times 2.67}{2} = 4$$

$$Ac_{\#1} = \frac{4.5 \times 4.33}{2} = 9.7$$

$$Ad_{\#1} = \frac{3 \times 4.33}{2} = 6.5$$

$$A_{\#1} = 6 + 4 + 9.7 + 6.5 = 26.2$$

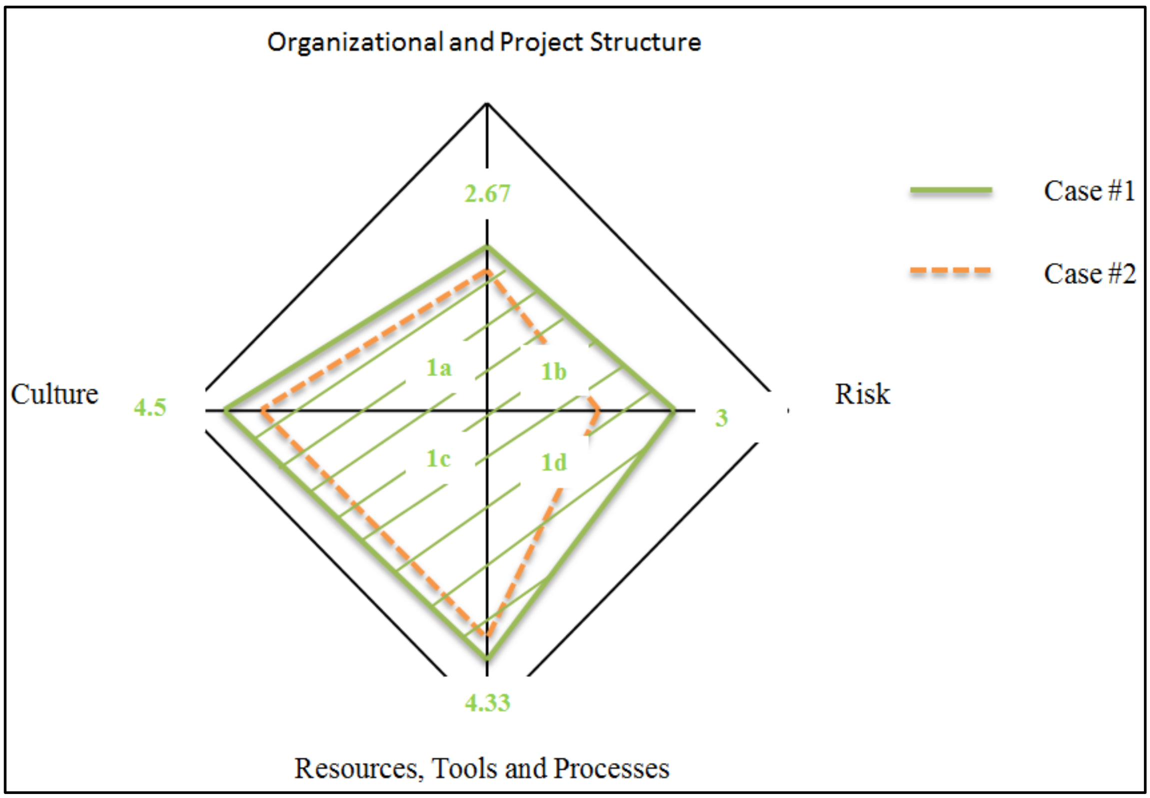

Figure 2.18 Area enclosed by case study #1

In Figure 2.19, the area enclosed by case study #2 is shadowed with a series of orange lines, and the area is separated into four sections for ease of calculation. The areas are calculated using Equations 2.5, 2.6, 2.7, 2.8, and 2.9.

$$Aa_{\#2} = \frac{4 \times 2.33}{2} = 4.7$$

$$Ab_{\#2} = \frac{2.25 \times 2.33}{2} = 2.6$$

$$Ac_{\#2} = \frac{4 \times 4}{2} = 8$$

$$Ad_{\#2} = \frac{2.25 \times 4}{2} = 4.5$$

$$A_{\#2} = 4.7 + 2.6 + 8 + 4.5 = 19.8$$

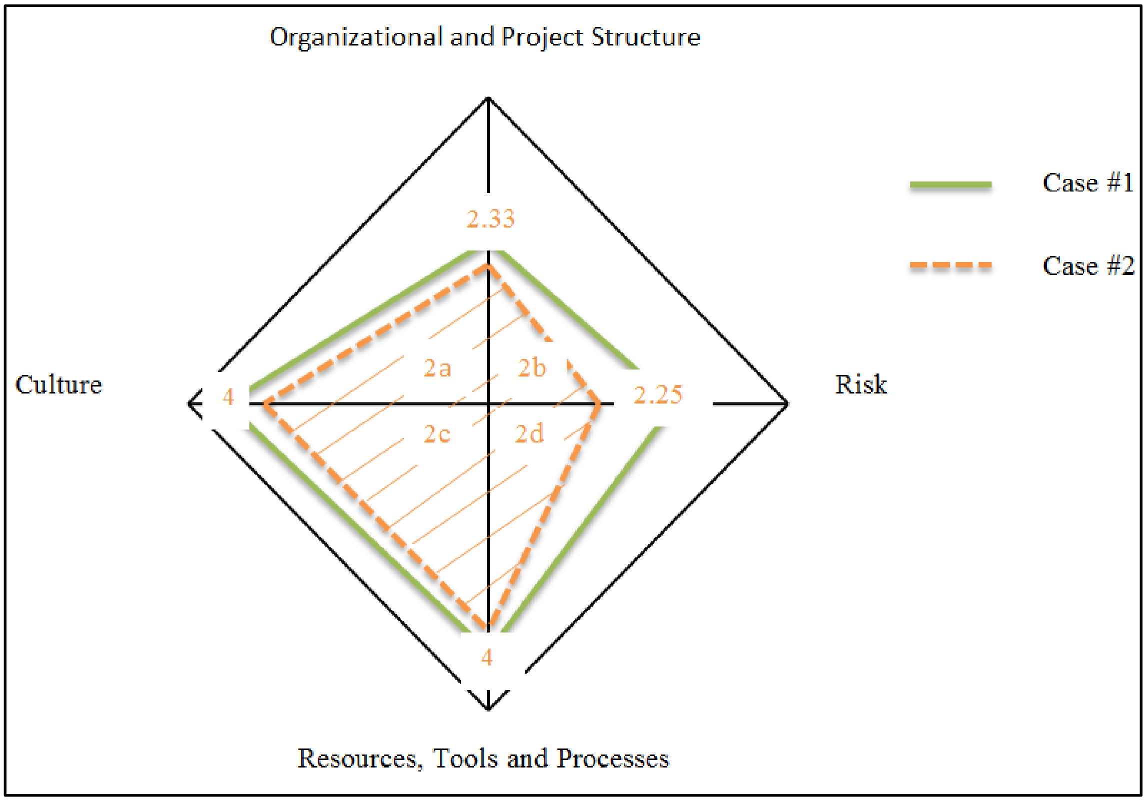

Figure 2.19 Area enclosed by case study #2

The area enclosed by case study #2, which is 19.8, is totally enclosed by the area of case study #1. Therefore, the common area counts for 75.6% of the total area of case study #1, and 100% of case study #2. If case study #2 is not completely within case study #1 (similar to the situation shown in Figure 2.20), the ratio of the overlapping area to area of case study #1 is still very likely to be different from the ratio of the overlapping area to the area of case study #2. Figure 2.20 shows a typical situation for comparing two projects when Project A and Project B have an overlapping area that is only part of Project A or Project B.

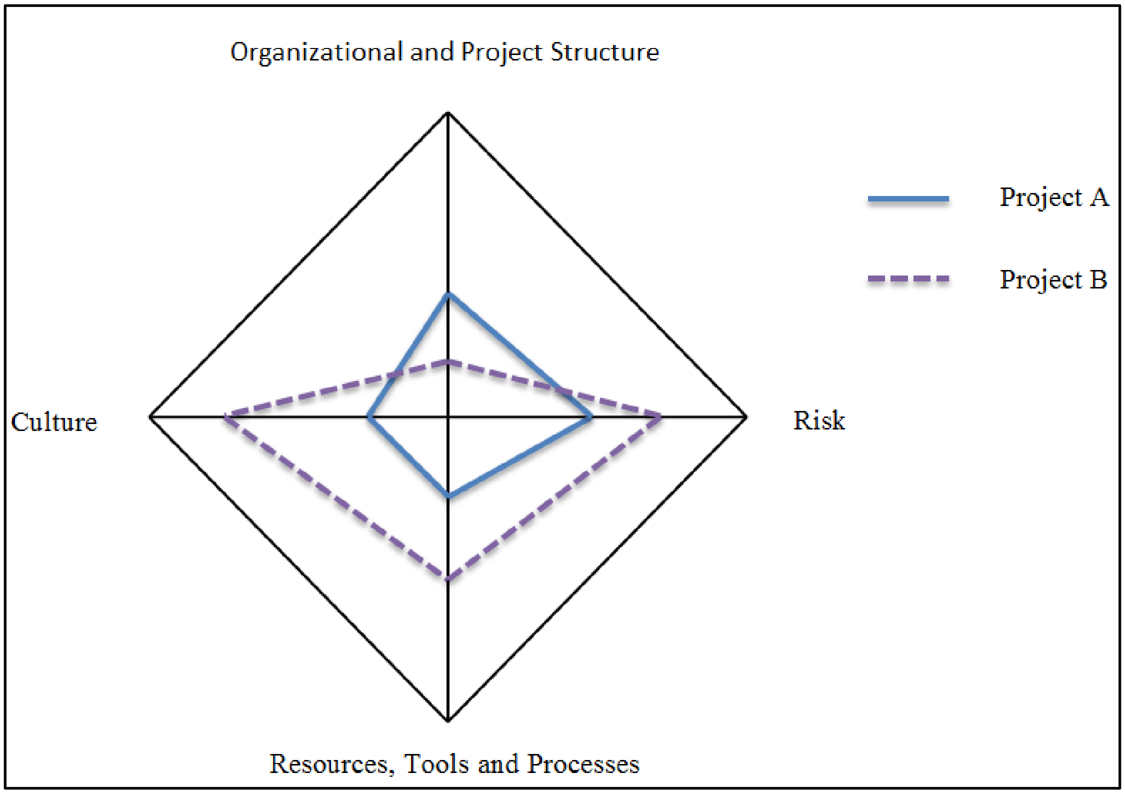

Figure 2.20 A typical situation for comparing two projects

Considering the situation of the two case studies being compared in this section, it is not reasonable to say that case study #1 is 75.6% similar to case study #2, and case study #2 is 100 % similar to case study #1. A different method to define the similarity between projects is needed, and the author proposes using the ratio of the overlapping area to the area covered by either case study #1 or case study #2, and the equation is shown as follows:

$$\text{Project Similarity} = \frac{A_{\#1} \cap A_{\#2}}{A_{\#1} \cup A_{\#2}} \qquad \text{(Eqn. 2.10)}$$

$$\text{Project similarity between \#1 and \#2} = \frac{19.8}{26.2} = 0.756$$

According to the Equation 2.10, the similarity between case study #1 and case study #2 is 75.6%, and this is a more reasonable expression. However, while calculating the areas for case study projects, the author noticed that the area enclosed by a project depends not only on the value of each attribute but also on how the attributes are arranged in a spider chart. For example, if we exchange the location of Risk with Resources, Tools and Processes, the new spider chart will look like that shown in Figure 2.21.

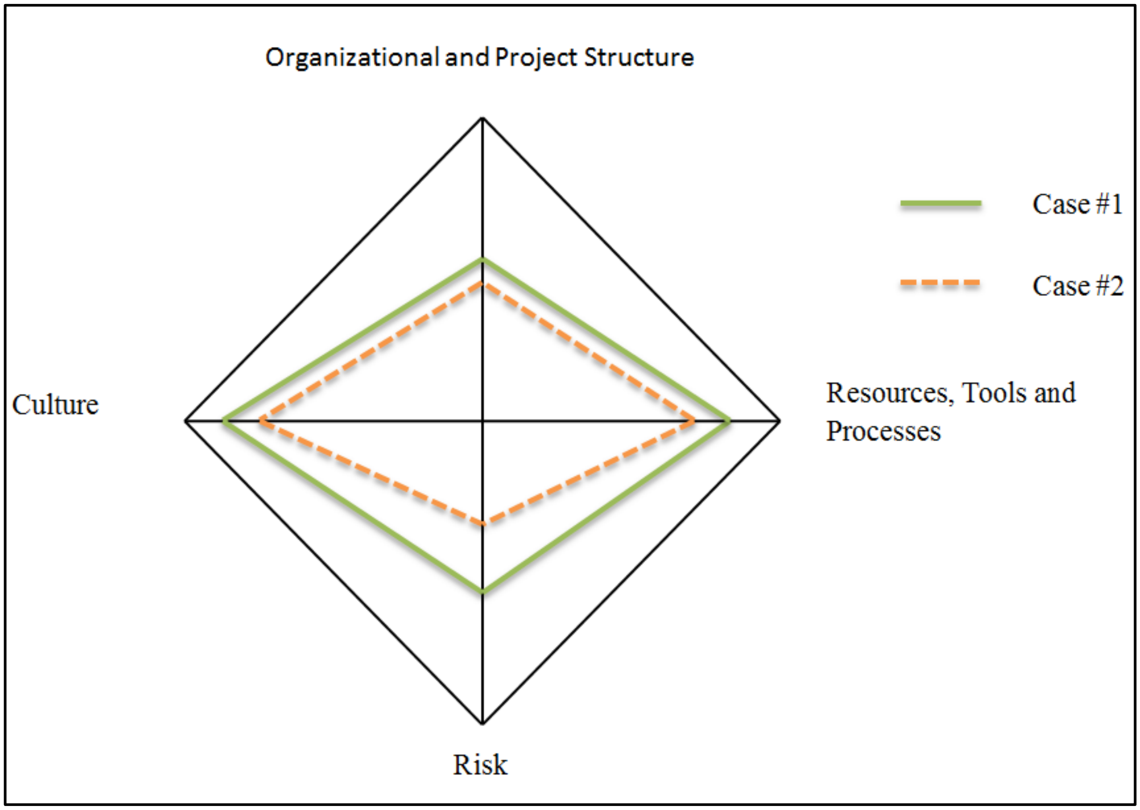

Figure 2.21 A different spider chart with attributes in different locations

According to the arrangement in Figure 2.21, the new area for case study #1 is 25.03, and for case study # 2 is 18.32. The similarity between projects is 73.2 %, which is different from the previous calculation of 75.6%, and the difference is 2.4 %. The order and arrangement of attributes in different spokes affect the final results. However, the difference is small, and could be omitted in this case.

2.5.5 Alternative solutions

In previous sections, the attribute of Physical Form and Function has been assigned to serve as a prerequisite and excluded from the spider chart because it is a categorical factor and cannot be quantified. However, categorical variables can be assigned the values of “0” and “1” with “0” representing not in the category and “1” representing in the category. In this way, all five attributes can be put into the same chart as shown in Figure 2.22.

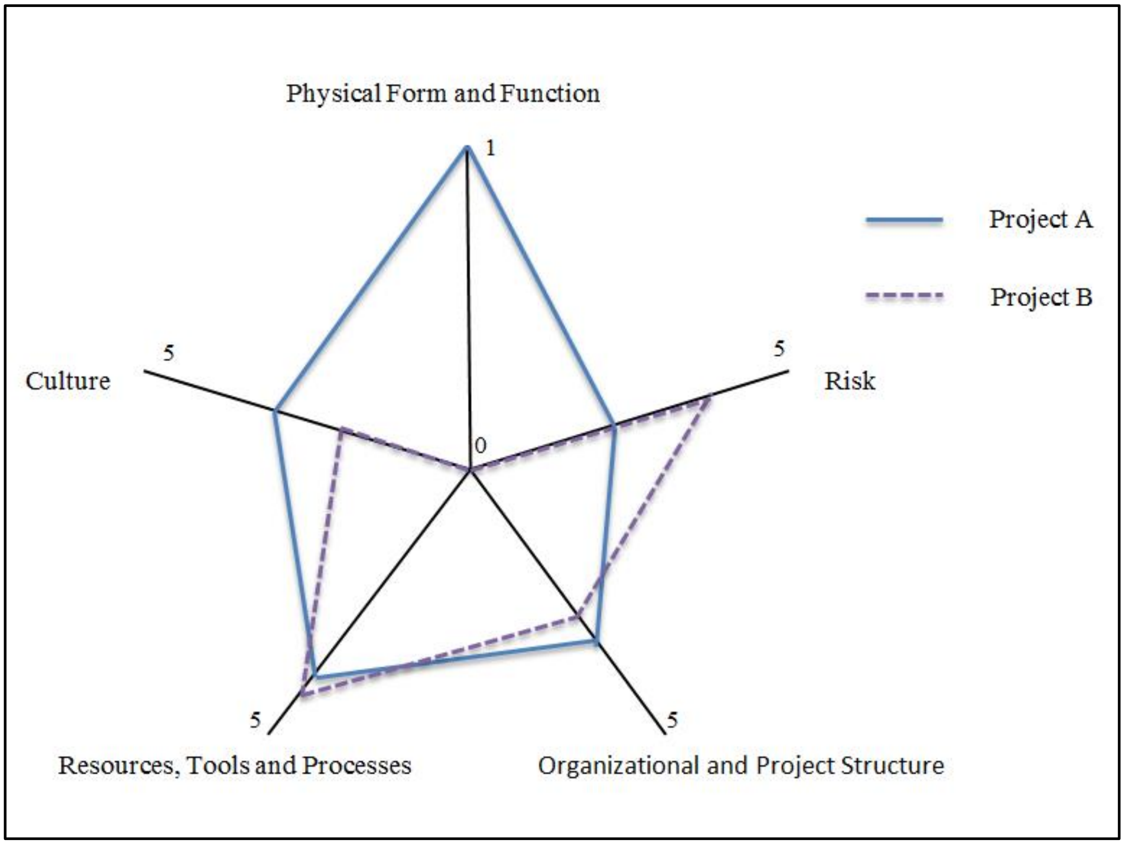

Figure 2.22 A spider chart including Physical Form and Function

In Figure 2.22, solid blue lines represent Project A and dashed purple lines represent Project B. Project A and Project B are different types of projects. We need to determine which project type is assigned the value of “1”. After that, all the other types will have the value of “0”. If the entire project includes different types of construction, for example, part of the Project B is a building construction and the other part is a roadway construction. Building construction has been assigned the value of “1”. As a result, Project B can be assigned a value between “0” and “1” according to the proportions of building construction to the whole project.

The above figure shows a solution to put all five attributes in the same chart but it does not solve the problem of different arrangement of the locations for attributes resulting in different areas for projects. Figure 2.23 shows another alternative solution. Instead of using the overlapping area to represent similarity, use the sum of proportions on each line to represent a project. Equation 2.11 shows the calculation of Project A rating using the new method.

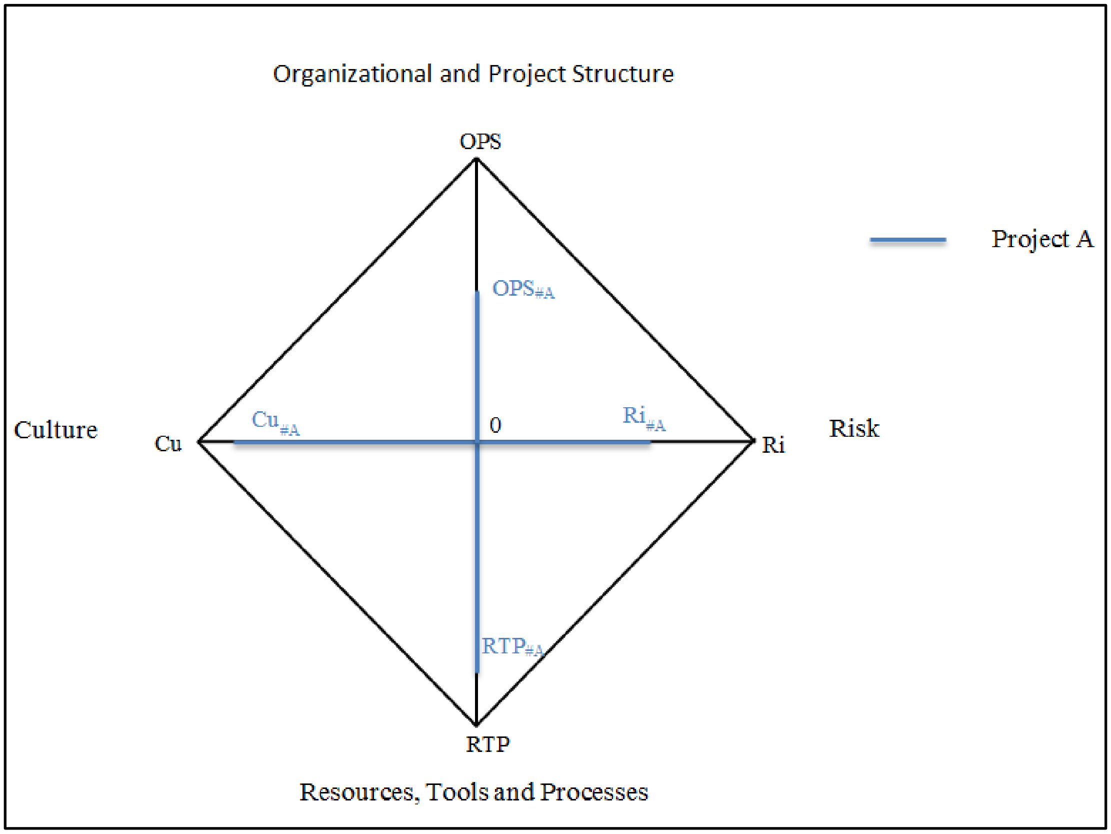

Figure 2.23 An alternative solution without using areas

$$\text{Project A rating} = \frac{Cu_{\#A}}{Cu} + \frac{OPS_{\#A}}{OPS} + \frac{Ri_{\#A}}{Ri} + \frac{RTP_{\#A}}{RTP} \qquad \text{(Eqn. 2.10)}$$

Figure 2.23 shows a solution of using the sum of proportion on each line instead of using enclosed areas. It solves the problem of different arrangement of locations resulting in different areas but it brings a new problem that every project gets a rating and how to use the ratings to compare projects is not a question with easy answers.

2.6 Conclusions and recommendations

This manuscript describes the development of a framework for the concept of Foundational Attributes of construction projects. A literature review is conducted in order to explain and to find elements for each attribute. It is concluded that the attribute of Physical Form and Function is a completely categorical factor, and cannot be quantified. This attribute has many levels and serves as a prerequisite for project comparison. If projects have similar first three levels of Physical Form and Function, they can be compared further using the spider chart developed to host the other four attributes.

The attribute of Organizational and Project Structure can be viewed as a categorical variable as well, but it is quantifiable when comparing certain project outcomes. The project structure is determined by the project delivery method, and the organizational structures for different project participants can be different. The organizational structure usually depends on the company culture, this makes the attribute of Organizational and Project Structure a dependent of the attribute of Culture.

The attribute of Resources, Tools and Processes consists of three different components (resources, tools and processes), and they were discussed separately because they are very distinct from each other. This attribute can be quantified depending on which project outcome is being compared. In general, it can be quantified by the level of appropriateness of using the specific tools and processes, and to what extend the resources limit project performance.

The attribute of Culture refers to company culture, not the project climate. This attribute can be quantified by the degree to which major project participants' organizational cultures are aligned. However, it can be quantified in other ways when a specific project outcome is compared.

The attribute of Risk has two facets. One is the risk associated with the project in different project participants' perspectives, and the other one is the risk tolerance/threshold of major project participants. For each organization, the attribute of Risk can be quantified by the overall level of project risk, and the tolerance level of the organization.

The spider chart can be used to host for the concept of Foundational Attributes, after excluding the attribute of Physical Form and Function. To compare different outcomes of projects, different methods need to be used to quantify the attributes. The similarity between projects can be calculated by using the overlapping area divided by the entire area covered by all projects. Alternative solutions are discussed to put all five attributes in the same spider chart and to use the sum of proportions on each line instead of using overlapping area to represent project similarity.

This research is based on many assumptions and many simplifications have been made in order to proceed. Each assumption and simplification can be a future research direction, and a few of them are listed below.

- A thorough development of each attribute can become an independent research study. More papers need to be read and more scientific methods need to be applied to fully develop each attribute.
- Rethinking the allocation of attributes. For example, organizational structure and project structure can be two attributes, or organizational structure can be relocated to the attribute of Culture.
- Resources, Tools and Processes needs to be separated into three attributes because they are very different components.
- The current method to quantify each attribute is to have a project outcome in mind and to give a rating to each project based on project information and the researcher's judgment. It may have a broader application if all attributes can be quantified according to a reference point so that the rating for each attribute does not change for different project outcomes of interest.
- To reduce the bias from the researcher, a rubic or a standard procedure to evaluate each attribute is needed.
- Instead of using average rating for each attribute, using other methods to calculate the rating that represent each attribute to address the differences between each component within an attribute.

- Since the spider chart has limitations in hosting the concept of Foundational Attributes, consider other graphical/non-graphical methods to describe the concept and compare projects.
- Concept validation is needed before further application.

In summary, this manuscript describes an initial effort on developing a framework for the concept of Foundational Attributes. It is an attempt, not a proof or validation. This is an interesting topic which needs further development and validation, and this manuscript serves as a basis for future work.

Chapter 3 Looking back into the history of construction (Manuscript 2)

3.1 An overview

Construction projects are unique when considering all aspects of a project. However, when considering the similarity between projects, maybe not all aspects need to be accounted for. Twenty percent of traits of a construction project may be responsible for 80 % of the outcome. Finding the important attributes to a construction project is the primary objective of this manuscript.

Looking back to the history of construction will shed light on our future. By looking at what happened in the past, we will understand the fundamentals of construction projects, and discover the aspects that do not change, and the aspects that are most important. To understand the trend and the development of the construction industry, an intensive review of the construction history was conducted, from the very first structure in the Stone Age to the construction industry we have now.

3.2 Review of the history of construction

Construction is one of the largest and oldest industries in the world. From the first shelter ever built to moderate the living environmental to the complex high-rise buildings which are commonly seen today, the construction industry has experienced so many changes. The history of construction is closely associated with the history of architecture, the history of urban development, and the history of materials and resources. To review the history of construction, many documents and records need to be studied. The review begins with the first man-made structure in the Stone Age, followed by describing a few famous structures of each major period in human history.

3.2.1 Stone Age construction

The Stone Age refers to a broad prehistoric period that lasted roughly 3.4 million years and ended between 4500 BC and 2000 BC when people began to use metal tools (NaturalHistoryMuseum 2015). The primary tool used at that time was stone, and the Stone Age is usually subdivided to the Old Stone Age and the New Stone Age based on the tools in use.

3.2.1.1 Old Stone Age construction

During the Old Stone Age, people needed to travel around to hunt and to gather food for a living. The beginning of construction history started from the building of a shelter. Shelters provided a moderated controlled environment to keep people warm/cool and away from the rain. It is safe to say that construction is an ancient human activity, and has a very long history. The earliest shelters could last for a few days or weeks, and were made of materials available at that time, like animal bones, skins, branches, leaves, and stones. The shelters were usually hand-made by people who were using it.

The archaeological record shows some examples of the early shelters. The first evidence of a man-made structure is the Terra Amata, referring to an archeological site dated back to about 400,000BC, located in Southern France (Kostof 1984). Figure 3.1 shows a reconstruction drawing of a hut on Terra Amata.

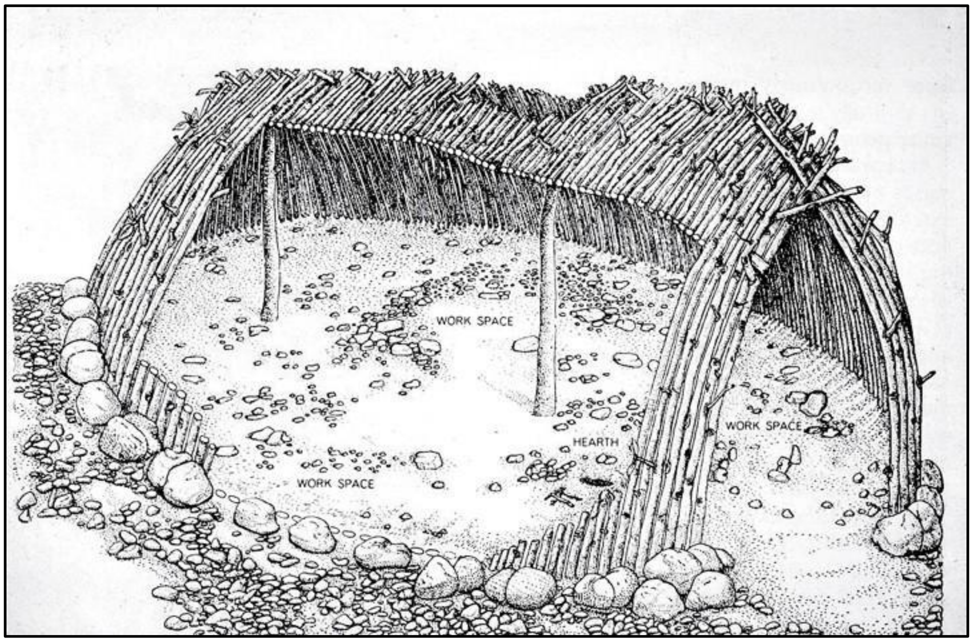

Figure 3.1 A reconstruction drawing of Terra Amata (Kostof 1984)

The site is located in a cove by the beach, and some archaeologists believe that about twenty huts were built on top of another—a new hut built after the old one collapsed. The huts were oval in shape and measured about 25 to 50 feet in length and 13 to 20 feet in width, which could fit about 15 persons (Kostof 1984). As shown in Figure 3.1, the hearth was in the middle, protected from the prevailing northwest wind by a screen of pebbles. Further out from this fireplace were work spaces, and a hole was left in the top to allow the smoke to escape.

Archaeologists found evidence of early huts in the central Russian Plain, dated to about 14,000 BC. The huts were made of mammoth bones and pine poles, with a lining of animal skins and a central hearth. Archaeologists also found clusters of skin-covered huts dated to about 12,000 BC between Moscow and Novgorod, and some other sites in Europe had circular rings of stones which are evidence of some kind of shelter (Chang 2015, Moffet et al. 2004).

In summary, the earliest construction is building temporary shelters, and the materials used were those that could be gathered from the surrounding area and readily used with little or no additional effort to process.

3.2.1.2 New Stone Age construction

The New Stone Age, usually referred to Neolithic Era, began from about 10,200 BC when the earth became warmer, and it is the beginning of farming, including the use of wild and domestic crops and domesticated animals (Bellwood 2004). In this period, people no longer needed to travel to find food, and they could stay in one place and be fed on harvested crops and meat from domestic animals. This era brought a big change to the construction of buildings and other structures, because it brought a need for more permanent dwellings, and enabled the development of a larger community. Furthermore, the agricultural surplus enabled some people to divert from food production to assume specialized roles, such as priests, rulers, merchants, craftsmen, and other trades (Moffet et al. 2004).

One of the earliest urban settlements was Jericho, which was on the site of Tell es-Sultan, a few miles from the current city of Jericho, Israel. Archaeologists have found the remains of more than 20 successive settlements in Jericho, the first of which dated back to about 9000 BC (Pillalamarri 2015). Jericho was developed into a fortified settlement, with a massive stone wall over 12 feet high. Figure 3.2 shows the unearthed site of Jericho. The dwellings on the site consisted of circular huts, made of clay and straw bricks, plastered together with a mud mortar. It is considered to be the first mud brick ever produced in human history, which was formed by hands rather than wooden molds (Pillalamarri 2015, Chang 2015, Moffet et al. 2004).

Figure 3.2 Dwelling foundations unearthed at Tell es-Sultan in Jericho (Viator 2015)

The largest and best-preserved Neolithic site found to date is Çatalhöyük, dated back to 7500 BC to 5700 BC, located in southern Anatolia, Turkey. Çatalhöyük was a densely packed town with a large number of buildings clustered together as shown in Figure 3.3. No footpaths or streets were developed at the ground level, and the buildings were accessed by holes in the roofs. The rooftops also served as a place for inter-family activities (Kleiner and Mamiya 2006, Moffet et al. 2004).

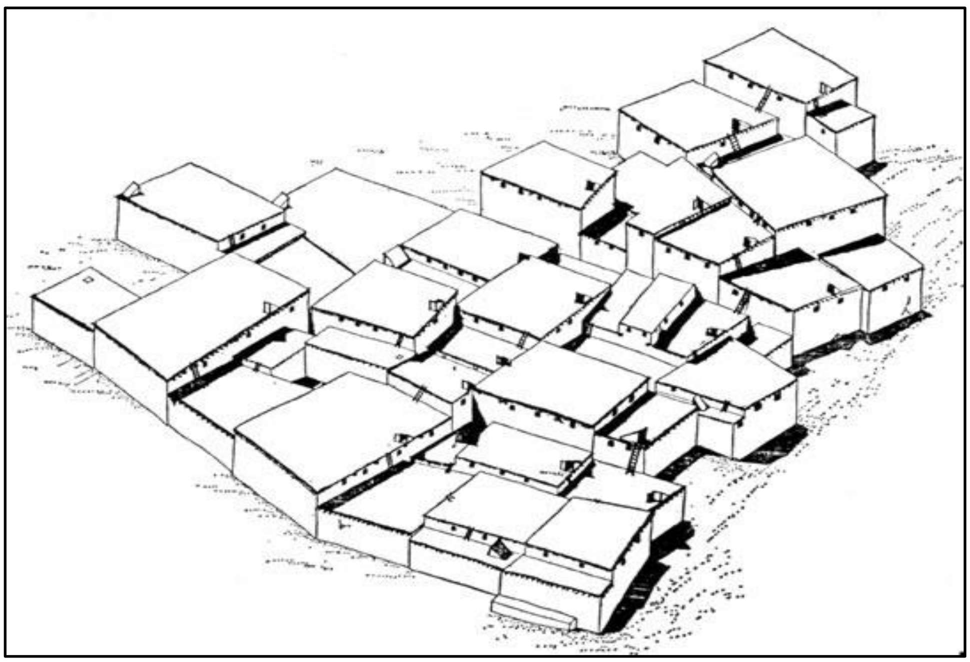

Figure 3.3 Reconstruction view of buildings for Çatalhöyük (Brynmawr 2015)

The buildings were made of mud brick walls and with post-lintel timber frames to enclose rectangular spaces. The houses were packed together to support each other. The interiors of the houses were considered to be something similar to what is shown in Figure 3.4. A timber ladder to the roof was usually on the south wall of the room where cooking hearths were located. Since no doors or windows were present, the opening on the roof may serve as the ventilation channel as well. It is believed that the interior walls were plastered to a smooth finish as shown in Figure 3.4(Moffet et al. 2004, Kleiner and Mamiya 2006).

Figure 3.4 Restoration of a typical interior of buildings for Çatalhöyük (TurkeyTravelPlanner 2015)

The most famous structure in the Neolithic Era is Stonehenge (Figure 3.5), located in southwestern England. Archaeologists believe that this monument is a burial ground for early human remains (Pitt 2008).

Figure 3.5 A picture of the present-day Stonehenge (Tallbloke 2015)

As shown in Figure 3.5, Stonehenge was composed of many pieces of mega rocks, and this type of structure also is called megalithic, which is a structure or monument made of large stones, and utilizing an interlocking system without the use of mortar. Some of the massive stones weigh about twenty tons, and they were prefabricated and transported from nearby quarries and erected on site. The size of these mega stones brought great challenges to the builders at that time. There is no way to know how exactly the builders solved those problems, however, modern experiment has shown that it is possible to use a simple lever, inclined planes, a sledge, greased track, wooden scaffolds, stout ropes, and about 130 people to move and erect mega rocks on the scale of Stonehenge (Moffet et al. 2004).

In Summary, during the New Stone Age after the Agriculture Revolution, more permanent houses were desired, and larger settlements were formed. The materials used in construction expanded to clay, mud brick, mega stone, and timber. The construction of structures was not limited to fulfill basic survival needs, and people began to spend great effort to build monuments, tombs, and temples. The builders probably had sophisticated construction skills and surveying methods.

3.2.2 Bronze Age construction

The Bronze Age lasted from about 3300 BC to 1200 BC. During this period, two major changes happened: the beginning of written records and the widely spread use of metal tools. Large urban communities were formed, and two civilizations which are considered the cradles of Western world civilizations were developed: Mesopotamia and Egypt.

3.2.2.1 Mesopotamia construction

The Mesopotamian civilization is located in today's Iraq. The earliest massive buildings were found in Mesopotamia, and the most famous structure is the ziggurat which is considered to be the major part of a temple complex. Figure 3.6 shows one of the best preserved ziggurats—the Ziggurat at Ur, built about 2100 BC. This massive structure was about 210 feet in length, 148 feet in width and over 98 feet in height. As shown in the picture, only the foundation has survived, so the height is estimated. A ziggurat was mainly constructed of sun-dried bricks bonded with bitumen, and the face layer was made of kiln-fired bricks for weather resistance (Moffet et al. 2004).

Figure 3.6 A picture of the Ziggurat at Ur (Epistematica 2015)

It is believed that the world's first cities emerged on the plains of Mesopotamia. Figure 3.7 shows a plan of the city of Ur, a typical city in Mesopotamia in ancient times. In the center of the city is a large enclosed sacred precinct, and a ziggurat is located within it. On the contrary, the residential area is densely packed. The right half of the figure shows a plan for the residential area. It shows that houses were organized around courtyards, which is a design that promotes urban density while also providing privacy and fresh air to each house (Moffet et al. 2004). Houses were mainly made of bricks due to the abundance of clay in that region. The bricks were usually dried under the sun because fired bricks cost labor and fuel.

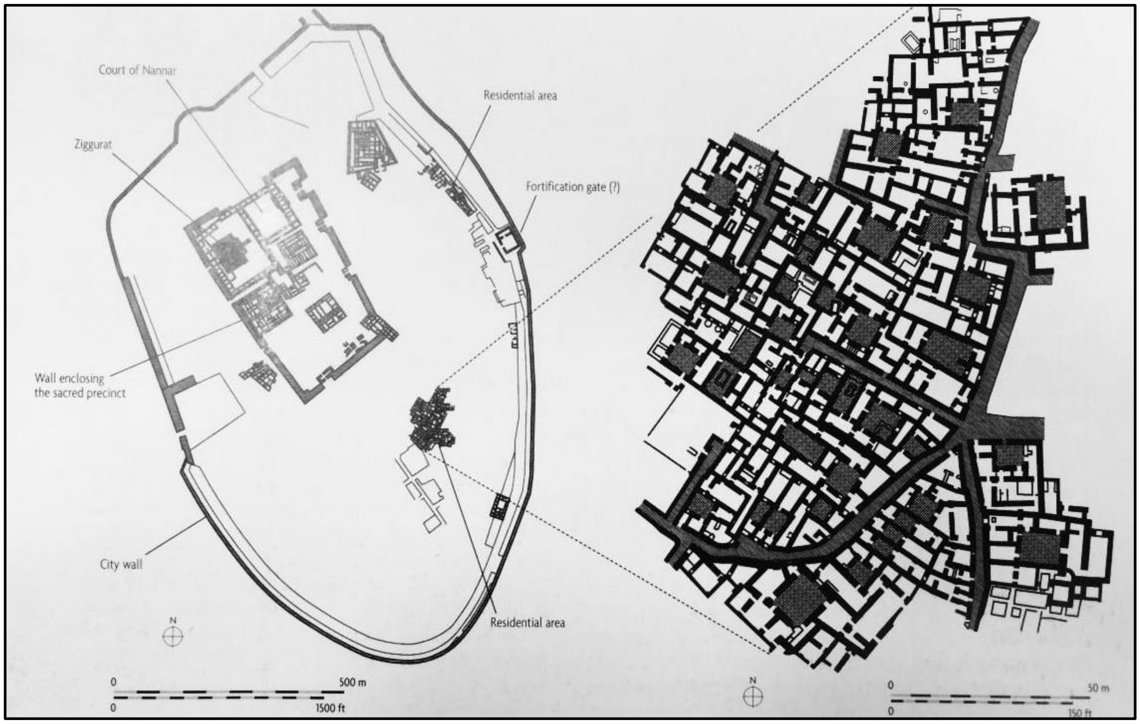

Figure 3.7 Plan of the City of Ur in ancient Mesopotamia (Moffet et al. 2004)

3.2.2.2 Ancient Egypt construction

The most famous structures in the Bronze Age are the pyramids in Egypt. The ancient Egyptians strongly believed in the afterlife, so the tombs for pharaohs became marvelous structures (Moffet et al. 2004). The largest pyramid is the Great Pyramid of Giza (Figure 3.8), also called the Pyramid of Khufu, which was initially at 481 feet high, built around 2580 BC, and the oldest of the Seven Wonders of the Ancient World. It consisted of about 2.3 million stone blocks mostly transported from nearby quarries, while the largest granite stones, weighing about 80 tons were transported from 500 miles away. It is estimated that 5.5 million tons of limestone, 8,000 tons of granite stones, and 500,000 tons of mortar were used in the construction of the pyramid (Clarke and Engelbach 1991).

Figure 3.8 The Pyramid of Khufu (Thune 2005)

In summary, during the Bronze Age, large cities were formed and the ancient people began to build massive structures for religion purposes. Clay bricks dried by the sun and fired bricks were used in the ancient Mesopotamian civilization because clay was abundant near the river bank but stones were scarce in the area. Timber was largely used due to the development of metal tools and the creation of saws. The Egyptians favored large stones because they were abundant, and they used sun-baked mud bricks for normal houses. Timber was scarce in the area due to the dry weather. Manpower is still the major tool and energy source for construction. It is believed that the Egyptians built those marvelous structures with primitive technology. However, it is reasonable to believe that they had sophisticated surveying skills and engineering knowledge.

3.2.3 Iron Age construction

The Iron Age occurred from about 1200 BC to about 500 AD, when the Roman Empire ended. During that time, the use of iron as tools and weapons was widespread, and the ancient Greeks and the Romans made tremendous progress in science and technology.

3.2.3.1 Ancient Greek construction

The ancient Greeks had many inventions that facilitated the construction process. The crane for lifting heavy loads was invented around 500 BC. Extensive plumbing systems were developed for personal or public use. Central heating was also invented, and the heated air was circulated through flues laid in the floor. The watermill was invented to utilize hydraulic power (Wilson 2002, Lewis 1997).

The ancient Greeks also made progress in urban planning. They used a grid plan for residential and public areas, and major streets to connect different quarters. The main street of Elea was 16 feet wide, paved with square limestone blocks, and contained a small gutter on one side for the drainage of rainwater. Residential buildings were constructed with sun-dried clay bricks or wooden framework, and doors and windows were present for the buildings at that time (Boardman et al. 1967, Fletcher 2001).

For public structures, the Greek temples were the most famous structures. Temples were first built with timbers, using a post-lintel structure, and evidence shows that some temples used a timber roof truss to extend the room span. Later the Greeks used stones to replace timbers to make the temple stand longer. Figure 3.9 shows a picture of the famous ancient Greek temple The Parthenon, dedicated to the goddess Athena, built around 440 BC.

Figure 3.9 The Parthenon – Greek Temple of Athena (Britannica 2015)

Every Greek city had its own open-air theater which could accommodate a good portion of its population for public meetings and performances. Attending dramatic performances was encouraged to promote civic values. The theater was usually set on a hillside out of the city and had rows of tiered seats set in a semicircle around the central performance area, and the orchestra (Moffet et al. 2004). Figure 3.10 shows an example of the ancient Greek theater, the Epidaurus.

Figure 3.10 Epidaurus – Greek Theater (Historvius 2015)

3.2.3.2 Ancient Roman construction

Roman building practices, like roman culture, were derived from many sources, especially Greek, Etruscans, and Egypt, but they were unique. The Romans were practical builders who preferred durable roads and bridges across the length and breadth of their empire. They brought clean water into cities through a series of aqueducts, and they carried away wastewater in underground sewers (Moffet et al. 2004). The Romans adopted lightly used inventions from other civilizations, and developed the application of them to a new level, like central heating for houses, the arch and vault structure, the roof truss, the water wheel, and many others. They built many structures and built them so well that a large amount of their work has survived until today.

The Romans invented concrete which is a very strong and long-lasting material. Together with the extensive use of the arch, vault, and dome forms, the Romans built many magnificent civil engineering structures, public buildings, and military facilities, including amphitheaters, temples, aqueducts, roads, bridges, and dams (Bunson 2009). Figure 3.11 shows the most famous amphitheater in the Roman age, the Colosseum, built around 80 AD, commonly known as an iconic symbol of Imperial Rome. Figure 3.12 shows the Pantheon, built around 120 AD, which is a circular temple with a dome structure. The right side of the figure shows the interior of the Pantheon. The Romans were the first to use a dome structure to create a large interior space. The roof truss was widely used in the Roman period due to the larger span that a truss can provide compared to a column-lintel structure.

Figure 3.11 Colosseum—Roman Amphitheater (Diliff 2007)

Figure 3.12 Pantheon—Roman Dome Temple (Studyblue 2015)

The ancient Romans made great progress in civil engineering works. Aqueducts were constructed to transport fresh water into the cities, for domestic, farming, and industrial usage. Figure 3.13 shows the Aqueduct of Segovia, which is well preserved and located in today’s Spain. The Romans used hydraulic power extensively so they built many dams in their colonies as well.

Figure 3.13 The Aqueduct of Segovia, Spain (BornToVacation 2015)

Roads were common at that time, and the Romans improved the pavement design and the use of materials so that many of the roads are still in use today. For most of the higher quality roads, a five layer design was used. The Romans built a lot of bridges because when a road encountered an obstacle, the Romans preferred to engineer a solution to the obstacle rather than redirect the road around it. Therefore, bridges were constructed over all waterways and marshy ground, and hills were often cut or tunneled through, and the tunnels were made with square hard rock block (Gagarin and Fantham 2010).

3.2.4 Medieval construction

After the fall of the Western Roman Empire, the Western world started to live in the Dark Age, the Medieval Age, which ranged from the 5th century to the 15th century when the Renaissance started. During that period, many fortified houses and castles were built to withstand enemy attacks. The most famous structures were still for religion purposes, and many famous cathedrals and churches were built during this time.

3.2.4.1 Eastern Europe construction

In the Eastern Roman Empire, which lasted more than a millennium, Byzantine and Islamic architecture dominated structures in Eastern Europe. The Hagia Sophia (Figure 3.14), built around 535 AD, is the masterpiece of Byzantine architecture. The building was originally used as a church than an imperial mosque and has a 107-foot diameter central dome rising 180 feet above the floor. Two half domes on the sides together with the main dome provide a clear span of about 250 feet (Moffet et al. 2004).

Figure 3.14 The Hagia Sophia (Worldwonders 2015)

3.2.4.2 Western Europe construction

In Western Europe, the Gothic architecture style became dominant during the late Medieval period. The Gothic architecture used a skeletal system that transfers roof loads at discrete points, so no continuous large walls were needed for load bearing. Therefore, large openings in walls for big windows were possible. Large colored glass windows were used in many Gothic cathedrals. Other key elements for Gothic structures are pointed arches, rib vaults, and flying buttresses (Moffet et al. 2004). Figure 3.15 shows the famous west front, the flying buttresses from the east side, and the nave of the Notre Dame Cathedral in France, also known as the Notre Dame de Paris.

Figure 3.15 Notre Dame Cathedral, west, east and interior (Sanchezn 2007, DXR 2014, Myrabella 2013)

The design and construction of these marvelous structures in the Middle Age was sophisticated. Some of the building drawings are still preserved from that age. As the labor for construction projects, paid workers who processed certain craft skills were usually hired to do the job. A building designer was usually also in charge of the construction process, called a master builder at that time. The training of a master builder started from the learning of language and mathematical skills in a grammar school run by the local priest or monastery. Geometry was the theoretical core of medieval architecture. After studying in school, the student became an apprentice in one of the building trades (carpentry or masonry), working under the direction of a master craftsman. The apprentice was taught all aspects of the craft and would be certified as a journeyman which is a qualified worker to work on projects. After a few years working as a journeyman at different job sites, the journeyman could advance to the level of master if he could present a masterpiece to his craft guild. After becoming a master of the trade, he could direct journeymen and teach apprentices. Only the most capable and experienced master craftsmen would be entrusted to direct a whole project and get the title of the master builder (Moffet et al. 2004).

3.2.5 Renaissance construction

The Renaissance is an important transition period between the Medieval Age and the Modern Age. It started with a culture movement in Florence, Italy in the 14th century, and the spread to the rest of Europe. People started to learn from the ancient Greeks and Romans, and to treasure rationality and the ability to make and act upon empirical observations of the physical world. Many changes happened in the building structure as well. The emerging nation-states of Europe began to compete with the church as the center of power. The Roman Empire was the model of the nation-state, so the use of

Roman building styles, especially the use of a dome roof was preferred by those European countries in the Renaissance. Architects favored simple forms such as the square and circle, and abandoned the complex, geometric transformations of the medieval structures (Moffet et al. 2004, Chang 2015).

Starting from this time, the architects were separated from craftsmen by only doing the design work and providing detail drawings for craftsmen to build. The architects were mainly painters or sculptors who did not require much knowledge of building technology (Chang 2015, Moffet et al. 2004). The famous architect Filippo Brunelleschi (1377-1446) was a goldsmith, and later became the designer of many structures including the Florence Cathedral (Figure 3.16).

Figure 3.16 Santa Maria del Fiore -- Florence Cathedral (ParadoxPlace 2015)

3.2.6 Modern Age construction

The modern Age is a period with significant developments in the fields of science, technology, politics, and warfare. It started with the end of the Renaissance in Europe and includes major changing periods like the industrial revolution and world wars.

3.2.6.1 Construction in 18th Century

The Age of Reason and the Age of Enlightenment came to Europe after the Renaissance and laid out the foundation of modern science and technology. The Industrial Revolution took place in England starting in about 1760. During that time, steam-powered machines started to replace manpower or horsepower in many areas, including the production of building materials. The widespread use of iron is one symbol of the Industrial Revolution. Cast-iron was used for building columns and also in building bridges. The Coalbrookdale Iron Bridge (Figure 3.17) was built in 1779 and is the world’s first all-metal bridge. The bridge has an arch structure, placing the iron completely in compression and ignoring its great strength in tension (Moffet et al. 2004).

Figure 3.17 The Coalbrookdale Iron Bridge (OpenBuildings 2015)

The development of science and technology during this age enabled many changes in construction, including the new and improved methods for making building materials, and using scientific methods to design structures. As a result, a separation of architects and engineers started to develop. A growing body of scientific data on materials provided the basis for civil engineering, which was taught at schools organized apart from architectural academies. Civil engineers were in charge of roads, bridges, mines, factories, warehouses, and canals, while architects were employed on buildings when aesthetics and symbolism outweighed pragmatism (Moffet et al. 2004).

3.2.6.2 Construction in 19th Century

Many changes occurred during the Industrial Revolution. A major development is the production of chemicals, which enabled improvements in making glass, textile, paper, iron, and steel (Landers 2003). Steel could be produced cheaper and in large quantities starting from the mid-19th century, and this enabled the construction of large span bridges, railroads, skyscrapers, and large ships. The construction of infrastructure was booming in the late 1870s in the US. Bridges, dams, and other infrastructure set new records and introduced equipment and methods that revolutionized the industry (ENR 1999). One example of those projects is the Brooklyn Bridge as shown in Figure 3.18. It has a span of 1,595.5 feet, completed in 1883.

Figure 3.18 Brooklyn Bridge (ShutterStock 2015)

Another major improvement was the replacement of wood with coal as the major fuel, which was more abundant and cost less. Portland cement was invented and patented in 1824 by a British bricklayer. The use of concrete became popular again after disappearing with the Roman Empire about 1000 years before. Reinforced concrete was invented and developed during this period, and later it was used on mass spans and tall structures in the 20^{th} Century.

In the early 19^{th} century, large-scale gas lighting was used to allow factories and stores to remain open longer than using candles or oil, and it allowed night life to flourish in cities. Other than the improvements in the lighting systems, the plumbing and sanitation systems in buildings also advanced rapidly. Due to the use of cast-iron in producing pipes, high-pressure water supply powered by steam power was made possible. Sewage treatment plants were introduced in the 1860s, and permanent plumbing fixtures appeared in buildings with water supply and drainage (Chang 2015).

The Second Industrial Revolution started from the late 19^{th} century, and during that time, more advanced technologies were invented. The production and refining of petroleum began in 1848. The first widely used internal combustion engine was developed in 1876. In 1882, Thomas Edison started the world's first large-scale electric power network. In 1886, Karl Benz patented the world's first automobile (Engelman 2015). All these technology innovations had a great impact on the construction industry and every aspect of human lives.

3.2.6.3 Construction in 20th Century

The 20th century witnessed rapid changes in the construction industry. In the US, nearly all types of construction projects were in high demand after World War II. As the complexity of projects increased, more professional management skills were desired in the area of scheduling, estimating, contracting, business managing, etc. Construction management gradually became an academic discipline (Robson and Bashford 1995, Harris 1992, Oglesby 1990). More powerful equipment was invented and the types of materials used in construction have been largely expanded due to the development of material science. For example, PVC pipes have been largely used in small diameter water and sewer pipelines, and they are light, strong, and resistant to corrosion (ENR 1999).

Drinking water quality became a concern of people in the 1910s, and many drinking water treatment plants were built to provide higher quality water. Wastewater treatment plants began to be built in the 1920s. In the late 20th century, people began to realize that we need to protect our living environment, and sustainable development gradually made a larger and larger impact on the practice of construction.

MEP systems in buildings have become more and more complex. Now, the fire protection, security, lighting, heating, ventilating and air-conditioning systems can “talk” to each other through building automation communications. This function helps to provide a safer, more energy-efficient and healthier indoor environment (ENR 1999).

The invention and development of the computer and the technologies associated with it has changed the practice of the construction industry since the 1960s. Computer-Aid Design drawings have become the standard document of the industry, and in the 1990s, 3D models began to replace 2D drawings, and became more and more popular on large scale projects. Many construction companies use commercial software to help them with project management, scheduling, and estimating. In the construction industry, so many changes happened in the 20th Century that they cannot all be listed in this section.

3.3 Summary of trends

The construction industry has a long history, and the development of the construction industry is closely associated with the development of human society, religion, philosophy, culture, science, and technology. In this section, the development of construction is summarized in the areas of function and purpose, materials, equipment, tools and power source, people who build the structures and the relationship between different parties.

3.3.1 Function and purpose

The function and purpose of built structures have been changing over time. Table 3.1 shows the function and purpose of structures in each time period. It is noticeable that one aspect that has not changed is that the purpose of a structure is always to fulfill an owner's need. However, the owner's need has been changing over time.

Table 3.1 Summary of function and purpose of structures

Timeline	**Function and Purpose**
Old Stone Age	• Traveling around for hunting and food gathering • Temporary shelter to moderate the environment
New Stone Age	• Mud brick house • Stone wall for defense • Village, cluster of houses, no street • Megalithic, monument made of mega stones • Temple • Tomb
Bronze Age	• Urban cities, house around courtyard, few streets, walls around the city and temple • Massive structure used as temple (ziggurat) • Pyramid, massive tomb in Egypt • Reservoir • Canal • Dam
Iron Age	• Urban grid plan, major streets paved with limestone blocks • Plumbing system • Central heating system • Greek and Roman temples • Theatres • Aqueduct • Arch bridge • Tunnel
Medieval	• Castle for defense • Cathedral and church
Renaissance	• Castle • Cathedral and church
18^{th} Century	• Factory • Warehouse • Iron bridge
19^{th} Century	• Steel bridge • Railroad • Elevator system
20^{th} Century	• Skyscraper • High-speed highway • Drinking water treatment plant • Air-conditioning system • Fire protection system • Utility distribution system

From the very first temporary shelter to today's skyscraper, building structures to moderate the living environment have always been a major purpose of construction projects, and it is a basic need for human survival. Another major purpose of structures is for religious purposes. Structures built to serve religious purposes appeared much earlier than structures serving other purposes (not including for dwelling purposes). Tombs appeared early in history too because people wanted to bury the dead properly. A tomb is kind of a religious purpose as well because people believe in an afterlife so they need to give the dead a comfortable place to stay. After cities were formed, the construction of infrastructure began. Walls used for defense and city streets used for transportation are examples of early infrastructure elements. Later on, more heavy civil structures were built to make people's lives easier. After the Industrial Revolution, buildings were needed for industrial and commercial purposes.

3.3.2 Materials

The materials used in a time period depended on natural abundancy and available tools. Table 3.2 shows the material trends for different time periods. Many western countries used bricks and stones as major construction materials for a long time. In Asia, timber was the major construction materials due to the abundance in the area. Sometimes, locally abundant material is the only choice due to the lack of transportation capability in the past. The variety of materials used in construction expanded dramatically after the

Renaissance, largely due to the advance in science and technology, especially in chemistry.

Table 3.2 Summary of material trend

Timeline	**Materials**
Old Stone Age	• Animal bones and skins • Branches, leaves • Stone
New Stone Age	• Mud and straw brick, plastered with mud mortar • Timber, post-lintel frame • Mega rocks, stone
Bronze Age	• Sun-dried brick and kiln-fired brick • Stone • Timber
Iron Age	• Brick • Stone • Timber • Roman concrete
Medieval	• Brick • Stone • Timber • Glass for window
Renaissance	• Brick • Stone • Timber
18^{th} Century	• Brick • Stone • Timber • Cast-iron used as building columns and bridge structure
19^{th} Century	• Brick • Stone • Timber • Portland cement and concrete • Plywood
20^{th} Century	• Brick • Stone • Timber • Reinforced concrete • Plastic and PVC pipe • Asphalt

3.3.3 Equipment, tools and power sources

Table 3.3 summarizes the trend related to equipment and power sources. The trend is mainly affected by the development of science and technology. The use of more powerful equipment liberates people from using manpower to build projects. It seems that more powerful equipment enables the building of some mega projects, but this may not be true. In ancient times, people managed to build Stonehenge, Ziggurat, the pyramids, and many other amazing mega structures, using limited yet unknown methods and technology. People’s willingness to build is a much stronger enabler than the available science and technology.

Table 3.3 Summary of equipment, tools, and power sources

Timeline	Equipment and Power Source
Old Stone Age	• Stone tools • Manpower to build structure • Fire for warming
New Stone Age	• Stone tools • Manpower • Unknown method to move and erect mega stones
Bronze Age	• Fire for kiln-fired brick • Metal tools • Manpower • Horse, donkey and camel for hauling goods • Unknown method to move and erect mega stones
Iron Age	• Crane, invented by ancient Greek to lift heavy load • Watermill • Horse, donkey and camel for hauling goods
18th Century	• Steam power and steam-powered machine
19th Century	• Coal to replace burning wood • Petroleum • Gas • Electricity
20th Century	• Nuclear • Solar • Bioenergy

3.3.4 Builders and project delivery methods

The role of builders has changed significantly as shown in Table 3.4. In the very beginning, the builders were the users of the structure, so it was self-built. People performed similar tasks, and there were no specialized jobs. After the agricultural revolution, people began to choose different roles due to a surplus of food and no need for everyone to hunt. People who specialized in building structures were craftsmen, and they were in charge of designing and building the structure. As the structure became more complex, master builders were developed who were in charge of designing and building large structures. During the Renaissance, designers and builders started to separate, and after the 18th Century, the architect and engineer started to separate due to the use of scientific methods in designing structures.

Table 3.4 Summary of trend for builders

Timeline	**Builders**
Old Stone Age	• People who use the shelter • One or a few people
New Stone Age	• Separated roles due to food surplus • Craftsman • Sophisticated construction and survey skills • Mega structure took a lot of people a long time to build
Bronze Age	• Craftsman • Sophisticated construction and survey skills • Mega structure took a lot of people a long time to build
Iron Age	• Craftsman, carpentry or masonry
Medieval	• Master builder • Craftsman • Sophisticated geometric knowledge
Renaissance	• Designer and builder started to separate • Craftsman
18th Century	• Separation of architect and engineer due to development in using scientific methods to design structures • Craftsman
19th Century	• Architect and engineer getting formal education • Craftsman
20th Century	• Formal education for constructor • Professionalization of construction • Development of education and research in construction • Trade craftsman/subcontractor

Project delivery methods are a modern concept, and they refer to the contracting relationships between major project participants. At the very beginning of human history, construction projects were owner self-perform projects. After specialized craftsman emerged and before the roles of designer and builder were separated, construction projects were design-build projects. After that, the major project delivery methods were design-bid-build methods. Nowadays, more innovated project delivery methods are emerging to address specific situations of a project.

3.4 Conclusions

The development of the construction industry is closely associated with the development of human society, religion, philosophy, culture, science, and technology. Many aspects of construction projects have been changing and evolving, including the purpose of structures, the materials used in construction, equipment, tools and power sources, the role of builders, and the project delivery methods. However, some fundamental things have never changed. The purpose of a structure is to fulfill a certain need of an owner, and the biggest drive to finish a project is the owner's desire to have that structure, regardless of the limitations and constraints. The most important factor to make a project successful is the intelligence and determination of the builder. It is the people who are the center of a construction project, not the final structure.

Chapter 4 Introducing the concept of Project Metabolism (Manuscript 3)

4.1 An overview

This manuscript describes the concept of Project Metabolism and a framework for it. The information used to define and develop the concept is from literature review. Concept mapping methods are used to organize the information and help the author develop the concept. A survey is conducted to gather construction industrial professionals' opinion on this subject and help the author develop a framework for the concept of Project Metabolism.

4.2 The origin of the concept of Project Metabolism

The idea of developing a new concept called Project Metabolism was inspired by the findings described in the first two manuscripts in this dissertation, and comes along with the author's interest in sustainable construction. The first manuscript describes the foundational attributes for construction projects. The detailed project information needed to establish the Foundational Attributes makes project comparisons difficult. After reviewing the history of the construction industry, the author concludes that the people's resolution is the primary drive for a construction project, and this conclusion draws the author's attention from the physical aspects of a construction project to the people who are involved in the process. Together with the author's long-term interest in sustainable construction, the concept of Project Metabolism was born.

4.2.1 From sustainability and human metabolism to Project Metabolism

Sustainability has always been an interest of the author. Over the past few decades, human beings have greatly impacted the natural environment which supports our lives. The consumption of non-renewable resources and the creation of wastes have been identified as the most significant issues that our society must pay attention to (Lave et al. 1999, Lingard et al. 2001). If we continue consuming and polluting at the current rate, the earth's ability to provide resources and absorb pollution will be very limited. To raise awareness of these issues, a new concept was introduced in the Brundtland Commission report for the United Nations in 1987 (Brundtland 1987). Being defined as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs", the concept of sustainable development has attracted more and more attention from the public.

The construction industry has a tremendous impact on many aspects of people's lives, and it plays a very important role in overall sustainable development. The construction industry consumes large amounts of energy and resources, releases pollution to the air, ground, and aquatic environment, and is the dominant user of most minerals. It is estimated that by 2030 the world will run out of many raw materials for buildings, and we may have to recycle and mine landfills (Gorgolewski 2006). Therefore, achieving sustainable development in the construction industry is a very important and urgent task.

Many efforts have been undertaken and significant progress has been achieved in terms of sustainable construction. In the building sector, many rating systems have been established and are being improved constantly. For infrastructure projects, rating systems and evaluation tools are being developed as well. One feature in common for most of the rating systems and tools is their focusing on specific end results. For example, to obtain the LEED Water Efficiency Credit 1.1 for New Construction, you need to reduce the water used for landscaping by 50% (USGBC 2005).

Using rating systems is an inductive and direct approach that is effective in evaluating performance and awarding certifications. However, very little effort has been expended to describe sustainable construction from a deductive and indirect approach. To explain sustainable construction in an indirect and deductive approach, it is important to understand the differences among those approaches.

Figure 4.1 provides a simplified example of the direct and indirect approaches, and Figure 4.2 gives the basis of an example of inductive and deductive approaches. In Figure 4.1, to describe the point (x, y) in an X-Y coordinate system, a direct approach is to specify the values of x and y. An indirect approach is to indicate the starting point and then explain the trend or equation of a projection that will pass through the point (x, y).

Figure 4.2 shows a set of circles and dots. To describe the set, we may try to describe all the circles and dots, and this is an inductive approach. We may also describe the common characters of the circles and dots, or relationships among them, in order to explain the whole set. This second means is a deductive approach.

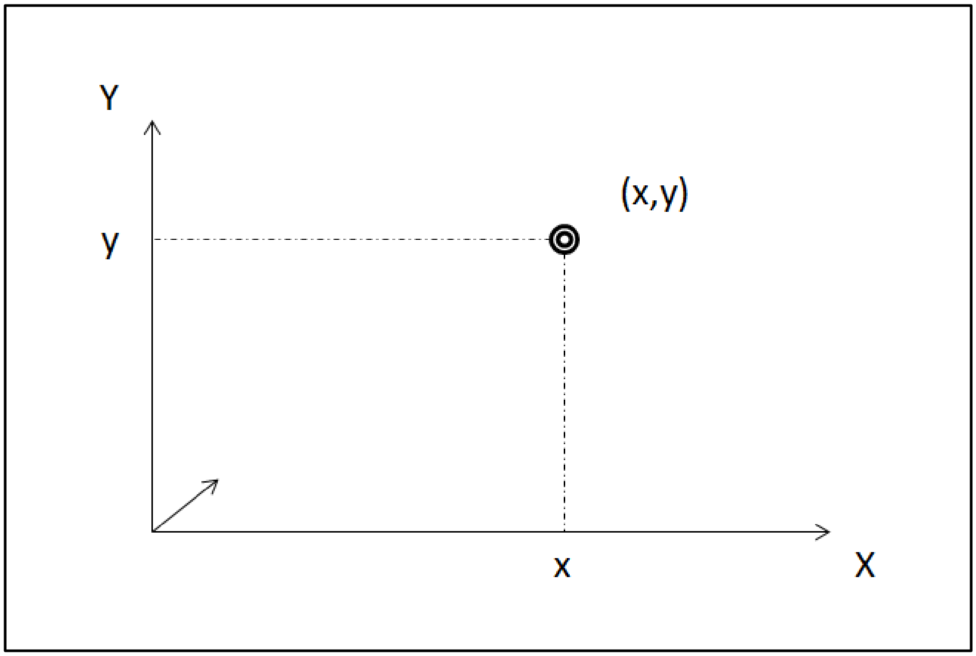

Figure 4.1 A simplified example of direct and indirect approaches

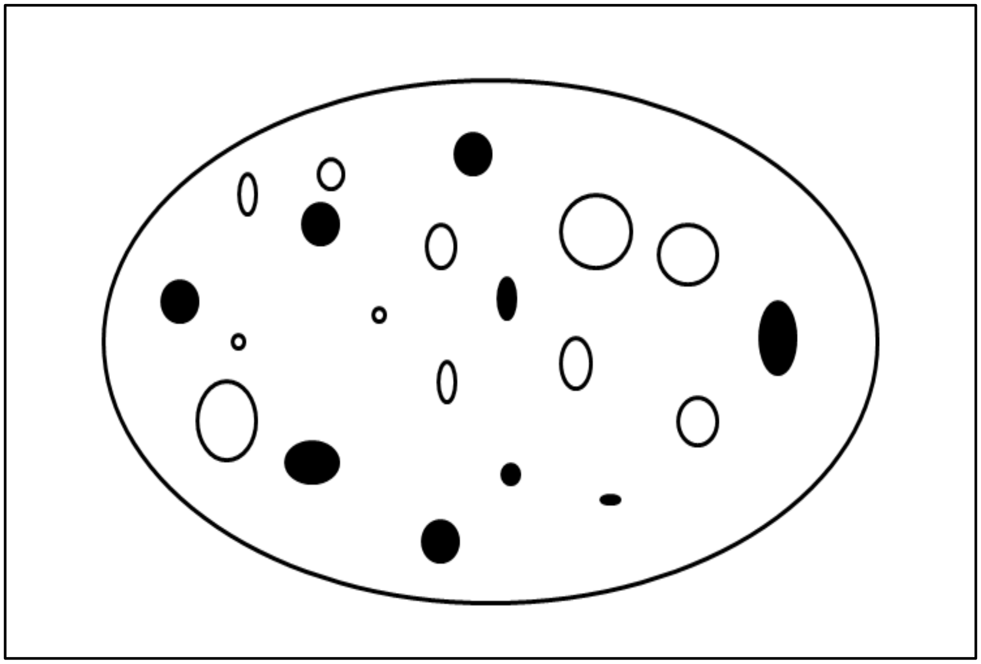

Figure 4.2 An illustration of deductive and inductive approaches

In construction, describing a sustainable project from a deductive approach is like describing a healthy system which produces sustainable results. The system may contain different parties involved in a project, the relationships among different parties, and the information flow among the different parties. In that sense, it is like a human body, composed of different organs and substances flowing throughout the body. Figure 4.3 illustrates the resemblance between human metabolism and Project Metabolism.

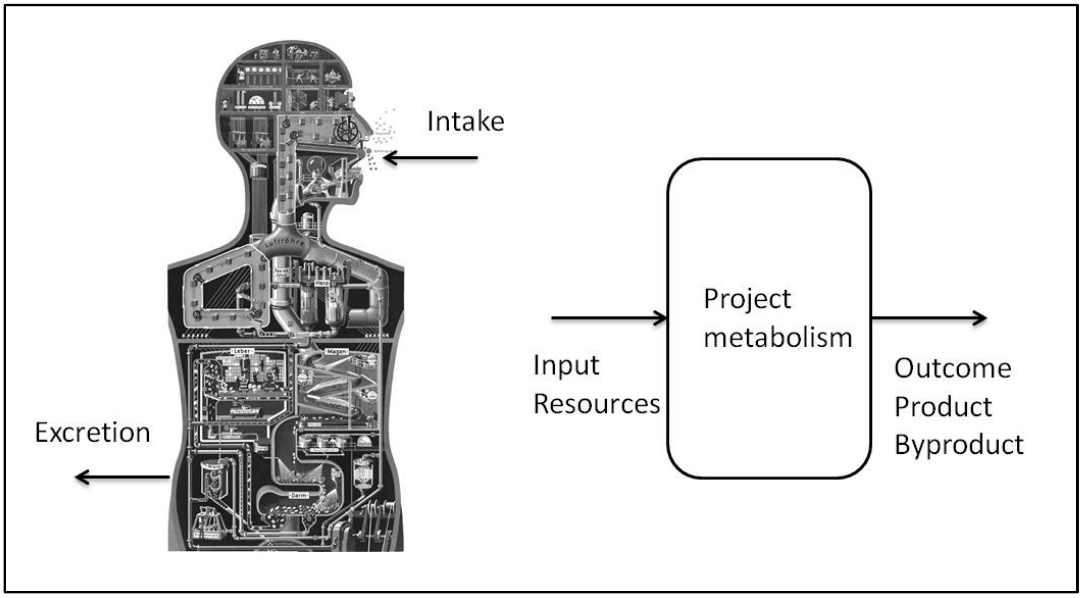

Figure 4.3 Resemblance between human metabolism and Project Metabolism

A healthy body needs a healthy metabolism, and a sustainable project needs a sustainable metabolism. If we extend the concept of metabolism to a project, and view a project like a living body, then the term Project Metabolism may be used to describe a certain aspect of a project. This model can then be used to predict the outcome of the project, similar to using the trend or equation of a projection in Figure 4.1 to predict the value of y. Consequently, using Project Metabolism to describe a project is a deductive approach.

This is how the term “Project Metabolism” came to the author’s mind. Starting with interests in sustainable construction, to try to describe sustainable construction in a deductive way, together with the parable to healthy human metabolism, the concept of Project Metabolism was born.

4.2.2 Project success and Project Metabolism

Project Metabolism is a new concept and term. As a result, no research was found on this topic. Having the belief that we should develop our research study based on previous research and work, the author tried to link the concept of Project Metabolism to some developed research topics and areas. Thinking about the desired outcome of a project, it could be a sustainable project, or more generally, a successful project. Many research studies have been conducted to explore project success. The concept of Project Metabolism can be used to predict project success.

In the process of searching for information on the topic of project success, one paper caught the author's eye. It started with describing the research approach in project management which frequently involves a comparison of two elements: an input or independent variable, and an outcome or dependent variable (Griffith et al. 1999). Figure 4.4 illustrates this approach. The approach involves changing certain independent variables and measuring the impact on certain dependent variables. Some examples of independent variables are: project manager experience, level of communication, pre-planning effort, and project team integration. The dependent variable is usually project success (Griffith et al. 1999).

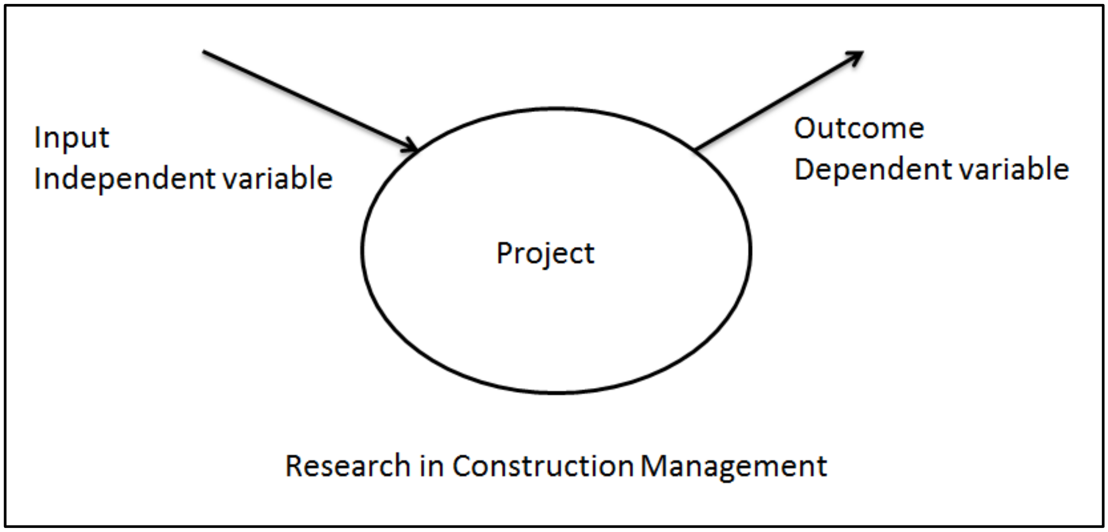

Figure 4.4 An illustration of research effort in construction management

The authors also mentioned that construction projects are different by nature, but when considering measuring project success, the difference in type or size may not play an important role. In other words, one method to measure project success can be used in different types of projects and projects with different magnitude.

This assumption is very similar to the assumption of Project Metabolism. Using a specific method to describe all kinds of projects regardless of the type or size is the primary goal of developing the concept of Project Metabolism and also the primary goal of this research. The concept of Project Metabolism could hold the key to solve the problem of comparing construction projects.

For example, if we change an independent variable, like the extent of preplanning, we want to say it caused the change in the dependent variable. For a construction project, the change already happened, and cannot happen again. As a result, one needs to use a second project as the control to conclude that the change in the independent variable caused the change in the dependent variable. However, the two projects are not the same. But if their metabolism is the same, maybe we can be more confident to attribute the change to the change in the independent variable. In that case, developing the concept of Project Metabolism solves the problem of comparing different projects, and gives researchers a way to use statistical tools to analyze data at the project level.

4.3 Research plan

The major goals of this study are to define the concept of Project Metabolism and to develop a framework for implementing the concept. The information used to define and develop the concept is from a review of the literature. Concept mapping methods are used to organize the information and help the author to develop the concept. A survey is conducted to gather construction industrial professionals' opinion on this subject and to help the author to develop a framework of Project Metabolism. The results of the survey are summarized and analyzed using statistical tools. The research process is illustrated in Figure 4.5.

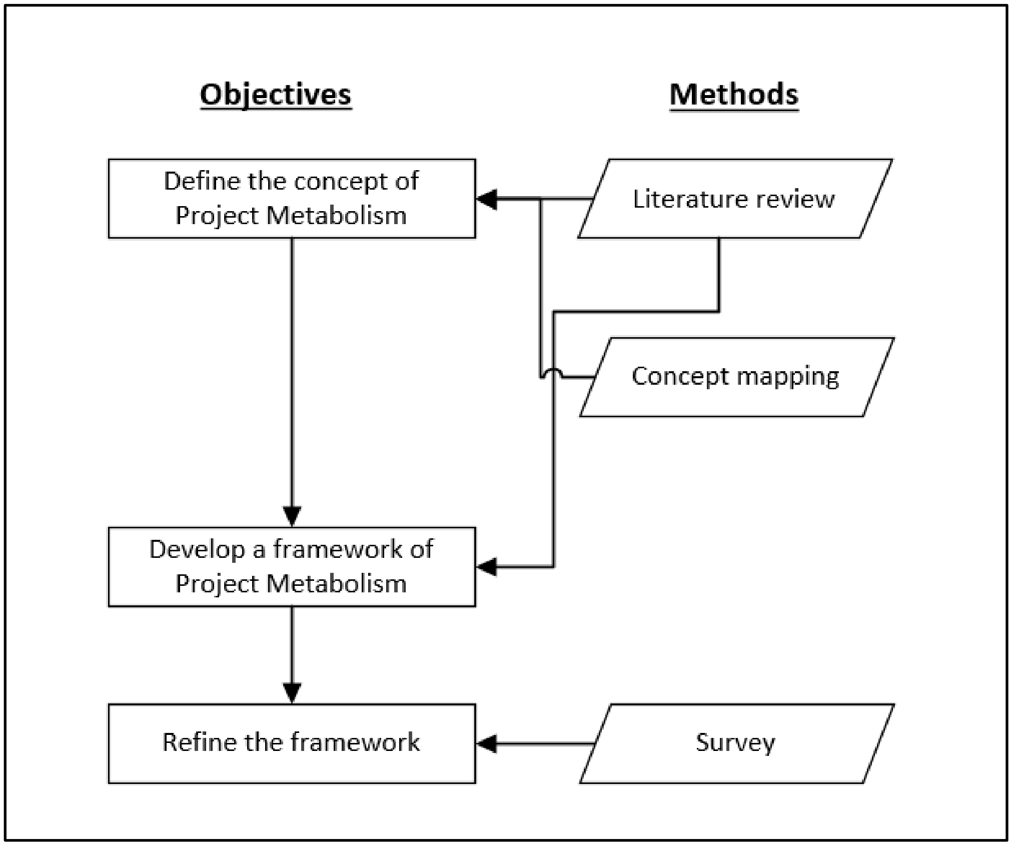

Figure 4.5 The research process

4.4 Literature review

No studies about Project Metabolism were found. However, research studies on the topic of project success are related to the concept that is being defined here. So a comprehensive literature review on the construction project success was conducted to obtain information, and a review of the concept of metabolism as used in other fields was conducted to determine if there is anything we can learn from other academic fields.

4.4.1 Construction project success

Project success is a major concern of project management practitioners and the construction research community. Many studies have been conducted on the subject of project success, but it is very difficult to get a consensus definition of it and a method to measure it. Project success is a very subjective issue, and everyone could have their own definition of it. The following research papers describe a few approaches to explain project success. It is noticeable that the definition of project success has changed over time.

The papers related to project success fall into two areas: success factors and success criteria. Success factors are items that affect or pre-determine project outcomes, and success criteria are the standards or measurements used to judge whether or not a project is successful (Gibson and Hamilton 1994). The literature review in this section is divided based on these two research areas.

4.4.1.1 Project success factors

The majority of research papers regarding project success are about success factors. It is widely agreed that many factors could affect the outcome of a project, and identifying a few which have major impact on project success is the primary goal of the majority of the research studies.

The term “critical success factors” was first mentioned by John F. Rockart (Rockart 1982). He defined critical success factors as “the few key areas of activity in which favorable results are absolutely necessary for a particular manager to reach his or her goals” (Rockart 1982). Some other definitions and explanations are listed below.

> “They are events or circumstances that require the special attention of management because of their significance to the corporation. They may be internal or external and be positive or negative in their impact. Their essential character is the presence of a need from special awareness or attention to avoid unpleasant surprises or missed opportunities or objectives. They may be identified by evaluating corporate strategy, environment, resources, operations (Ferguson and Dickinson 1982).”

> “Those few things that must go well to ensure success for a manager or organization, and therefore, they represent those managerial or enterprise areas that must be given special and continual attention to bring about high performance. Critical Success Factors include issues vital to an organization’s current operating activities and its future success (Boynton and Zmund 1984).”

Many researchers have made an effort to identify critical success factors for construction projects. Ashley et al. (1987) identified the following six critical factors: planning effort, project team motivation, project manager goal commitment, scope and work definition, control systems, and project manager technical capabilities (Ashley et al. 1987). Pinto and Slevin (1987) listed ten critical success factors: project mission, top management support, project schedule/plan, client consultation, personnel, technical tasks, client acceptance, monitoring and feedback, communication, and troubleshooting (Pinto and Slevin 1987).

Sanvido et al. (1992) found four critical factors (Sanvido et al. 1992):

1) A well-organized, cohesive facility team to manage, plan, design, construct, and operate the facility. Team chemistry was typically developed by common goals and activities.

2) A series of contracts that allow and encourage the various specialists to behave as a team without conflicts of interest and differing goals. These contracts must allocate risk and reward in the correct proportions.

3) Experience in the management, planning, design, construction, and operations of similar facilities.

4) Timely, valuable optimization information from the owner, user, designer, contractor, and operator in the planning and design phases of the facility.

Chua et al. (1999) identify 67 success related factors in their study to find critical success factors for different project objectives. Table 4.1 lists the factors that related to project success. The factors are categorized into four project aspects (Chua et al. 1999).

Table 4.1 Success-related factors (Chua et al. 1999)

Project Aspects	Success-related Factors
Project Characteristics	(1) political risks; (2) economic risks; (3) impact on public; (4) technical approval authorities; (5) adequacy of funding; (6) site limitation and location; (7) constructability; (8) pioneering status; (9) project size.
Contractual Arrangements	(10) realistic obligations/clear objectives; (11) risk identification and allocation; (12) adequacy of plans and specifications; (13) formal dispute resolution process; (14) motivation/incentives.
Project participants	(15) PM competency; (16) PM authority; (17) PM commitment and involvement; (18) capability of client key personnel; (19) competency of client proposed team; (20) client team turnover rate; (21) client top management support; (22) client track record; (23) client level of service; (24) capability of contractor key personnel; (25) competency of contractor proposed team; (26) contractor team turnover rate; (27) contractor top management support; (28) contractor track record; (29) contractor level of service; (30) capability of consultant key personnel; (31) competency of consultant proposed team; (32) consultant team turnover rate; (33) consultant top management support; (34) consultant track record; (35) consultant level of service; (36) capability of subcontractors key personnel; (37) competency of subcontractors proposed team; (38) subcontractors team turnover rate; (39) subcontractors top management support; (40) subcontractors track record; (41) subcontractors level of service; (42) capability of suppliers key personnel; (43) competency of suppliers proposed team; (44) suppliers team turnover rate; (45) suppliers top management support; (46) suppliers track record; (47) suppliers level of service.
Interactive Processes	(48) formal design communication; (49) informal design communication; (50) formal construction communication; (51) informal construction communication; (52) functional plans; (53) design complete at construction start; (54) constructability program; (55) level of modularization; (56) level of automation; (57) level of skill labors required; (58) report updates; (59) budget updates; (60) schedule updates; (61) design control meetings; (62) construction control meetings; (63) site inspections; (64) work organization chart; (65) common goal; (66) motivational factor; (67) relationships.

Kraft and Chinowsky (2003) used project success as a basis for defining and measuring organizational success. The authors argued that the construction industry has a long history of using project success to determine the success of an organization, and due to the pressure resulting from globalization, technology, and market changes, the construction industry needs to realize that organizational management and long-term business planning is becoming more and more important. The decision process should be guided by the overall strategy of a company, not only by the success of a project (Kraft and Chinowsky 2003).

Chan et al. (2004) reviewed seven major journals in the construction field about previous works on project success. The authors identify five major groups of independent variables that are crucial to project success. A conceptual framework on critical success factors was developed based on the reviews as shown in Figure 4.6. In their paper, the authors suggested that the hypothesis for the research is that project success is a function of project-related factors, project procedures, project management actions, human-related factors, and external environment and that these variables are interrelated (Chan et al. 2004).

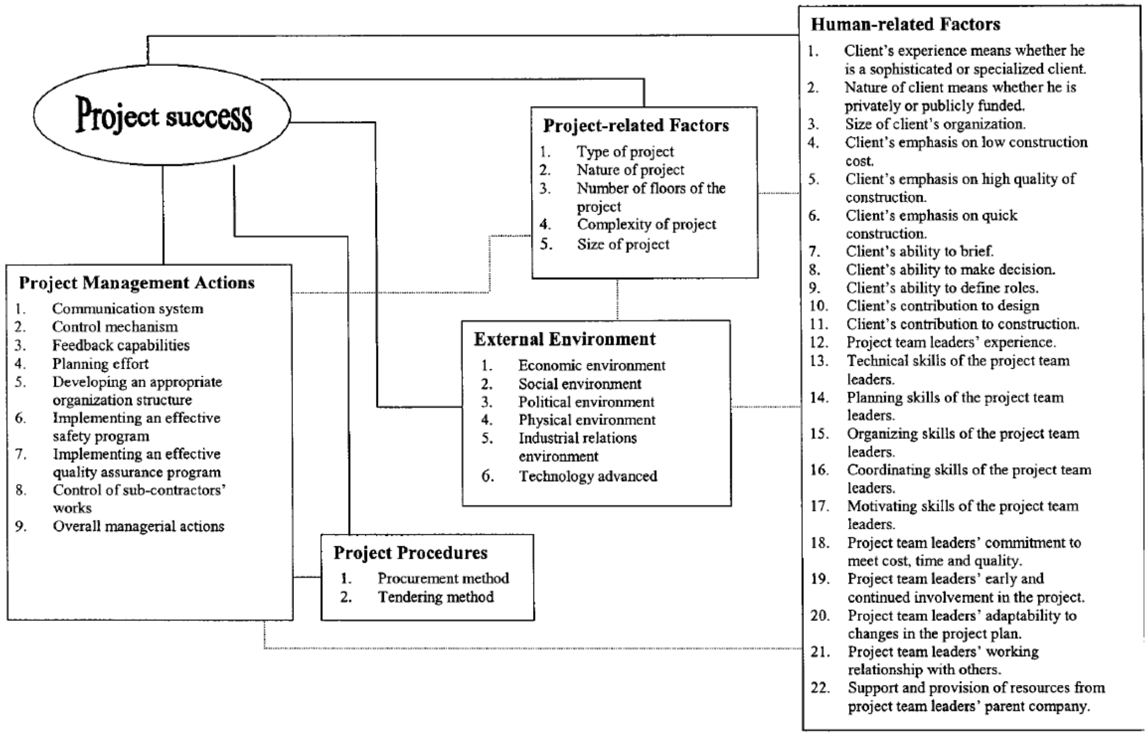

Figure 4.6 New conceptual framework for factors affecting project success (Chan et al. 2004)

Other assumptions used in the research by Chan et al. are listed below:

- A project will be executed more successfully if the project complexity is low.
- If the project has a shorter duration, it is more likely to be successful.
- If the overall management actions are effective, the project is more likely to be successful.
- If the project is funded by a private and experienced client, it is more likely to be successful.
- If the client is competent in preparing project briefing and making decisions, the project is more likely to be successful.

- If the project team leaders are competent and experienced, the project is more likely to be successful.
- If the project is executed in a stable environment, it is more likely to be successful.
- If the project has an appropriate organization structure, it is more likely to be successful (Chan et al. 2004).

Pheng and Chuan (2006) conducted a research study to examine the effect of the working environment on the performance of project managers. It is well known that the project manager's performance is a critical factor for project success, so knowing how the working environment affects the project manager's performance will be crucial to project success. The authors concluded that of all 15 working environment variables examined in the study, 13 of them have an impact on project manager's performance, and they are: salary, job satisfaction, job security, availability of information, project environment, time availability, complexity of project, team relationship, materials and supplies, duration of project, project size, level of authority, and type of client. The two factors that do not have an impact are working hours and company size. Team relationship is ranked as the most important factor that affects a project manager's performance (Pheng and Chuan 2006).

Ko and Cheng (2007) developed an evolutionary project success prediction model to fulfill the dynamic prediction of project success. The model is developed based on a hybrid approach which combines genetic algorithms, fuzzy logic and neural networks

(Ko and Cheng 2007). The authors suggest that project managers can use this tool to help them make proper decisions to control the project, and to take corrective actions according to the predicted result.

Shokri-Ghasabeh et al. (2010) connected project success and project selection because the authors argued that these variables share many common traits. The authors identified the common overlapping themes which are shown in Table 4.2 and developed a new model called “Integrated Construction Project Selection Process” (Shokri-Ghasabeh et al. 2010).

Table 4.2 Common categories between project success and project selection (Shokri-Ghasabeh et al. 2010)

Categories	**Covered Project Selection Criteria**	**Covered Project Success Criteria and Factors**
Project Stakeholders	General public; political environment	Stakeholders satisfaction
Client Organizational Strategy	Client organization policy and strategy	Organization and management
Project Product	Product related factors	Quality
Project HR	Human Resources	Project team and project manager
Market	Market opportunities and competition	Business opportunity and market impact
Project Technical Issues	Technical related factors	Technical related factors
Resources Availability	Availability of resources	Resource availability
Project Time	Time and schedule	Time
Project Monetary Issues	Project budget; profitability; financial situation	Cost
Project Risk	Project risk management	Project risk management
Project Environmental Impacts	Environmental related factors	Environmental impact
Project Safety	Health and safety	Safety
Project Contracts	Terms of contract	Project contracts
Project Size	Project size	Project size

Tabish and Jha (2012) believed that project success is influenced by success traits, and the authors defined success traits as human factors and management actions, as shown in Figure 4.7. The authors used a statistical tool called structural equation modeling to analyze their conceptual model (Tabish and Jha 2012).

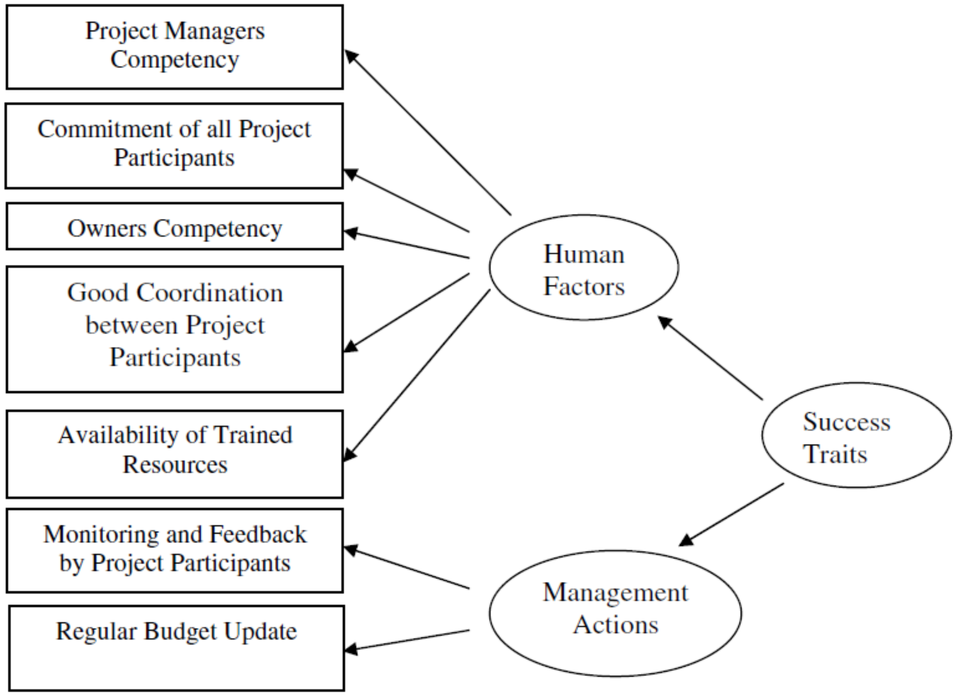

Figure 4.7 Model of success traits (Tabish and Jha 2012)

Molenaar et al. (2013) explored the effectiveness of using project peer review as an early indicator of project success. The process of project peer review is illustrated in Figure 4.8. The authors found that project peer reviews can help to predict project success, and 80 of the original peer review questions have strong correlations to one or more of the project success metrics of cost, schedule, and project peer rating. The authors also identified that questions regarding working relationships, communication, timing, project controls, and the relational approach to other participants had strong correlations to the project outcomes. This was especially true for the relationship between the contractor and the designer which should not be overlooked (Molenaar et al. 2013).

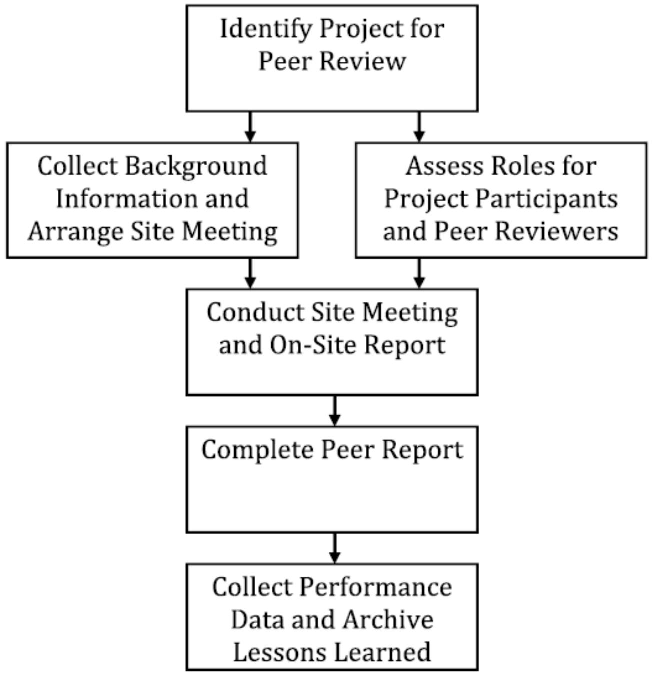

Figure 4.8 Model of peer review process (Molenaar et al. 2013)

Hwang and Lim (2013) conducted a research study to identify critical success factors for different project players and their objectives in Singapore's construction industry. The authors reviewed previous studies on success factors and summarize the definition of success as shown in Table 4.3. They also identified 32 critical success factors and put them into four categories (Table 4.4). The authors concluded that construction project success depends on a mix of human-related factors, project-related factors, project management-related factors, and external environmental factors. Project participants have different interests in a given project depending on their roles. However, all participants must agree on project objectives and certain key critical factors so that they can achieve their own objectives (Hwang and Lim 2013).

Table 4.3 Summary of success definitions (Hwang and Lim 2013)

Reference	**Definition of Success**
Tuman (1986)	All project requirements anticipated and needs met with sufficient resources, in a timely manner

De Wit (1986)	A project is considered an overall success if it:
	• Meet the technical performance specifications or mission to be performed;
	• Results in high level of satisfaction concerning project outcome among:
	    ○ Key people in parent organization
	    ○ Key people on project team
	    ○ Key users or clients of project effort

Ashely et al. (1987)	Results are better than expected or normally observed in terms of cost, schedule, quality, safety, and participant satisfaction
Pinto and Slevin (1987)	A successful project fulfills four criteria: • Completed on schedule • Completed within budget • Achieved all goals originally set for it • Accepted and used by clients for whom project is intended
Wuellner (1990)	A successful project: • Completes on time, within budget, and with an acceptable profit margin • Satisfies client expectations • Produces a high-quality design or consulting services • Limits firm’s professional liability to acceptable levels

Notes: Additional sources (De Wit 1986, Ashley et al. 1987, Pinto and Slevin 1987, Wuellner 1990, Tuman 1986)

Table 4.4 project success factors (Hwang and Lim 2013)

Project aspect	**Success-related factor**
Project characteristics	1. political risks 2. economic risks 3. adequacy of funding 4. constructability 5. pioneering status
Contractual arrangements	6. realistic obligations/clear objectives and scope 7. risk idenrification and allocation 8. adequacy of plans and specifications 9. motivation/incentives
Project participants	10. project manager competency and authority 11. project manager commitment to established schedules and budget 12. nature of project manager's authority 13. owner involvement and frequent feedback 14. owner commitment to estabilished schedules and budget 15. owner satisfaction with delivered project 16. capability of contractor key person 17. contractor commitment to established schedules and budget 18. contractor team capability and commitment 19. capability of consultant key person 20. consultant commitment to established schedules and budget 21. consultant team capability and commitment
Interactive process	22. frequent feedback from parent organization 23. monitoring and feedback on project 24. communication throughout project duration 25. adequate planning and control techniques 26. sufficient working drawing details 27. availability of backup strategies 28. budget updates 29. schedule updates 30. design control meetings 31. construction control meetings 32. site inspections

Liu et al. (2015) developed a research study to explore the key contractor characteristic factors that affect project success under different project delivery systems. The authors identified 12 contractor characteristic factors through a literature review (Table 4.5).

Afterward, a questionnaire was sent to project stakeholders who were previously involved in successful projects by their own definition. The questions were regarding contractor characteristic factors and project delivery method for specific projects. Based on the results, the authors used rough set theory to identify the key factors. The method is shown in Figure 4.9. The results indicate that coordination and communication, contractor's experience with similar types of projects, contractor's ability in financial management, and contractor's design capability are the four key factors (Liu et al. 2015).

Table 4.5 Contractor characteristic factors (Liu et al. 2015)

Number	**Contractor characteristics**
C1	Adequacy of contractor's plant and equipment
C2	Experience required for a particular delivery
C3	Contractor's prior working relationship with the owner
C4	Contractor's prior working relationship with consultants
C5	Magnitude of change orders in contractor's past projects
C6	Magnitude of claims and disputes in contractor's past projects
C7	Contractor's experience with similar sized projects
C8	Subcontractors' experience and capability
C9	Contractor's experience with similar types of projects
C10	Contractor's track record for completion on time and on budget
C11	Contractor's ability in financial management
C12	Contractor's design capability

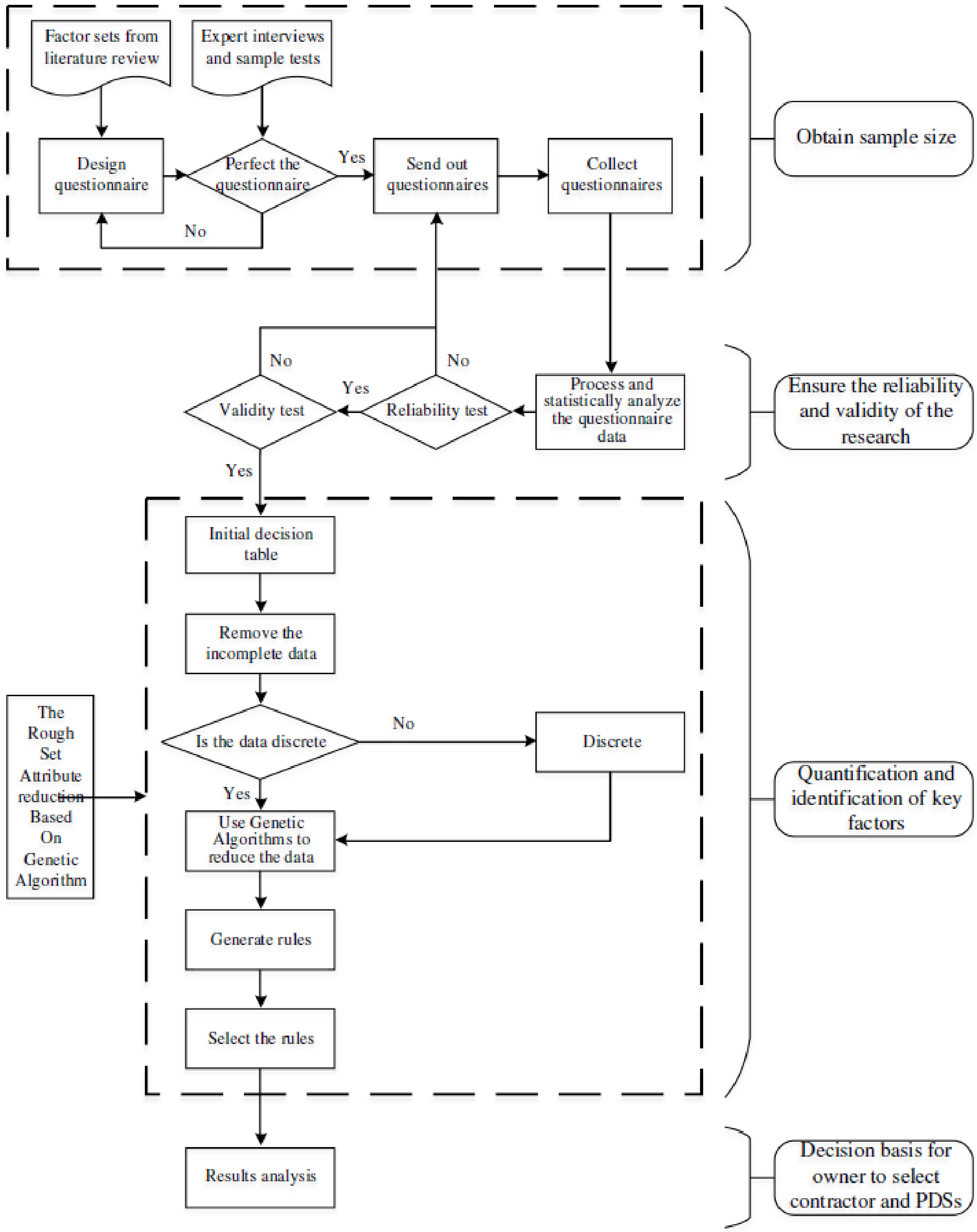

Figure 4.9 Research flowchart (Liu et al. 2015)

4.4.1.2 Project Success Criteria

Many researchers have noticed that to define or measure project success, it is necessary to distinguish between project success (some researchers use product success) and the success of the project management effort (De Wit 1986, Liu et al. 2014). It is widely agreed that project success is a subjective measurement that can change over time and largely depends on which party is evaluating the project outcome. A highly successful project for one stakeholder may be a disaster for another. Sanvido et al. (1992) summarized project success criteria for building projects from the owner's, designer's and contractor's viewpoints, and the results are shown in Table 4.6.

Table 4.6 Success criteria for different participants (Sanvido et al. 1992)

Role	**Success Criteria**
Owner	On schedule; on budget; function for intended use (satisfy users and customers); end result as envisioned; quality (workmanship, products); aesthetically pleasing; return on investment (responsiveness to audiences); building must be marketable (image and financial); and minimize aggravation in producing a building.
Designer	Satisfied client (obtain or develop the potential to obtain repeated work); quality architectural product; met design fee and profit goal; professional staff fulfillment (gain experience, learn new skills); met project budget and schedule; marketable product/process (selling tool, reputation with peers and clients); minimal construction problems (easy to operate, constructible design);no claims (building functions as intended); socially accepted (community response); client pays (reliability); and well defined scope of work (contract and scope and compensation match).
Contractor	Meet schedule (preconstruction, construction, design); profitable; under budget (savings obtained for owner and/or contractor); quality specification met or exceeded; no claims (owners, subcontractors); safety; client satisfaction (personal relationships); good subcontractor buy out; good direct communication (expectations of all parties clearly defined); and minimal or no surprises during the project.

Griffith et al. (1999) created a simple and direct measurement of project success for capital facility construction projects although the authors understood that project success is a complex and dynamic concept. They argue that an objective measurement that can be used to test the effect that a specific input has on project outcomes, as well as making reasonable comparisons between different projects of different types and sizes, is invaluable. The authors utilized data collected from completed projects and telephone interviews to develop an index to measure project success, and this index is composed of four variables: budget achievement, schedule achievement, design capacity and plant utilization (Griffith et al. 1999). The result of their research is presented in Table 4.7.

Table 4.7 Variable and equation for project success index (Griffith et al. 1999)

Variable	**Range**	**Value**
Budget achievement (***B***) (measured against authorization cost budget)	Under authorization budget At authorization budget Over authorization budget	5 3 1
Schedule performance (***S***) (measured against authorization schedule)	Under authorization schedule At authorization schedule Over authorization schedule	5 3 1
Percent design capacity attained at 6 months (***C***) (measured against planned capacity)	Over 100% of planned 100% of planned Under 100% of planned	5 3 1
Plant utilization at 6 months (***U***) (measured against planned utilization)	Over 100% of planned 100% of planned Under 100% of planned	5 3 1
Success Index = $0.6\times(0.55\times\boldsymbol{B} + 0.45\times\boldsymbol{S}) + 0.40\times(0.70\times\boldsymbol{C} + 0.30\times\boldsymbol{U})$		
Consider “at authorized budget” and “% of planned” to be within ±2.5%.		

Cho et al. (1999) utilized project success factors in their research to develop the project definition rating index (PDRI) for building projects. The researchers performed regression analysis between PDRI and project success index (Cho et al. 1999). This research is based on the result of previous CII research on project success index for industry projects. The authors developed another project success index (PSI) for building projects as shown in Equation 4.1.

$$\text{PSI} = \frac{BudgetAchievement + ScheduleAchievement + DesignSizeAchievement}{3} \quad \text{(Eqn. 4.1)}$$

Chan et al. (2002) developed a research study to establish success criteria for design/build projects. Figure 4.10 shows the project success criteria identified by the authors. The authors reviewed a large amount of previous works and develop a framework with objective (time, cost, quality and safety) and subjective (meeting specification requirements, conformance to expectation, satisfaction of project team members, functionality, aesthetics, and reduction in dispute) success criteria for design/build projects (Chan et al. 2002).

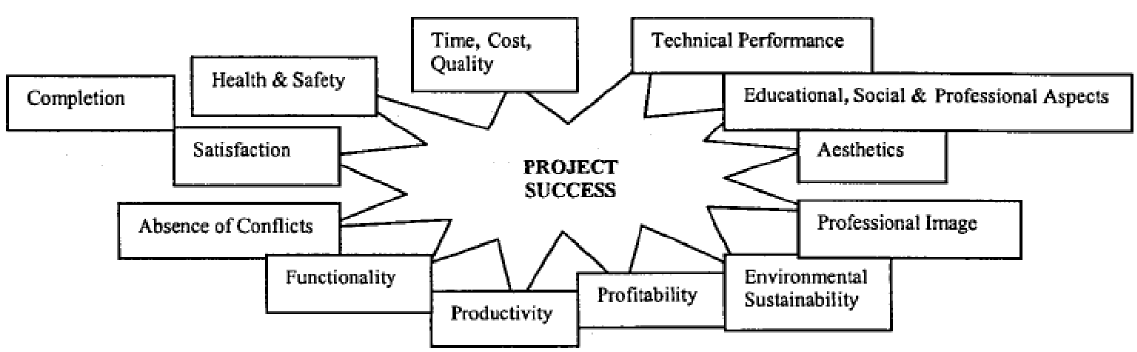

Figure 4.10 Project success criteria (Chan et al. 2002)

Shields et al. (2003) developed an equation to measure construction phase project success for industrial projects. The authors used cost, quality, schedule and safety as the success variables to form the equation (David R. Shields et al. 2003). The result is shown in Figure 4.11.

Construction Phase Success = 0.4 CGS + 0.25 SGS + 0.3 RFS + 0.05 LWCIRS

CGS (construction cost growth) =
(actual construction phase cost – initial predicted construction phase cost)/ initial predicted construction phase cost

SGS (construction schedule growth) =
(actual construction phase duration – initial predicted construction phase schedule)/ initial predicted construction phase schedule

RFS (rework factor to represent quality) =
Total direct cost of field rework/actual construction phase cost

LWCIRS (lost workday case incident rate to represent safety) =
(Number of lost workday cases×200,000)/site craft workhours

Figure 4.11 Construction phase success equation (David R. Shields et al. 2003)

Lam et al. (2008) explored the determinants of successful design-build projects, and developed a project success index for design-build projects using key performance indicators of time, cost, quality and functionality (Lam et al. 2008). The equation for project success index for design/build project (PSI-D&B) is shown in Equation 4.2.

$$\text{PSI-D\&B} = 0.54\times\text{time}+0.55\times\text{cost}+0.47\times\text{quality}+0.4\times\text{functionality} \quad \text{(Eqn. 4.2)}$$

4.4.2 Literature review on metabolism

4.4.2.1 Metabolism – architecture

The word "metabolism" has been used in the AEC community to refer a certain type of building which has a megastructure with individual cells attached to it to mimic organic growth. This architectural movement occurred in the middle of the 20th century in Japan (Lin 2010, Boyd 1968). Some buildings that employed the principles of metabolism were built in the 1960s and the 1970s, and Figure 4.12 shows one of the examples – the Nakagin Capsule Tower.

Figure 4.12 Nakagin Capsule Tower, exterior and interior (Meow 2013, Kurokawa 2016)

The word "metabolism" was the translation of a Japanese word "Shinchintaisha". The group of Japanese architects who explored the organic nature of buildings used the word Shinchintaisha as being symbolic of the essential exchange of materials and energy between organisms and the exterior world. The Japanese meaning of the word has a feeling of replacement of the old with the new and the group further interpreted this to be equivalent to the continuous renewal and organic growth of the city. They felt that a more universal word should be used to present their projects at a world conference. They looked up the definition of Shinchintaisha in a Japanese-English dictionary, and the translation they found was the word "metabolism" (Kurokawa 2016, Lin 2010, Boyd 1968).

4.4.2.2 Metabolism – human

The term metabolism is used to refer to all the chemical and energy transformations that occur in a body (Ganong 1989). During the process, human organs oxidize carbohydrates, proteins, and fats, producing primarily CO_2, H_2O, and the energy necessary for life. Then the essential nutrition and energy is transferred through the circulatory system to other organs. Other sources explain the word metabolism at both cellular level chemical transformation and the chemical reactions and substance transportation within and between organs. It is also interpreted as all changes in a body which allow organs to maintain their structures, to grow, to respond to their environments, and to work together to sustain life.

The speed of changes, which is usually referred to as metabolic rate, is measured by the rate of energy production in a body. It is difficult to measure the energy produced within a body directly, so the energy production is calculated by the amount of O_2 consumed. O_2 consumption is usually measured with some form of the oxygen-filled spirometer and a CO_2 absorbing system as shown in Figure 4.13.

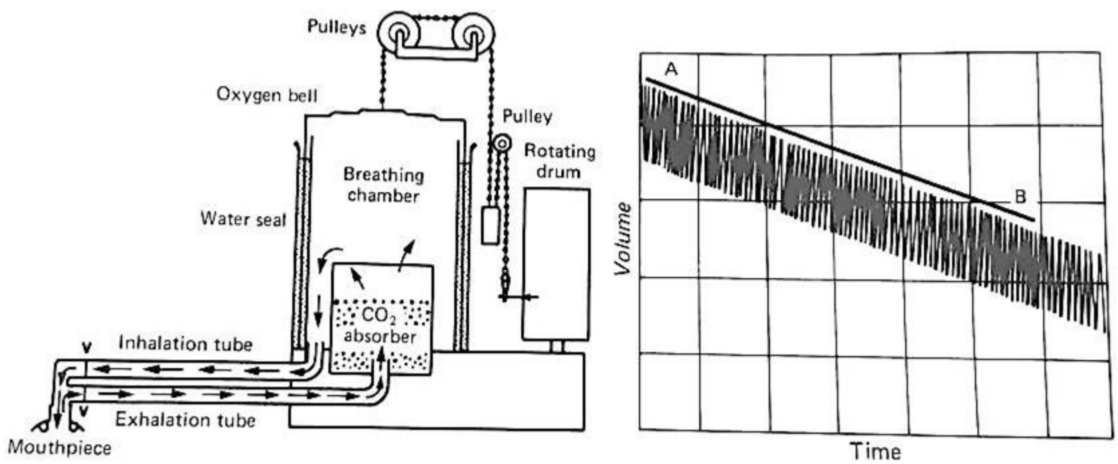

Figure 4.13 A recording spirometer for measuring human O_2 consumption (Ganong 1989)

As shown in the figure, the spirometer bell is connected to a pen that writes on a rotating drum as the bell moves up and down. The slope of the line is proportionate to the O_2 consumption. Then the amount of O_2 consumed per unit of time is corrected to standard temperature and pressure. The energy production is calculated by using O_2 consumed multiplied by 4.82 kcal/L. It has been shown that the metabolic rate is affected by many factors. Age, sex, emotional state, body temperature, and activities undertaking all affect the metabolic rate of a person (Ganong 1989).

4.5 Defining the concept of Project Metabolism

Much information has been gathered through literature review, and the next challenge is to organize and analyze the information to come up with the definition of the concept of Project Metabolism. The concept mapping method is used to help with concept development.

4.5.1 The method of concept mapping

Concept mapping is a graphical tool which was initially used to help students to organize knowledge and have a meaningful learning experience (Novak 1990). In this method, concepts are usually enclosed in circles or boxes, and relationships between concepts are indicated by lines between concepts. Figure 4.14 shows an example of a concept map (Novak and Canas 2008). It is suggested that concept maps need to be read progressing from the top to the bottom.

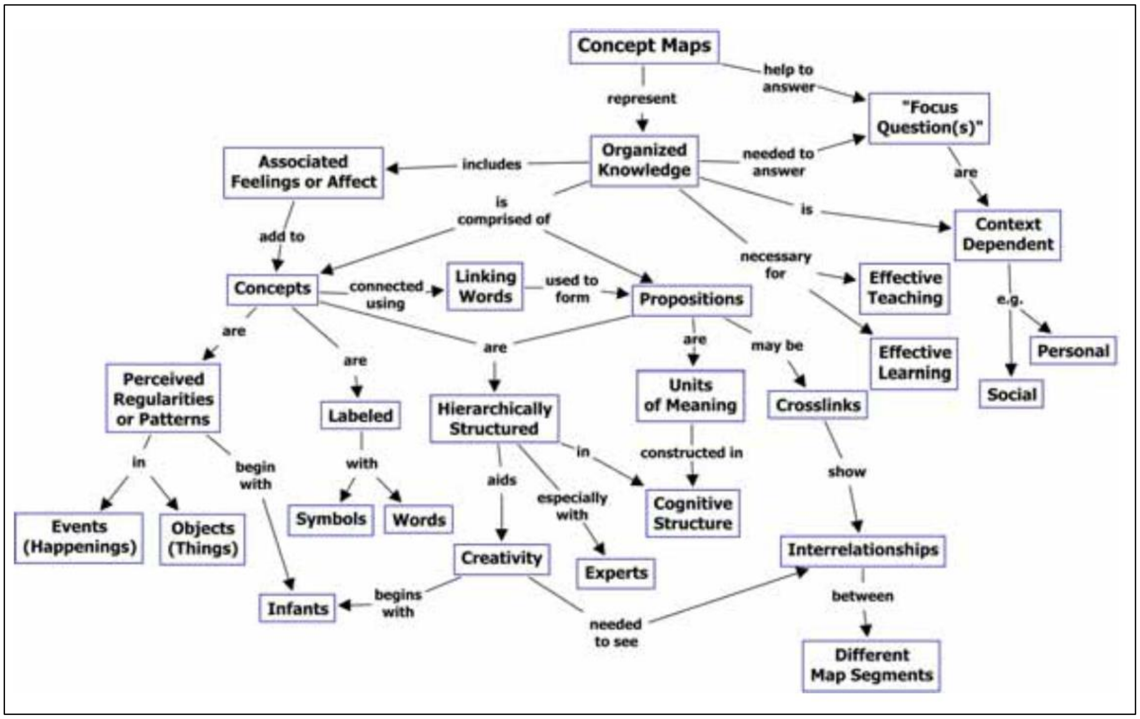

Figure 4.14 A concept map showing the key features of concept mapping (Novak and Canas 2008)

Several methods share the name of concept mapping, and have a similar graphic look, but they use different approaches and purposes. One method is for gathering expert opinion on a given topic from a group of experts, and Figure 4.15 shows the procedure of using concept mapping to analyze experts' opinions (Valdes-Vasquez and Klotz 2013, Trochim 1989). Another method is for gathering and comparing different stakeholder's perceptions on a given subject, which is similar to gathering expert opinions (Michalski and Cousins 2000).

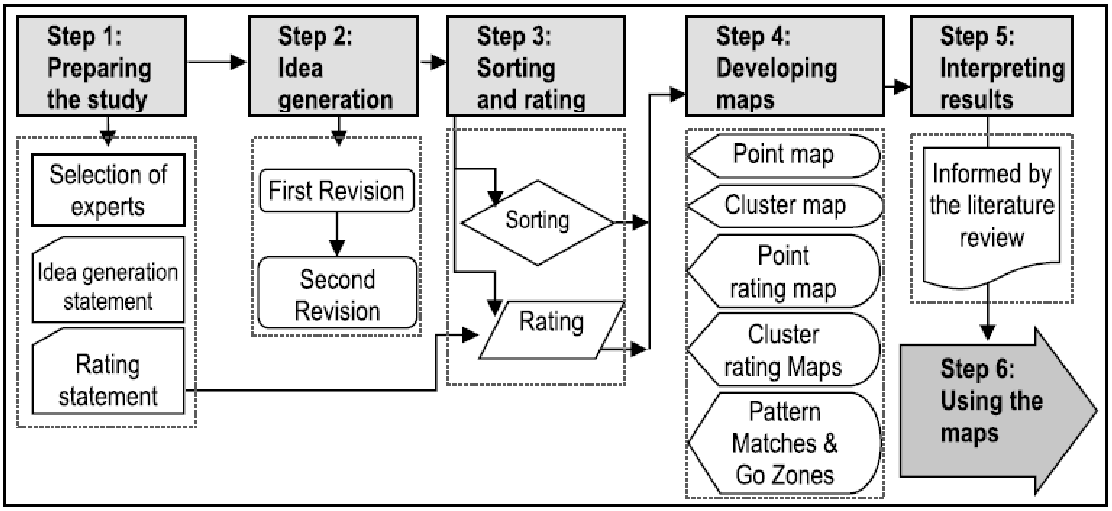

Figure 4.15 Steps for concept mapping (Valdes-Vasquez and Klotz 2013)

The concept mapping methods used in the present research are more like the initial concept mapping which is used to understand and organize ideas from the user in order to develop a framework of knowledge. Berg (2009) suggested using concept mapping to develop a research design and to create a theoretical framework, and he listed eight steps in creating a concept map (Berg 2009). The author created a five-step approach based on Berg's eight steps. Figure 4.16 shows the five steps which will be used to develop the concept map for Project Metabolism in the next section.

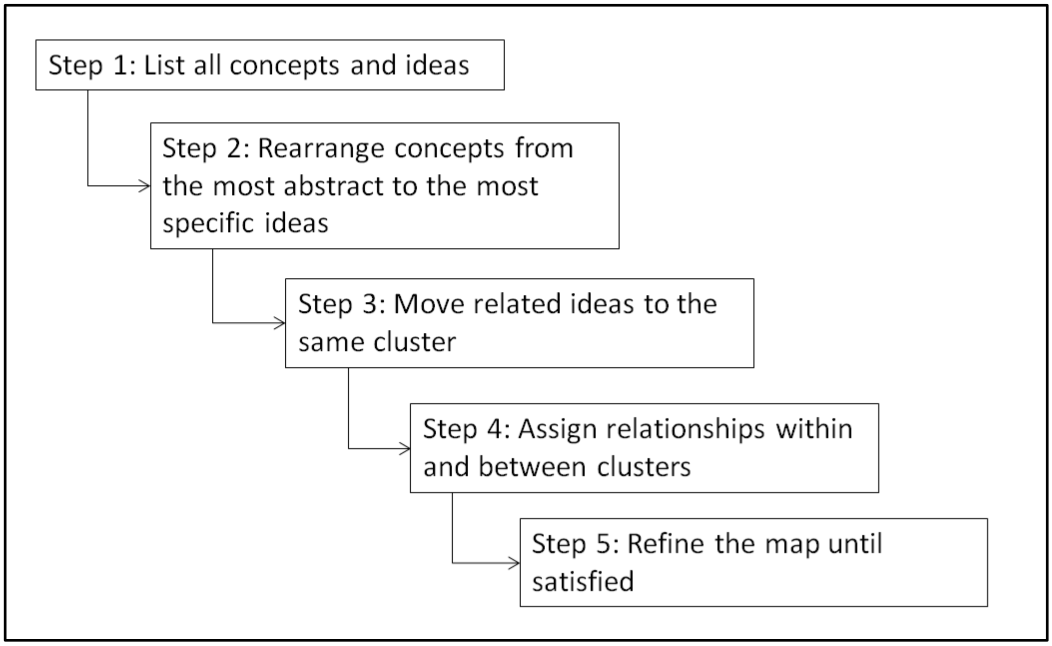

Figure 4.16 Five steps for developing a concept map

4.5.2 Initial concept maps for Project Metabolism

To develop the concept of Project Metabolism, the author followed the five steps listed in Figure 4.16. All of the information gathered from the literature review, previous research meetings with advising professor, and all other sources are listed in Appendix A. The table in Appendix A has three columns, namely the Number of the idea, summary of the idea, and the full explanation of the idea. The Number and summary of each idea were put on a sticky note, and all of the notes were put on a whiteboard as shown in Figure 4.17.

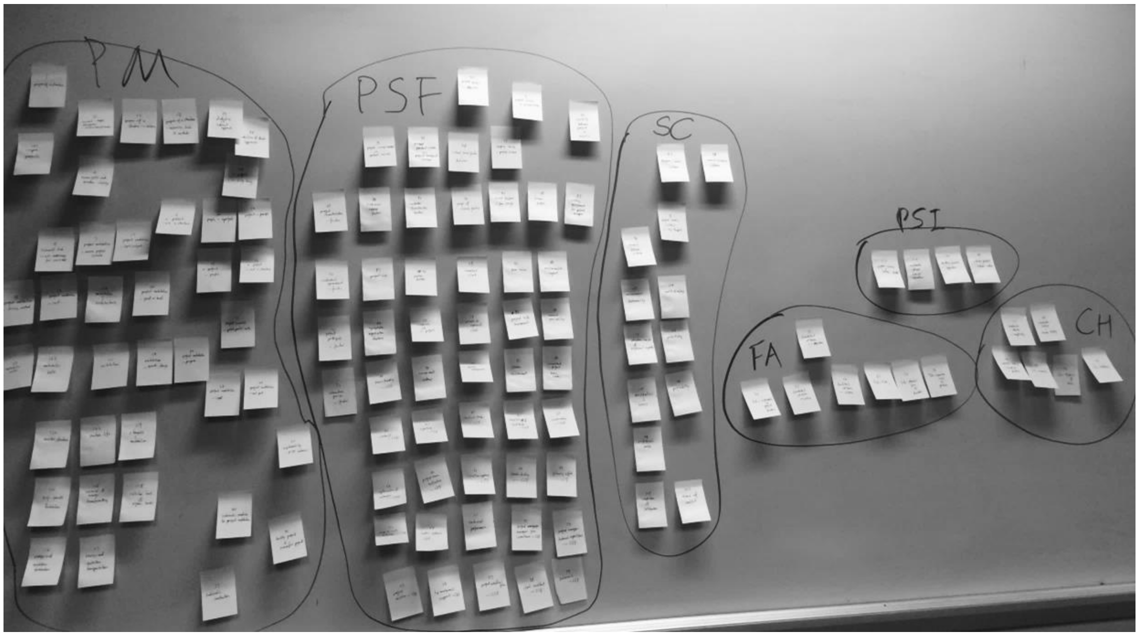

Figure 4.17 Initial concept mapping for Project Metabolism

Figure 4.17 shows the initial mapping, which includes six clusters, namely Project Metabolism (PM), project success factors (PSF), success criteria (SC), foundational attributes (FA), project success index equations (PSI), and construction history (CH). The initial concept mapping had too much information to make connections, so the author tried to put them in subgroups and began to eliminate less relevant data. The numbers in each group are shown in Table 4.8.

Table 4.8 Number of ideas in each concept group

Group	Numbers
PSI	99, 101, 112, 113
FA	26, 31,32, 33, 34, 35, 36
CH	27,43,44,45,46,47
SC	8,96,97, 98, 102, 103, 104, 105, 106, 107, 108, 109, 110
PM-project	1,2,6,10,11, 12,13,14,15,16,100
PM-metabolism	4,7,9,17,18,19,20,21,22,23,24,25,28,29,30,37,38,39,40,41. 114,115,116,117,118,119,120,121,122,123
PSF-PS definition	3,5,42,48,73,93,95
PSF-people	50,51,54,58,59,61,63,64,65,67,71,72,77,78,79,80,83,89,90 ,91,94
PSF-others	49,52,53,55,56,57,60,62,66,68,69,70,74,75,76,81,82,84,85 ,86,87,88,92,111

The ideas for each subgroup were used to define the proposed concept of Project Metabolism as described in the following section of this paper. Additional information was added when necessary. Sub-maps for different aspects of Project Metabolism were drawn and connections between concept ideas identified.

This section explains the initial effort of defining the concept of Project Metabolism. It is started with giving the definition and scop0e of a project, followed by the definition of project success used in this research paper, and last but not least, the definition of Project Metabolism.

4.5.3 Define a project

To define Project Metabolism, first, it is important to know what a project is. Table 4.9 shows a list of definitions of the word “project” from different sources (Merriam-Webster 2015, Dictionary 2015, Wikipedia 2015).

Table 4.9 Definitions of project

Source	**Definition**
Merriam-Webster	1: a planned piece of work that has a specific purpose and that usually requires a lot of time. 2: a task or problem in school that requires careful work over a long period of time.
Dictionary.com	1. something that is contemplated, devised, or planned; plan; scheme. 2. a large or major undertaking, especially on involving considerable money, personnel, and equipment. 3. a specific task of investigation, especially in scholarship. 4. a supplementary, long-term educational assignment necessitating personal initiative, undertaken by an individual student or a group of students.
Wikipedia	1. a collaborative enterprise, involving research or design, that is carefully planned to achieve a particular aim. 2. a set of interrelated tasks to be executed over a fixed period and within certain cost and other limitations. 3. temporary social systems or work systems that constituted by teams within or across organizations to accomplish particular tasks under time constraints.

Based on the information in Table 4.9 and the cluster of information on project in the initial concept mapping, the following concept mapping for the definition of a project was developed and shown in Figure 4.18.

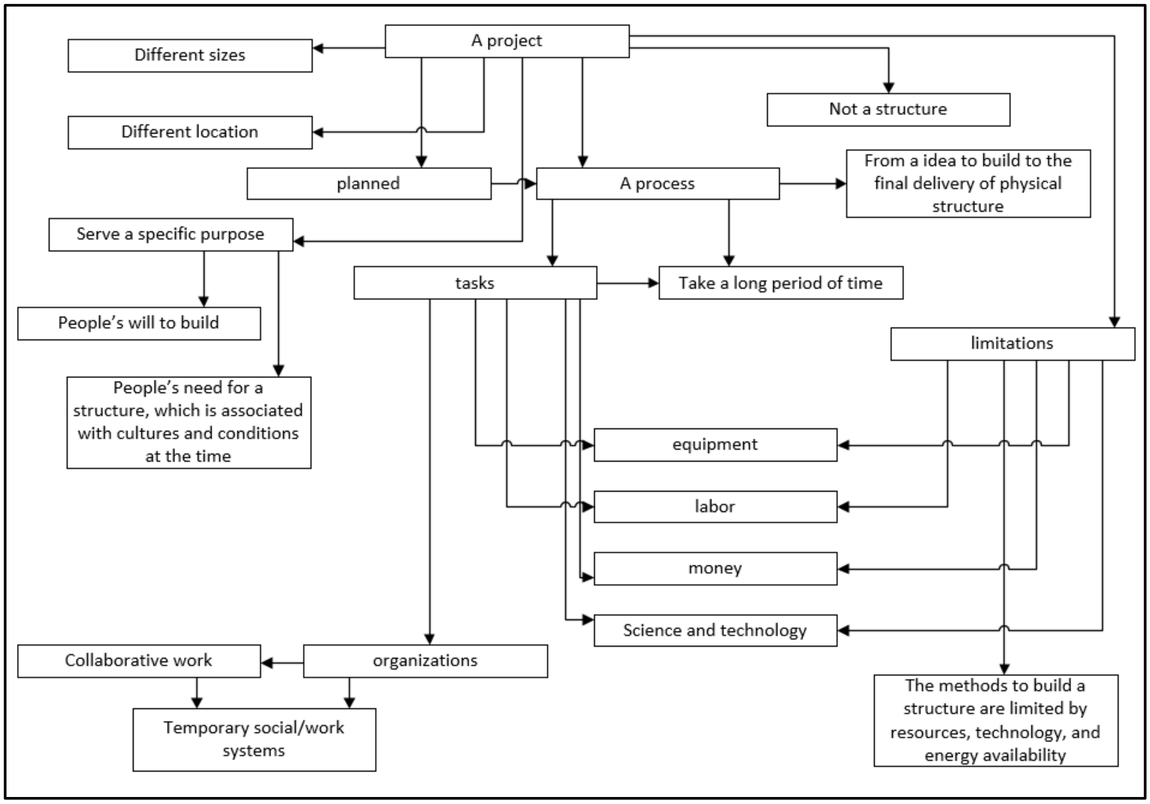

Figure 4.18 Concept mapping for the definition of a project

Based on the information in the above figure, a project can be defined as *a planned process, usually taking a long period of time, starting with the owner having an idea to build a certain structure to fulfill a specific need, to the end of the construction process which is the delivery of the final physical structure*. It is noted that a project is a process, not a structure/final product.

A project usually involves multiple organizations to work collaboratively to form a temporary social/work system to perform various tasks which require equipment, labor, money and science and technology. Participants in a project need to work around limitations to deliver the final product to fulfill the owner's need.

4.5.4 Define project success

Since the project refers to a process, not the final physical product, project success mentioned here is not product success, but a project management success or a process success, which is usually defined in terms of cost, schedule, scope, and safety. Figure 4.19 shows the concept mapping for project success. The concept of project success used in this research can be defined as *projects that are finished on time, within budget, with good quality, with a satisfy safety record, and the organizations involved in the projects earn a good reputation and build lasting relationships so that the organizations are willing to work with each other again in future projects*.

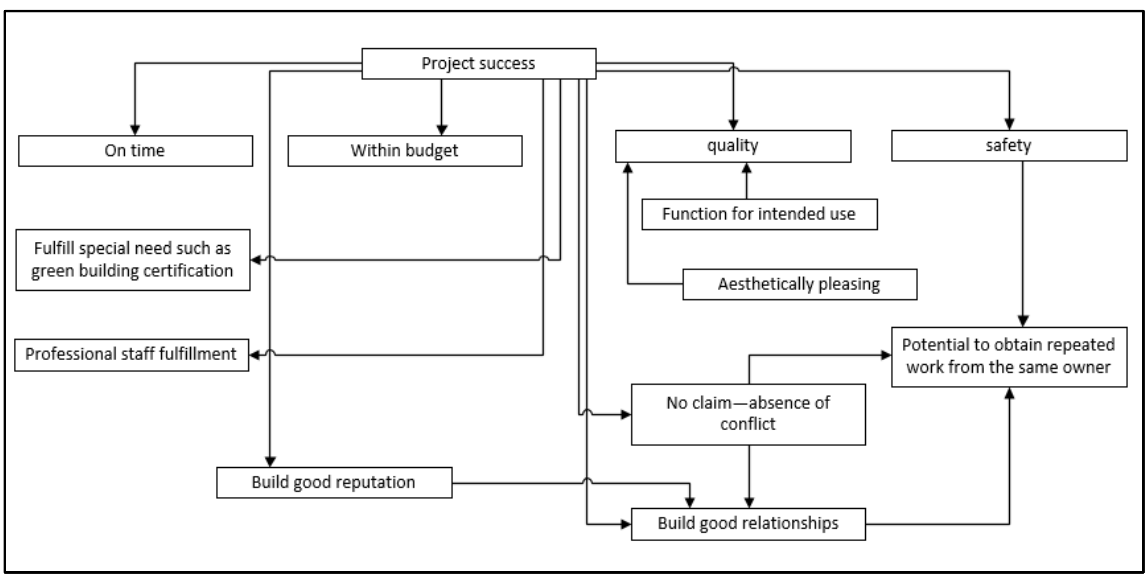

Figure 4.19 Concept mapping for project success

As mentioned in the literature review, several research studies have developed equations to calculate project success index for industrial projects, building projects, the construction phase of projects, and design-build projects. All of the equations contain schedule, cost, and quality, and one of them includes safety in the equation. However, none of them mentioned building a good reputation, relationships and the potential to obtain future repeated work. The omission may be because those criteria are difficult to measure quantitatively. However, for the purpose of the present research, these qualitative aspects of project success are too important to be omitted, so no equation will be used to quantitatively measure project success in this research. The determination of overall project success will solely depend on a person's experience and interpretation.

4.5.5 Define Project Metabolism

The term metabolism for a living body refers to both cellular level chemical transformation and the chemical reactions and substance transportation within and between organs. In a construction project, all the organizations are like organs in a living body. The relationships among them, contractual and non-contractual, affect the substance transportation between them. The substance here refers to information and something that is not material, like the chemicals and signals. So the concept of Project Metabolism describes a system or a process with different organizations and the information flow/relationships/links between them. It could also describe a system that transforms raw materials to the final physical structure. This is the substance transportation and transformation. A concept map for Project Metabolism is shown in

Figure 4.20. Figure 4.21 shows the similarity between a human body and a project and it helps to define the concept of Project metabolism based on the existing concept of human metabolism.

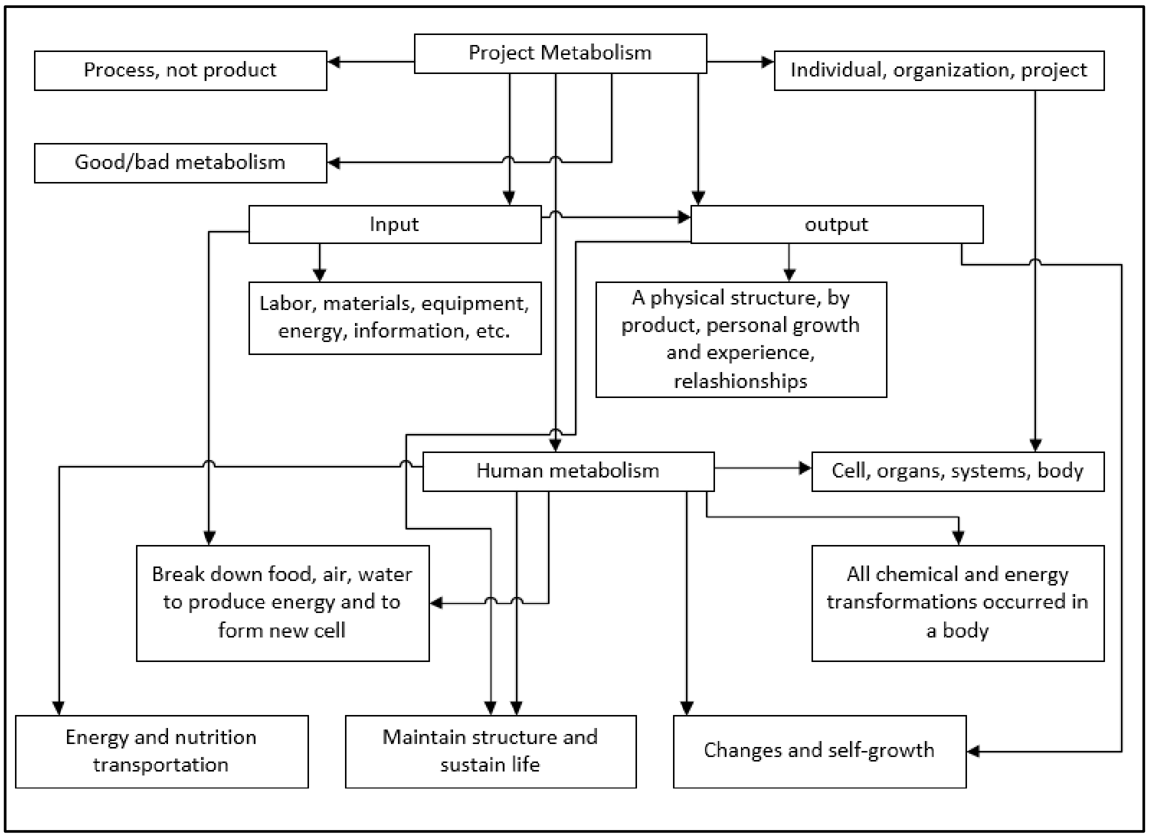

Figure 4.20 Concept mapping for Project Metabolism

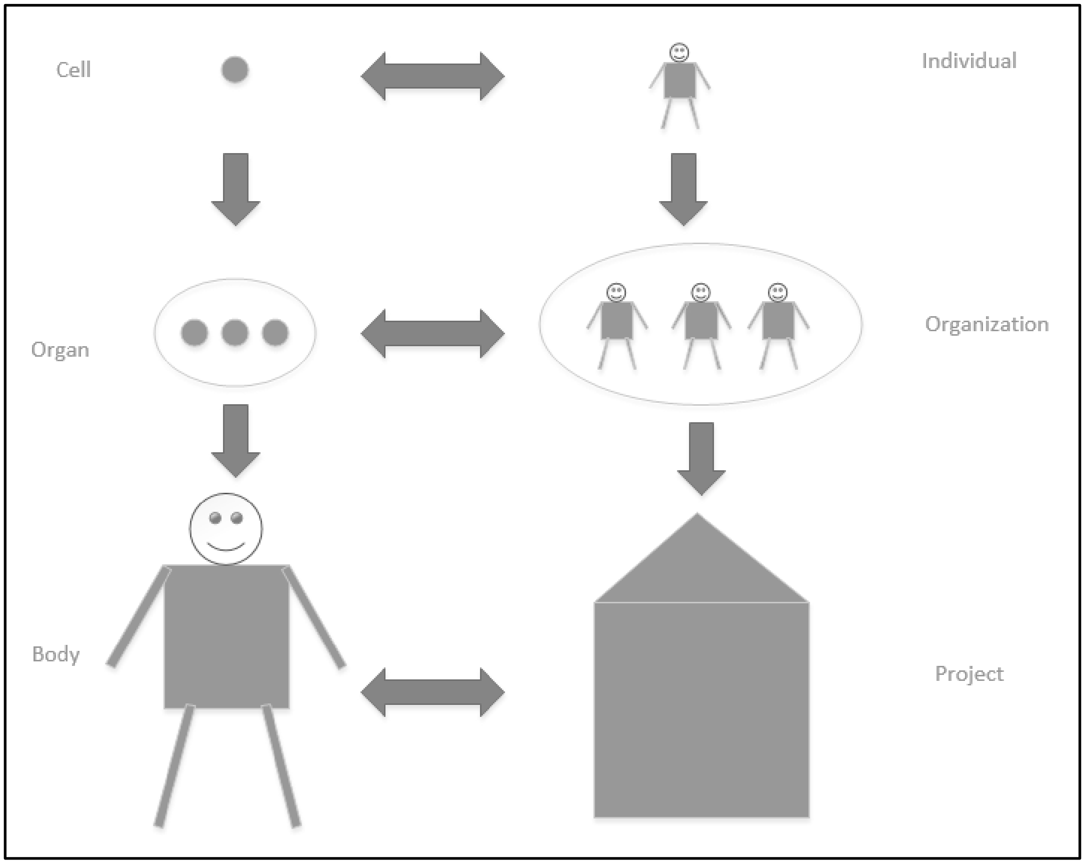

Figure 4.21 Similarity between a body and a project

The concept of Project Metabolism can be defined as *all interactions between major project participants during the process of a construction project, and the transformation and combination of labor, materials, equipment to get a final physical product.* A good Project Metabolism sustains the projects, produces a desired final physical structure, and enables individual and organizational growth. The concept of Project Metabolism has two folds. One is about people and interactions between them, and the other one is about materials transformation. The discussion in this paper focuses on the people part, and the material part can be the topic of a future research study.

4.6 A framework of Project Metabolism

A good Project Metabolism enables a successful project. The elements used to construct a framework of Project Metabolism can be found from project success factors. A list of success factors is provided in Appendix B. Table 4.10 shows the first few rows of the list. The authors who identified those factors are listed in the first column and the factors are listed in the second column. The third column shows whether or not the factor is applied to the concept of Project Metabolism. To determine whether or not the factor can be applied to the concept of Project Metabolism, the author used the following standards:

- The factor is related to any stakeholder in a construction project, or
- The factor involves something at the organization level, or
- The factor shows the character, ability, or a value of an individual person, or
- The factor is related to inter-organization relationships or procedures.

Table 4.10 A sample of Appendix B

Author	**Factors**	**Apply to metabolism**
Ashley et al. (1987)	Planning effort	N
	Project team motivation	Y
	Project manager goal commitment	Y
	Scope and work definition	N
	Control systems	N
	Project manager technical capabilities	Y
Pinto & Slevin (1987)	Project mission	Y
	Top management support	Y
	Project schedule/plan	N
	Client consultation	Y
	Personnel	Y

After the initial selection, 133 factors were determined to be related to the concept of Project Metabolism. In order to make a tool or framework useful, it needs to be simple and easy to implement. So a final list of no more than 20 factors was targeted. After obtaining the survey results, the top 10 factors are identified and used to construct a framework of Project Metabolism.

Of all the 133 factors that are related to Project Metabolism, some are the same or very similar. For qualitative data analysis, data reduction is a very important step, and it goes along with the data analysis process. Research has shown that the human brain is effective when processing a small amount of information, but when there is too much information, it is very difficult to just read the information and make sense out of it.

There are two major ways to analyze large amounts of information. The first method is to manually put information into categories and sub-categories in order to reduce the amount of information the human brain needs to digest. The second method is to use special computer software (other than MS Office) to assist with the analysis. 133 factors are not too overwhelming, so the author decided to analyze them manually by putting them into categories and giving each of them a code. Firstly, the author put the 133 factors into a MS Excel spreadsheet, and sorted them. It is obvious that some factors are identical to others, so the author deleted the redundant factors. After careful consideration and discussion with advising professor, the final list is shown in Table 4.11.

Table 4.11 Elements for Project Metabolism

Level	**Item**	**Description**
Individual	Key personnel experience	Project manager and other key personnel's experience in similar projects
	Key personnel capability	Project manager and other key personnel's capability in managing the project
	Commitment	People's commitment to the project
Organizational	Top management support	Having support from top management of their own organization (Owner, designer, contractor).
	Owner's will	Owner's preference on quality, cost, schedule, and safety
	Organization's experience	Owner, designer, and contractor's experience in similar projects
	Organization structure	A well-defined organization structure for owner, designer and contractor
	Peer review	Having a formal peer review process within the organization
Project	Project mission	Having a clear project mission/common goal
	Contractual relationship	The project delivery method encourages communication and information flow between different organizations
	Trust and respect	Having high level of trust and respect between different organizations
	Communication	Formal and informal communication during all phases of the project
	Information flow	Timely, valuable optimization information between the owner, designer, and contractor during the whole duration of the project
	Trouble shooting	Having a trouble shooting procedure
	Formal dispute resolution process	Having a formal dispute resolution process
	Monitoring and feedback	Having an established procedure for monitoring and feedback

As shown in Table 4.11, sixteen factors are in the final list, and they are grouped into three categories: individual level, organizational level, and project level. The second column in the table lists a brief description of each factor, and the third column explains each factor in details. One of the reasons to put factors into different categories is that a shorter list is easy to manage and respond during the survey process. Another reason is that it may be possible to create a framework for Project Metabolism in different levels as well.

4.7 Survey industry professionals

The elements for a framework of Project Metabolism are identified from the literature regarding construction project success. To get a better understanding of the elements shown in Table 4.11, the survey method is chosen to gather opinions from industry professionals. The target population is construction industry professionals, working for different types of companies and having experience on different types of construction projects. The primary objectives of the survey are to understand industry professionals' opinion on project success and project success factors related to the concept of Project Metabolism and to determine important elements for a framework of Project Metabolism. After getting the responses, statistical tools are used to analyze data and to achieve these objectives.

4.7.1 Questionnaire development

A survey was conducted to gather information on project success and impacting factors that are related to Project Metabolism. The questionnaire used to conduct the survey is based on the list of factors identified in the previous section. IRB approval was obtained before the distribution of the questionnaire. Participation in the questionnaire was voluntary, and the responses were kept confidential.

The questionnaire was web-based, developed by using Qualtrics. It is mobile compatible and takes about 5 minutes to finish. The questionnaire was tested with the Gambatese Research Group members, who are mainly Ph.D. students in Construction Engineering Management at Oregon State University, before distributing to the industry professionals. An updated version was developed to address the comments and feedback from group members.

A copy of the full questionnaire is attached in Appendix C. There are three sections in this questionnaire. Section 1 is about demographics of the respondents, including information on types of company, types of project, position, experience in years, and ages. The second section is about respondents' opinions on project success, and the third section is about their opinions on impacting factors, separated into individual level factors, organizational level factors, and project level factors. For the second and third sections, opinions are gathered on a Likert scale with "5" equal most important or having the most significant impact, "1" equal not very important or very little impact, and "0" equal not important or no impact at all. Details can be found in Appendix C.

4.7.2 Questionnaire distribution

The target population of the survey is construction industry professionals in the US, working for different types of companies and having experience on different types of construction projects. A list of contacts was obtained from the AGC industry liaison at the School of Civil and Construction Engineering at Oregon State University. Most of the contacts on the list graduated from the Construction Engineering Management undergraduate program at OSU, and they are currently working for companies in the Pacific Northwest. This list of contacts is a convenience sample, and it is not a good representation of the target population. The reason for choosing this sample is because it is easy to obtain and likely to result in high response rate within a short period of time.

The questionnaire was sent out to industry professionals to gather their opinions on project success and impacting factors that are related to Project Metabolism. The contact list includes contact information of 560 industry professionals. The author sent the questionnaire to the first 300 of them on a Friday morning using Oregon State University email system. The reason for not sending to all is because the email system only allows 300 Blind carbon copy (Bcc) recipients in one email. The author had an interesting conversation with a colleague about when is the best time of the week to send a questionnaire to construction industry professionals after sending out the questionnaire to the first 300 recipients. In order to figure out when is a better time to send a questionnaire, beginning of the week or the end of the week, the author decided to postpone sending out the questionnaire to a Monday so that the response rates of these two groups can be compared.

Some of the contact information is out of date. As a result, only 263 people from the first group received the questionnaire (263 out of 300). The second group includes 260 contacts in the email list, and 218 of them received the questionnaire. A reminder was sent about one week after the initial distribution of the questionnaire for each group. Table 4.12 describes detailed information of responses for both groups at different time periods, namely within one day, after one day and within one week, and after reminder sent. Total responses and response rates are calculated for both groups.

Table 4.12 Survey responses in different time periods

	1st group	**2nd group**
Number of recipients	263	218
Responses within one day	31	16
Additional responses within one week	9	1
Reponses after reminder	14	16
Total responses	54	33
Response rate	20.5%	15.1%

As shown in Table 4.12, the response rate for the first group is 5% higher than the response rate for the second group. 5% in response rate is a big difference in conducting a survey. The major difference is the responses within one day of the initial distribution of the questionnaire. The first group has 31 responses, and the second group has 16 responses. The first group was sent out on a Friday morning around 10 am, and the second group was sent out 10 days later on a Monday morning around 10 am. It is likely that survey sent out on Friday morning will get a higher response rate. This conclusion is not statistically tested. To make a more convincing argument, the author should randomly separate the contacts into more groups and send out the questionnaire to multiple groups on different days of a week.

4.8 Results

The total responses to the questionnaire are 87, and 78 of them are complete and valid. So the overall response rate is 18.1%, and the complete rate is 89.7% of all responses. The majority of the respondents finished the questionnaire around 3 minutes.

4.8.1 Summary of demographics

The first section of the questionnaire is about the demographics of each respondent. Table 4.13 and Figure 4.22 summarize the types of companies that the respondents are working for. It shows that 69% of the respondents are working for general contractors, and 18% of them work for specialty contractors. Four of them work for owners and only two of them work for designers. Five of the respondents work for other types of companies.

Table 4.13 Summary of types of companies

Types of companies	**Responses**	**Percentage**
General contractor	58	69%
Specialty contractor	15	18%
Owner	4	5%
Designer	2	2%
Others	5	6%

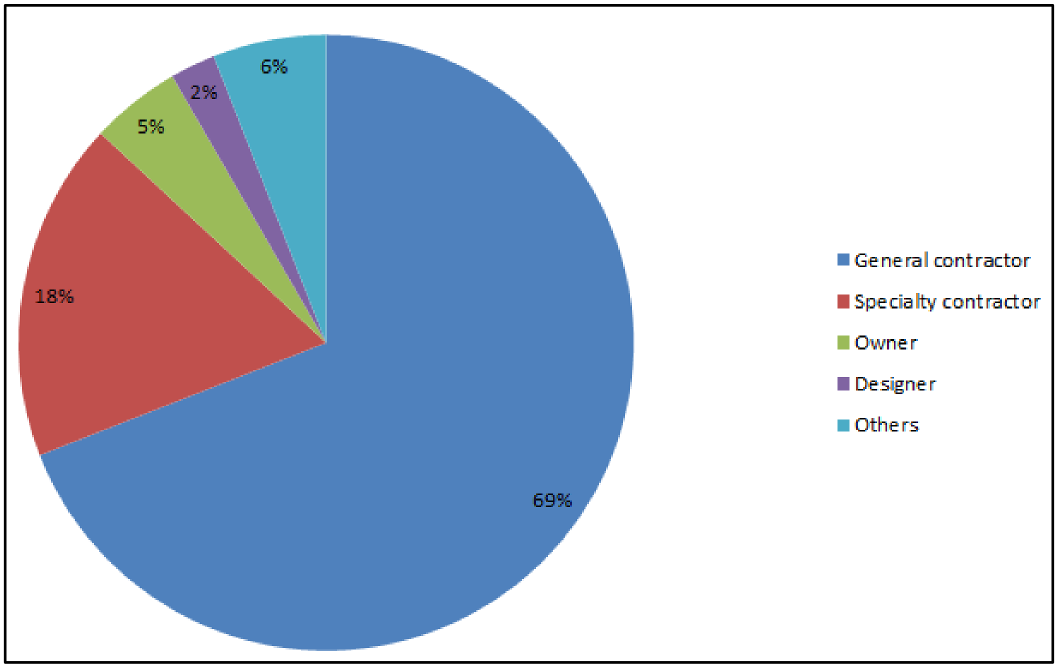

Figure 4.22 Pie chart for types of companies

Table 4.14 and Figure 4.23 summarize the types of projects that the participants have worked on. It shows that many of them have experience on multiple types of projects, and 37% of the respondents have worked on commercial building projects, and 24% of them have experience on heavy civil projects. 20% of them worked on industrial projects, and 9% of them have experience on residential building projects.

Table 4.14 Summary of types of projects

Types of projects	**Responses**	**Percentage**
Commercial building	51	37%
Residential building	13	9%
Industrial	28	20%
Heavy civil	33	24%
Others	14	10%

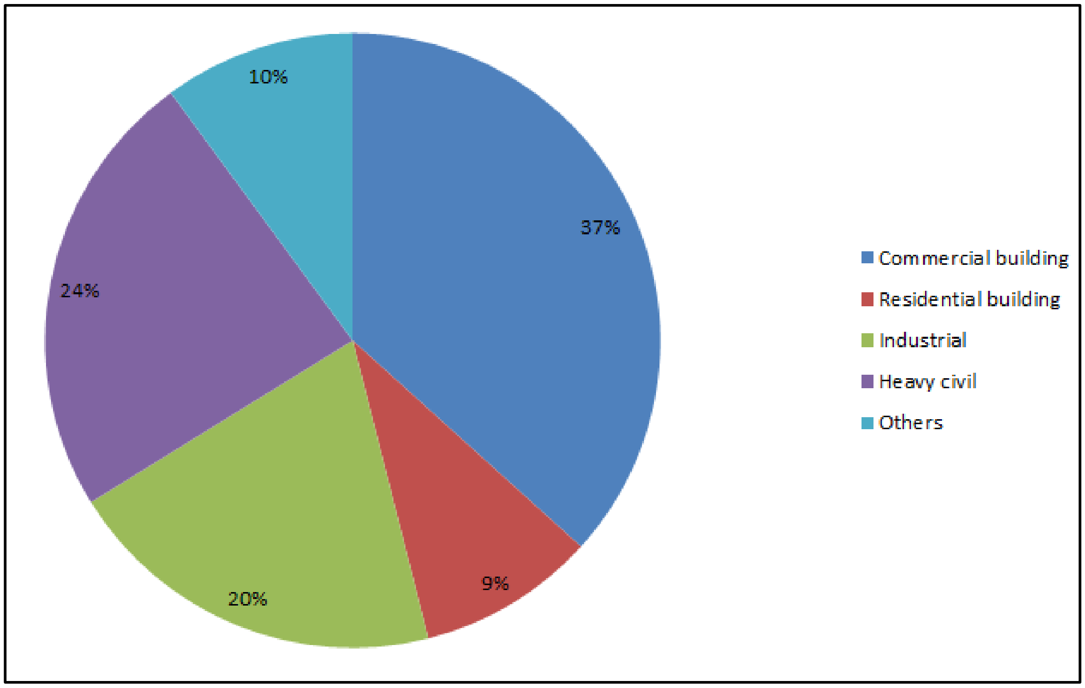

Figure 4.23 Pie chart for types of projects

Table 4.15 and Figure 4.24 summarize the positions of respondents, and for those who choose other, they listed their positions including HR, staffing, estimator, sales, operations process manager, president, company owner, construction executive, division manager, recruitment manager, VP of operations, and project executive. It is noticeable that the majority of respondents are project managers which account for 44% of all respondents.

Table 4.15 Summary of positions

Positions	Responses	Percentage
Project manager	37	44%
Superintendent	3	4%
Project engineer	7	8%
Owner's representative	2	2%
Others	36	42%

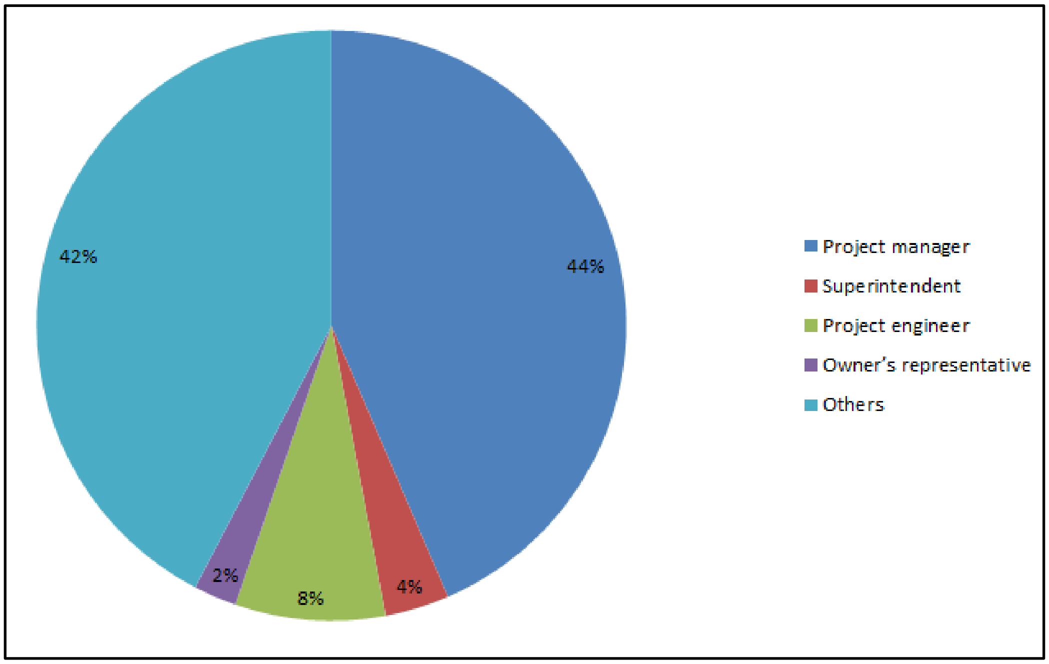

Figure 4.24 Pie chart for positions

Table 4.16 and Figure 4.25 summarize respondents' experience in years. 45% of the respondents have more than 20 years of experience in the construction industry. Only 13% of respondents have less than 5 years of experience. 15% of respondents have 5-10 years of experience and 27% of respondents have 10-20 years of experience.

Table 4.16 Summary of experience in years

Experience in years	Responses	Percentage
Less than 1	3	4%
1-5	8	9%
5-10	13	15%
10-20	23	27%
More than 20	38	45%

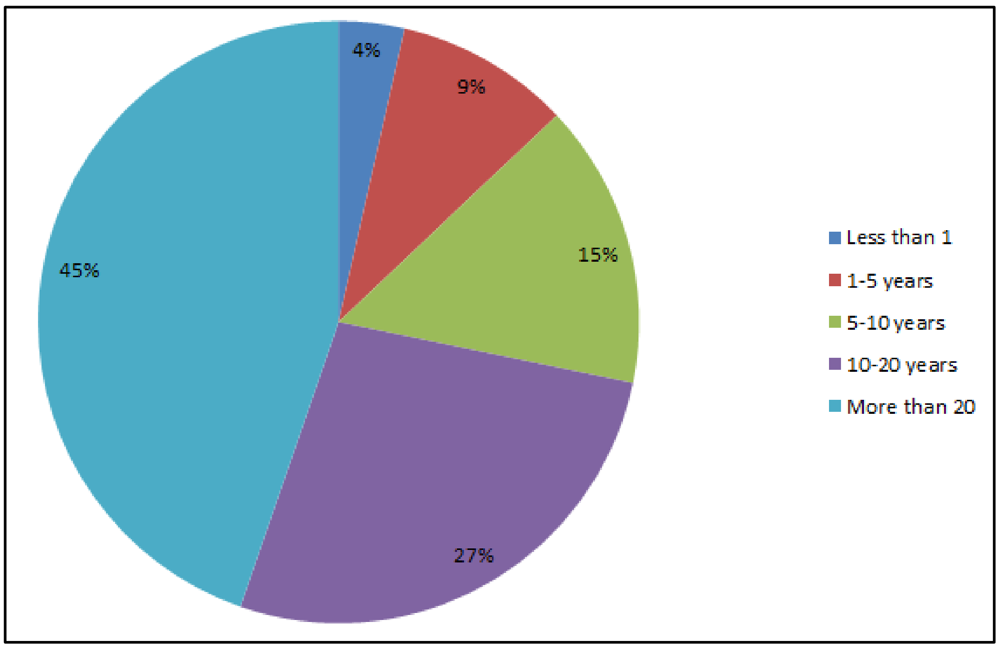

Figure 4.25 Pie chart for experience in years

Table 4.17 and Figure 4.26 show the distribution of respondents' ages. The ages of respondents follow a normal distribution with the majority of them around 25-54 years old. Very few respondents are less than 25 years old or more than 64 years old. It is interesting to see the comparison between respondents' ages and years of experiences as shown in Figure 4.27.

Table 4.17 Summary of respondents' ages

Age in years	**Responses**	**Percentage**
Less than 25	1	1%
25-34	21	25%
35-44	26	31%
45-54	22	26%
55-64	12	14%
More than 64	3	4%

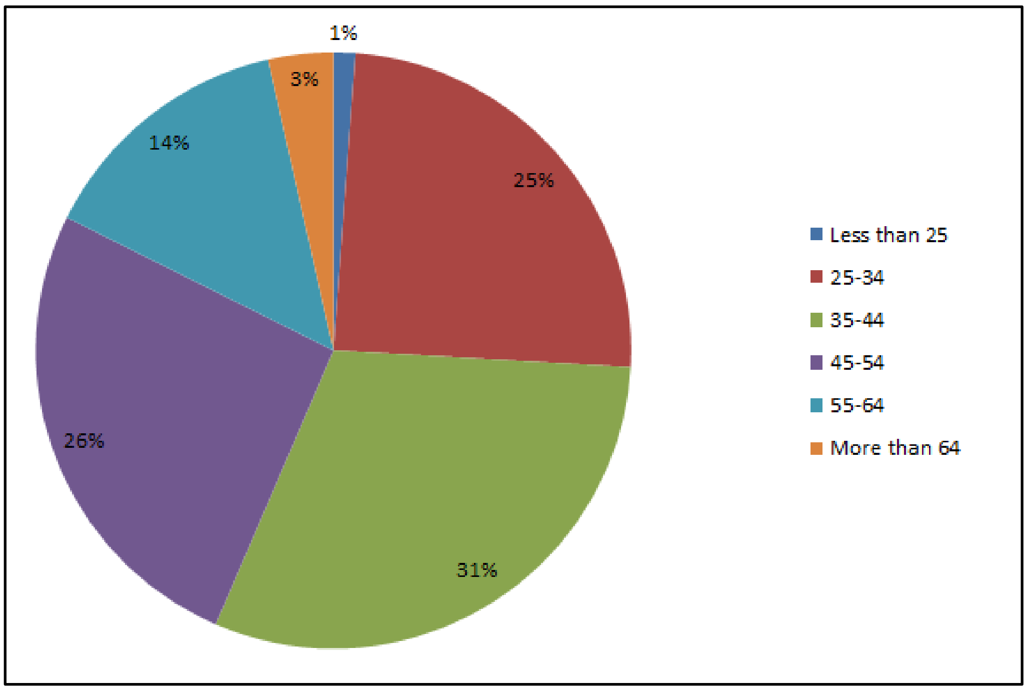

Figure 4.26 Pie chart for age in years

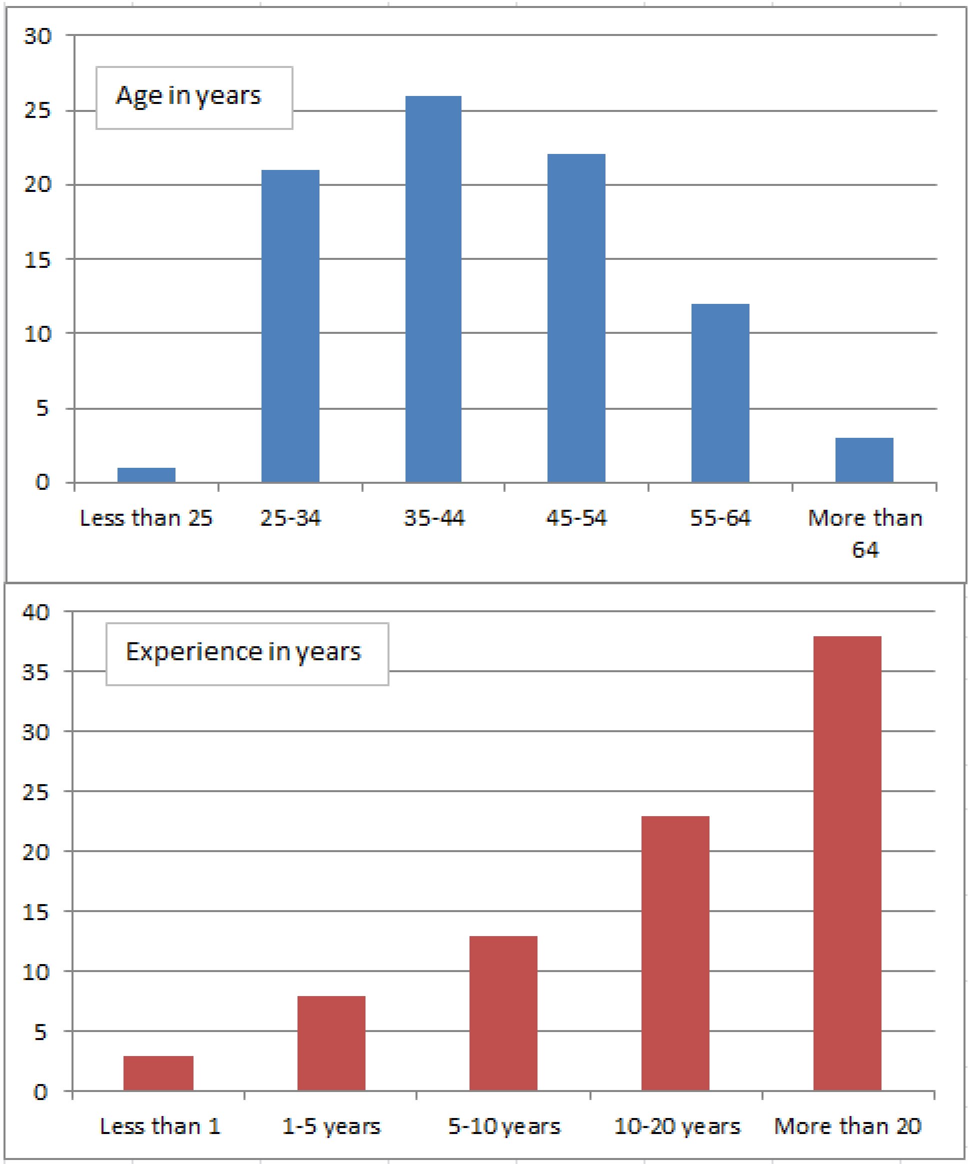

Figure 4.27 Comparison between respondents' ages and years of experience

In Figure 4.27, the distributions of respondents' ages and years of experience are very different. The ages follow a normal distribution and the years of experience almost follow a straight line. One explanation could be many respondents in this sample started to work young and stay in the construction industry for a long period of time.

In summary, the majority of respondents working for general contractors, and many of them have been working on multiple types of projects. More than half of them are in management roles, such as project managers, presidents, project executives, division managers, and VP of operations. 72% of respondents have more than 10 years of experience in the construction industry.

4.8.2 Summary of project success

Section 2 of the questionnaire is to gather industrial professionals' opinions on project success. The opinions are described on a Likert scale with "5" equal most important and "0" equal not important at all. The items listed in the questionnaire are: on time, within budget, good quality, satisfying safety record, and building a long-term relationship with clients. Table 4.18 summarizes the results regarding project success. Of all the respondents, 56 of them believe finishing a project on time is a significantly important measurement (56 of them chose "5" for the item of "on time"). The average rating for finishing on time is 4.61 as shown in the last column of Table 4.18.

Table 4.18 Summary of project success

Project success measurements	**0**	**1**	**2**	**3**	**4**	**5**	**Average**
On time	0	0	1	3	24	56	4.61
Within budget	0	0	0	1	30	53	4.62
Good quality	0	0	0	2	20	62	4.71
Satisfying safety record	0	0	1	4	11	67	4.73
Building a long-term relationship with clients	0	1	1	4	24	54	4.52

The average ratings for all five project success measurements listed in Table 4.18 are very similar, ranging from 4.52 to 4.73. Having a satisfying safety record is considered to be the most important measurement among the five, and building a long-term relationship with clients is the least important comparing to the others.

4.8.3 Summary of impacting factors

Section 3 of the questionnaire is about impacting factors that affect overall project success. Opinions are gathered on a Likert scale with “5” equal having most significant impact and “0” equal no impact at all. All the factors are grouped into three categories: individual level, organizational level, and project level. They are summarized separately in following tables.

Table 4.19 summarizes the results regarding individual level factors, including project manager and other key personnel’s experience in similar projects, project manager and other key personnel’s capability in managing the project, and people’s commitment to the project. The results show that key personnel’s experience in similar projects does not have a significant impact on project success (average rating equal 3.95). Key personnel’s capability (average rating equal 4.63) and commitment to the project (average rating 4.54) are more important than experience. The average rating for overall individual level factors are calculated by adding average ratings for all individual level factors and dividing the sum by the number of factors in this category.

Table 4.19 Summary of individual level factors

Individual level factors	**0**	**1**	**2**	**3**	**4**	**5**	**Average**
Key personnel experience	0	1	1	22	37	23	3.95
Key personnel capability	0	0	0	3	25	56	4.63
Commitment	0	1	0	5	25	53	4.54
Overall individual level factors	--	--	--	--	--	--	4.37

Table 4.20 summarizes the results regarding organizational level factors. Having a formal peer review process within the organization is the least important impacting factor with an average rating of 3.02. Having support from top management of project participants' organizations is rated to be the most significant impacting factors in the organizational category. Owner's preference on quality, cost, schedule, and safety is the second most important impacting factor in this category with an average rating of 4.01. The average rating of overall organizational level factors is calculated the same way as the average rating of overall individual level factors.

Table 4.20 Summary of organizational level factors

Organizational level factors	**0**	**1**	**2**	**3**	**4**	**5**	**Average**
Top management support	0	0	1	5	43	33	4.32
Owner's will	0	0	3	17	38	24	4.01
Organization's experience	0	1	3	18	43	3	3.65
Organization structure	0	1	5	16	33	27	3.98
Peer review	1	5	22	22	25	6	3.02
Overall organizational level factors	--	--	--	--	--	--	3.80

Table 4.21 summarizes the results regarding project level factors. Within this category, formal and informal communication during all phases of a project is rated to be the most significant impacting factor with an average rating of 4.59, followed by having a high level of trust and respect between different organizations (average rating equal 4.49). The least significant factor in this category is having a formal dispute resolution process (average rating 3.25), followed by having an established procedure for monitoring and feedback (average rating 3.27).

Table 4.21 Summary of project level factors

Project level factors	**0**	**1**	**2**	**3**	**4**	**5**	**Average**
Project mission	0	0	6	11	31	33	4.12
Contractual relationship	0	0	1	15	28	37	4.25
Trust and respect	0	0	1	6	26	48	4.49
Communication	0	0	0	2	29	50	4.59
Information flow	1	1	2	9	29	39	4.23
Trouble shooting	1	2	6	25	32	14	3.59
Formal dispute resolution process	3	5	11	25	23	14	3.25
Monitoring and feedback	1	6	10	30	21	13	3.27
Overall project level factors	--	--	--	--	--	--	3.97

Overall, individual level factors have the highest rating among different categories, with an average rating equal 3.47, followed by overall project level factors with an average rating of 3.97. Organizational level factors are the least significant ones comparing to the other two categories.

All impacting factors are put together and ranked by their average ratings to get the top 10 factors as shown in Table 4.22. Key personnel’s capability is ranked to be the most significant factor, followed by communication, commitment, trust and respect, and top management support.

Table 4.22 Top 10 impacting factors ranked by average rating

Rank	**Impacting factors**	**Average rating**
1	Key personnel capability	4.63
2	Communication	4.59
3	Commitment	4.54
4	Trust and respect	4.49
5	Top management support	4.32
6	Contractual relationship	4.25
7	Information flow	4.23
8	Project mission	4.12
9	Owner’s will	4.01
10	Organization structure	3.98

The ranked list shown in Table 4.22 is the sample results based on the information gathered through the questionnaire. When doing research, having only sample results is not satisfying. Descriptive statistics are great in showing sample summaries, but inferential statistics are necessary to make inferences and predictions about the target population based on the data from the sample.

4.9 Data analysis

Karl Pearson once said that “statistics is the grammar of science.” The major purposes of statistics are to help us understand and describe phenomena and draw reliable conclusions, after accounting for randomness and uncertainty. The statistical tools used to analyze data are determined by research questions and the characteristics of the data. The research questions needed to be answered by the survey results are as follows:

- Are the responses related to each impacting factor depending on demographical groups?
- Are the responses related to each project success measurement depending on demographical groups?

The next step is to find data distribution of the sample and to determine what to do with the data to answer above research questions. The research questions are about comparing dependent variables between different groups. Before choosing the appropriate tools, we need to take a closer look at the data. Graphical displays of the data are presented in the next section.

4.9.1 Data display

In the questionnaire, five project success measurements and 16 impacting factors are being evaluated. Therefore, altogether 21 dependent variables need to be displayed. Figure 4.28 shows the histogram for the dependent variable building a long-term relationship with clients. The graphical displays for all dependent variables are shown in Appendix D.

Figure 4.28 An example of histograms of dependent variables

The histograms of dependent variables in Appendix D show that most of the dependent variables do not have normal distributions. Organizational level factor (OLF) 3 and 5, and project level factor (PLF) 6, 7, and 8 have distributions close to normal ones. The most commonly used statistical tools to compare group means are t-test and one-way ANOVA which require normal distributions. Therefore, nonparametric/distribution-free tools are more appropriate to analyze the data from this sample. Rank Sum test is usually used to compare two independent groups, and Kruskal-Wallis nonparametric Analysis of Variance is commonly used to compare more than two independent groups. The nonparametric tools can be used to analysis normally distributed data as well. To make it consistent, only nonparametric tests will be applied in the next section.

4.9.2 Success measurements vs. company types

The majority of the respondents who completed the survey are working for general contractors (55 respondents) or specialty contractors (13 respondents). Only two people are working for design firms and three people are working for owners, and the numbers are too small to be used in statistical analysis. Therefore, the comparison will be given to the group of general contractors and the group of specialty contractors. Table 4.23 shows the mean scores regarding project success measurements and differences between the general contractor group and the specialty contractor group. Table 4.24 shows the p-values from Rank Sum tests. The means for data from irregular distributions do not represent as much information as means for normal or some other well-known distributions. However, the author cannot find better statistics to represent the sample, so means are reported in all tables in the analysis section.

Table 4.23 Mean scores for project success measurements vs. company types

Project success measurements	**Mean scores for general contractors**	**Mean scores for specialty contractors**	**Differences**
On time	4.76	4.61	0.15
Within budget	4.67	4.84	-0.17
Good quality	4.74	4.61	0.13
Satisfying safety record	4.82	4.69s	0.13
Building long-term relationship with clients	4.56	4.62	-0.06

Table 4.24 P-values for project success measurements vs. company types

Project success measurements	**P-value from Rank Sum test**
On time	0.28
Within budget	0.22
Good quality	0.60
Satisfying safety record	0.52
Building long-term relationship with clients	0.39

P-values represent the possibility of randomization alone causing a sample to be as extreme as it is. The smaller the p-value, the less likely the sample results are caused by chance, so it is most likely something else, ideally the research interest, that causes the sample to have a result as it is. Figure 4.29 provides guidance on how to interpret p-values and shows how small is good enough for a p-value. For example, the research interest is to analyze two samples and to figure out if the populations represented by two samples have the same means. After the analysis, if getting a p-value greater than 0.10, it means that the differences between two sample groups are just by chance, and the means for two populations are the same. If the p-value is between 0.05 and 0.10, it means that there is suggestive but inconclusive evidence that population means are different. If the p-value is between 0.01 and 0.05, there is moderate evidence that population means are different. If the p-value is less than 0.01, there is convincing evidence that population means are different.

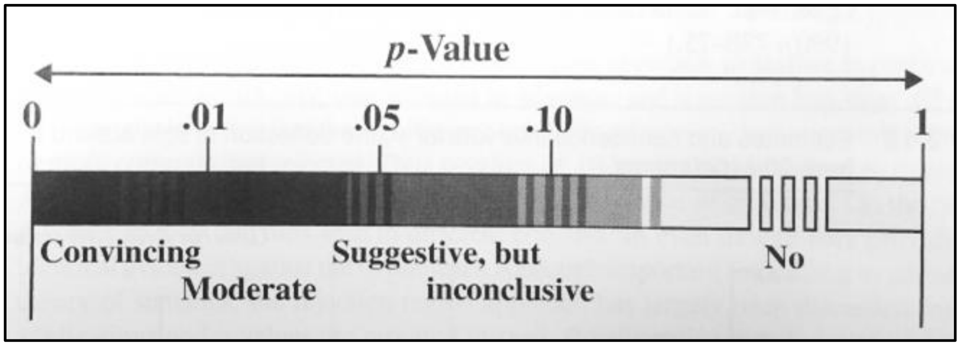

Figure 4.29 Interpreting the size of a p-value (Ramsey and Schafer 2002)

Using similar methods to interpret results shown in Table 4.24, it is clear that people working for general contractors and people working for specialty contractors have similar opinions on project success (all p-values > 0.10).

4.9.3 Impacting factors vs. company types

Table 4.25 shows the mean scores regarding project success measurements and differences between the general contractor group and the specialty contractor group. Table 4.26 shows p-values from Rank Sum tests.

Table 4.25 Mean scores for impacting factors vs. company types

Impacting factors	**Mean scores for general contractors**	**Mean scores for specialty contractors**	**Differences**
Key personnel experience	3.85	3.85	0
Key personnel capability	4.67	4.69	-0.02
Commitment	4.53	4.77	-0.24
Top management support	4.29	4.31	-0.02
Owner’s will	4.04	3.92	0.12
Organization’s experience	3.82	3.92	-0.1
Organization structure	4.07	3.77	0.3
Peer review	2.98	2.92	0.06
Project mission	4.13	4.08	0.05
Contractual relationship	4.31	4.15	0.16
Trust and respect	4.51	4.46	0.05
Communication	4.64	4.38	0.26
Information flow	4.29	4.54	-0.25
Trouble shooting	3.58	3.46	0.12
Formal dispute resolution process	3.25	2.77	0.48
Monitoring and feedback	3.20	3.46	-0.26

Table 4.26 P-values for impacting factors vs. company types

Impacting factors	**P-value from Rank Sum test**
Key personnel experience	0.69
Key personnel capability	0.68
Commitment	0.22
Top management support	0.98
Owner’s will	0.69
Organization’s experience	0.59
Organization structure	0.25
Peer review	0.69
Project mission	0.71
Contractual relationship	0.45
Trust and respect	0.67
Communication	0.17
Information flow	0.55
Trouble shooting	0.36
Formal dispute resolution process	0.065
Monitoring and feedback	0.60

The information in Table 4.25 and Table 4.26 shows that there is suggestive but inconclusive evidence that people have different opinions on having a formal dispute resolution process (p-value = 0.065). The general contractors put more importance on having a formal dispute resolution than the specialty contractors. For all the other impacting factors, the opinions of the general contractor group are the same as the opinions of the specialty contractor group (p-values > 0.10).

4.9.4 Success measurements vs. positions

Of all the completed questionnaires, 35 respondents are project managers, and 5 respondents are project engineers. The numbers of respondents for other position types are small, so the comparison in this section is only for project managers and project engineers, and the results are shown in Table 4.27. The p-values listed in Table 4.28 are results from Rank Sum tests. The results show that project engineers and project managers have similar opinions on project success (all p-values > 0.10).

Table 4.27 Mean scores for project success measurements vs. positions

Project success measurements	**Mean scores for project engineers**	**Mean scores for project managers**	**Differences**
On time	4.60	4.74	-0.14
Within budget	4.40	4.71	-0.31
Good quality	4.80	4.74	0.06
Satisfying safety record	4.60	4.74	-0.14
Building long-term relationship with clients	5.00	4.63	0.37

Table 4.28 P-values for project success measurements vs. positions

Project success measurements	**P-value from Rank Sum test**
On time	0.80
Within budget	0.17
Good quality	0.87
Satisfying safety record	0.80
Building long-term relationship with clients	0.15

4.9.5 Impacting factors vs. positions

The information in Table 4.29 and Table 4.30 shows project engineers and project managers' opinion on impacting factors. The results indicate that there is suggestive but inconclusive evidence that project engineers and project managers have different opinions on having a formal peer review process within the organization (p-value = 0.09), having a clear project mission (p-value = 0.06), and having a formal dispute resolution process (p-value = 0.09). Project engineers gave higher ratings on having a formal peer review process, having a clear project mission, and having a formal dispute resolution process than project managers. For all the other impacting factors, the opinions of the two groups are the same (p-values > 0.10).

Table 4.29 Mean scores for impacting factors vs. positions

Impacting factors	**Mean scores for project engineers**	**Mean scores for project managers**	**Difference**
Key personnel experience	3.6	3.89	-0.29
Key personnel capability	4.40	4.69	-0.29
Commitment	4.40	4.51	-0.11
Top management support	4.20	4.14	0.06
Owner's will	3.40	4.06	-0.66
Organization's experience	3.4	3.8	-0.4
Organization structure	3.80	3.86	-0.06
Peer review	3.60	2.82	0.78
Project mission	4.8	3.91	0.89
Contractual relationship	4.8	4.14	0.66
Trust and respect	5	4.5	0.5
Communication	4.8	4.54	0.26
Information flow	4.2	3.91	0.29
Trouble shooting	4.0	3.29	0.71
Formal dispute resolution process	4.0	2.82	1.18
Monitoring and feedback	3.8	2.82	0.98

Table 4.30 P-values for impacting factors vs. positions

Impacting factors	**P-value from Rank Sum test**
Key personnel experience	0.37
Key personnel capability	0.47
Commitment	0.58
Top management support	0.98
Owner's will	0.12
Organization's experience	0.35
Organization structure	1
Peer review	0.09
Project mission	0.06
Contractual relationship	0.10
Trust and respect	0.13
Communication	0.37
Information flow	0.76
Trouble shooting	0.23
Formal dispute resolution process	0.09
Monitoring and feedback	0.12

4.9.6 Success measurements vs. project types

Many respondents have experience on different types of projects. One of the assumptions of using Rank Sum tests to assess the difference between two groups is that the two groups need to be independent. Therefore, the same respondent cannot be included in multiple groups. If a person has worked on different types of projects, his/her responses are excluded in this part of the analysis. 18 respondents only worked on commercial construction projects and 21 respondents only worked on heavy civil construction projects. The responses from these people are used in the analysis in this and the next sections. Table 4.31 and Table 4.32 list the results regarding project success measurements for people working on different types of projects.

Table 4.31 Mean scores for project success measurements vs. project types

Project success measurements	**Mean scores for commercial projects**	**Mean scores for heavy civil projects**	**Differences**
On time	5.00	4.52	0.48
Within budget	4.78	4.62	0.16
Good quality	4.83	4.71	0.12
Satisfying safety record	4.89	4.81	0.08
Building long-term relationship with clients	4.83	4.24	0.59

Table 4.32 P-values for project success measurements vs. project types

Project success measurements	**P-value from Rank Sum test**
On time	0.0018
Within budget	0.29
Good quality	0.39
Satisfying safety record	0.50
Building long-term relationship with clients	0.0036

There is convincing evidence that people working on different types of projects have different opinions on finishing projects on time (p-value = 0.0018) and building long-term relationships with clients (p-value = 0.0036) in term of project success. All respondents working on commercial projects agree that finishing projects on time is significantly important to overall project success. On the contrary, respondents working on heavy civil projects don’t share this opinion. Building long-term relationships with clients is more important for people working on commercial projects than those working on heavy civil projects. The opinions on budgets, quality, and safety are the same (p-values > 0.10).

4.9.7 Impacting factors vs. project types

Table 4.33 and Table 4.34 show the responses regarding impacting factors from people working on different types of projects. There is suggestive but inconclusive evidence that people working on different types of projects have different opinions on the impact of project manager and other key personnel's experience on project success (p-value = 0.097). All other responses are the same (p-values > 0.10).

Table 4.33 Mean scores for impacting factors vs. project types

Impacting factors	**Mean scores for commercial projects**	**Mean scores for heavy civil projects**	**Differences**
Key personnel experience	3.72	4.14	-0.42
Key personnel capability	4.67	4.67	0
Commitment	4.61	4.52	0.09
Top management support	4.33	4.57	-0.24
Owner's will	3.78	4.19	-0.41
Organization's experience	3.89	3.95	-0.06
Organization structure	3.94	4.14	-0.2
Peer review	3.22	3.00	0.22
Project mission	4.28	4.00	0.28
Contractual relationship	4.28	4.38	-0.1
Trust and respect	4.50	4.48	0.02
Communication	4.50	4.71	-0.21
Information flow	4.33	4.14	0.19
Trouble shooting	3.39	3.52	-0.13
Formal dispute resolution process	3.00	3.57	-0.57
Monitoring and feedback	3.17	2.90	0.27

Table 4.34 P-values for impacting factors vs. project types

Impacting factors	**P-value from Rank Sum test**
Key personnel experience	0.097
Key personnel capability	0.81
Commitment	0.59
Top management support	0.18
Owner's will	0.10
Organization's experience	0.89
Organization structure	0.44
Peer review	0.64
Project mission	0.31
Contractual relationship	0.59
Trust and respect	0.65
Communication	0.27
Information flow	0.61
Trouble shooting	0.72
Formal dispute resolution process	0.20
Monitoring and feedback	0.54

4.10 Conclusions and recommendations

This manuscript introduces the concept of Project Metabolism. The concept of Project Metabolism is defined as "all interactions between major project participants during the process of a construction project, and the transformation and combination of labor, materials, equipment to get a final physical product." A framework of Project Metabolism is developed with 16 elements which are identified from a literature review. The elements are categorized into three groups: individual level factors, organizational level factors, and project level factors. A survey is developed to gather construction industrial professionals' opinions on project success and factors impacting project success.

The responses are summarized and analyzed using statistical tools. The results show that general contractors and specialty contractors have similar opinions on construction project success and impacting factors. Project engineers and project managers share the same opinion regarding project success and the majority of impacting factors. Project engineers gave higher ratings on having a formal peer review process, having a clear project mission, and having a formal dispute resolution process than project managers. People working on commercial projects agree that finishing projects on time is significantly important to overall project success, but people working on heavy civil projects don’t share this belief. Building long-term relationships with clients is more important for people working on commercial projects than those working on heavy civil projects.

Factors impacting project success are ranked by their average ratings. Top 10 impacting factors as listed in Table 4.22 are used to construct a framework for Project Metabolism. Project managers and other key personnel’s capability in managing projects has been ranked as the most significant impacting factor, followed by formal and informal communication during all phases of projects. People’s commitment to the project is ranked the third and having a high level of trust and respect between different organizations is the fourth most important factor. The results indicate that industrial professionals agree that people and interaction between them have a significant impact on overall project success.

This manuscript describes an initial effort to define and develop the concept of Project Metabolism. Many other research studies can be done to further develop the concept. For example, incorporating the research studies and findings of key performance indicators may enrich the current concept of Project Metabolism. Based on the CII research on Project Definition Rating Index, we can develop a Project Metabolism Rating Index to measure the level of Project Metabolism. The materials side of the concept has been left alone in this research study and it could be a very interesting topic for future studies. After all, the changing from materials to a final physical product mimics the process of human metabolism closely.

In summary, the concept of Project Metabolism is defined and developed in this research study. Elements of a framework for Project Metabolism are identified and ranked based on industrial professionals' opinions. The next step could be finding a way to link or combine them to make a structured framework. This study only explores the people part of the Project Metabolism. It may be worthwhile to find how the materials part of the concept fit into the big picture. Furthermore, how to use the framework to assess project similarity was not discussed in this manuscript. It needs to be addressed in future research studies.

Chapter 5 General conclusion

The uniqueness of construction projects has brought great challenges to construction industry professionals as well as researchers and educators in the construction discipline. This characteristic brings limitations to researchers when they try to compare multiple projects and make inferences, as well as to industry professionals when they try to make decisions based on previous projects. If a method or a model can be developed to assess the similarity between projects and make project comparisons more science than art, we can increase the confidence level of researchers when they conduct analyses and make conclusions, and we can help industry professionals to make better decisions based on better information.

This dissertation describes three attempts to try to solve the problem brought by the uniqueness of construction projects. Manuscript 1 describes the development of a framework for the concept of Foundational Attributes of construction projects. Four of the Foundational Attributes are quantified and put in a spider chart to be used to calculate the similarity between projects. The similarity between two projects is calculated by using the overlapping area divided by the entire area covered by all projects. This manuscript describes an initial effort on developing a framework for the concept of Foundational Attributes. It is an attempt, not a proof or validation. The concept of Foundational Attributes needs further development and validation, and this manuscript serves as a basis for future work.

Manuscript 2 describes a review of the history of the construction industry. The author finds that the development of construction history is closely associated with the development of human society, religion, philosophy, culture, science, and technology. Many aspects of construction projects have been changing and evolving, including the purpose of structures, the materials used in construction, equipment, tools and power sources, the role of builders, and the project delivery methods. However, some fundamental things have never changed. The purpose of a structure is to fulfill a certain need of an owner, and biggest drive to finish a project is the owner's desire to have that structure, regardless of the limitations and constrains. The most important factor to make a project successful is the intelligence and determination of the builder. It is the people who are the center of a construction project, not the final structure.

Manuscript 3 introduces the concept of Project Metabolism, by giving a definition of Project Metabolism and developing a framework of it. The concept of Project Metabolism is defined as "all interactions between major project participants during the process of a construction project, and the transformation and combination of labor, materials, equipment to get a final physical product." A framework of Project Metabolism is developed with 16 elements which are identified from a literature review, and top 10 impacting factors are determined based on a survey result. A survey is developed to gather industrial professional's opinions on this subject. The results show that general contractors and specialty contractors have similar opinions on construction project success and impacting factors. Project engineers and project managers share the same opinion regarding project success and the majority of impacting factors. Project engineers gave higher ratings on having a formal peer review process, having a clear project mission, and having a formal dispute resolution process than project managers. People working on commercial projects agree that finishing projects on time is significantly important to overall project success, but people working on heavy civil projects don't share this belief. Building long-term relationships with clients is more important for people working on commercial projects than those working on heavy civil projects. Project managers and other key personnel's capability in managing projects has been ranked as the most significant impacting factor, followed by formal and informal communication during all phases of projects. People's commitment to the project is ranked the third and having a high level of trust and respect between different organizations is the fourth most important factor. The results indicate that industrial professionals agree that people and interaction between them have a significant impact on overall project success.

In summary, this dissertation describes three attempts to solve the problem brought by the uniqueness of a construction project. The concept of Foundational Attributes is developed and methods to quantify the similarity between projects are illustrated in a few spider charts. However, further development of the framework and more robust methods to calculate similarity are needed. After a review of the history of construction, the author finds that people are the center of a project and decides to develop a new concept to focus on the people and the interaction between them in a project. The concept of Project Metabolism is defined and developed. It is a promising tool to assess project similarity but further development is needed as well. For both models, concept validations are necessary.

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Appendices

Appendix A: Ideas for concept mapping

No.	**Ideas on stickers**	**Explanation for the idea**
1	Purpose of a structure	The purpose of a structure is to fulfill a certain need of people. To serve people.
2	Ancient mega structures – technology and tools	In ancient time, there was not enough science and technology for calculation and planning, but we still have many amazing structures, like Pyramid, etc.
3	Project success in ancient time	Finish the project is the only concern—the product success. No need to worry about time, money, and safety.
4	Human rights and freedom—safety	The human history has evolved from barbaric to civilization. Every person is free and has rights. Safety cannot be overlooked. Everyone's rights need to be respected.
5	Project success vs product success	Mega structures used to serve the king, now they serve all people. Project success cannot be product success anymore. Only finishing the structure is not success. Need to make all stakeholders satisfied.
6	A project—not a structure	The main purpose of a project is to deliver a structure, but a project is not a structure. A project is a process. Like a human being. Developed from fetus, to baby, to adult. A project from the concept to build a structure to the final physical structure.
7	Project Metabolism—ensure project success	A good/certain kind of metabolism ensures project success.
8	Project success criteria—my thoughts	Project needs to be finished on time, within budget, and it needs to be profitable and public need to be ok with the process. Need to obey building code, local zoning regulations and law. Need to be a green building or structure if desired. Need to be incident free.
9	Science and technology—not necessary for success	Science and technology enable us to do a lot of things, but they do not assure you a successful project.
10	People—a project	People make things happen, not science and technology, nor tools. People should be the center of a project.
11	Project success—participants' will	Having a strong will to get things done and solve all problems, within ethic boundary, to make a project success.

12	Purpose of a structure—culture	From the history, we know the purpose of a project is to fulfill a need, and the need is associated with cultures and conditions at the time.
13	Purpose of a structure—resources, tools and methods	The methods used to fulfill the need to build a structure are limited by resources, technology, and energy availability.
14	Project – process	Maybe it is not the destination that matters, maybe it is the journey. A project is like a living being, and it grows from a fetus to a fully grown adult. The journey to become an adult matters as much as the final product of an adult.
15	A project—people	A project is a cluster of all participants, interacting with each other, working with all constraints and available resources.
16	A project—not structure	The finish of the structure is not the end. If people worked together happily, they carry the good relationship with them after the project. This will help with future projects.
17	Project Metabolism—input/output	How a project process all input to produce output/outcomes.
18	Project Metabolism—project delivery methods	Project Metabolism may be related to project delivery methods.
19	Project Metabolism—not	It is not a green building rating system. Not about a life cycle of a structure.
20	Project Metabolism—good or bad	Define good/bad metabolism
21	Sustainability—P/PC balance	The ability to produce now and the capacity to produce in the future. This is true effectiveness.
22	Metabolism	Break down food, air, water to produce energy, to form new cell, to enable self-growth. It is a chemical reaction. It is done by systems which consist of organs. Human organ systems (digestion, respiration, cardiovascular) vs project systems? Product of a project is a physical structure and anything else?
23	Metabolic rate	Evaluate the process, not the product; How much energy a body can generate to sustain life and growth.

24	Project Metabolism—input	Labor, material, equipment, energy, information, etc.
25	Project Metabolism—output	A physical structure, by product (material waste, co2 from vehicles, noise, dust, other negative impact on neighborhood), a broken or better relationship between stakeholders; personal growth and experience.
26	Foundational attributes—culture	The concept of organizational culture: patterns of behavior; values and beliefs. Traditional/non-traditional, human relationships, promotion and dismissal, training programs, motivation and incentives, evaluation, absenteeism and rotation, communication processes, conflict resolution.
27	Construction industry—complexity	The increasing complexity of construction projects desires professional project management effort, and research and innovation in construction means and methods.
28	A project—living being	Think of it as a living being. People serve it. Take care of it, as parents, doctors, babysitters, teachers, to help it grow.
29	Metabolism—growth, changes	Growth, changes.
30	Project Metabolism—purpose	Evaluate current project, identify problems and take corrective actions.
31	Foundational attributes—definition	Fundamental elements of all projects that establish a project's nature and shape a project's outcomes, and the disposition of a project's foundational attributes must be known in order to understand and characterize a project, to compare one project to another, and to determine how to effectively impact a project's outcomes
32	Foundational attributes—culture	The patterns of interacting elements and the accumulated learning of a group. The ways of thinking, feeling and perceiving the world that has made the group successful and shape its interpretations and actions. The shared beliefs in the minds of all employees.
33	Foundational attributes—risk	The potential that an action, activity, or condition will lead to a loss. Risk tolerance/threshold. Probability, severity, exposure.
34	Foundational attributes—organizational and project structure	Project delivery method: the formal relationships established between the project team members that define the interconnectivity and interactions between the parties.

		The formal relationships within an organization which establish the roles and responsibilities of the employees, and the relationships between the employees on a project.
35	Foundational attributes—physical form and function	The physical properties of a project's design and the construction features and processes. Shape, size, weight, texture, materials, stress, strain. The nature and arrangement of construction activities undertaken to construct a project.
36	Foundational attributes—resources, tools and processes	The devices and resources utilized to design and construct a project and the means and timing in which they are implemented. The materials, equipment, labor, money, and time needed and available to construct a projects.
37	Sustainable construction	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs
38	Inductive and direct approach	The green building rating systems
39	Deductive and indirect approach	Project Metabolism
40	Sustainable construction to Project Metabolism	In construction, to describe a green project from a deductive approach is like describing a healthy system which produces sustainable results. The system may contain different parties involved in a project, the relationships among different parties, the resources needed for the project, the information flow, etc. To that sense, it is like a human body, composed with different organs and substances flowing throughout the body. Figure 1.4 shows the resemblance between human metabolism and Project Metabolism. Every party is like a vital organ of a living body, an indispensable, interconnected part of the body. A healthy body needs a good metabolism. If we extend the concept of metabolism to a project, and viewing a project like a living body, then the term Project Metabolism may be used to describe something of a project that is similar to the trend or equation of a projection in Figure 1.2. After describing the metabolism of a project, the outcome y will be easy to predict by giving the value of x.
41	Healthy project to success project	Thinking about the desired outcome of Project Metabolism, it could be a healthy project, or more generally, a successful project. Many research studies

		have been done to explore project success. Figure 1.5 illustrates this approach, which is changing certain independent variable and measuring the impact on certain dependent variable. Some examples of independent variables are project manager experience, level of communication, pre-planning effort, and project team integration. The dependent variable is usually project success.
42	Similarity between project in project success	This paper also mentioned that construction projects are different by nature, but when considering measuring project success, the difference in type or size may not play an important role. In another word, one certain method to measure project success can be used in different types of projects and projects with different magnitude. This assumption is very similar to the assumption of Project Metabolism. One certain method to describe all kinds of projects is the primary goal of developing the concept of Project Metabolism.
43	Construction history—human history	the development of construction industry is closely associated with the development of human society, religion, philosophy, culture, science and technology
44	Construction history—function and purpose	From basic survival need, shelter, to village, city, large structure.
45	Construction history—material	Based on natural abundancy, tools, and transportation ability. Local building materials.
46	Construction history—equipment and tools	Science and Technology development
47	Construction history—builders	More and more specialized.
48	Critical success factor—definition	the few key areas of activity in which favorable results are absolutely necessary for a particular manager to reach his or her goals; They are events or circumstances that require the special attention of management because of their significance to the corporation. They may be internal or external and be positive or negative in their impact. Their essential character is the presence of a need from special awareness or attention to avoid unpleasant surprises or missed opportunities or objectives. They may be identified by evaluating corporate strategy, environment, resources, operations

		Those few things that must go well to ensure success for a manager or organization, and therefore, they represent those managerial or enterprise areas that must be given special and continual attention to bring about high performance. Critical Success Factors include issues vital to an organization's current operating activities and its future success
49	Planning effort—CSF	Critical success factor (CSF)
50	Project team motivation—CSF	Critical success factor (CSF)
51	Project manager goal commitment—CSF	Critical success factor (CSF)
52	Scope and work definition—CSF	Critical success factor (CSF)
53	Control system—CSF	Critical success factor (CSF)
54	Project manager technical capabilities—CSF	Critical success factor (CSF)
55	Project mission—CSF	Critical success factor (CSF)
56	Top management support—CSF	Critical success factor (CSF)
57	Project schedule/plan—CSF	Critical success factor (CSF)
58	Client consultation—CSF	Critical success factor (CSF)
59	personnel—CSF	Critical success factor (CSF)
60	Technical tasks—CSF	Critical success factor (CSF)
61	Client acceptance—CSF	Critical success factor (CSF)
62	Monitoring and feedback—CSF	Critical success factor (CSF)
63	Communication—CSF	Critical success factor (CSF)
64	Trouble shooting—CSF	Critical success factor (CSF)
65	Well-organized cohesive team, team chemistry—CSF	A well-organized, cohesive facility team to manage, plan, design, construct, and operate the facility. Team chemistry was typically developed by common goals and activities.

66	Contracts—CSF	A series of contracts that allow and encourage the various specialists to behave as a team without conflicts of interest and differing goals. These contracts must allocate risk and reward in the correct proportions
67	Experience—CSF	Experience in the management, planning, design, construction, and operations of similar facilities.
68	Optimization of information—CSF	Timely, valuable optimization information from the owner, user, designer, contractor, and operator in the planning and design phases of the facility
69	Project characteristics—factor	(1) political risks; (2) economic risks; (3) impact on public; (4) technical approval authorities; (5) adequacy of funding; (6) site limitation and location; (7) constructability; (8) pioneering status; (9) project size.
70	Contractual Arrangements—factor	(10) realistic obligations/clear objectives; (11) risk identification and allocation; (12) adequacy of plans and specifications; (13) formal dispute resolution process; (14) motivation/incentives.
71	Project participants—factor	(15) PM competency; (16) PM authority; (17) PM commitment and involvement; (18) capability of client key personnel; (19) competency of client proposed team; (20) client team turnover rate; (21) client top management support; (22) client track record; (23) client level of service; (24) capability of contractor key personnel; (25) competency of contractor proposed team; (26) contractor team turnover rate; (27) contractor top management support; (28) contractor track record; (29) contractor level of service; (30) capability of consultant key personnel; (31) competency of consultant proposed team; (32) consultant team turnover rate; (33) consultant top management support; (34) consultant track record; (35) consultant level of service; (36) capability of subcontractors key personnel; (37) competency of subcontractors proposed team; (38) subcontractors team turnover rate; (39) subcontractors top management support; (40) subcontractors track record; (41) subcontractors level of service; (42) capability of suppliers key personnel; (43) competency of suppliers proposed team; (44) suppliers team turnover rate; (45) suppliers top management support; (46) suppliers track record; (47) suppliers level of service.
72	Interactive Processes—factor	(48) formal design communication; (49) informal design communication; (50) formal construction communication; (51) informal construction communication; (52) functional plans; (53) design

		complete at construction start; (54) constructability program; (55) level of modularization; (56) level of automation; (57) level of skill labors required; (58) report updates; (59) budget updates; (60) schedule updates; (61) design control meetings; (62) construction control meetings; (63) site inspections; (64) work organization chart; (65) common goal; (66) motivational factor; (67) relationships.
73	Company success – project success	Construction industry has a long history of using project success to determine success of an organization, and due to the pressure resulting from globalization, technology and market changes, the construction industry needs to realize that organizational management and long-term business planning is becoming more and more important. The decision process should be guided by the overall strategy of a company, not only by the success of a project
74	Groups of success factors	Project-related factors , project procedures, project management actions, human-related factors and external environment
75	Complexity of a project	Project will be executed more successfully if the project complexity is low
76	Shorter duration	If the project has shorter duration, it is more likely to be successful
77	Effective management	If the overall management actions are effective, the project is more likely to be successful.
78	Private and experienced client	If the project is funded by a private and experienced client, it is more likely to be successful
79	Competent client	If the client is competent on preparing project briefing and making decisions, the project is more likely to be successful
80	Competent project team leaders	If the project team leaders are competent and experienced, the project is more likely to be successful
81	Stable environment	If the project is executed in a stable environment, it is more likely to be successful
82	Appropriate organization structure	If the project has an appropriate organization structure, it is more likely to be successful
83	Working environment for project manager	Salary, job satisfaction, job security, availability of information, project environment, time availability, complexity of project, team relationship, materials and supplies, duration of project, project size, level of authority, and type of client.
84	Resource	Success factors

	availability	
85	Project risk management	Success factors
86	Environmental impact	Success factors
87	Project size	Success factors
88	Technical related factors	Success factors
89	Human factors	Project manager competency, commitment of all project participants, owner competency, good coordination between project participants, availability of trained resources
90	Management actions	Monitoring and feedback by project participants, regular budget update
91	Peer review	Success factors and tool (Molenaar, Javernick-Will et al. 2013)
92	Success factors—four groups	human-related factors, project-related factors, project management-related factors, and external environmental factors
93	Project success definition	All project requirements anticipated and needs met with sufficient resources, in a timely manner A project is considered an overall success if it: • Meet the technical performance specifications or mission to be performed; • Results in high level of satisfaction concerning project outcome among: o Key people in parent organization o Key people on project team o Key users or clients of project effort Results are better than expected or normally observed in terms of cost, schedule, quality, safety, and participant satisfaction A successful project fulfills four criteria: • Completed on schedule • Completed within budget • Achieved all goals originally set for it • Accepted and used by clients for whom project is intended A successful project: • Completes on time, within budget, and with an acceptable profit margin • Satisfies client expectations • Produces a high-quality design or consulting services

	• Limits firm's professional liability to acceptable levels
94	Contractor characteristic factors	coordination and communication, contractor's experience with similar types of projects, contractor's ability in financial management, and contractor's design capability
95	Product success and project management success	Project success definition, depend on who is evaluating the project.
96	Owner's success criteria	On schedule; on budget; function for intended use (satisfy users and customers); end result as envisioned; quality (workmanship, products); aesthetically pleasing; return on investment (responsiveness to audiences); building must be marketable (image and financial); and minimize aggravation in producing a building.
97	Designer's success criteria	Satisfied client (obtain or develop the potential to obtain repeated work); quality architectural product; met design fee and profit goal; professional staff fulfillment (gain experience, learn new skills); met project budget and schedule; marketable product/process (selling tool, reputation with peers and clients); minimal construction problems (easy to operate, constructible design);no claims (building functions as intended); socially accepted (community response); client pays (reliability); and well defined scope of work (contract and scope and compensation match).
98	Contractor's success criteria	Meet schedule (preconstruction, construction, design); profitable; under budget (savings obtained for owner and/or contractor); quality specification met or exceeded; no claims (owners, subcontractors); safety; client satisfaction (personal relationships); good subcontractor buy out; good direct communication (expectations of all parties clearly defined); and minimal or no surprises during the project.
99	Success index for industrial project	Success Index = $0.6\times(0.55\times\boldsymbol{B} + 0.45\times\boldsymbol{S}) + 0.40\times(0.70\times\boldsymbol{C} + 0.30\times\boldsymbol{U})$, (Griffith, Gibson et al. 1999)
100	Compare projects	An objective measurement that can be used to test the effect a specific input has on project outcomes, as well as making reasonable comparisons between different projects of different types and sizes, is invaluable
101	Building success equation	Project success rating=0.33 budget+0.33schedule+0.33design size achievement
102	Absence of conflict	Project success criteria
103	Completion and	Project success criteria

	satisfaction	
104	Health and safety	Project success criteria
105	Productivity	Project success criteria
106	Profitability	Project success criteria
107	Environmental sustainability	Project success criteria
108	Professional image	Project success criteria
109	Aesthetics	Project success criteria
110	Educational, social and professional aspects	Project success criteria
111	Technical performance	Project success criteria
112	Construction phase success equation	Construction phase success = 0.4cost+0.25schedule+0.3quality+0.05safety, (David R. Shields, Tucker et al. 2003)
113	PSI-D&B	Project success index=0.54time+0.55cost+0.47quality+0.42functionality
114	Metabolism-architecture	A megastructure with individual cells attached to it to mimic organic growth The group of Japanese architects who explore the organic nature of buildings used the word Shinchintaisha as being symbolic of the essential exchange of materials and energy between organisms and the exterior world. The Japanese meaning of the word has a feeling of replacement of the old with the new and the group further interpreted this to be equivalent to the continuous renewal and organic growth of the city.
115	Chemical and energy transformations	The term metabolism is used to refer to all the chemical and energy transformations that occur in a body
116	Energy and nutrition generation	During the process, human organs oxidize carbohydrates, proteins, and fats, producing primarily CO_2, H_2O, and the energy necessary for life.
117	Energy and nutrition transportation	Metabolism—human
118	Cellular level and organ level chemical reaction	Metabolism—human
119	Changes	Metabolism—human
120	Maintain structure	Metabolism—human
121	Self-growth	Metabolism—human
122	Sustain life	Metabolism—human

123	Metabolic rate	The speed of changes, which is usually referred to as metabolic rate, is measured by the rate of energy production in a body. It is proved that the metabolic rate is affected by many factors. Age, sex, emotional state, body temperature, and activities undertaking all affect the metabolic rate of a person

Appendix B: Factors for project success

Author	**Factors**	**Apply to metabolism**
Ashley et al. (1987)	Planning effort	
	Project team motivation	Y
	Project manager goal commitment	Y
	Scope and work definition	
	Control systems	
	Project manager technical capabilities	Y
Pinto & Slevin (1987)	Project mission	Y
	Top management support	Y
	Project schedule/plan	
	Client consultation	Y
	Personnel	Y
	Technical tasks	
	Client acceptance	Y
	Monitoring and feedback	Y
	Communication	Y
	Trouble-shooting	Y
Sanvido et al. (1992)	A well-organized, cohesive facility team to manage, plan, design, construct, and operate the facility. Team chemistry was typically developed by common goals and activities.	Y
	A series of contracts that allow and encourage the various specialists to behave as a team without conflicts of interest and differing goals. These contracts must allocate risk and reward in the correct proportions	Y
	Experience in the management, planning, design, construction, and operations of similar facilities	Y
	Timely, valuable optimization information from the owner, user, designer, contractor, and operator in the planning and design phases of the facility	Y
Chua et al. (1999)	Political risks	
	Economic risks	
	Impact on public	Y
	Technical approval authorities	
	Adequacy of funding	

	Site limitation and location	
	Constructability	
	Pioneering status	
	Project size	
	Realistic obligations/clear objectives	Y
	Risk identification and allocation	Y
	Adequacy of plans and specifications	
	Formal dispute resolution process	Y
	Motivation/incentives	Y
	Project manager competency	Y
	Project manager authority	Y
	Project manager commitment and involvement	Y
	Capability of client key personnel	Y
	Competency of client proposed team	Y
	Client team turnover rate	Y
	Client top management support	Y
	Client track record	Y
	Client level of service	Y
	Capability of contractor key personnel	Y
	Competency of contractor proposed team	Y
	Contractor team turnover rate	Y
	Contractor top management support	Y
	Contractor track record	Y
	Contractor level of service	Y
	Capability of consultant key personnel	Y
	Competency of consultant proposed team	Y
	Consultant team turnover rate	Y
	Consultant top management support	Y
	Consultant track record	Y
	Consultant level of service	Y
	Capability of subcontractors key personnel	Y
	Competency of subcontractors proposed team	Y
	Subcontractors team turnover rate	Y
	Subcontractors top management support	Y
	Subcontractors track record	Y
	Subcontractors level of service	Y
	Capability of suppliers key personnel	Y
	Competency of suppliers proposed team	Y
	Suppliers team turnover rate	Y
	Suppliers top management support	Y
	Suppliers track record	Y
	Suppliers level of service	Y
	Formal design communication	Y

	Informal design communication	Y
	Formal construction communication	Y
	Informal construction communication	Y
	Functional plans	
	Design complete at construction start	
	Constructability program	
	Level of modularization	
	Level of automation	
	Level of skill labors required	Y
	Report updates	
	Budget updates	
	Schedule updates	
	Design control meetings	Y
	Construction control meetings	Y
	Site inspections	
	Work organization chart	Y
	Common goal	Y
	Motivational factor	Y
	Relationships	Y
Chan et al. (2004)	Communication system	Y
	Control mechanism	
	Feedback capabilities	Y
	Planning effort	
	Developing an appropriate organization structure	Y
	Implementing an effective safety program	
	Implementing an effective quality assurance program	
	Control of sub-contractors' works	Y
	Overall managerial actions	Y
	Procurement method	
	Tendering method	
	Type of project	
	Complexity of project	
	Size of project	
	Technology advanced	
	Client's experience	Y
	Private or public funded client	Y
	Client's emphasis on low construction cost	Y
	Client's emphasis on high quality of construction	Y
	Client's emphasis on quick construction	Y
	Client's ability to brief	Y

	Client's ability to make decision	Y
	Client's ability to define roles	Y
	Client's contribution to design	Y
	Client's contribution to construction	Y
	Project team leaders' experience	Y
	Technical skills of the project team leaders	Y
	Planning skills of the project team leaders	Y
	Organizing skills of the project team leaders	Y
	Coordinating skills of the project team leaders	Y
	Motivating skills of the project team leaders	Y
	Project team leaders' commitment to meet cost, time and quality	Y
	Project team leaders' early and continued involvement in the project	Y
	Project team leaders' adaptability to changes in the project plan	Y
	Project team leaders' working relationship with others	Y
	Support and provision of resources from project team leaders' parent company	Y
Tabish and Jha (2012)	Project managers competency	Y
	Commitment of all project participants	Y
	Owners competency	Y
	Good coordination between project participants	Y
	Availability of trained resources	
	Monitoring and feedback by project participants	Y
	Regular budget update	
Molenaar et al (2013)	Peer review	Y
Hwang and Lim (2013)	Political risks	
	Economic risks	
	Adequacy of funding	
	Constructability	
	Pioneering status	
	Realistic obligations/clear objectives and scope	Y
	Risk identification and allocation	Y
	Adequacy of plans and specifications	
	Motivation/incentives	Y
	Project manager competency and authority	Y
	Project manager commitment to established schedules and budget	Y

	Nature of project manager’s authority	Y
	Owner involvement and frequent feedback	Y
	Owner commitment to established schedules and budget	Y
	Owner satisfaction with delivered project	Y
	Capability of contractor key person	Y
	Contractor commitment to established schedules and budget	Y
	Contractor team capability and commitment	Y
	Capability of consultant key person	Y
	Contractor commitment to established schedules and budget	Y
	Contractor team capability and commitment	Y
	Capability of consultant key person	Y
	Consultant commitment to established schedules and budget	Y
	Contractor team capability and commitment	Y
	Capability of consultant key person	Y
	Consultant commitment to established schedules and budget	Y
	Consultant team capability and commitment	Y
	Frequent feedback from parent organization	Y
	Monitoring and feedback on project	Y
	Communication throughout project duration	Y
	Adequate planning and control techniques	
	Sufficient working drawing details	
	Availability of backup strategies	
	Budget updates	
	Schedule updates	
	Design control meetings	Y
	Construction control meetings	Y
	Site inspections	
Liu et al. (2015)	Adequacy of contractor’s plant and equipment	
	Experience required for a particular delivery	Y
	Contractor’s prior working relationship with the owner	Y
	Contractor’s prior working relationship with consultants	Y
	Magnitude of change orders in contractor’s past projects	Y
	Magnitude of claims and disputes in contractor’s past projects	Y
	Contractor’s experience with similar sized	Y

	projects	
	Subcontractors' experience and capability	Y
	Contractor's experience with similar types of projects	Y
	Contractor's track record for completion on time and on budget	Y
	Contractor's ability in financial management	Y
	Contractor's design capability	Y

Appendix C: Survey

Recruitment email

Dear Sir or Madam,

Your expertise is greatly needed to help with a study which is to evaluate factors that impact overall project success. Please note that the information you provide will be kept confidential, and participation is voluntary.

The following link will direct you to a survey, which will take about 5-10 minutes to complete. The survey is mobile compatible, so you may use your smartphone to do it. Thank you for your help!

Regards,

Fan

http://oregonstate.qualtrics.com/SE/?SID=SV_7UpafSyJBVI7HeZ

A copy of the questionnaire

OSU Oregon State UNIVERSITY

Section 1: Demographics

1. Type of company you work for:

- ○ General Contractor
- ○ Specialty Contractor
- ○ Owner
- ○ Designer
- ○ Other ________

2. Types of projects you work on (please select all that apply):

- ☐ Commercial building
- ☐ Residential building
- ☐ Industrial
- ☐ Heavy civil
- ☐ Other ________

3. Position

- Project manager
- Superintendent
- Project engineer
- Owner's representative
- Other

4. Experience in design or construction (in years)

- Less than 1
- 1-5
- 5-10
- 10-20
- >20

5. Age (in years)

- <25
- 25-34
- 35-44
- 45-54
- 55-64
- >64

0% 100%

Section 2: Project success

In your opinion, how important is each of the listed measurement to the overall project success?

0 = not important at all
5 = significantly important

	0	1	2	3	4	5
On time	○	○	○	○	○	○
Within budget	○	○	○	○	○	○
Good quality	○	○	○	○	○	○
Satisfying safety record	○	○	○	○	○	○
Building long-term relationship with clients	○	○	○	○	○	○
Other 1	○	○	○	○	○	○
Other 2	○	○	○	○	○	○
Other 3	○	○	○	○	○	○

Please provide any other comment on project success here.

0% 100%

<< >>

OSU Oregon State UNIVERSITY

Section 3: Impacting factors

1. Individual level factor: please select the magnitude of impact that each of the listed factor has on the overall project success.

0 = no impact at all
5 = significant impact

	0	1	2	3	4	5
Project manager and other key personnel's experience in similar projects	○	○	○	○	○	○
Project manager and other key personnel's capability in managing the project	○	○	○	○	○	○
People's commitment to the project	○	○	○	○	○	○

0% 100%

<< >>

Section 3: Impacting factors

2. Organization level factor: please select the magnitude of impact that each of the listed factors has on the overall project success.

0 = no impact at all
5 = significant impact

	0	1	2	3	4	5
Having support from top management of their own organization (Owner, designer, contractor).	○	○	○	○	○	○
Owner's preference on quality, cost, schedule, and safety	○	○	○	○	○	○
Owner, designer, and contractor's experience in similar projects	○	○	○	○	○	○
A well-defined organization structure for owner, designer and contractor	○	○	○	○	○	○
Having a formal peer review process within the organization	○	○	○	○	○	○

0% 100%

<< >>

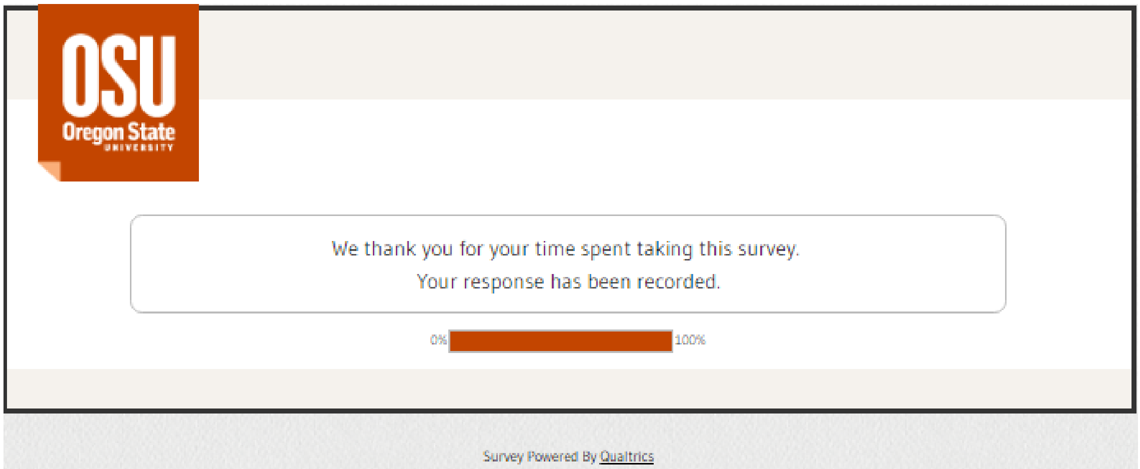
Section 3: Impacting factors

3. Project level factor: please select the magnitude of impact that each of the listed factors has on the overall project success.

0 = no impact at all
5 = significant impact

	0	1	2	3	4	5
Having a clear project mission/common goal	○	○	○	○	○	○
The project delivery method encourages communication and information flow between different organizations	○	○	○	○	○	○
Having high level of trust and respect between different organizations	○	○	○	○	○	○
Formal and informal communication during all phases of the project	○	○	○	○	○	○
Timely, valuable optimization information between the owner, designer, and contractor during the whole duration of the project	○	○	○	○	○	○
Having a trouble shooting procedure	○	○	○	○	○	○
Having a formal dispute resolution process	○	○	○	○	○	○
Having an established procedure for monitoring and feedback	○	○	○	○	○	○

Please provide any other comment on impacting factor here.

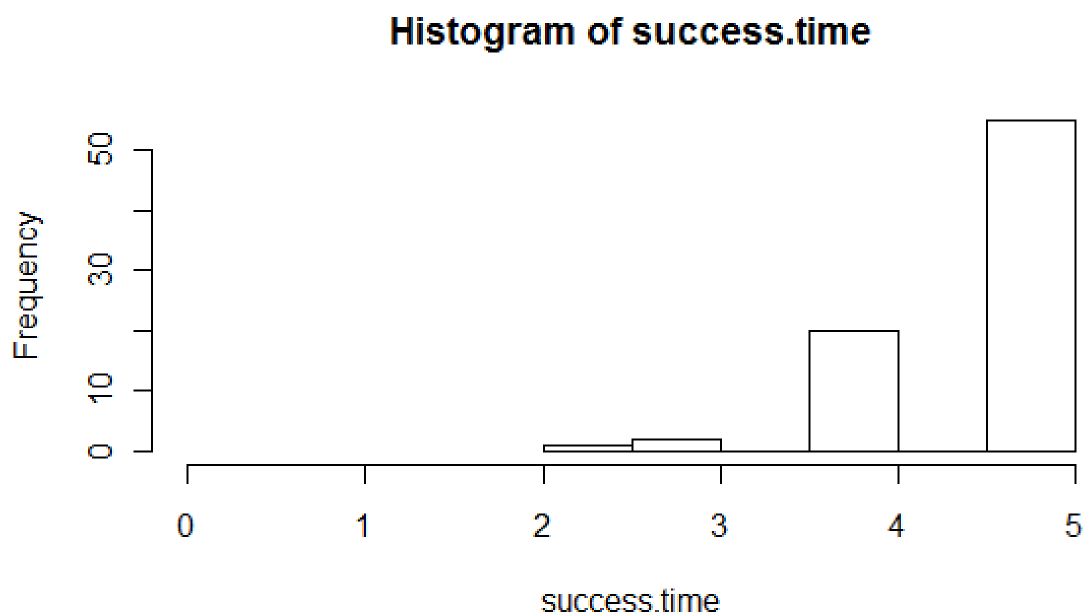

OSU
Oregon State
UNIVERSITY
We thank you for your time spent taking this survey.
Your response has been recorded.
0%
100%
Survey Powered By Qualtrics

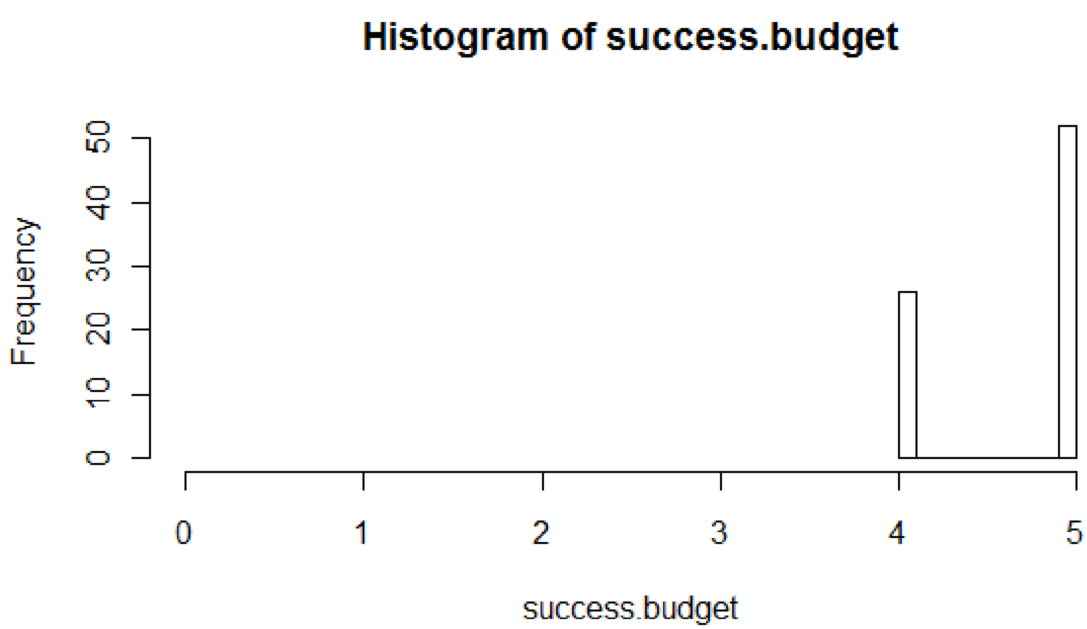
Appendix D: Graphical display of survey results

Independent variables in analysis and their represented items in the questionnaire

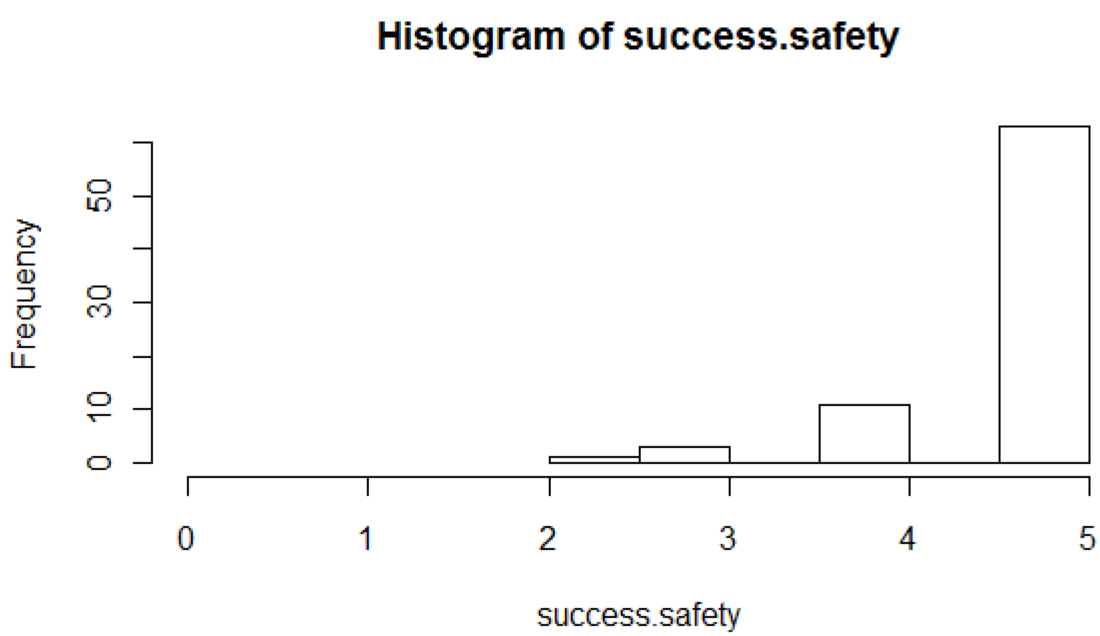
Names for independent variables in statistical analysis	**Category**	**Represented items in questionnaire**
Success.time	Success measurement	On time
Success.budget	Success measurement	Within budget
Success.quality	Success measurement	Good quality
Success.safety	Success measurement	Satisfying safety record
Success.relashionship	Success measurement	Building a long-term relationship with clients
ILF1	Individual level factor	Key personnel experience
ILF2	Individual level factor	Key personnel capability
ILF3	Individual level factor	Commitment
OLF1	Organizational level factor	Top management support
OLF2	Organizational level factor	Owner’s will
OLF3	Organizational level factor	Organization’s experience
OLF4	Organizational level factor	Organization structure
OLF5	Organizational level factor	Peer review
PLF1	Project level factor	Project mission
PLF2	Project level factor	Contractual relationship
PLF3	Project level factor	Trust and respect
PLF4	Project level factor	Communication
PLF5	Project level factor	Information flow
PLF6	Project level factor	Trouble shooting
PLF7	Project level factor	Formal dispute resolution process
PLF8	Project level factor	Monitoring and feedback

Histograms of independent variables

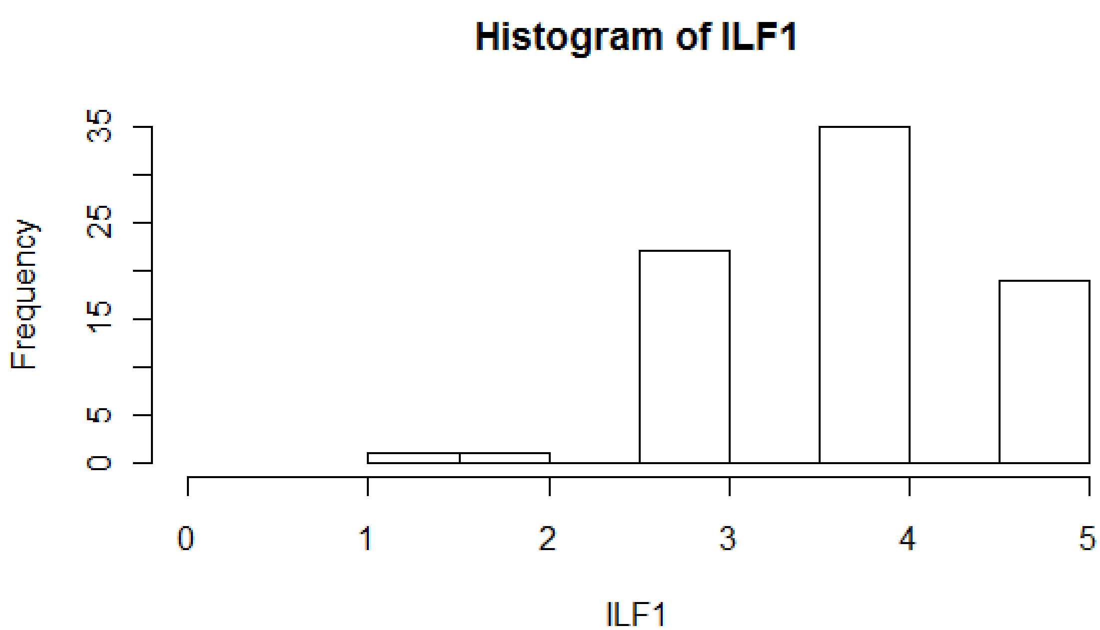


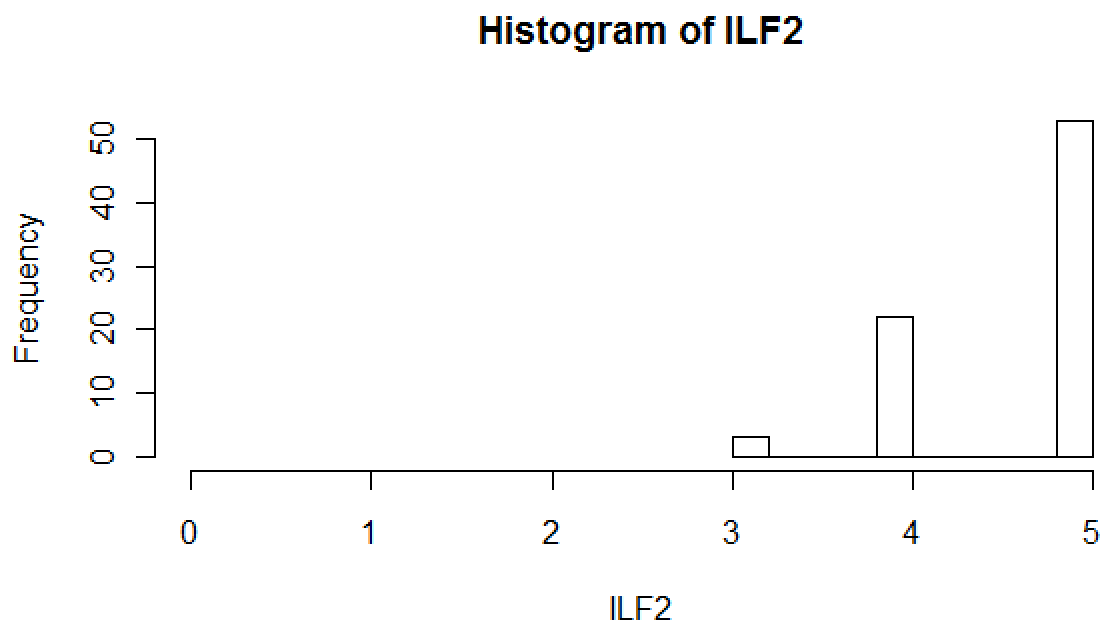


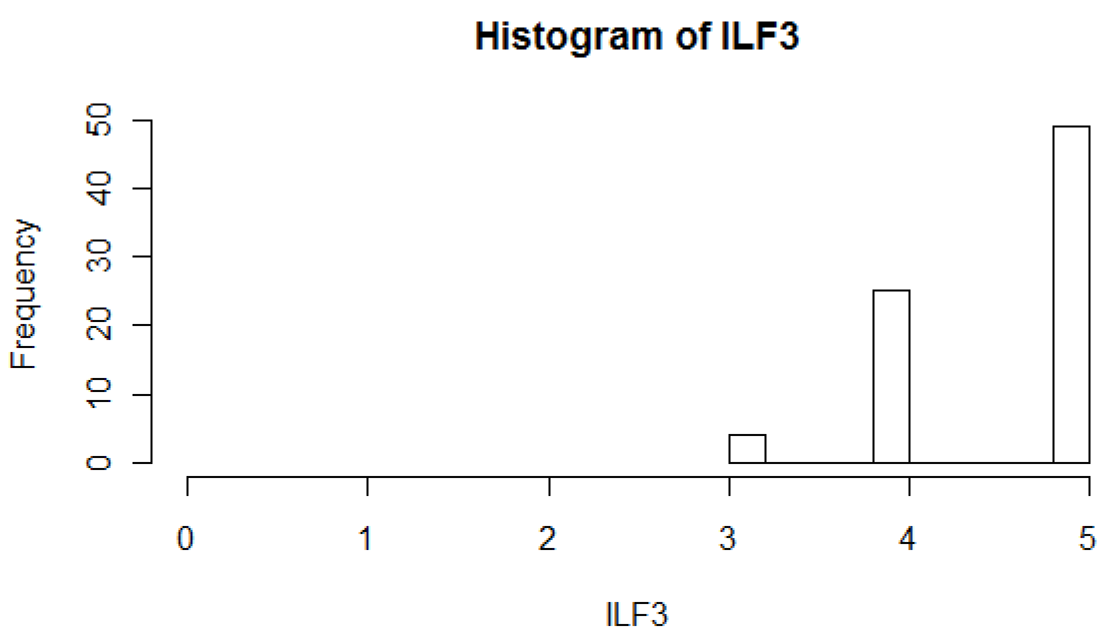

Histogram of success.quality
Frequency
0
10
30
50
0
1
2
3
4
5
success.quality


Histogram of success.safety
Frequency
0
10
30
50
0
1
2
3
4
5
success.safety


Histogram of success.relationship
Frequency
0
10
20
30
40
50
0
1
2
3
4
5
success.relationship


Histogram of ILF1
Frequency
0
5
15
25
35
0
1
2
3
4
5
ILF1


Histogram of ILF2
Frequency
0
10
20
30
40
50
0
1
2
3
4
5
ILF2


Histogram of ILF3
Frequency
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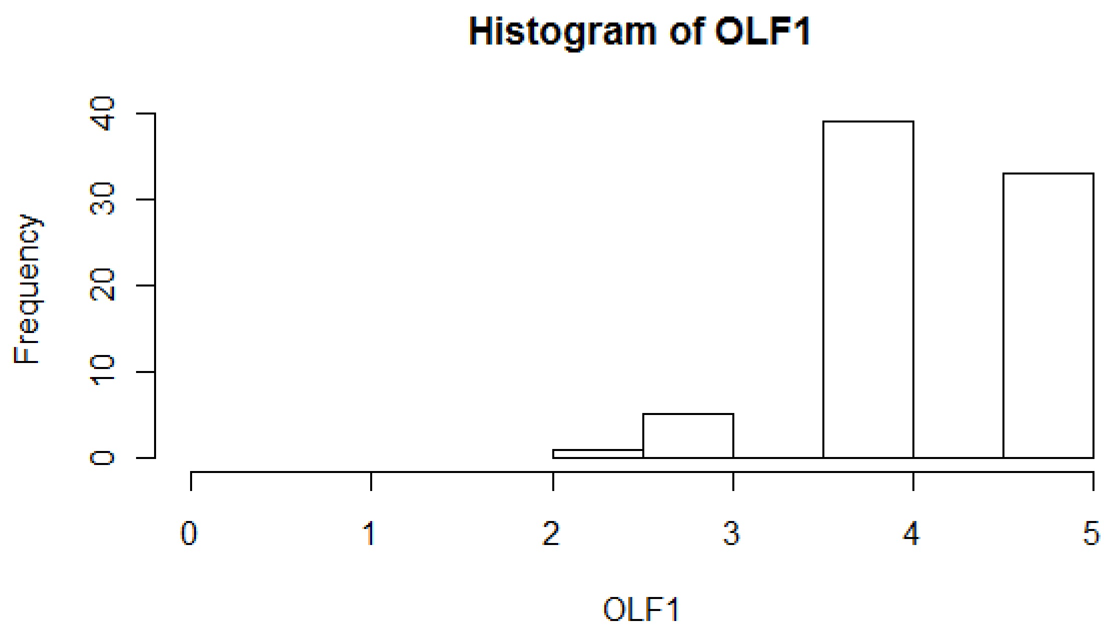
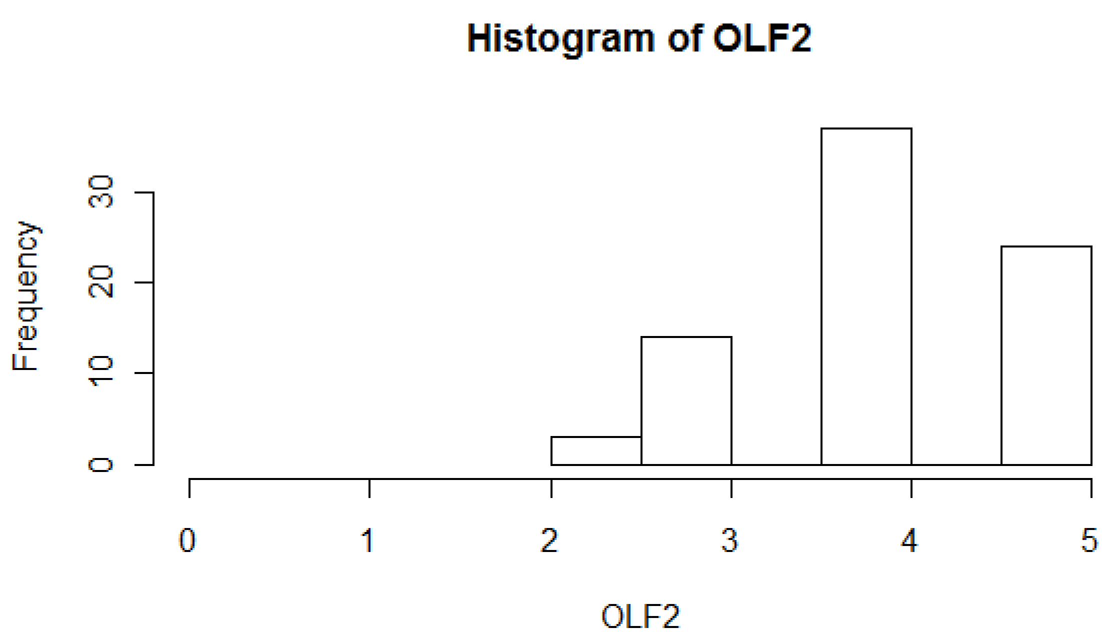
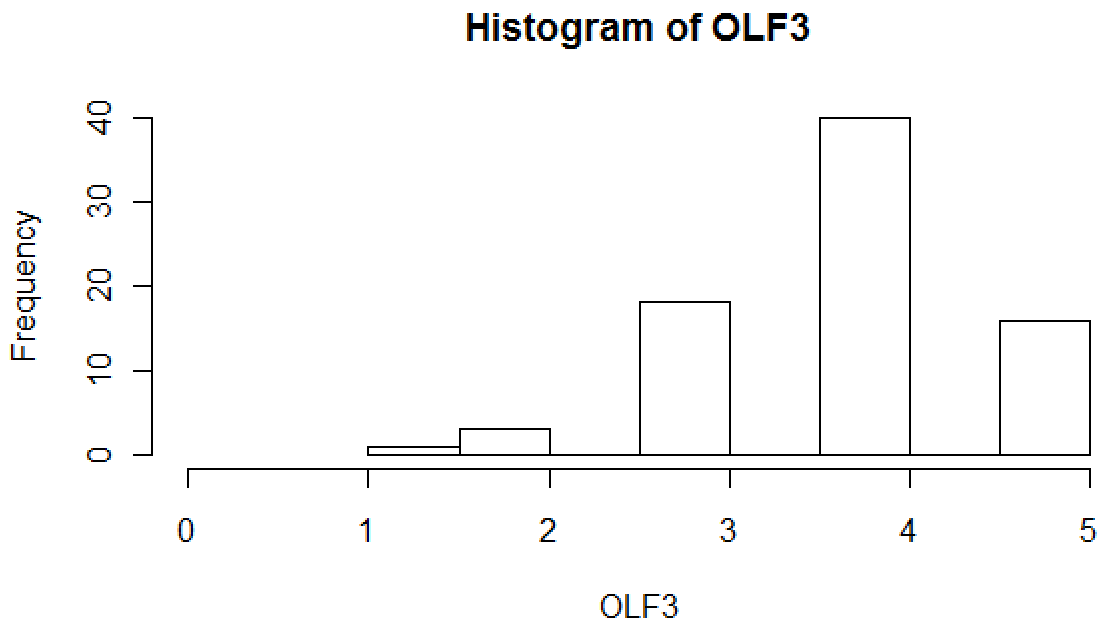
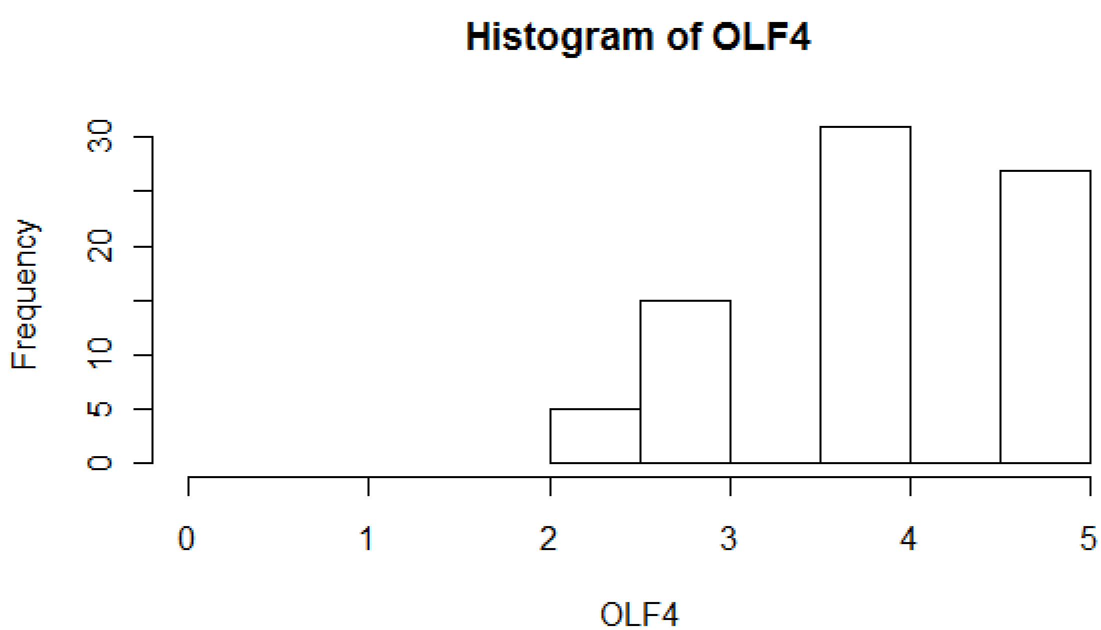
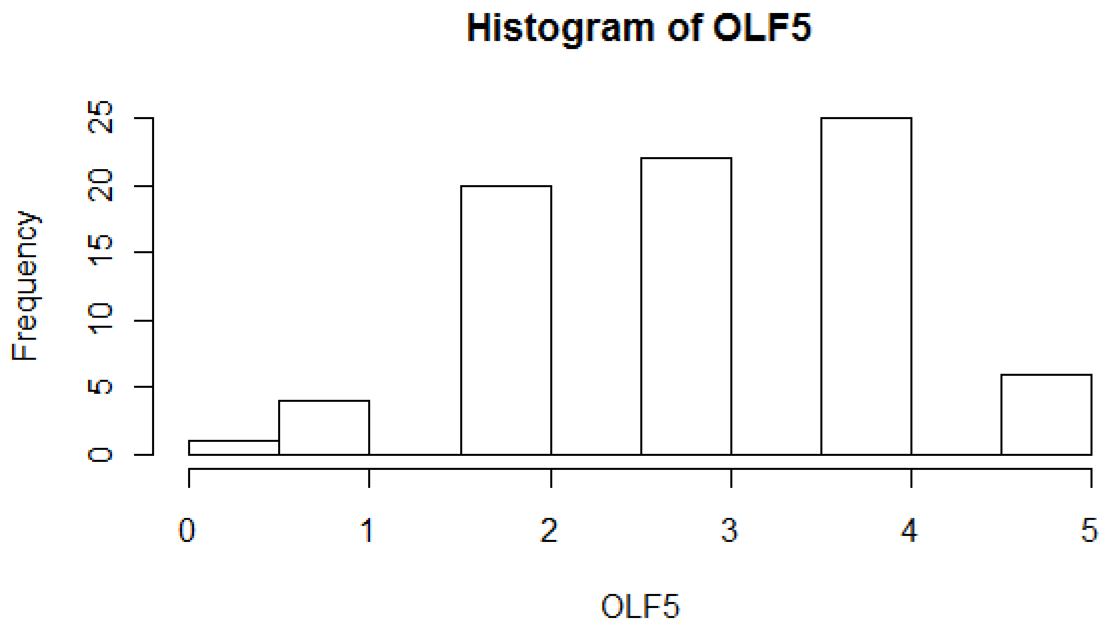
10
20
30
40
50
0
1
2
3
4
5
ILF3

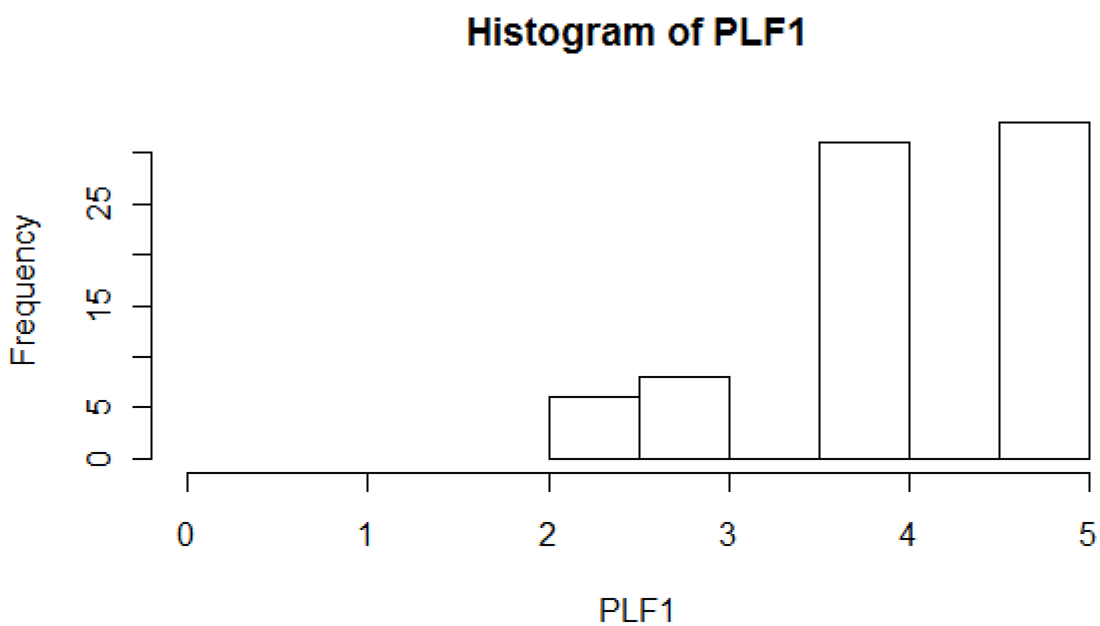

Histogram of OLF1
Frequency
0
10
20
30
40
0
1
2
3
4
5
OLF1

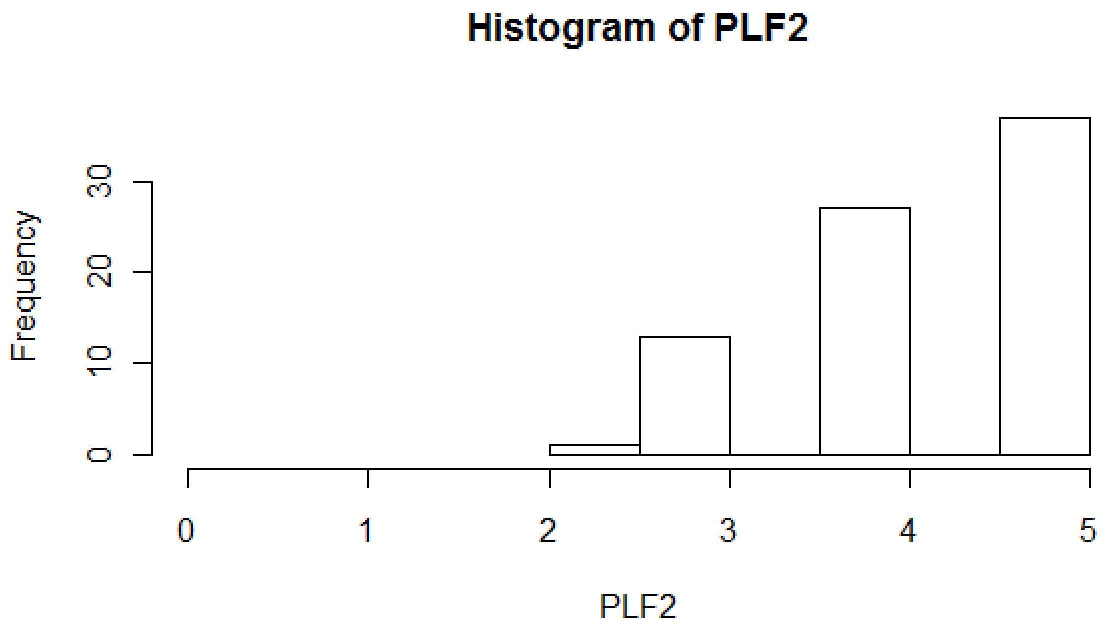

Histogram of OLF2
Frequency
0
10
20
30
0
1
2
3
4
5
OLF2

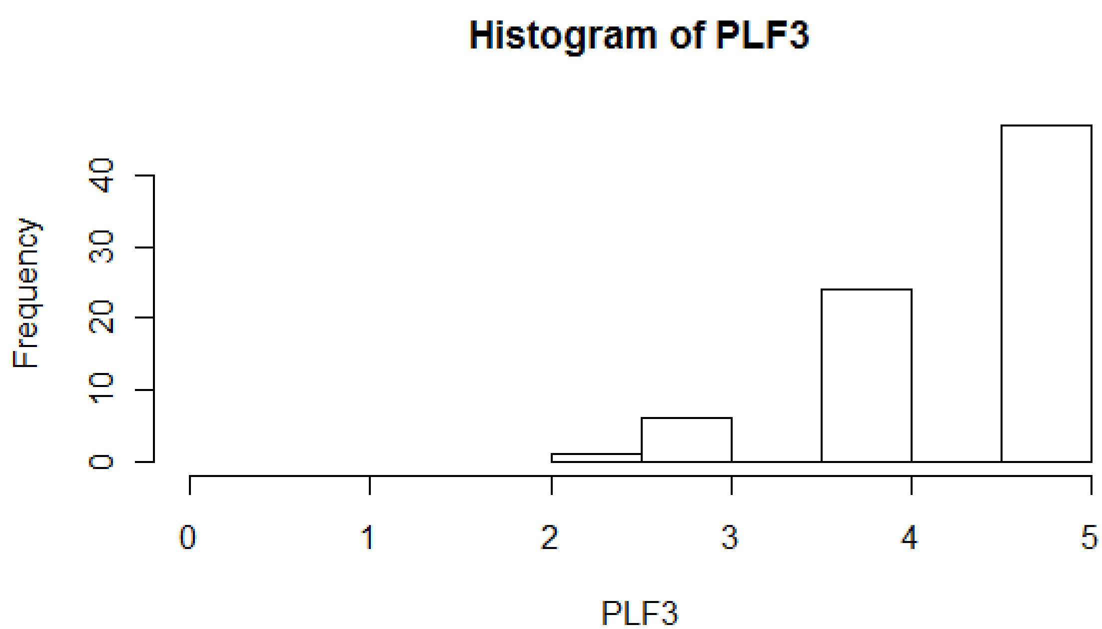

Histogram of OLF3
Frequency
0
10
20
30
40
0
1
2
3
4
5
OLF3

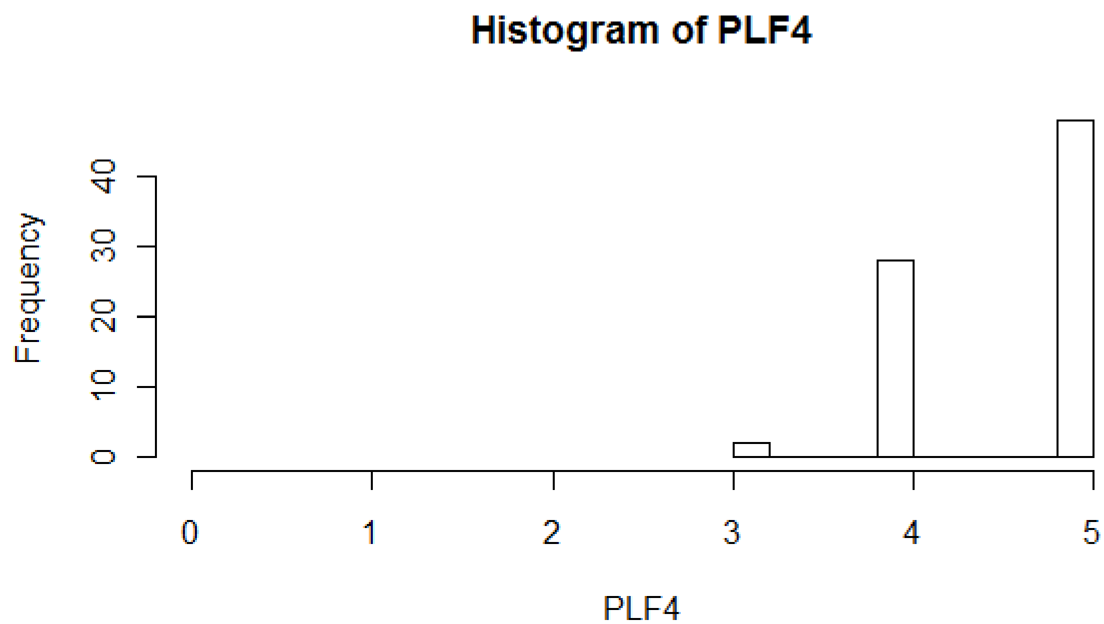

Histogram of OLF4
Frequency
0
5
10
20
30
0
1
2
3
4
5
OLF4

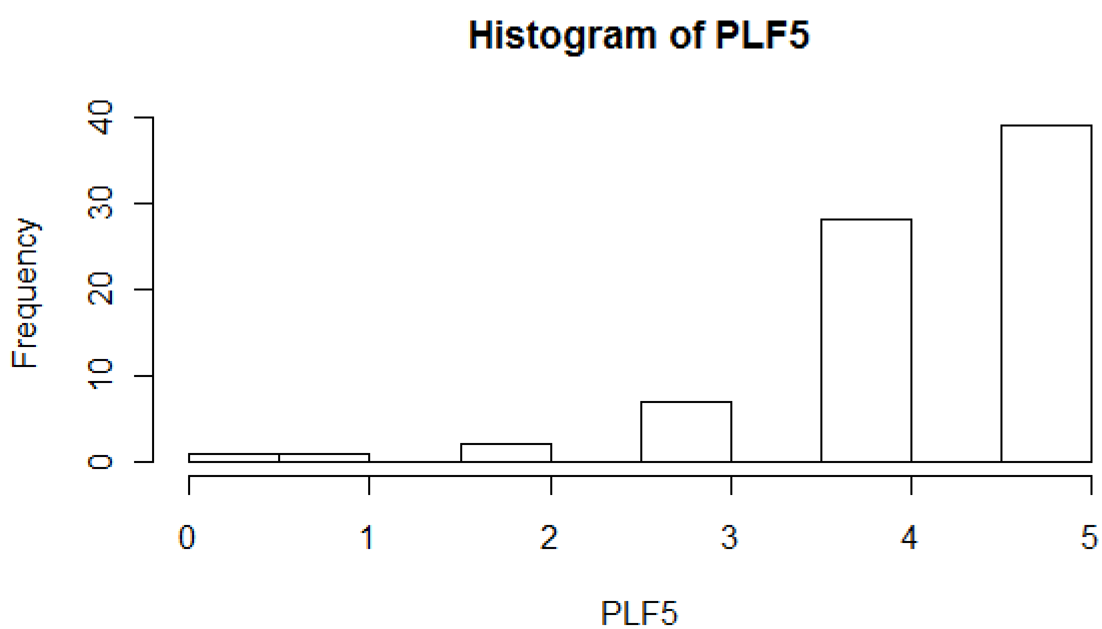

Histogram of OLF5
Frequency
0
5
10
15
20
25
0
1
2
3
4
5
OLF5

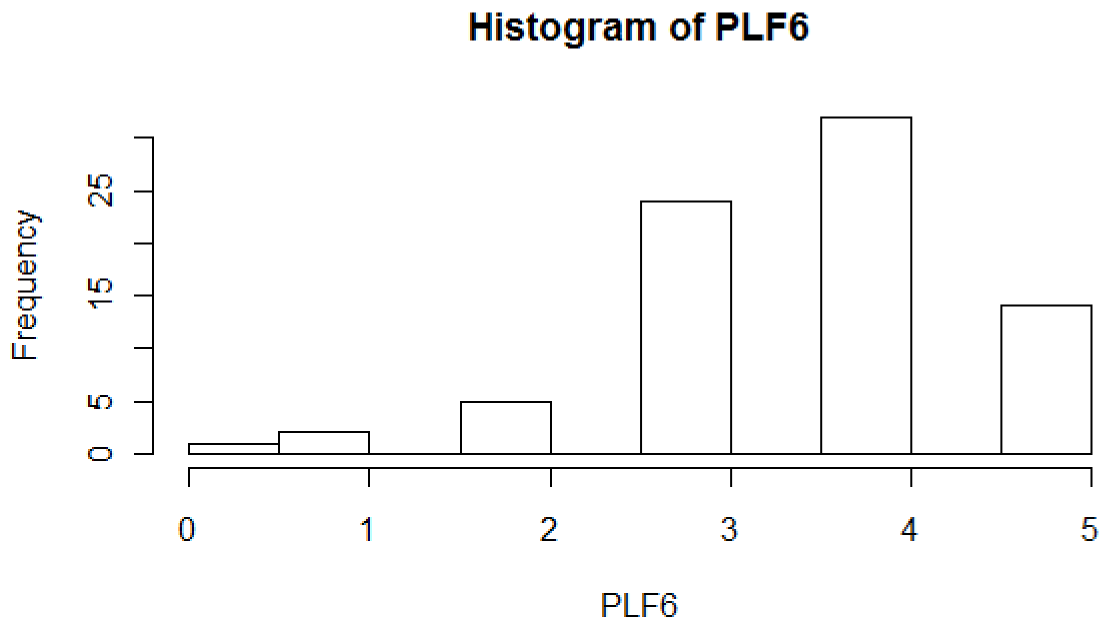

Histogram of PLF1
Frequency
0
5
15
25
0
1
2
3
4
5
PLF1

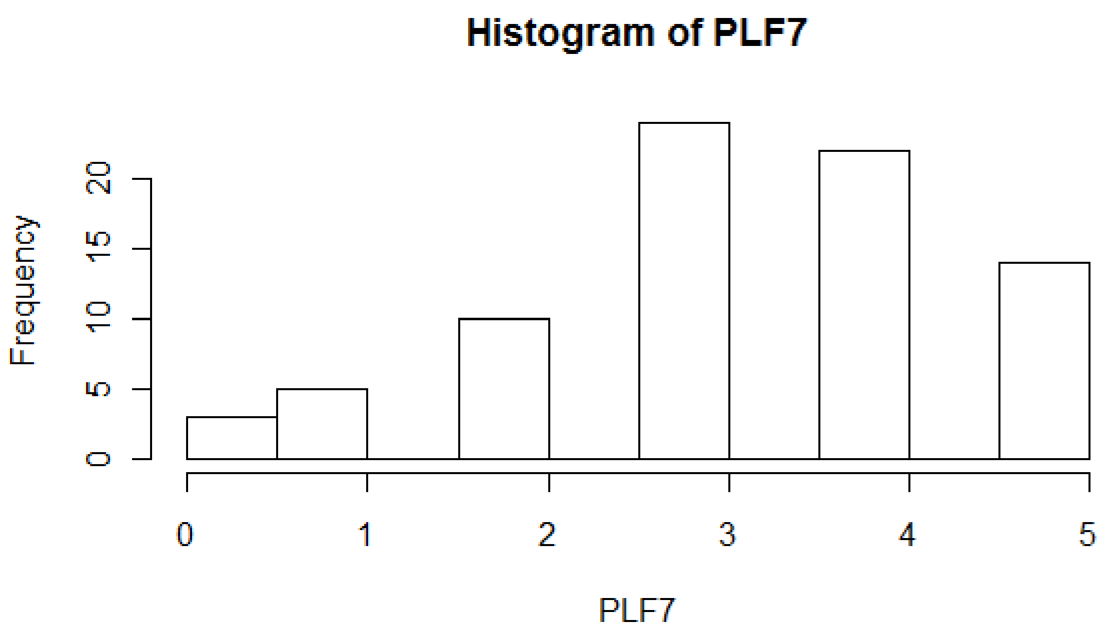

Histogram of PLF2
Frequency
0
10
20
30
0
1
2
3
4
5
PLF2

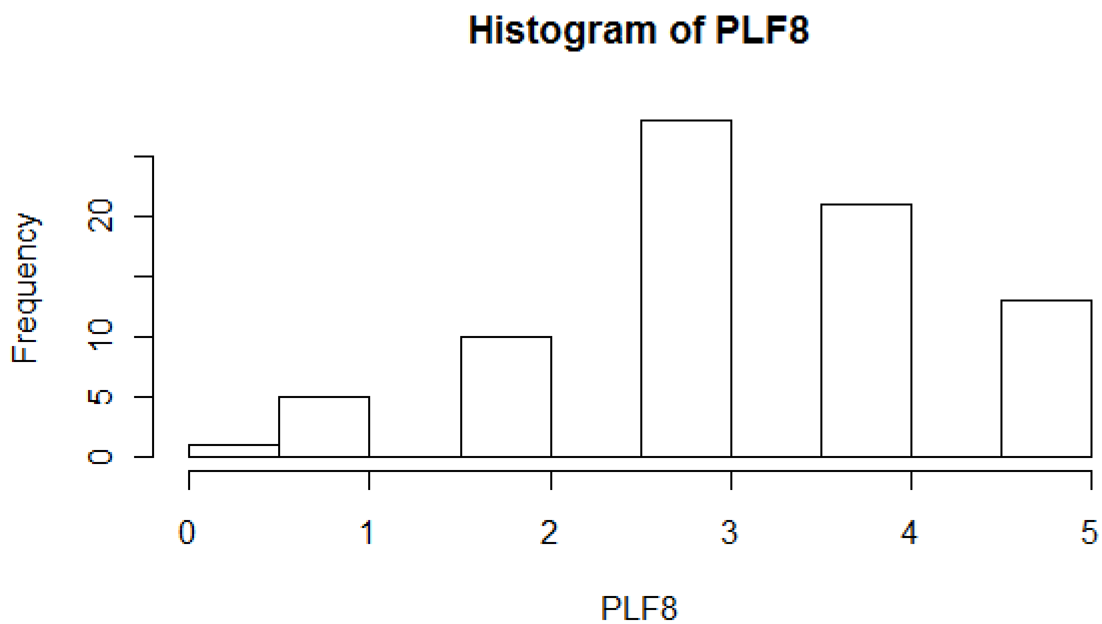

Histogram of PLF3
Frequency
0
10
20
30
40
0
1
2
3
4
5
PLF3


Histogram of PLF4
Frequency
0
10
20
30
40
0
1
2
3
4
5
PLF4


Histogram of PLF5
Frequency
0
10
20
30
40
0
1
2
3
4
5
PLF5


Histogram of PLF6
Frequency
0
5
15
25
0
1
2
3
4
5
PLF6


Histogram of PLF7
Frequency
0
5
10
15
20
0
1
2
3
4
5
PLF7


Histogram of PLF8
Frequency
0
5
10
20
0
1
2
3
4
5
PLF8