

**A FORMAL MODEL FOR MEASURING THE DIFFERENT LEVELS OF  
IT-BASED DESIGN AND CONSTRUCTION INTEGRATION (ITDCI)  
IN COLLEGES AND UNIVERSITIES**

by

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A Dissertation

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

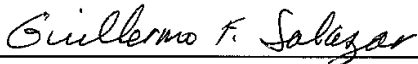
Degree of Doctor of Philosophy

in

Civil Engineering

May 2009

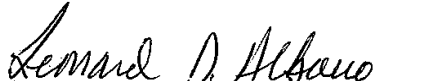
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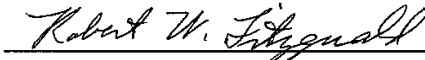
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## **Abstract**

Modern manufacturing processes are becoming more integrated and relying on measuring performance to better identify ways of improvement. The AEC industry is now moving in this direction through IT-based Design and Construction Integration (ITDCI). ITDCI is a collaborative knowledge-based activity in which each participant continuously and timely contributes and shares his/her knowledge to realize a specific goal, bonded by a unified and cohesive culture with the use of the supportive IT-tools. Executing the project in an ITDCI fashion requires the satisfaction of these conditions. This research developed a formal model that consists of 75 ITDCI mechanisms distributed over the different phases of the facility development process within colleges and universities to enable the knowledge transfer process and achieve the highest level of integration. The level of ITDCI involved in a particular project can be then measured by quantifying the number of ITDCI mechanisms introduced.

The research methodology included the following activities: reviewing the related literature, developing and validating a scenario for the facility development process within typical colleges and universities through literature review and interviews, providing a definition for each phase of the process to be executed in an ITDCI fashion and finally identifying actions or mechanisms that have to be activated to obtain the highest level of ITDCI. The model was validated through an online survey that targeted the members of the Society of Colleges and Universities (SCUP) and a case study. WPI's new East Hall residence facility was used as a case study to validate the model.

This model is a significant contribution to the construction industry because it acts as a measuring tool to assess the corresponding level of ITDCI in the facility development process. It also helps to develop a common understanding among industry practitioners on what is required to achieve a desired level of ITDCI in their project. This comprehension would guide them to a better recognition of the benefits and consequences of each specific level of IT-based integration on their project outcomes. It will also enable them to execute more accurate cost/benefit analyses and eventually opt for the optimum ITDCI level. For future work, the model could be expanded to include other types of facilities, such as residential, healthcare and commercial facilities to achieve wider adoption within the AEC industry.

## Acknowledgments

I would like to first thank my advisor, Professor Guillermo Salazar, whose guidance, support, and friendship have allowed me to finish this work. I would like to express my gratitude to my committee members: Professor Leonard Albano and Professor Robert Fitzgerald for their time, effort and support .

I want to acknowledge Professor Hart for supporting me financially through the CEE department by providing me with a Teaching Assistantship position.

My special thanks to Prof. Elkorchi who was always smiling and encouraging me especially at these hard days that I am going through.

This thesis is dedicated to both my father and mother. Without the qualities and morals that they have instilled in me, none of what I have done in my life would have been possible.

I would also like dedicate my work to the souls of both my mother and father in law. I really miss them.

Thanks for Agata who was always there to help and encourage me. Thanks Agata for grabbing my attention to apply for the Backlin fund.

I really want to thank Joan Murphy in the office of Graduate studies and Provost McGimpsey for helping and awarding me the Backlin fund.

I certainly acknowledge Heather La Hart, WPI '07 for her contribution to the analysis of the case study used in this research.

Thanks for my wonderful friend Chiara for her love, encouragement and help.

Thanks Laila for being such a wonderful and lovely friend and officemate.

I thank my sister Abeer for her love, care, continuous support and robust comments. I really love my sister Shawshaw and would like to thank her for all the love and encouragement that she offered me via her kind phone calls. Thanks for my brother Ahmed and sister in law Sarah for their love and support.

And finally, I would like to thank my wonderful husband Mohamed, “Big Mo” for his endless love, support in all possible ways to accomplish and finalize this research.

My deepest love to my “awesome” son Omar for encouraging me to finalize this research. Thank you my princess Farida for being patient enough supporting your mom to get her degree done.

I especially want to thank my dearest friend Doaa. Our friendship has mainly started when I started my Ph.D. and now she is literally one of my family members. I would also like to thank my best friend forever, Dr Amal Raouf and her husband Ahmed for their continuous love and care sharing so many moments together.

Finally, I would like to thank Julia and Paul McHugh for their cherished friendship and wonderful support.

# Table of Contents

Abstract-----	2
Acknowledgments -----	4
Table of Contents -----	6
List of Figures -----	10
List of tables -----	12
List of Equations -----	13
Chapter 1. Introduction -----	14
1.1 Background -----	14
1.1.1 IT tools as enabler for integration -----	19
1.2 Problem Statement -----	20
1.3 Research Hypothesis-----	22
1.4 Research objectives -----	22
1.5 Research Scope -----	23
1.6 Summary of the dissertation -----	24
1.7 Summary of the contribution -----	25
Chapter 2. Literature Review -----	28
2.1 Design and construction Integration- related literature -----	28
2.1.1 Integration definitions -----	28
2.1.2 History of integration-----	29
2.1.3 Need of integration -----	30
2.1.4 Means of integration-----	31
2.1.5 Integration promoting factors -----	33

2.1.4 Integration deterring factors -----	36
2.2 Importance of measurement and quantification-----	37
2.3 Models used in the A/E/C industry -----	38
2.3.1 Process Model -----	39
2.3.2 Product Model -----	40
2.3.3 Product/Process/Decision Model -----	42
2.4 Information Technology- related literature-----	43
2.4.1 Online Collaboration Project Management technology (OCPM)-----	43
2.4.2 Potential Benefits of the use of OCPM -----	47
2.4.3 Financial, cultural and legal barriers -----	49
Chapter 3. Methodology -----	53
3.1 Research Methods Introduction -----	53
3.2 Research Process -----	55
3.2.1 Literature Review -----	55
3.2.2 A global definition for ITDCI through literature and interviews -----	56
3.2.3 Identifying a preliminary list of ITDCI indicators -----	57
3.2.4 Developing a scenario for the development process for colleges and universities facilities-----	58
3.2.5 Developing the ITDCI model -----	58
3.2.6 Developing the survey -----	58
3.2.7 Case Study -----	59
Chapter 4. The ITDCI model-----	61
4.1 An overview of the ITDCI model-----	61

4.2 IT-based Design and Construction Integration-----	64
4.3 Knowledge exchange patterns-----	64
4.4 IT-based Design and Construction Integration indicators-----	66
4.4.1 Process Related Indicators-----	67
4.4.2 Product related Indicators-----	71
4.4.3 Organization related Indicators-----	72
4.3 Traditional development process for colleges and universities facilities-----	75
4.4 IT-based integrated life cycle for colleges and universities.-----	77
4.4.1 IT- based Integrated Planning and programming-----	77
4.4.2 IT-based Integrated Design-----	82
4.4.3 IT-based integrated procurement process:-----	86
4.4.4 IT-based integrated construction process:-----	90
4.4.5 IT-based integrated O&M process:-----	93
Chapter 5 Academic survey-----	95
5.1 Objectives-----	95
5.2 Survey design-----	95
5.3 Survey Results-----	97
5.4 Discussion-----	112
Chapter 6. Case Study: WPI New Residence Hall-----	116
6.1 Background-----	116
6.2 Goals of Project-----	118
6.3 Design Stages-----	118
6.3.1 Conceptual Design-----	118



6.3.2 Design Development -----	119
6.3.3 Construction Documents-----	120
6.4 Parties involved-----	121
6.4.1 WPI -----	121
6.4.2 Cannon Design -----	122
6.4.3 Gilbane Building Company -----	122
6.5 Project integration analysis using Rahman and Kumaraswamy factors-----	123
6.5.1 Project work environment -----	123
6.5.2 Project Organizational Structure-----	124
6.5.3 Data Collection-----	126
6.6 Project integration using the meeting minutes of the project -----	134
6.7 Project integration using the ITDCI model-----	135
6.8 conclusion -----	136
Chapter 7 Conclusions & Future work -----	138
7.1 Conclusions -----	138
7.2 Research Contributions-----	143
7.3 Future Research -----	143
8. Bibliography-----	145
Appendices -----	157
Appendix A Interviews-----	157
Appendix B Hardcopy of the survey-----	163
Appendix C WPI new residence hall meeting minutes -----	180
Appendix D Survey responses for case study analysis-----	187

## List of Figures

Figure 1-1 Relationship between expected benefits and level of integration .....	15
Figure 1-2 The different levels of ITDCI .....	18
Figure 1-3 Schematic structure of the ITDCI model .....	26
Figure 2-1 Design/Construction process organizational model [95] .....	40
Figure 2-2 Product/Organization model Adopted from [47] .....	41
Figure 2-3 Product/Process/Decision model.....	42
Figure 2-4 Realized benefits of OCPM tools according to users---- [7].....	50
Figure 4-1 Different levels of ITDCI & corresponding points .....	62
Figure 4-2 The ITDCI model.....	63
Figure 4-3 Knowledge exchange patterns.....	64
Figure4-4 Traditional Development Process of colleges/universities .....	77
Figure 4-5 Integrated Design Process--- adopted from the international initiative for sustainable built environment .....	84
Figure 5-1 Overall responses to the ITDCI mechanisms in the planning phase.....	98
Figure 5-2 Percentage of the different project parties involvement in the kick off meeting .....	100
Figure 5-3 Overall responses to the ITDCI mechanisms in the design phase .....	101
Figure 5-4 Overall responses to the ITDCI mechanisms in the procurement phase .....	103
Figure 5-5 Overall responses to the ITDCI mechanisms in the construction phase.....	105
Figure 5-6 ITDCI score w/& w/out IT mechanisms .....	112

Figure 6-1 Aerial view of WPI Residence Hall on Boynton Street .....	117
Figure 6-2 Design Scheme [14 ] .....	119
Figure 6-3 3-D Design Development Perception [14].....	120
Figure 6-4 : Rendering along Arts Walk [14].....	121
Figure 6-5 Usage levels and importance levels of the integration driving factors. ....	128
Figure 6-6 Usage and importance level correlation .....	131
Figure 6-7 Parties involved average usage levels .....	131
Figure 6-8 Deterrent Factor Importance & Usage Level Integration Evaluation .....	133
Figure 6-9 ITDCI score for parties involved in the project .....	136

## List of tables

Table 2-1 Driving factors for integration.....	35
Table 2-2 Deterring factors for integration.....	36
Table 2-3 Potential benefits of adopting the OCPM technology.....	48
Table 5-1 shows the number of questions in each part.....	96
Table 5-2 Overall ITDCI score on all responses .....	107
Table 6-1: WPI Residence Hall Organizational Breakdown .....	125

## **List of Equations**

- Equation 1 The degree of interaction among the project participants [85]..... 74
- Equation 2 Correlation Coefficient between the highest usage and most importance .. 129

# Chapter 1. Introduction

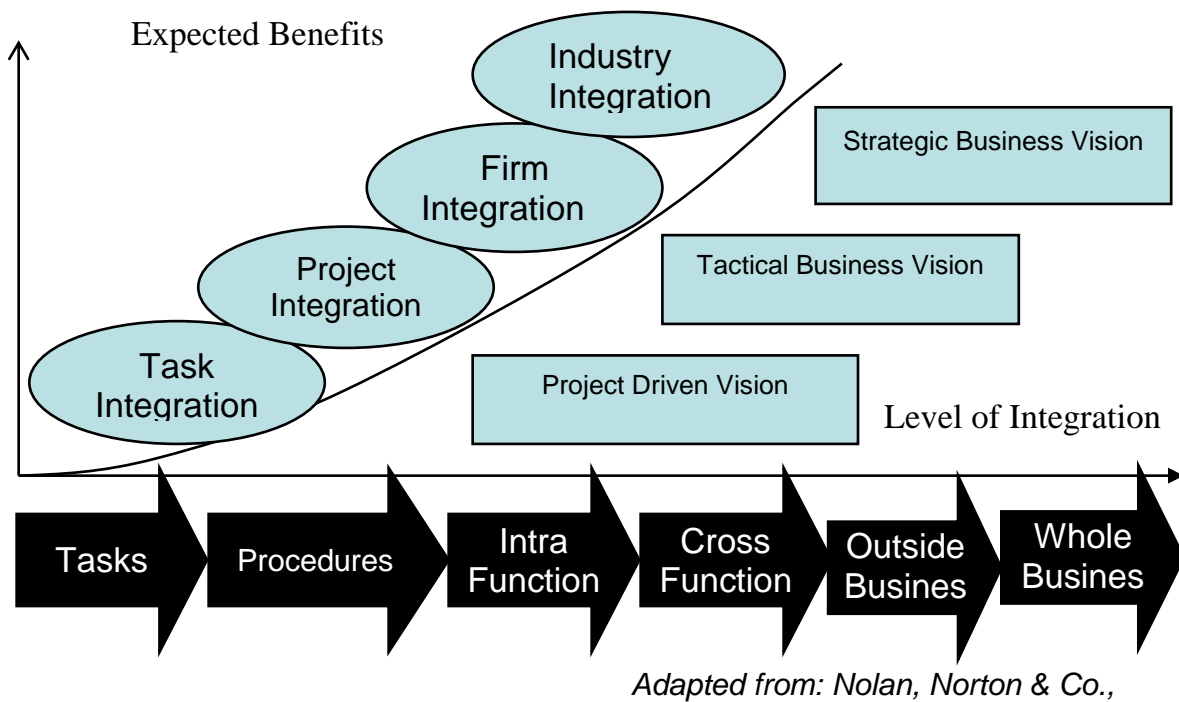
## 1.1 Background

Construction is one of the largest industries in the United States and worldwide economics, with 13% of the gross national product and 5-6% of the labor force [105]. Consensus estimates indicated that 30% of the cost of a project can be attributed to the failures in the design-construct-manage process [12]. A big portion of this percentage has been blamed on the low performance of the fragmented teams.

Given the unique nature of construction projects, the Architectural/ Engineering/ Construction (AEC) industry is very fragmented while it is an information-intensive industry. To deliver its projects, the industry depends on the knowledge, skills and resources of multiple firms and professionals who are mostly regionally distributed. This fragmentation requires high coordination among the many participants to maintain continuity in the communication of the design as it evolves from a simple idea to a completed physical product. In order to make the coordination and communication more efficient, research in the construction industry has placed a significant emphasis on the development of collaborative approaches and on the use of emerging Information Technologies (IT). As a result of this effort, the industry is now promoting and increasingly embracing the use of more integrated project delivery systems such as Design-Build and Construction Management and Integrated Project Delivery (IPD) proposed by the American Institute of Architects (AIA) [2].

Introducing those collaborative approaches in the construction projects allows information and knowledge to be shared and processed from one discipline to one another until reaching the project objective. These approaches also help to leverage the

level of integration by facilitating communication and coordination. Integration is defined as a knowledge-centric activity where each project participant has to contribute his/her knowledge in the form of rules, algorithms, and proprietary practices like the master builder during the 19th century, when building design was substantially simpler and one person could hold most of the necessary knowledge in their head. The expected benefits of integration are huge. The higher the level of integration involved, the more benefits gained. See Figure 1-1 below.



**Figure 1-1 Relationship between expected benefits and level of integration**

Augmenting the Information Technology with the previously discussed collaborative approaches can promote integration significantly. IT tools can facilitate communication and knowledge sharing which is the backbone of integration.

Over the last 10-15 years, the AEC industry has seen an extensive increase in the use of these tools and technologies such as electronic mail, project websites, 3D solid modeling and remote wireless communications. More sophisticated software packages have also been developed to support the design and construction processes such as NavisWorks® by Autodesk which helps to create fully consistent and coordinated design visualizations of construction project. Vico® Constructor also is a new software by Vico® Software, Inc. that supports design and construction integration by providing early identification of constructability problems and synchronizing design, cost and schedule.

Information Technology has a significant potential to bring all industry participants to work together and derive extensive benefits through improved information flow and timely knowledge sharing along the different design and construction work processes.

Yet, the potential of those tools as a reliable knowledge transfer mechanisms in the construction industry are not fully utilized. These still interface inefficiently, lacking interoperability with one another to disseminate and integrate the efforts and knowledge of different companies or organizations involved in the same construction project. As a matter of fact, these have been used for exchanging traditional 2-D printed documents in a digital format rather than encoding the information and storing it in an exchangeable and interoperable format. These inefficient approaches for data exchange cause extra transactional costs that are still incurred due to lack of effective communication and data dissipation during information exchange.

From the literature review and the results of a previous research study conducted by the author [66], it was found that several studies focused on analyzing the transactional costs associated with this improper utilization of data exchange and seeking other alternatives



to minimize them. The study done by NIST [50] in August 2004 quantified part of these costs in terms of the efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability among computer-aided design, engineering, and software systems. In that report interoperability is identified as "the ability to manage and communicate electronic product and project data between collaborating firms and within individual companies' design, construction, maintenance, and business process systems" [50]. It sees interoperability really as a vehicle for integration of the processes and workflows of all the participants, across all the phases of the lifecycle of a facility. According to this study, the lack of standard file formats for representing building-related data and processes directly contributed to the \$15.8 billion interoperability waste estimate. Another interesting finding from the study was the breakdown of the interoperability cost estimate across the stakeholder group and by the lifecycle phase. Owners and operators bore the highest share: \$10.6 billion, about two-thirds of the total estimated costs. Architects and engineers had the lowest interoperability costs at \$1.2 billion, while the general contractors and specialty fabricators and suppliers bore the balance at \$1.8 billion and \$2.2 billion respectively. The breakdown according to lifecycle phase shows that the highest transactional cost is incurred at the operations and maintenance phase, \$9.1 billion, followed by the construction phase at \$4.1 billion, and finally, the planning, design, and engineering phase at \$2.6 billion. The factors that contribute to these costs include the highly fragmented nature of the industry, the continuation of paper-based business practices, and inconsistent technology adoption among all the participants in the design, construction, occupation and maintenance phases. This means that the responsibility of bringing in greater interoperability and reducing the waste does not rest

only on the vendors of software applications, but equally, if not more, on the industry professionals themselves. They need to give up paper-based processes and embrace technology more whole-heartedly. The change needs to be initiated from owners/operators, who shoulder a large percentage of money loss and therefore need to drive the entire team towards more widespread and efficient use of technology. Without this push, the pace of change will be very slow and the potential for significant cost savings in the construction industry will remain low.

Conflicts and misinterpretation between different design and construction organizations and operations should be replaced by efficient knowledge transfer, collaborative relationships and better Design and Construction Integration (DCI). Utilizing the appropriate IT tools to integrate the different involved processes and all of project participants is also known as IT-based Design and Construction Integration (ITDCI) [7], [8],[30],[31]. Different levels of ITDCI can be achieved in each project. The more collaborative and integrated processes and participants based on the use of the efficient IT tools, the higher level of ITDCI can be achieved

If we look at the integration as a pyramid, Information Technology together with the involved project participants can be considered as the base of this pyramid.

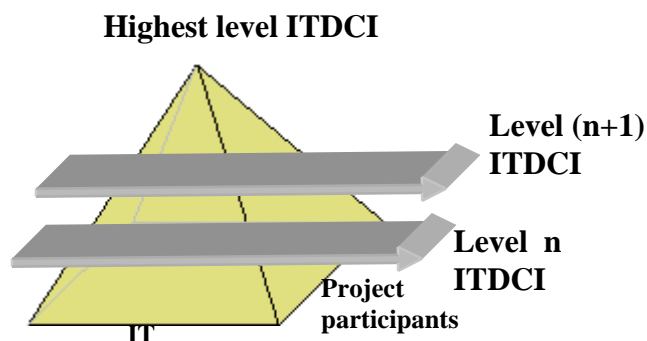


Figure 1-2 The different levels of ITDCI

To reach the top of this pyramid (Highest level ITDCI), the knowledge of all the project participants, as well as tasks and different activities involved should be highly orchestrated using IT as a facilitating tool for integration. Each horizontal plane from the base to the top of the pyramid represents different level of ITDCI. The level of ITDCI is primarily dependant on the effectiveness and ability to integrate the knowledge related to all of the involved processes, organizations and product associated information. Such an environment necessitates the elimination of barriers that hinder the integration and to let knowledge and information to flow seamlessly from party to party, from one process to another and from one involved organization to the other.

### **1.1.1 IT tools as enabler for integration**

In the above discussion, the author emphasized the role of the IT tools as an enabler and facilitator for DCI. In this section, the discussion is continued with the listing of some of the factors that impede the full utilization of these tools in the DCI.

To successfully drive more extensive use of IT throughout the construction delivery process, it is necessary to build up a critical mass of IT users within the construction industry. Owners and stakeholders should take a lead in adopting IT in their organizations and committing different resources for successful implementation of the various IT into their everyday operations. The problem in this regard is to convince them to take this lead by providing them with objective assessment tools to facilitate the quantification of the costs and benefits associated with their investment in the IT.

There are number of the factors that can inhibit a higher IT take-up in integrating design and construction processes. Some of these factors were identified and summarized in a previous research paper published [111] by the author as follow:

- (a) The fragmented nature of the industry which impedes the wider adoption of common IT tools across disciplines.
- (b) Absence of a conducive environment due to the lack of common standards and a common data infrastructure.
- (c) Low awareness at the management levels of the potential benefits of IT.
- (d) Lack of practical application solutions (available software packages) in the marketplace that suit the uniqueness of each construction project.
- (e) High initial development cost and uncertain return on investment.
- (f) Low IT literacy and awareness among construction personnel.

## **1.2 Problem Statement**

Worldwide research attempts and concepts have tried to enhance the performance of the industry by integrating the knowledge and expertise of the different organizations in the early phases of the project and bringing them to work together to eliminate uncertainties and reduce complexities. Some of these concepts suggested to implement a contractual agreement such as partnering to enforce integration. Other researchers suggested executing constructability analysis, Value Engineering, etc. Concepts such as Lean Construction and Concurrent engineering also had been suggested for more DCI [12], [31], [100]. On the other hand, researchers have also called for utilizing new emerging technologies such as: Virtual Design and Construction (VDC) and Building Information

Modeling (BIM) throughout the different phases of the development process to leverage the level of collaboration and integration among the project team [96], [99].

Over the last five years, the AEC industry is moving through complementing design and construction integration with those emerging technologies toward IT-based Design and Construction Integration (ITDCI). ITDCI can be defined as a knowledge-based activity in which each participant continuously and timely contributes and shares his/her knowledge to realize a specific goal bounded by a unified and cohesive culture and supportive IT-tools. [60], [65], [72]

However, the AEC industry still needs to develop a clear way to identify the level of investment that is needed to promote IT- based Design and Construction Integration (ITDCI) with the expected benefits derived from it.

There is not an easy answer to this dilemma. The main ingredient in this process that is still missing and has not yet been identified is the development of a standard method to determine the level of ITDCI involved. Being able to measure the different levels of ITDCI, will make the assessment of the costs and benefits for each level of ITDCI more objective. Hence, the project participants would be able to take better informed decisions regarding the optimum ITDCI level that suits their project. Another value added is that only what is measured is what actually can be improved.

Measurement or quantifying the results, also known as benchmarking, is one of the key elements of the concept of continued improvement which is the main objective in Total Quality Management and Lean Production management.

### **1.3 Research Hypothesis**

Executing the project in an ITDCI fashion requires consistent and timely transfer of the project participants' knowledge with the use of the appropriate IT-tools to facilitate the transfer process

This research assumes that the level of ITDCI is primarily influenced by the extent to which the knowledge of the project participants regarding the involved processes and the output product is incorporated and shared throughout the project in a continuous and timely fashion enabled by IT tools.

### **1.4 Research objectives**

The main objective of this research was to develop a formal model to measure the different levels of ITDCI. The researcher focused on the development projects within colleges and universities (As explained in the next section (1.6). In order to develop the model, the following approach was pursued:

- Developed and validated a scenario for the facility development process within colleges and universities.
- Provided a definition for each phase of the process to be executed in an IT-based integrated fashion and identified the desired outcome of each phase.
- Identified actions or mechanisms that have to be activated in each phase to maintain and promote ITDCI.
- Compiled all of the developed mechanisms to form the model

The level of integration can then be determined by quantifying the extent to which those previously identified actions were introduced in the project.

## **1.5 Research Scope**

The AEC industry is very large and has many types of projects. While there are common issues to all building projects, the impact and how these are dealt with varies within each group. For this reason, the researcher focused on colleges and universities facilities. The reasons for targeting this segment of the market are as follows:

- The sector is formed by organizations that demand fast, complex projects (laboratories, dorms, sport facilities, etc.) and specific design requirements including style and aesthetics factors. The nature of the projects demands the integration of multidisciplinary knowledge to execute such complex projects in a more collaborative and effective way.
- WPI is part of this market segment and there is readily available information from past major qualifying projects executed by WPI undergraduates. Another source for collecting data was through local design-build firms that are managed or owned by WPI alumni who have helped in the past and were willing to help. Examples of these companies are: Gilbane Building Company, Consigli and Cutler Associates
- The data was collected through a structured questionnaire was delivered to the Society for College and University Planning (SCUP) since WPI is already a member of this society.

## 1.6 Summary of the dissertation

This dissertation consists of seven chapters as follows:

**Chapter 1** gives a brief background about the state of the art of the design and construction integration and the newly emerged Information Technology tools that promote integration. In addition to that, the chapter included a discussion of the research objective and the research scope while explaining the reasons behind focusing on the educational facilities. Summaries of both the dissertation and the contribution of the research to the industry are also included.

**Chapter 2** provides the reader with some of the literature published recently in four main areas: 1) design and construction integration: starting with definitions, the need for integration, history of integration, different means of integration and finally the importance of measuring and quantification of integration.

2) The different models that are being used in the A/E/C industry such as: product model, process model, management model.

3) The importance of measurements and quantifications.

4) The role of the new emerging IT tools in promoting design and construction integration.

**Chapter 3** starts with a literature review related to the research methods used to develop this research. A detailed description of all of the steps that were involved in the research process then follows.

**Chapter 4** starts with an overview of the developed model for measuring the different levels of the ITDCI. A general description of what constitutes IT-based Design and



Construction Integration (ITDCI) then follows. The author then discusses the different patterns for knowledge transfer followed the ITDCI indicators that were developed in this study to identify the ITDCI mechanisms. The last two sections of this chapter discuss the different phases of the traditional development process of colleges and universities facilities and then how each phase of that process can be executed in an ITDCI fashion.

**Chapter 5** displays the different aspects of the survey conducted to validate the model. The survey targeted the society of colleges and universities planning. The chapter starts with the survey objective followed by the survey design then presents the obtained results and finally concludes with a discussion of those results.

**Chapter 6** is a part of the model validation process. The author chose WPI's new resident facility East Hall as a case study for that purpose. The chapter contains an analysis of the level of ITDCI that was involved in the project based on interviews and the analysis of the project documents. The ITDCI model was then used to assess the level of ITDCI. A comparison of the two scenarios and a conclusion then followed.

**Chapter 7** presents the conclusions at which the author arrived at after conducting this research. The future research work is also discussed.

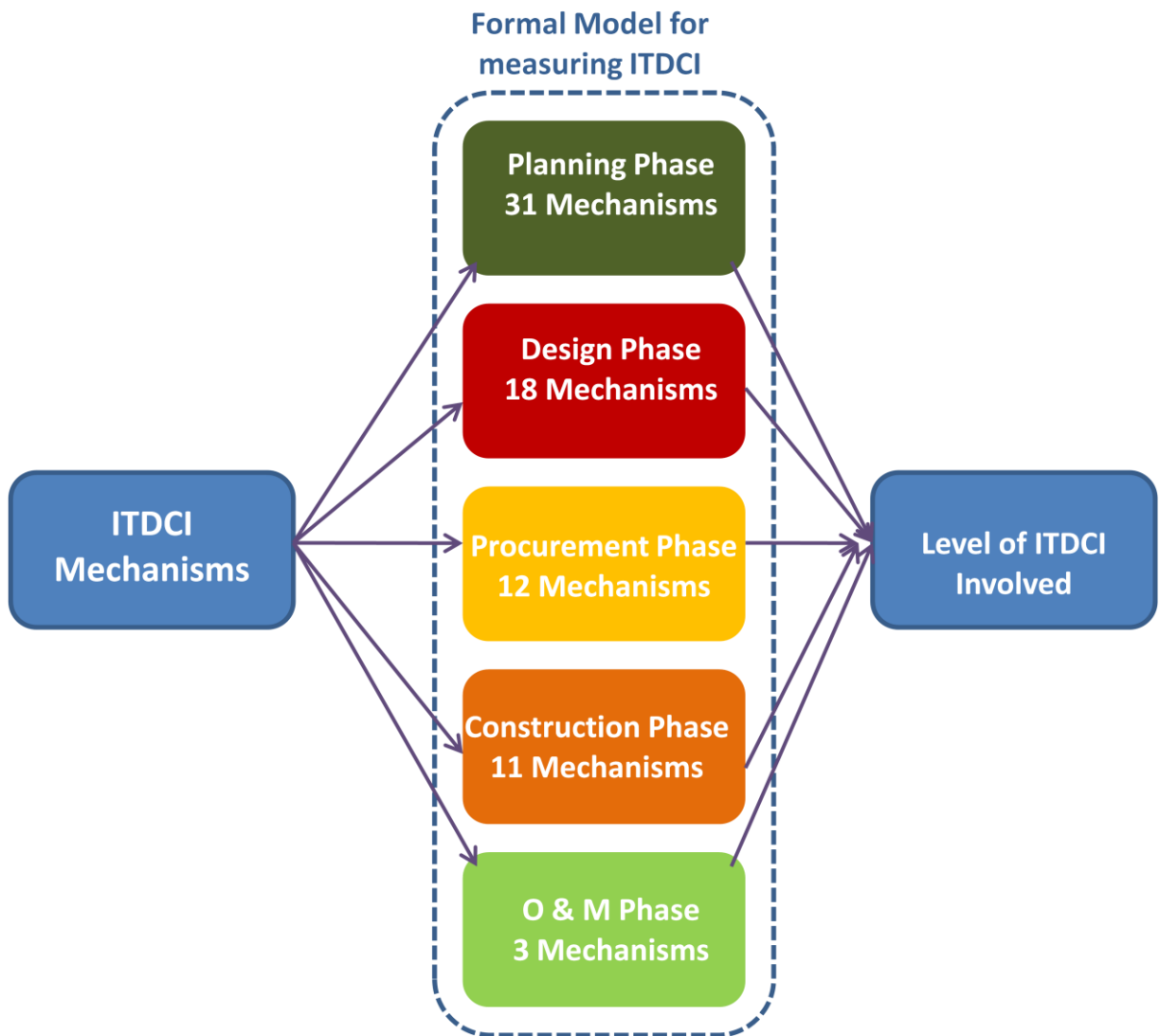
**Bibliographies** and references that were considered while developing the research are represented after chapter 7 ends.

Appendices of some of the materials referred to in the different chapters of this dissertation are also presented after the bibliographies section.

## **1.7 Summary of the contribution**

The research has yielded a major contribution to the AEC industry. A formal model was developed to measure the different levels of ITDCI involved in the facility development

process within colleges and universities facilities. Figure 1-3 below shows a schematic structure of the model with the number of the corresponding ITDCI mechanisms in each phase.



**Figure 1-3 Schematic structure of the ITDCI model**

The model is considered a significant contribution to the construction industry. It can be used to:

- Measure the corresponding level of ITDCI in each project.

- Develop a common understanding among the industry practitioners to identify the level of ITDCI they are standing at, to comprehend the benefits and consequences of this level on their project outcomes; and to execute cost/benefits analysis for other ITDCI levels. Hence users can take comprehensive decisions regarding the optimum integration leading to the most effective results for their project outcome-- (cost/benefits) wise.
- Measure and benchmark other projects to assess how integrated the members of the involved team performed, and to assess how well the facility performed in terms of realizing the previously specified quality, cost and time. This information can then be documented in a manual, “guide book” and offered for the use of other industry peers. Consequently, that would help to create a standardized language that can be used to communicate construction information between diverse parties.

## **Chapter 2. Literature Review**

This Chapter summarizes some of the most relevant previous research conducted to date related to the objective of this research. The author reviewed the related literature in four main topics: Design and construction integration, Information models in the construction industry, Importance of measurement and quantification, and emerging Information Technology tools in the construction Industry.

### **2.1 Design and construction Integration- related literature**

For the purpose of this research which is developing a formal model for measuring the different levels of ITDCI, the author had to find global definitions for DCI and ITDCI as a step to identify the mechanisms needed to be enforced to maintain integration.

#### **2.1.1 Integration definitions**

1. The bringing of people of different racial or ethnic groups into unrestricted and equal association, as in society or an organization; desegregation. [65]
2. The process of incorporating parts, components, elements into a larger defined unit, set and whole. [54]
3. DCI is a continuous interdisciplinary sharing of data, knowledge and goals among project participants. [31]
4. ITDCI is integration that relies on participants sharing their knowledge with the support of the appropriate IT tools, perhaps by encoding it in object-based technologies to model the building (commonly referred to as the Building Information Model, or BIM. [9, 31]

By examining the above definitions, it was found that all of them have the same concept. These definitions emphasized that integration or IT-based integration is bringing all of the participants involved in executing a certain process or processes to work together while having a common goal and unified culture. Besides they have to continually share their knowledge seamlessly in a timely manner. For effectively sharing their knowledge, they have to rely on the new emerging IT-tools to facilitate the knowledge transfer process.

### **2.1.2 History of integration**

The concept of design and construction integration had been introduced to the US construction industry many years ago. This was when the master builder concept was first established in the early 17<sup>th</sup> century by the Carpenters Company in Philadelphia [19]. Master builders were responsible for designing and surveying, laying out, and managing of construction projects according to the contract document [107]. By the late part of the 19<sup>th</sup> and the early part of the 20<sup>th</sup>, the function of the master builder became fragmented into designers and construction specialties due to the increasing sophistication in building, which led to a reduction in the use of master builder system for building projects [56] and to the introduction of the traditional design/bid/build delivery system. Using this delivery method, planning, design and construction of a typical construction project are executed separately by participants from different disciplines and in different phases, typically in an adversarial environment and with little interaction between phases and disciplines. Under this kind of specialization, arrangement, design and construction parties share their information at the end of the design phase and during the construction thus hindering the

construction knowledge to be available during the early phases of the design process. Consequently, this might result in inefficient designs, increased rework, higher costs and slipped schedules. In order to eliminate these drawbacks, researchers recommended to revive the master builder delivery system to help improve the construction project results [107]. Design-Build and Integrated Project Delivery (IPD) are emerging project delivery systems are examples of the ancient master builder system. Konchar and Sanvido (1998) developed performance metrics (cost, schedule and quality) and data collection instrument (structured survey) to test and empirically investigate the different delivery systems used in the U.S construction market. Konchar provided empirical evidence that projects executed using design/build delivery system as a method of integrating design and construction activities can achieve significantly improved cost and schedule advantages. Besides it can produce equal and sometimes more desirable quality performance than other methods.

### **2.1.3 Need of integration**

Research efforts have been conducted to explore the underlying factors that increase project cost attributed to the inefficient design-construct and manage processes that are observed in fragmented teams, resulting in dissipated efforts. It was found that a significant portion of these costs is credited to the incongruent and the consequent divergent behaviors of the various organizations participating in a construction project [67], [80]. Designers and contractors are often adversarial, inefficient, and resistant to innovation. [98] Some researchers related the problem to the lack of the construction knowledge during the early phases of design. Fischer and Tatum (1997) addressed that

the little and late involvement of the construction knowledge in the design phase leads to unfavorable frustration for not meeting the expectations. Besides, it results in slower and more costly construction periods due to increased transactional costs, rework, and non discretionary change orders due to errors and omissions.

According to the previously discussed consequences of the fragmentation researchers in the AEC industry have called for enhancing the performance of the construction projects by introducing design and construction integration. They recommended to integrate the knowledge of both the design and construction organizations involved in the early phases of the project. Blending and integrating the knowledge and expertise of different participants from the outset can eliminate the uncertainties involved in the different processes throughout the development process and affect the project outcomes positively.

#### **2.1.4 Means of integration**

In the last decade, efforts have been started to investigate the different ways of integrating design and construction. Nam and Tatum (1992) found that there are at least three means of integration in the U.S construction industry: organizational integration; contractual integration; and information integration [67]. They are different in their targeted goal, organizational boundary and information transfer environment. A brief description of each is followed below.

##### **2.1.4.1 Organizational integration**

The functions of design and production are integrated and performed together under one organizational boundary (vertical integration). Design-build firms are good examples of

this kind of integration at which all the design and construction function are executed collaboratively throughout the life cycle of the project under the responsibility of one entity.

#### **2.1.4.2 Contractual integration**

This kind of integration is based upon involving construction expertise in the process by integrating different organizations for relatively short time (Project duration) in order to achieve higher levels of goal congruency within the project team. A good example of this contractual integration is to form an alliance between the different participants (owner, designer, contractor, etc.) of the project to work seamlessly throughout the life cycle of the project to deliver a successful facility.

#### **2.1.4.3 Information integration**

This type of integration is usually achieved by integrating the information within an organization or across organizations to increase coordination and efficiency. Computer integrated construction (CIC) is an example of this integration in which a common database can be generated, accessed, and updated by multiple users. [99]

Moreover, Nam and Tatum described four major means to achieve integration between design and construction such as: (1) owner's leadership and involvement during the project execution, acting as link among the various organization; (2) the long-term business relationship that helps to develop an informal bond that facilitates inter-organizational learning; (3) employing integration champions; and (4) the



professionalism of project participants and their ability to cooperate to perfect the whole project.

Some researchers found that design and construction integration can be achieved by improving the constructability during the pre-construction stage. One example was Glavinich, 1995, who addressed two methods for improving constructability and decreasing design-related problems during the construction process, 1) Design phase scheduling, which involves the development and subsequent revision of a construction schedule throughout the design process in order to detect and correct potential construction and scheduling problems , and (2) In-house design phase constructability review to test the design philosophy in relation to the design criteria as well as the project constructability [38]. These two methods addressed by Glavinich are representing two means of integration according to Tatum and Nam previous classification presented in sections 2.1.4.1 and 2.1.4.3. They involve both organization integration in which both design and construction organizations are integrating their knowledge for more effective design. Besides, information integration through the use of IT tools such as construction scheduling software packages combined with object oriented design packages such as building information modeling (BIM) to explore and detect potential construction and scheduling problems prior to the actual construction time.

### **2.1.5 Integration promoting factors**

After identifying the different means of integration, the author reviewed the literature to investigate the factors promoting and deterring integration. This section discusses the

integration promoting factors while the integration deterring factors are discussed in section 2.1.6.

The type of project, contractual arrangements, organizational structure, and technological capabilities all affect the integration of the project. Mitropoulos and Tatum, 2000 found that the project uncertainty and complexity are directly proportional to the degree of integration. [65]

Sanvido, 1998 discussed how Design/Build and fast track projects were found to be the most common type of project delivery methods that promotes integration. These methods require cross functional integration among all project parties (design, engineering, construction, and owner). Additionally, the contractor participation during the design phase adds value by proposing cost effective alternatives and possible improvements in the constructability of the project.

Mitropoulos and Tatum, 2000 suggested some other mechanisms that can leverage the level of integration such as Value Engineering (VE) and Total Quality Management (TQM).

Value Engineering can be a part of the design process of the project. Integrating the builder's knowledge into the VE process impacts the design and helps in finding ways to reduce the cost of the project. Introducing a matrix organizational structure and building cross functional teams from the early phases of a project has been proven by the construction industry to be an effective tool in promoting integration [77].

However, these cross teams have to be working collaboratively and openly with a high level of mutual trust amongst each other. Partnering is a contractual agreement that can promote integration by encouraging teamwork and developing cooperative attitudes

between project participants. Rahman and Kumaraswamy, 2005 in their research identified 31 potential facilitators for integration. The table below summarizes these factors.

Enlightened and enthusiastic client
Knowledgeable client (about project processes and relational contracting (RC)
Client's initiative
Learning about RC approaches before contracting (all parties)
Co-operative learning within project organization
Familiarity/previous relationships with/among other parties
Reputation in the industry (each party)
Willingness/enthusiasm of involved parties
Previous experience in RC approaches (each party)
Aadequate resources and technical skills (each party)
Previous performance records on hard factors like time, quality, safety (each party)
Compatible organization culture of involved parties
Interpersonal relations/cultural harmony (individual)
Previous performance records on soft factors like joint decision making, problems, issues, etc. (each party)
Short listing capable and compatible potential project partners instead of price-only consideration
Disclosing project information to potential partners at early stages of the project for potential feedback
Seeking specific input on constructibility, construction methods, materials from potential partners
Bringing contractors, major subs and suppliers into the project team for long-term interactions
More workshops for better interactions to build trust/reliability
Use of single point responsibility
Group combined responsibility as against individual responsibility
Role of an independent full time facilitator in building trust, teamwork and can-do spirit
Role of project manager as facilitator as per item above given that PM has best understanding and control
Requirement of an independent full time facilitator to supplement PM
Company training policy to build adaptable individuals for working with diverse partners (each party)
Corporate strategy of building trust with potential partners by doing the right thing and meeting time & cost

**Table 2-1 Driving factors for integration**

They found that the three most important factors that promote integration were the reputation in the industry of each party, disclosing project information to potential partners at early stages of a project for any optional feedback, and previous performance records on soft factors such as joint decision making, joint problem solving, and compromises on unclear issues in each party. On the other side, the three least important factors were more workshops for better interactions to build trust and reliability, learning about RC approaches before contracting through workshops, seminar or training within the company, and the requirement of an independent full time facilitator to supplement

the project manage in building trust, team working and can do spirit and enhancing cooperative learning among contracting parties; thus workshops are of little importance and impact in integration. [57]

#### 2.1.4 Integration deterring factors

Rahman and Kumaraswamy's identified some factors that deter integration amongst project parties. A summary of those factors is provided in the below table.

Lack of client knowledge about project process and RC Lack of commitment from top management: client Lack of commitment from top management: other party Lack of client's initiatives Bureaucratic client organization Stringent/incompatible public sector rules and regulations Public sector accountability concerns Price-only selection methods Commercial pressures on contracting parties Opportunistic behaviour of one or more contracting parties Lack of trust and reliability among contracting parties Unwilling and unenthusiastic participation of contracting parties Interpersonal and cultural clash (individual level) Incompatible organizational culture Absence of any risk reward plan Separate and unrelated risk reward plans for different parties Exclusion of consultants in risk reward plan Exclusion of major subcontractors in risk reward plan Exclusion of major suppliers in risk reward plan Unfair risk reward plan Lack or absence of contractual relations between client and major subcontractors Lack of any relationships or communications between client and major suppliers Lack of any relationships or communications between subcontractors and suppliers Resistance of contracting parties to integrated project culture Failure to share information among contracting parties Uneven commitment of contracting parties Discontinuation of open and honest communication Improper planning, design errors and omissions Potential legal liabilities in resolving non-contractual issues
---

**Table 2-2 Deterring factors for integration**

According to their study [57], The highest ranked factors to deter integration were: (1) Lack of trust, open communication and uneven commitment, (2) Commercial pressures, absent or unfair risk-reward plan, incompatible personalities and organization cultures, (3) Lack of general top management commitment and client's knowledge and initiative, (4)

Lack of good relationships among the team players, and (5) Exclusion of some team players in risk-reward plan, errors and cultural inertia.

## **2.2 Importance of measurement and quantification**

Many researchers called for design and construction integration by introducing different approaches and methods. Some of them suggested enforcing contractual agreements such as partnering, design-build and IPD with the help of the technological advancements. Other researchers identified factors that promote and increase integration. However, most of these approaches are qualitatively based that cannot quantify the extent to which they would affect the level of integration involved in the project. In order to do that there should be a way to measure the different levels of integration. Having this type of measurement will help the AEC practitioners to better understand the ITDCI better and gain a better knowledge of how the different levels of integration would affect the performance of the project respectively. But, why measure? Having tangible metrics is—and has always been— helpful in any discipline. For example, the Richter scale in measuring the magnitude of earthquakes, Fahrenheit in measuring temperatures, and miles in distances. According to Lord Kelvin (and most scientists and engineers), measurement is the way we gain substantive knowledge about things. When Japan is hit by a 6.6 earthquake, people around the globe can understand what this means. Expressing knowledge in terms of numerical values helps to analyze and understand things better.

Sue Dyer, a pioneer industry professional in partnering process addressed that the critical lesson she learned through her profession journey was "You have to measure what it is you want to have happen". She added that if you want to change a behavior or culture,

then measure it. If you want to achieve a far reaching goal, then measure it. If you want to make sure your team stays together, then measure it. If you want to make sure a deadline will be met, then measure its progress.

Measuring or benchmarking is a concept of a continued improvement which is the main objective in Total Quality Management. It uses standard measurements in a service or industry for comparison to other organizations in order to gain perspective on the organizational performance.

Lean Construction approach which is a production-management based project delivery system that aims to build the project with maximizing the value while minimizing the waste and ensuring perfection for the benefits of the project stakeholders is also relying on measurement to revise the original plan and reasons for not meeting their pre-set goals. Actual measurement in lean construction is always a helpful tool to reveal that how they actually get done differs from what is supposed to be. It gives an insight of what project participants should have done and what they can do for improvements.

### **2.3 Models used in the A/E/C industry**

Construction projects involve a large amount of individuals and organizations that at different times and different locations are exchanging all sorts of data and knowledge from the early beginning of the project until the realization of the final product (building facility).

Over the last decades, models of products, process, and involved organizations had been developed by the AEC industry researchers to provide a structure that binds the three components together and hence identify the potential interface among them. [96]

As part of this research methodology, the author had to identify a standard and widely accepted model of each of the three components product, process and organization to identify the mechanisms and actions needed to achieve integration among them.

The following sections displays one of the models that had been considered while developing this research

### **2.3.1 Process Model**

Process models in the A/E/C industry and are used to represent the important steps that are need to be executed throughout the duration of a project. In 1990, Sanvido developed the integrated Building Process Model. The model subdivides the construction process into five different phases or processes: manage, plan, design, construct, and operate facility, where each individual phase had additional sub-processes. In 1992 Fisher and Yin developed a different model called the General Data-Flow Model which was based on the flow of information from a contractor's point of view. [32]

After reviewing the literature, the author adopted the below model developed by Ganeshan and Liu in 1996 to provide a scenario of the development process. Their model is a conceptual model of the overall design/construction Process and the responsible actors. It also shows how the information flows and associated decisions that are made through the different stages of the process. Besides, it identifies the professional responsible for each phase.

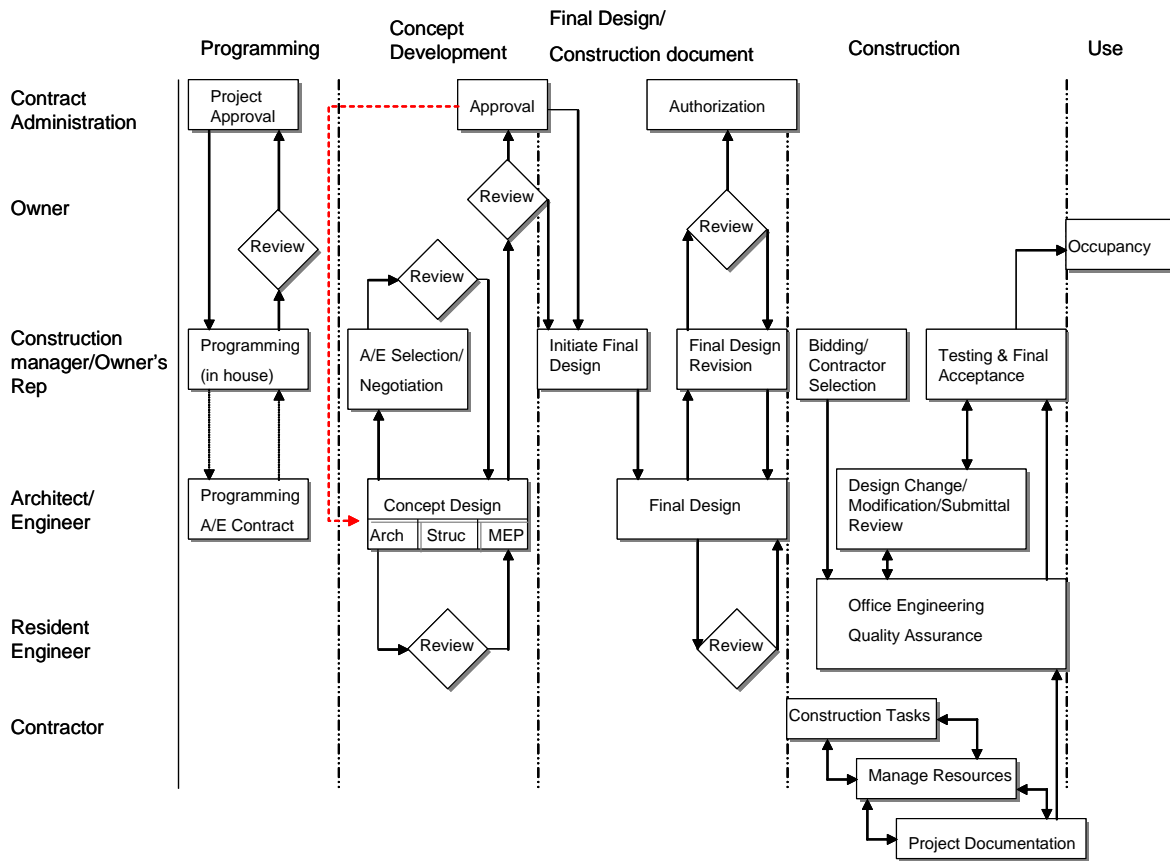


Figure 2-1 Design/Construction process organizational model [95]

### 2.3.2 Product Model

Product Models are another of models used by the AEC industry and provide an ordered structure for the product. The unified Approach Model developed by Bjork in 1992, the GenCOM Model by Froese in 1992, the BPM model by Luiten also in 1992, are all among the popular product models used in the A/E/C industry .[11],[34],[95]



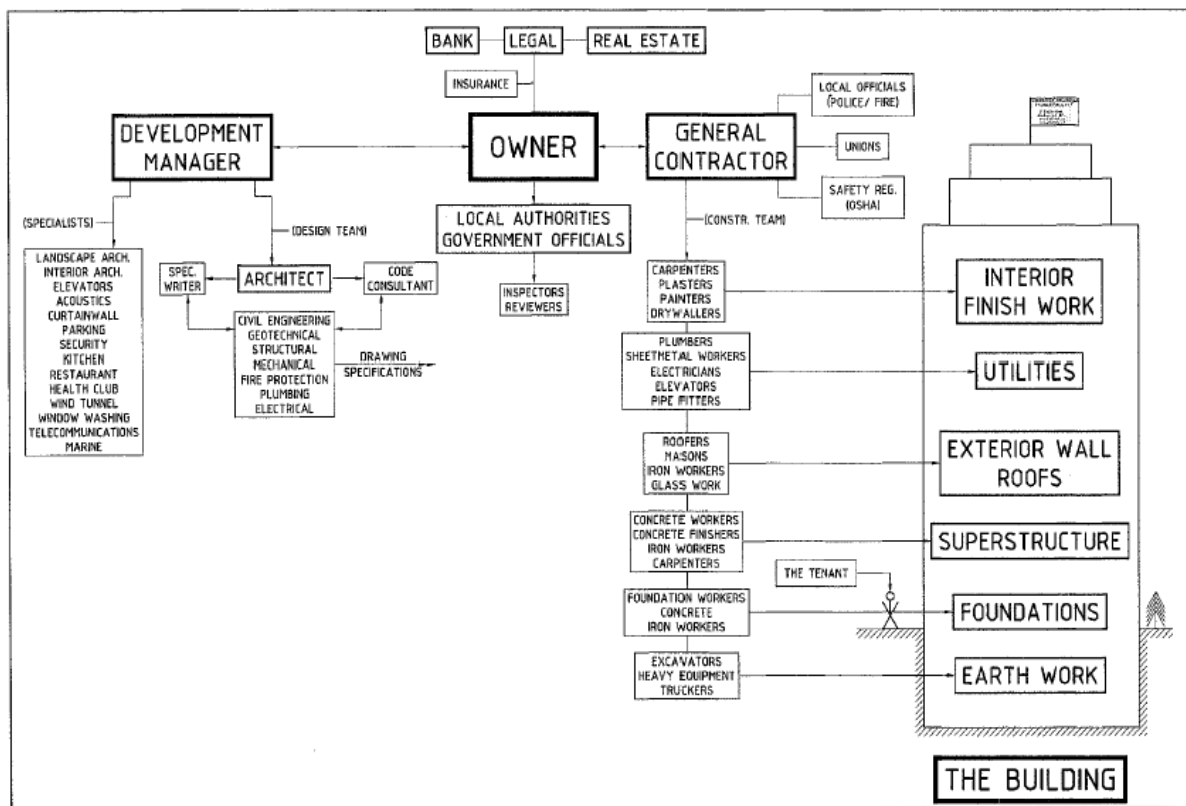
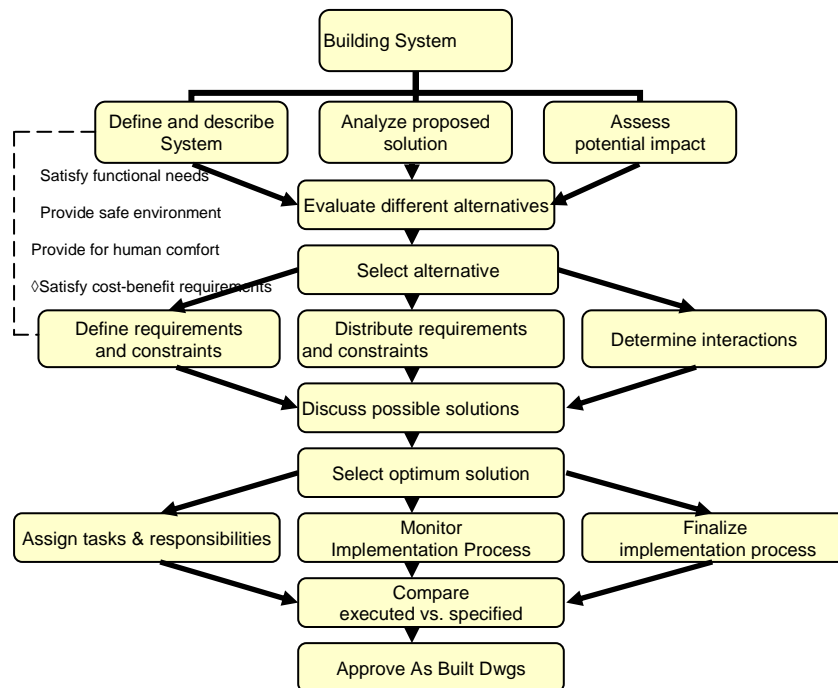


Figure 2-2 Product/Organization model Adopted from [47]

The above figure represents an example of the product model in terms of its building systems and organization (actors involved in the process). On the right side of the model, are the physical components of the building. To the left are the different trades related to each system of the building.

### 2.3.3 Product/Process/Decision Model

The below figure represents a simplified model of the decision making process developed by the author through the product life cycle starting from a concept to a realized product. It starts with defining and describing the (product) building system that needs to be installed and ends with approving the as built drawings. From the beginning until the end, several decisions have to be considered such as: evaluating the different alternatives; defining requirements and constraints; assign tasks and responsibilities, determine interactions, selecting the optimum solution; monitor the implementation process. Finally, comparing the executed versus specified and approving the as built drawings.



**Figure 2-3 Product/Process/Decision model**

## **2.4 Information Technology- related literature**

### **2.4.1 Online Collaboration Project Management technology (OCPM)**

Nowadays, some design and construction organizations are starting to depend on new emerging information technology tools (ITT) to execute their jobs and processes collaboratively. With the assistance of those ITT, construction project teams can become more flexible, adaptive, and competitive by improving their performance. [11]

IT enabled tools and techniques are available today for increasing the efficiency of the project teams and the effectiveness of the design and construction processes. Extranets and model-based 3D and 4D collaboration tools for information sharing, storing, and communication are some examples of these technologies. Nevertheless, despite the potential positive contribution of these tools to the design and construction processes and organizations, barriers do still exist for achieving success. [8] A paper-based submittal is still the common product of each part of the design phase, so the output results of tasks executed by IT are eventually printed on paper in the form of drawings and specifications for accomplishing tasks. On the other hand, even when the client demands a digital version of the design documents, such as drawings and specifications, this digital version of the documents is not legally binding and is being used at the client's risk for either archiving or for further processing in the future. There are several cultural and legal barriers for ITT adoption in the construction industry that slow down this adaptation.

### **2.4.1.1 Project Extranet**

A collaborative workroom or project extranet is an electronic network linking a number of different individuals or organizations for the purpose of exchanging information in digital form. Such networks have the opportunity to significantly improve the way the construction industry works and reduce the likelihood of mistakes and disputes, which are the biggest causes of waste and inefficiency in construction. [7] As early as 1999, at the Chicago Summit on the Future of Engineering Software, leaders from organizations such as Ford Motor Company, Microsoft, GSA and Bentley agreed that "within three years, no new engineering project of any consequence will be initiated without the use of a project website or extranet". [85] However, the take-off of this technology is still in its early phases. Small to medium-sized contractors are still reluctant to embrace the concept claiming that these systems are expensive, difficult to use, and only suited for largest companies.

Today there are a number of hosted extranet solutions all over the world, an example of those solutions is CJ Collaboration [46], the product of a joint venture between premier UK construction industry newspaper Contract Journal, and 4Projects, the leading provider of extranet and collaboration solutions in the UK. The aim of the new venture is to break down the current barriers to entry to collaborative working so as to enable more firms to save time and money by improving their project management processes. Another example in the US industry is Meridian systems.

Meridian Systems<sup>®</sup> provides project management software for optimizing the Plan, Build and Operate phases of real estate, construction, and other physical

infrastructure projects and programs to improve top-line revenue and reduce capital construction costs. [51] They offer several products such as: Proliance<sup>®</sup>, Prolog<sup>®</sup> and ProjectTalk<sup>®</sup>

#### **2.4.1.2 Model-Based Collaboration**

In addition to information sharing thorough e-mails and project extranets, the construction industry experienced increased use of model based collaboration over the last two decades to facilitate the communication and collaboration among the project teams. Examples of these models are 3D models and 4D models.

##### **2.4.1.2.1 3D Models**

The primary uses of computers in the construction industry have been shifting, over the past decades, from the 2D graphical representation of the proposed design solutions to model- based approaches that facilitate collaboration among the various professionals who are involved in the project.

Incorporating these models as basis for communication in the construction industry, replacing the paper-based communication is gradually growing. Organizations have started to focus on using 3D models collaboratively and make it accessible by other organizations involved to link their information on the model. These models are linked to central databases that store all model related information and attributes.

The Building Information Model (BIM) is a good example of the 3D models that are being widely adopted by the industry.

The benefits of communicating over a 3D model are many, such as compatibility

of the work of the different organizations involved, easier access to the information in a timely manner, less errors and omissions in the drawings, and eventually more effective transfer of the design data to construction. In addition, those 3-D models are very helpful in the coordination of the building different systems like the architectural, mechanical system and the structural systems. These can identify any potential clashes or conflicts before the actual construction begins. However, the current industry practices and the development of specialized software applications with limited interoperability, limit the adaptation of this new emerging technology to a certain extent.

#### **2.4.1.2.2 4D Models**

The use of 4D models, 3D plus time represents a fundamental change in project planning, design, and construction management strategies. 4D models have the potential to dramatically reduce project costs, schedule, and risk. Their major benefits are that they enable project team members to:

- Better communicate the design and schedule of a construction project.
- Better execute site planning and logistics studies.
- Promptly reflect design and schedule changes.
- Solicit more robust feedback and input from all project participants based on their interpretation of the developed models.

4D models enhance the project team's ability to plan and control construction projects through evaluation, feedback, and suggestions from a range of project participants who can identify potential problems more easily and then rapidly explore and evaluate design and schedule alternatives. Additional functionality of 4D tools which has been shown to

be useful is comparing schedules from the subs with the general contractor's and owner's schedules to assess the schedules' compatibility and to identify schedule and space conflicts prior to construction.

While the work of related subcontractors is typically coordinated through 2D overlays, that allow a project team to identify some spatial conflicts in the design, visualizing the construction schedule can introduce new spatial conflicts that are very difficult to identify with 2D overlays.

#### **2.4.2 Potential Benefits of the use of OCPM**

Making use of collaborative technology to manage the flow of information on a construction project should lead to cost savings. For example, most systems allow for the sharing of documents, drawings, schedules, specifications and many other forms of data via cross-platform viewer, eliminating the need for all parties to commit to licensing the originating software. Moreover, secure e-mail and discussion forums providing instant communication with the project team, meeting and travel costs should shrink. Also, the expensive task of distributing hard copy documents can be eliminated, while paper and printing costs will be reduced. It is clear that these tangible benefits alone will provide savings for the majority of construction projects, yet the intangible savings in time and risk can pay for the extranet costs many times over. Using a collaborative system will cut down the time taken to generate, track and file documents, and will enable quick and efficient searching through both live and archived information.

In addition, distributing project documents electronically will ensure that all members of

the project team have access to the most up-to-date versions of the various project documents so that mistakes generated by someone working from an outdated document or drawing are removed. And where mistakes do happen, the system will provide a reliable record of all communications which would help to avoid the likelihood of costly litigation.

**Table 2-3 Potential benefits of adopting the OCPM technology**

Improved data availability
Enabled faster reporting and feedback.
Reduced paper and printing costs.
Improved information management.
Enabled better project and program control
Reduced time to make a decision.
Improved quality of the output product.
Reduced rework/data entry
Faster launch to market due to faster delivery
Reduced errors and omissions.
More effective communication
Reduced travel costs and transportation
Bring new team members up to speed quickly
Reduce design time and effort.
Increase productivity of crews
Reduce time needed to evaluate an alternative
Improved constructability studies
Improved evaluation of schedule



Speed up evaluation of schedule
Reduce number of change orders

**2.4.3 Financial, cultural and legal barriers**

Although the construction industry has enjoyed the benefits of different design and construction software during the last few decades, it is still laggard to adopt new ways of collaboration. Also, although there have been some successful examples, the benefits of these tools are not proven industry-wide. Moreover, there are legal and cultural barriers need to be overcome for a widespread adoption of collaboration technology in the construction industry. Examples of these barriers are:

- 1. Financial and organizational learning risk
- 2. Legal Barriers.

**2.4.3.1 Financial and Organizational Learning risk**

Financial risk is one of the causes that slow the adoption of the online project management collaborative systems. Financial risk is expressed as a belief that the introduction of OCPM technology represents additional costs that cannot be justified in turn of its benefit, or that clients do not perceive the value in designing in 3D or the value of electronic document exchange and storage. Moreover, the industry practitioners: architects and contractors are reluctant to spend for additional hardware and software. Also, high expenses of training employees with a possible lowered productivity during the transition or the change process. In addition, not having a standard tool for information sharing similar to CAD system is creating frustrations in the industry as each new tool means going through another set of learning curves. Architects and designers

are especially subject to this problem as these tools are usually brought on board by the owner or the contractor

Unproven price-to-performance is representing a major issue that does not promote the adoption process. Normally, the primary motivator for the AEC industry personnel to embrace new technology innovations is the opportunity for direct gains and benefits in their work processes. In order for those personnel to realize these benefits there must be a framework in place to measure the relevant cost and benefits associated with the investment [60]. Although there have been some initial efforts to study ROI, there are no valid results available today to encourage industry stakeholders towards faster adoption. As it can be also observed from the below figure , there are some benefits that are obvious such as improved communication, reduced printing, mailing, faxing costs, and reduced RFI and submittal turnaround time. However, the users are less confident that they will enjoy the benefits of reduced claims and litigation costs, increased competitive advantage or reduced change order costs. [8]

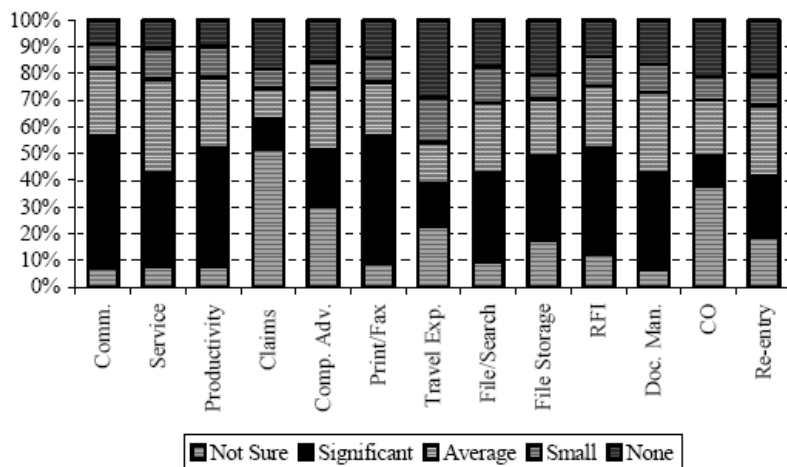


Figure 2-4 Realized benefits of OCPM tools according to users---- [7]

In order to overcome these financial barriers, vendors of these systems are now encouraging companies interested in using their systems by offering them free trials, and conducting live webinars and workshops. At these webinars and workshops, they invite industry practitioners who had previous experience using the software to provide their insights and work experience.

### **2.4.3.2 Legal Barriers**

Until recently, the legal framework in the construction industry that protects information as a property right represents real obstacles to change and start adopting the OCPM technology. The standard practices advocated by the industry governing organizations such as the American Institute of Architects, Associated General Contractors, or National Society of Professional Engineers tend to institutionalize non-collaborative practices. For example, the American Institute of Architects “AIA” has numerous standard contracting forms for design and construction related services which discourage technology enabled collaboration. For example, the AIA-B141—Standard Form of Agreement between owner and architect includes provisions that assume that: the owner has “full information” on project conditions while in a collaborative environment full information is shared with the designer, builder, subcontractors and suppliers as with the owner. Contract documents in a traditional agreement are proprietary while it cannot be proprietary in a collaborative environment for a number of reasons. First, proprietary ownership of information does

not lead to sharing of that information across the team. More importantly, interactive, or web enabled design documents are neither static nor authored by a single team member.

However, in 2007 the concept of integrated project delivery (IPD) developed by the AIA society altered the previous way of communication between the architects, contractors and other participants of the project and provided a strong initiative to overcome those legal barriers. Integrated Project Delivery as defined in the IPD guide developed by the AIA is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.

IPD principles can be applied to a variety of contractual arrangements and IPD teams can include members well beyond the basic triad of owner, architect, and contractor.

## **Chapter 3. Methodology**

This chapter starts with a description of the research methods used for conducting this research. A step- by- step description of the research process is then followed.

### **3.1 Research Methods Introduction**

Research can be divided into three main categories: exploratory, problem solving and hypothesis testing. [76] The research methods used in this research are a hybrid these approaches.

Exploratory research is often conducted because a problem has not been previously defined, or its real scope to some extent was unclear at the outset of the project. Typically, it is not possible to make a detailed work plan in advance. This research method is usually used to investigate little understood problems, identify important variables or generate hypotheses for future research. This research was conducted to develop a formal model or a framework to measure the different levels of IT-based design and construction integration. The author first started by reviewing the literature to identify previous research done for measuring design and construction integration. After reviewing the literature, it was concluded that although researchers have suggested some methods to promote design and integration, there were no previous methods for quantifying the level of integration involved in a building project.

Since limited or almost no research has been conducted in measuring ITDCI, an exploratory research method was used in this research to solve the research problem. At

the beginning of the research, the author did not have a clear vision of the research direction or how to proceed. From the literature review, the author found some research initiatives that helped with her research. For example, the POP model introduced by the Center of Integrated Facilities Engineering CIFE at Stanford university in which they use a software tool to model the required product and link it to the involved organization and the process models to better enhance the product. Other concepts such as Key Performance Indicators (KPI), Quality Management (QM) or Total Quality Management (TQM), which are all different ways for ensuring that all the activities necessary to develop a product or service are effective and efficient with respect to the system and its performance, helped to gain gradual precision of how to proceed with the research [45]. The concept of “Quality Management” previously known as “Total Quality Management” from the manufacturing industry helped in this direction. Quality Management is defined as a method for ensuring that all the activities necessary to design, develop and implement a product or service are effective and efficient with respect to the system and its performance [48].

The two research strategies used in this exploratory research were interviews and case studies. [63] In addition to that, a structured survey was used to validate and test the developed model.

## **3.2 Research Process**

A summarized step-by- step methodology is provided in this section followed by a more detailed description of the major steps.

1. Reviewed the literature
2. Developed a global definition for ITDCI through literature and interviews.
3. Identified a preliminary list of ITDCI indicators.
4. Developed and validated a scenario for the facility development process within colleges and universities.
5. Developed the ITDCI model.
6. Developed a structured survey to validate the developed mechanisms
7. Collected the questionnaire results.
8. Analyzed and sorted the content of the questionnaire results.
9. Tested the developed model using WPI's new residence hall as a case study.

### **3.2.1 Literature Review**

A literature review was conducted in four main topics: 1) Design and construction integration, 2) Models used in the construction industry, 3) Importance of measurement and quantification, and 4) The role of the emerging Information Technology tools in the construction Industry to promote integration.

After reviewing the literature, the author was able to identify the current state of the art in the integration area and the newly emerging information technologies that promote integration. Also, the author was able to identify the research problem, develop the

research questions and have better idea of how to solve the research problem (research methodology).

### **3.2.2 A global definition for ITDCI through literature and interviews**

In order to identify a global definition for IT-based design and construction integration, the researcher reviewed the literature and ran preliminary interviews with three members of the AEC industry, each one of whom represents one principal party in the project: Owner, John Miller, Director of physical plants services at Worcester Polytechnic Institute; Designer, Robert Taylor, AIA, Vice President of Planning and Design at Cutler Associates; and Contractor, William Kearney, Project executive at Gilbane Building Company.

#### **3.2.2.1 Interviews**

Interviewing can be an extremely useful method of gathering information, which is not otherwise available to a researcher. [95]

The purposes of the interviews were to collect the interviewees' view on design and construction integration, and to verify the relevancy of their reply to the literature review. In addition, the interviews served as a basis to structure a questionnaire that the researcher developed and sent to industry practitioners. The interviews also helped to identify new issues that were not identified during the literature review. Each interview included three main questions as follows:

- *In your perception, what is design and construction integration?*
- *How do you recognize whether a project is a well integrated or not? What indicators should one look for to identify integration in a project?*



- *What is the role of emerging information technologies such as OCPM, BIM and others in promoting design and construction integration?*

In addition to the previous questions, the author gathered the interviewees' view on the potential benefits of integration based upon their experience from integrated projects.

A full script of the questions and the answers by the interviewees are presented in Appendix A. After analyzing the results of the interviews, the author got better insight on a definition for design and construction integration; all of them agreed that the condition for integration involves that all project participants working together and sharing their information, knowledge and responsibility seamlessly from the early phases of the project." As far as the indicators that one should look for to identify integration, they suggested: more effective communication, less RFIs, less time to make decisions, and less change orders. As for the new emerging IT tools that promote integration, they all replied that they have been exploring a variety of those tools like: Webinar which allows people to communicate together remotely, and BIM for modeling, cost estimating and clash detection. The interviewees also added that using IT-tools such as Prolog or project websites can promote collaboration and integration to a significant extent.

### **3.2.3 Identifying a preliminary list of ITDCI indicators**

The previous interviews conducted also helped the researcher to consolidate the findings from the literature review to come up with a list of twenty-one integration indicators presented in Chapter 4: Section 4.4.

### **3.2.4 Developing a scenario for the development process for colleges and universities facilities**

A scenario for the facility development process within colleges and universities facilities was first developed and validated to identify the ITDCI mechanisms that need to be activated to promote integration.

### **3.2.5 Developing the ITDCI model**

In order to develop the ITDCI model, the author used the previously identified scenario for the traditional development process and then for each phase of the process:

- Provided a definition of the phase when executing it in an integrated fashion.
- Identified the desired results of each phase, and then identified actions and mechanisms that have to be activated to ensure the presence of integration.

From the literature review, interviews, brainstorming and personal experience, the researcher was able to identify the ITDCI mechanisms that have to be activated in the different phases of the project to integrate the knowledge of the project participants. Some of those mechanisms are organization related, process related and product related. In addition, some IT-related mechanisms that have to be in place to ensure the effectiveness of the information technology in facilitating integration were also identified.

### **3.2.6 Developing the survey**

A survey is a process of examining a social phenomenon involving an individual or a group, by gathering information through observation or asking. [22]

Commonly, surveys are conducted through questionnaires and interviews. [29] Questions have two primary types, open and closed. Open questions are designed to allow the respondents to answer in whatever form and content they wish. This kind of questions is easy to ask but difficult to analyze the data. Closed questions have a set number of predetermined responses that respondents can choose.

The questionnaire developed for this research introduced both types. Closed questions were used to quantify more accurately the extent to which the ITDCI mechanisms and action were introduced throughout the different phases of the project and hence determine the level of ITDCI that was presented. Some of these questions were measured on a five-points Likert scale.

The survey was developed and published using Survey Monkey website.

A request for participating in the questionnaire was sent to the Society for College and University Planning (SCUP) members (architectural, design, engineering and consulting firms that support higher education) through their weekly newsletter to capture their real life experience. The results were then collected through the Survey Monkey website. For further analysis, the results were exported to Microsoft Excel. The results of the survey, discussion of the results and conclusion are presented in chapter five.

Open questions were also used in the survey to capture other actions that were taken by the responders and were not introduced included in the content of the survey's questions.

### **3.2.7 Case Study**

“A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and

context are not clearly evident” [29]. It helps to deeply explore specific instances within the context of the research.

The case study used for this research is WPI’s new residential building facility East Hall. The reason behind selecting that case study was because the related information was readily available and well documented: some senior students were involved in the development process of this project with their MQPS and witnessed a highly integrated working environment among the different parties.

The researcher used the case study to execute integration analysis of the project using two different scenarios: the first scenario using the driving/deterrent factors of integration developed by Kumaraswamy and Mohan in 2005; and the second scenario using the ITDCI model to measure the level of integration of ITDCI that was presented in the project. Finally, a comparison of the two scenarios was conducted.

## **Chapter 4. The ITDCI model**

This Chapter starts with section 4.1, an overview of the proposed model for measuring the different levels of IT- based design and construction for colleges and universities facilities (Fig 4-1). The rest of the chapter is organized as follows:

Section 4.2 gives a general description of what constitutes IT-based Design and Construction Integration (ITDCI).

Section 4.3 discusses the different patterns for knowledge transfer.

Section 4.4 gives an overview of the ITDCI indicators that were used to develop the ITDCI mechanisms.

Section 4.5 discusses the different phases of the traditional development process of colleges and universities facilities.

Section 4.6 describes how each phase of the traditional development process can be executed in an ITDCI fashion.

### **4.1 An overview of the ITDCI model**

The ITDCI model acts as a universal framework to activate ITDCI in the development process of colleges and universities. It works as a rating system to measure the overall level of ITDCI in each project after determining the level of ITDCI that was involved in each phase. A full description of the model development and how it works is presented later in this chapter. The main idea behind the development of the model is to give a clear prescription to the project participants to maintain ITDCI in the development process, ensuring that all parties are continually exchanging their knowledge in a timely manner

while depending on the appropriate IT-tools to support the integration process. The author looked closely at each phase of the development process and came up with the corresponding ITDCI mechanisms that have to be activated to support the knowledge transfer process. Mechanisms to ensure the introduction of the appropriate IT tools were also considered in each phase.

The model consists of 75 mechanisms (points) distributed over the five phases of the development process: planning, design, procurement, construction and operation. Thirty one mechanisms have to be activated in the planning phase, eighteen in the design phase, twelve in the procurement, eleven in the construction phase and three in the operation and maintenance phase. Approximately 25 % of the seventy five mechanisms are IT-tools related. Figure 4-2 is a snapshot of the ITDCI model.

The level of ITDCI in the project can be then determined by quantifying the total number of ITDCI mechanisms activated over the five phases of the process.

Different categories of ITDCI can be realized based on the total number of points obtained as shown in the figure below:

level 5	75 points
level 4	65 points & above
level 3	55 points & above
Level 2	45 points & above
level 1	35 points& above

**Figure 4-1 Different levels of ITDCI & corresponding points**

# ITDCI metrics

## Metrics for measuring IT-based Design and Construction Integration

### In the development process of colleges & Universities

It-based integrated planning phase		Total points = 31	Y/N	It-based integrated design phase		Total points = 18
1-	An initial kickoff meeting held to bring the project team together? (Owner, Chief of Officer, dean of students, director of students affairs and campus life, director of physical plants, designers and contractors and students as end users)	1		1.	Effective involvement and contribution of the owner in the design process in a timely manner.	1
2-	Specific actions taken to set the tone for cooperation throughout the project toward a common goal. (Training programs, incentives, etc.)	1		2.	Assigning a some one in the project (design facilitator) to identify in a timely manner potential conflicts among different design disciplines and acquire design specialists inputs as required.	1
3-	Owner's (Board of trustees, President) plans and expectations expressed and understood by all team members. (Characteristics of the desired facility, constraints, etc.)	1		3.	Continuous inter-disciplinary collaboration between architects, engineers, cost engineers, operation staff and other relevant actors right from the beginning of the design process.(up stream).	1
4-	All team members share a compatible philosophy with the owner for this project. (culture, vision and goal congruence)	1		4.	Establishing procedures to ensure that alldesign decisions that require multidisciplinary input are made in a timely manner.	1
5-	Clear and complete objectives established and communicated to all project members.	1		5.	Setting an agreement between the owner and the designers upon the relative importance of the various performance issues.	1
6-	Enforcing a contactual agreement(or otherwise) requirement set by the owner for the use of IT- tools to support the communication coordination process. (Project website, webinars, e-mail, BIM, etc.)	1		6.	Considering the harmonization of the facility with other campus facilities.	1
7-	Implementing organizational changes to enable effective utilization of information technology. (creation of a customized job to serve this service)	1		7.	Identifying and emphasizing the project constraints in terms of time and cost continuously while developing the design.	1
8-	The owner allocate competent key role people who are capable of taking decision in a timely manner.	1		8.	Continuous testing of the conformance of the design to the design functional requirements according to the university codes and standards.	1
9-	Enforcing a prequalification criteria by the owner to assess the ability of the designer to integrate multi-disciplinary aspects of the facility with the institution short and long term needs and objectives	1		9.	Communicating and understanding the developed design to/by all design professionals.	1
10-	Establishing procedures to ensure the sufficiency between the personnel and the role they perform. ( The right knowledge, etc.)	1		10.	Evaluating different alternatives for cost/schedule and logistics constraints.	1
11-	Committing and dedicating representatives from the different parties involved to the project.	1		11.	Evaluating alternatives against fabrication and lead time constraints.	1
12-	Putting mechanisms (contractual agreements) in place to enforce mutual respect and open/honest communication flow amongst the different parties involved	1		12.	Evaluating different alternatives for operability and maintenance.	1
13-	Conveying the program developed by the designer in clear and concise terms to clear and minimize uncertainties.	1		13.	Identifying specific dates for reviewing key submissions and deliverables for compliance with program goals and design objectives.	1
14-	Considering most or all of the performance-based objectives in the planning phase. (Quality, cost/schedule contro and Value Engineering)	1		14.	Using BIM to develop the design documents.	1
15-	Establishing procedures to allow the owner and designers exchange the information in a continuous manner.	1		15.	Using BIM as a reliable database for communication and collaboration.	1
16-	Setting Standard protocols and format for communication between all project team members.	1		16.	Using coordinated information network for designers to ensure the availability of the required knowledge related to the design intent, procedures and options in a timely manner.	1
17-	Setting a contingency plan to manage possible breaching of the previously identified mechanisms.	1		17.	Creating a central file repository to post /store and access the different materials or systems catalogues and brochures.	1
18-	Establishing and approving the time schedules and campus schedule-related contingency plans by every affected party.	1		18.	Used any software package ( like Navis work) or any similar one to detect clashes and interferences between different design disciplines.	1
19-	Developing format to integrate the expertise from the design and operation of other campus facilities to the design and construction of this facility?	1		<b>Total points</b>		<b>18</b>
20-	Establishing procedures and actions to solve technical issues that might arise in a timely manner.( equipments reliability, configuration control, etc.)	1		Y/N	It-based integrated construction phase	Total points = 11
21-	Incorporating the builder's perspective. (construction methods)	1		1.	Excuting constructability review sessions to ensure compatibility between the different systems of the building.	1
22-	Considering current/future operational conditions of the facility.	1		2.	Structuring procedures to force the sub-contractors to enhance the accuracy of the shop drawings. (incentives, penalties,standards, etc.)	1
23-	Creating a central file repository to post and store the entire project related documents and information	1		3.	Developing a standard process to shorten shop drawings submittal/approval time.	1
24-	Setting an interoperable file format for exchanging information and support feedback mechanisms/ (DWG, PDF,DWF,...)	1		4.	Discussing and optimizing the work sequencing among the different trade contractors.	1
25-	Deciding upon the software that is going to be used in the planning stage to support budget preparation and cost control and ensuring that it is operable with other CAD software that is being used by the designer.	1		5.	Revising and coordinating the delivery of materials and equipments according to the construction schedule to ensure efficient flow of work.	1
26-	Establishing pre-qualifications or selection criteria established to ensure that all project professionals are equipped with IT- tools that support their provided services and in the time disseminate their knowledge.	1		6.	Scheduling meetings on a regular basis between the design and construction teams to discuss the actual conditions of the construction process to minimize or eliminate field changes.	1
27-	Addressing the issue of technology interoperability to cross-pollinate their products-related knowledge. (share and co-produce electronic files)	1		7.	Considering and coordinating the required information for testing and inspection with the regulatory agencies.	1
28-	Pre-setting specifications to address the required BIM level of detailfor different areas and disciplines of the project.	1		8.	Using BIM to execute what if scenarios for site logistics studies.	1
29-	Using the Building Information Model to evaluate the different alternative. (sensitivity analysis)	1		9.	Tying the construction schedule to the BIM model to visualize and understand the construction progress.	1
30-	Using the AutoCAD Civil 3D to develop site analysis.	1		10.	Using the BIM model to generate a look ahead construction views to help optimize the construction activities and better track the construction progress.	1
31-	Developing a GIS map of the campus to better understand spending cycle, monitoring and analyzing the trends to optimize the planning process.	1		11.	Updating the BIM model continually according to the "as built" conditions	1
<b>Total points</b>		<b>31</b>		<b>Total points</b>		<b>11</b>
It-based integrated procurement phase		Total points = 12		It-based integrated operation & maintenance phase		Total points =3
1-	Incorporating of the vendors and suppliers expertise regarding the constructability, materials availability while preparing the bids documents.	1		1-	All the information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components of the building is gathered and well documented.	1
2-	The bidder certified to the owner that each engineer or architect of its team was selected based on demonstrated competence and qualifications.	1		2-	Obtained and updated the BIM model with the 'as built" information.	1
3-	Consideration of the owner or his representative of the bidder's experience, technical competence, capability to perform and the past performance of the bidder's team members.	1		3-	Tied and incorporated the previous information (information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components) in the BIM model.	1
4-	Evaluating of the bidders on the basis of the safety and long-term durability of the project.	1		<b>Total points</b>		<b>3</b>
5-	Evaluation of different alternatives to optimize and orchestrate the involved resources.	1		Overall score		75
6-	Full consideration of the design output performance specifications (bill of materials, schedule, cost targets, delivery requirements to solicit and evaluate bids, make source selection recommendations and place orders.	1				
7-	Establishing procedures to ensure the integration and compatibility of the different work packages.	1				
8-	Accommodating and communicating all of the implemented site changes to all of the affected parties and packages.	1				
9-	Using BIM to extract quantities for procuring the different work packages.	1				
10-	IT was in place to identify and solicit qualified bidders and support evaluation of source capabilities and ability to deliver.	1				
11-	Setting a reliable way of communication to ensure proper and standardized means of representing information/knowledge to support project management, project controls, material and labor tracking engineering and procurement functions.	1				
12-	Creating a central file repository to post /store and access the subcontractors/vendors quotations of different materials or systems to maintain on-line knowledge bases coupled with performance specifications.	1				
<b>Total points</b>		<b>12</b>				

Figure 4-2 The ITDCI model

## 4.2 IT-based Design and Construction Integration

IT- based Design and Construction Integration as previously defined in chapter 1 is a knowledge-based activity in which each participant continuously and timely contributes and shares his/her knowledge to realize a specific goal bounded by a unified and cohesive culture and supportive IT-tools. [60], [65], [72]. The level of ITDCI can be determined by assessing how effectively the project participants exchange and share their knowledge and how efficiently they utilize information technology to support and facilitate the exchange process.

## 4.3 Knowledge exchange patterns

Figure 4-3 below shows three different patterns of knowledge exchange. In the first pattern, the project participants are exchanging their knowledge on a random one-to-one basis that does not necessarily propagate the consequences of each exchange to other participants. As a consequence, the resultant knowledge of the participants is not consistent.

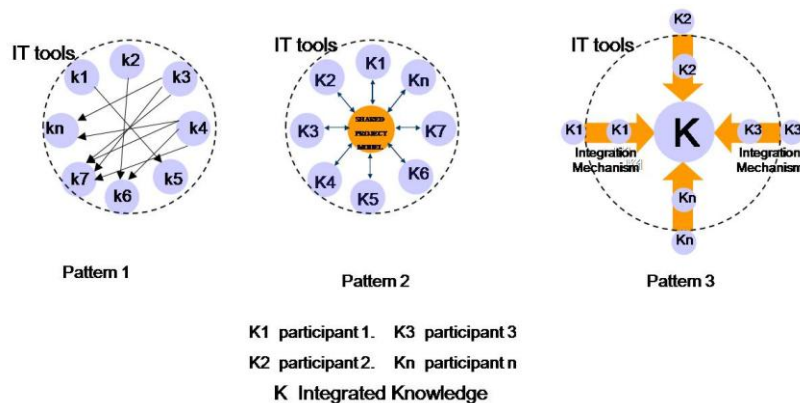


Figure 4-3 Knowledge exchange patterns



In the second pattern, each participant stores his knowledge in a central data base (shared project model) or “open book type” and makes it available for other participants. This does not guarantee that the knowledge is exchanged equally since it is mainly dependent on the different interpretations of the participants. In the third pattern, integration mechanisms and actions are put in place to integrate the knowledge of all of the participants seamlessly, as if only one participant has the resultant integrated knowledge (K). Some of those mechanisms are organization related, process related and others are product related. Regardless of the pattern that is being used for the knowledge transfer process, IT tools are there to support and facilitate the knowledge transfer process. However, in the third pattern, structured IT-related mechanisms are considered to ensure the effectiveness of the information technology in facilitating the integration.

Considering the definition of the ITDCI provided in section 4.3 and the third pattern of knowledge transfer, the author came to a conclusion that the level of ITDCI can be quantified by assessing the extent to which the project participants were sharing their knowledge and the extent they were using IT –tools to facilitate the sharing process

For the purpose of this research and in order to develop a measurement tool to quantify the level of integration in construction projects for colleges and universities, the following approach was pursued:

1. Developed a list of generic indicators to be used to develop the ITDCI mechanisms.
2. Validated a scenario for the development process of a typical educational facility.

3. Provided a definition for each phase of the process to be executed in an integrated mode.
4. Identified the desired outcome of each phase while executed in an IT-based integrated fashion.
5. Identified actions or mechanisms that have to be activated to maintain ITDCI.

#### **4.4 IT-based Design and Construction Integration indicators**

The level of ITDCI in a given project can be measured through ITDCI indicators. These indicators can be observed and are important to achieve integration. They can be identified by asking the following series of questions:

1. What is the difference between traditional design and construction process and an IT-based Integrated Process?
2. What is the difference between a traditional project organization and an IT-based Integrated Project Organization?
3. What is the role of information technology in promoting project integration?
4. What are the characteristics of an IT- based integrated project?

The research has identified a total of 21 major indicators that can be observed at the different stages within the engineering, procurement, and construction phases of a project and reflect the level of ITDCI involved. The cumulative level of ITDCI observed in all indicators determines the overall level of ITDCI in the project. The indicators are classified under four categories: process related, product related, organization related and IT-related.

#### **4.4.1 Process Related Indicators**

##### **1. Decision making process**

###### ***1.1 Time to make decision***

The time to make a decision is an important indicator because it reflects how efficient the communication process is and how well the tasks and responsibilities are defined. The decision should be mature enough in order not to affect the project performance negatively.

“A mature decision” is based upon less number of uncertainties. It can be obtained by having the right people at the right time in the right place. These key people have the appropriate knowledge and authority to make decision in a timely manner.

###### ***1.2 Number of decisions needed***

Number of decisions needed to finalize a certain task depends on the task complexity, parties involved and the interdependency of this task and how it affects the successive tasks. It is also affected by the project organization and the difficulty of the decision making process. The number of decisions can be figured out by the number of authorization requests granting approvals, and reporting procedures.

###### ***1.3 Frequency of meetings between the owner and the project team***

This indicator gives an idea of the project participants’ dedication and readiness to respond in a timely manner for any request for making a decision. Additionally, it ensures the availability of the right knowledge and authority needed.

This indicator is important because it keeps the owner informed and updated with the project circumstances. It reduces surprises and changes and enhances the predictability of the project's final cost and schedule.

## **2. Change Management Process**

This Indicator measures how effective is the change mechanism in the building process with the presence of an integrated organization to ensure stability and to achieve the desired goal. There are some controls that can be set as precautionary measures to ensure that the change process is going under control.

### ***2.1 Program control***

This indicator can be measured by determining the degree of adherence to the original scope. Most importantly is to monitor the timing at which changes to the original scope take place. If the changes occur at the design development phase that means that the parties are communicating in a satisfactory manner. On the other hand if these changes start happening beyond this point that means that there is a lack of communication between the parties. More frequent communication and collaboration helps the project team to achieve their original goal.

### ***2.2 Number of authorized changes addenda***

Number of authorized changes addenda sent to all participants to ensure that these changes are incorporated in the process in a satisfactory manner.

### ***2.3 Percentage of rework***

It can be expressed as a percentage of the work to be redone to the total preplanned. This indicator shows how collaborative are the project team members in exchanging their

knowledge. The less percentage of rework, the higher degree of collaboration and integration involved.

### **3. Request for Information (RFI) control process**

#### ***3.1 Number of RFIs***

RFI is a document prepared by one project participant to solicit information from another participant related to a particular part of the product. This information can be either missing, unclearly defined or misinterpreted by the requester. It is an indicator of the effectiveness of the communication among the project participants and how it helps to reduce uncertainty.

#### ***3.2 Time to respond to the RFIs***

The time needed to respond to the RFI can be measured by the “Coordination Latency”, The amount of time elapses between request of information or action and the satisfaction of this request. [36] The time to respond to the initiated RFI indicates the effectiveness of the communication and collaboration among the project team.

### **4. Cost and schedule control**

Effective and good communication will help the project participants to identify ways to exploit the project resources more effectively or come up with innovative methods for constructing the project faster and cheaper.

### **5. Information exchange process:**

The following attributes of the information exchange process are indicators of how well the project participants are transferring their knowledge.

- Incorporation of design information into production information.
- Incorporation of the builders’ perspectives.

- Data exchange format emphasizing seamless knowledge transfer.
- Communication mechanisms. (project websites, prolog web, etc.)

## **6. Degree of tasks interdependency**

The Coordination of interdependencies between tasks in collaborative environments is extremely important. There are two types of tasks interdependencies: temporal and resource management. Temporal interdependencies establish the execution order of tasks. Resource management dependencies deal with resource distribution among tasks. [18]

## **7. Involvement of Lean construction principles (Timeliness or JIT, Transparency)**

The inclusion of the lean construction principles will leverage the level of integration and enhancer collaboration. The three main principles are quality, timeliness or Just in Time (JIT) and transparency.

*Quality*, Emphasizing quality in the planning phase is a necessity to enhance productivity and improve the output product quality.

*Timeliness or JIT* means that production flow is pulled forward by downstream processes, and resources are provided at the needed time in the needed amount.

*Transparency* promotes the visibility of problems so that different participants will have the correct understanding of the work progress. With transparency in schedules, hidden constraints that delay processes unnecessarily can be identified, and correct decisions such as expediting the key constraints can be made. Thus, all participants can work toward the common goal.

Transparency increases the visibility of errors and stimulates motivation for improvement. Increasing transparency involves two parts: production process and project organizational structure. Facilitating communication is the key in this principle. All parties are

responsible for exchanging information to make their work processes more transparent to the others. [19]

## **8. Productivity**

Productivity is an economic indicator that measures the output per hour of work. It can be an indicator of how well the process is going.

### **4.4.2 Product related Indicators**

## **9. Number of change orders**

Change orders are typical in construction projects. These may be originated by the owner, the contractor, or the design engineer.

Owner changes are due to changes in the original scope of the functional or maintenance requirements for the project. The contractor might originate some changes, The design engineer might initiate some changes due to his/her inadequate knowledge of the existing conditions at project sites, design E&Os. So, less number of change orders is a good sign of higher level of collaboration and integration.

## **10. Percentage of errors & omissions**

Design errors and omissions (E&Os) are typically found in construction documents. E&Os are usually manifested in terms of incorrect or inconsistent dimensions and layouts in the construction documents, spatial interferences, or by the lack of timely and correct information that it is needed to build the project. These can be due to the designer's insufficient or poor knowledge of the construction process, or they might happen by implementing some changes in a specific area without proper assessment of the consequences of these changes. Another reason for those E&Os is inadequate communication of design information among the various design parties due to the poor

coordination procedures. It can be calculated as a % rework. E&Os % is a reflection of how well the project team is integrating their knowledge.

**11. Overall performance of the project.** The overall performance of the project can be assessed by calculating the following ratios (Budgeted cost/ Actual cost) and (original duration/actual duration), and also by comparing the specified quality with the output quality. This indicator captures how well the project performed which reflects the harmonization and integration of all aspects.

**12. Construction problems (Operability, constructability of design)**

This indicator quantifies the number of the construction problems that happened due to the constructability and operability of the design. The less the constructability problems are, the higher level of integration.

**4.4.3 Organization related Indicators**

**13. Efficiency in Dissemination of knowledge**

This indicator to measure the competence of the project participants in communicating their knowledge. It depends on the organization structure and how it is structured in a way to leverage the transfer, Motivation and enthusiasm of the participants to share their knowledge and receive new knowledge from other participant.

**14. Contractual agreement.**

Type of contractual agreement whether it is integration enabling or not. A contractual clause is usually used to enforce the participants to collaborate. (Partnership clause)



## **15. Mutual trust**

Mutual trust is defined as: “The confidence and reliance one party has in the professional competence and integrity of the other party to successfully execute a project in the spirit of open communication and fairness” [94]. As per this definition mutual trust considered an indicator for integrating the knowledge of the project team seamlessly and openly.

## **16. Professionalism of the participants**

The sufficiency between the personnel and the role they perform. This indicator can be measured by considering the expertise of the project participants. It can be detected by the number of licensed professional engineers in the project because they are supposed to exhibit a common set of high standards pertaining to their education, experience, examination, and ethics. This type of engineer is able to contribute to an improved relationship of the owner-designer-constructor team for any type of project. [38]

## **17. Organization Structure**

The organization structure of the involved organizations in the project determines the cultural and behavioral barriers. It is the formal decision-making framework by which job tasks are divided, grouped, and coordinated. The way the involved organizations are structured is definitely affecting the level of integration. For example the mechanistic or the bureaucratic structure does not support integration. Culture and behavior of the involved personnel is an indicator of integration. It captures the way those individuals act and respond in the work environment. Organizational culture is more about the processes used within the organization for communication and knowledge transfer. [4]

### 18. Group communication (Degree of interaction).

Degree of interaction is defined as the extent of interaction among designers, builders and project team members during the project execution. [85]. Pocock, et al. developed the below equation to capture the degree of interaction among the project participants in the different phases of the project. It is an indicator of integration as it captures the extent the project team is collaborating.

$$DOI = \frac{1}{CD} \times \sum_{k=1}^n P_k \times \left[ \sum_{i=1}^{m_k} \left( \frac{t_{ik}}{160} \right) \times D_{ik} \right]$$

Equation 1 The degree of interaction among the project participants [85]

Where DOI = degree of interaction based on man-hours; CD = construction duration in months; n number of project phases (six in this method); PK = weighting factor for each interaction phase, where k = 1,2,3 n; mk = number of persons participating in interaction for each phase (k); tjk h/month each person(i) spent in interaction for each phase (k), where i = 1,2,3 m; 160 = approximate work hours in month; and D<sub>ik</sub> = duration of each person's interaction in months.

### 19. Goals Congruence

Goals congruence is assessed by the extent that individuals and groups perceive their own goals as being satisfied by the accomplishment of organizational goals. It is an indicator of the extent the different organizations involved in the project are sharing the same goals and culture and willing to share his knowledge to accomplish the project successfully [44].

## **20. Deployment of an integration champion.**

Introducing an integration champion personnel is an indicator of integration. Having this personnel on board will facilitate knowledge sharing by considering the necessary actions.

### **4.4.2.4 IT-related Indicators**

## **21. Adoption of technological advancements**

This indicator captures the extent that the project participants adopting the new emerging Information technology tools to support and facilitate integration throughout the different phases of the project either for facilitating collaboration or supporting the different tasks involved in the project.

## **4.3 Traditional development process for colleges and universities facilities**

The building development process starts with a client realizing a need for a construction product (a constructed facility). Various participants then need to be engaged to contribute towards the realization of this particular facility.

According to Turner (2006), a project is a temporary organization that involves the bringing together of various resources to achieve a specific short-term objective. [103]

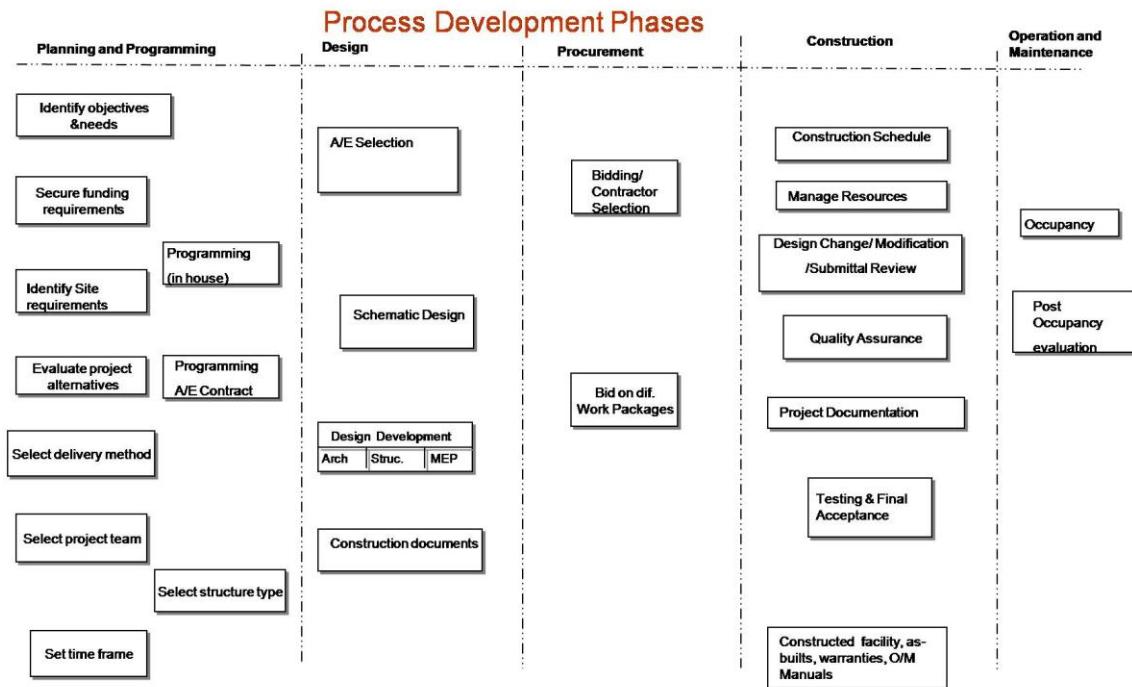
Newcombe (2003) defined the project as a coalition of powerful individuals and interest groups. This coalition is necessary because of the extensive fragmentation and specialization within construction [68]. This coalition, also referred to as a supply chain [43] must be constituted to bring together the various specializations, labor, capital and

other resources required for the project. Given that organizations are generally groups of people cooperating and/or working together to achieve specific objectives which cannot be achieved by any single individual, these construction supply chains can also be viewed as organizations, or more appropriately as a multi-organization and all the pre-requisites for effective functioning of an organization apply, including a common objective and an appropriate organizational culture that is congruent with the environment. [101]

Figure 4-4 below graphically displays the model of the development process of a typical educational facility. It has been obtained by reviewing the literature then validating it by interviewing the vice president for Facilities at Worcester Polytechnic Institute who provided some information based on his 25 years of experience in developing colleges and universities facilities.

The model has been then modified and expanded to show more breakdown of the process. The graph shows the breakdown of the development process into the five major phases nationally accepted by the A/E/C industry: Planning and Programming, Design, Procurement, Construction and Operation and Maintenance. Within each phase, the main tasks that have to be executed are listed.

The model is represented from the owner point of view and it assumes that the regulatory requirements related issues have been resolved and the project has been approved.



**Development Process of colleges/universities Facilities**

**Figure 4-4 Traditional Development Process of colleges/universities**

## 4.4 IT-based integrated life cycle for colleges and universities.

This section describes how each of the above phases of the process life cycle can be executed in an IT-based integrated fashion. In making these descriptions, the author has considered the fundamental conditions for IT-based integration.

### 4.4.1 IT- based Integrated Planning and programming

The planning and programming is the vehicle for superior performance of any construction project. It provides the basics or the essentials for subsequent phases to realize the final product. It also establishes the benchmark for the project control system to track the quality, cost and time previously allocated to execute the project. The

planning and programming phase incorporates several tasks such as: definition of objectives and needs, master planning to accommodate anticipated future needs; evaluation of project alternatives; identification of site requirements; structure type, funding requirements and selection of the project team.

At this stage, integration of the owner's knowledge with designers, contractor, and vendor's knowledge is essential to agree on the project requirements and develop a common vision, reduce uncertainties and potential for future conflicts and ensure that the owner's expectations are realistic within the available resources. [65] In order to accomplish this, the owner has to hire consultants as well as construction managers to utilize their expertise in programming and preconstruction planning.

Now for IT-based integration in the planning phase, there should be a coordinated electronic linkage thorough IT technologies such as: e-mails, project extranets, model-based collaboration and video conferencing between the different organizations involved to support the decision making process, facilitate communication and hence promote integration. Besides, computer systems and applications that can help embodying the knowledge specific to the different project participants [65] should be introduced in the planning phase to augment their knowledge while realizing their desired facility.

In the following section, the author will list the anticipated outcomes of executing the planning phase in an ITDCI fashion then identifies actions and mechanisms that need to be activated to facilitate knowledge transfer and promote integration while executing the different tasks involved.

Puddicombe, 1997 who addressed that knowledge creation can be seen as efforts to facilitate the combination and conversion of the knowledge and experiences embedded in

team members into a new form that support the development of a well defined and integrated product.

**Anticipated outcomes of an integrated planning phase:**

1. All project participants are working cooperatively toward a common goal.
2. Owner's (Board of trustees, President) plans and expectations expressed and understood by all team members. (Characteristics of the desired facility, constraints, etc.).
3. A well structured execution plan has been identified and communicated by all the involved parties.
4. Inclusion of the builders, suppliers and vendors perspective.
5. Project cost, schedule, quality have been identified to a greater level of detail.
6. Communication methodologies and technologies are identified and key parameters agreed upon
7. The right knowledge and the right personnel are selected to proceed with the project.
8. Performance goals are developed by the team: based on the complete building life span including operation.
9. Considering current/future operational conditions of the facility in the development process of the current facility.
10. All alternatives had been evaluated and considered.

#### **4.4.1.1 ITDCI mechanisms in the planning phase:**

- 1- Holding an initial kickoff meeting to bring the project team together. (Owner, Chief of Officer, dean of students, director of students affairs and campus life, director of physical plants, designers and contractors and students as end users)
- 2- Considering specific actions to set the tone for cooperation throughout the project toward a common goal. (Training programs, incentives, etc.)
- 3- Owner's (Board of trustees, President) plans and expectations expressed and understood by all team members. (Characteristics of the desired facility, constraints, etc.)
- 4- Sharing a compatible philosophy among the all team members and the owner. (Culture, vision and goal congruence)
- 5- Establishing and communicating clear and complete objectives to all project members.
- 6- Enforcing a contractual agreement (or otherwise) requirement set by the owner for the use of IT-tools to support the communication coordination process. (Project website, webinars, e-mail, BIM, etc.)
- 7- Implementing organizational changes to enable effective utilization of information technology. (creation of a customized job to serve this service)
- 8- Allocating competent key role people who are capable of taking decision in a timely manner.
- 9- Enforcing prequalification criteria by the owner to assess the ability of the designer to integrate multi-disciplinary aspects of the facility with the institution short and long term needs and objectives
- 10- Establishing procedures to ensure the sufficiency between the personnel and the role they perform.



- 11-Committing and dedicating representatives from the different parties involved to the project.
- 12- Putting mechanisms (contractual agreements) in place to enforce mutual respect and open/honest communication flow amongst the different parties involved
- 13- Conveying the program developed by the designer in clear and concise terms to clear and minimize uncertainties.
- 14- Considering most or all of the performance-based objectives in the planning phase.  
(Quality, cost/schedule control and Value Engineering)
- 15- Establishing procedures to allow the owner and designers exchange the information in a continuous manner.
- 16- Setting Standard protocols and format for communication between all project team members.
- 17- Setting a contingency plan to manage possible breaching of the previously identified mechanisms.
- 18- Establishing and approving the time schedules and campus schedule-related contingency plans by every affected party.
- 19- Developing format to integrate the expertise from the design and operation of other campus facilities to the design and construction of this facility
- 20- Establishing procedures and actions to solve technical issues that might arise in a timely manner. (equipments reliability, configuration control, etc.)
- 21- Incorporating the builder's perspective. (Construction methods)
- 22- Considering current/future operational conditions of the facility.

23- Creating a central file repository to post and store the entire project related documents and information

24- Setting an interoperable file format for exchanging information and support feedback mechanism/ (DWG, PDF, DWF, etc.)

25- Deciding upon the software that is going to be used in the planning stage to support budget preparation and cost control and ensuring that it is operable with other CAD software that is being used by the designer.

26- Establishing pre-qualifications or selection criteria established to ensure that all project professionals are equipped with IT- tools that support their provided services and in the time disseminate their knowledge.

27- Addressing the issue of technology interoperability to cross-pollinate their products-related knowledge. (Share and co-produce electronic files)

28- Pre-setting specifications to address the required BIM level of detail for different areas and disciplines of the project.

29- Using the Building Information Model to evaluate the different alternatives (sensitivity analysis)

30- Using AutoCAD<sup>®</sup> Civil 3D<sup>®</sup> to develop site analysis.

31- Developing a GIS map of the campus to better understand spending cycle, monitoring and analyzing the trends to optimize the planning process.

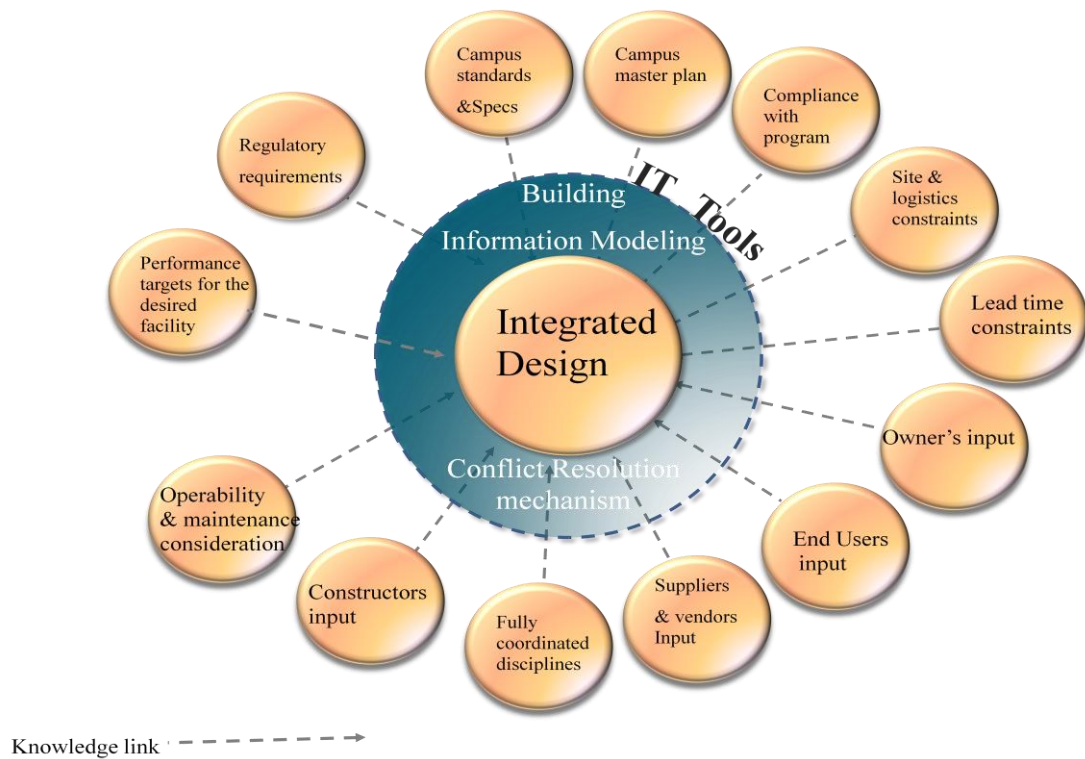
#### **4.4.2 IT-based Integrated Design**

The design process of any facility comprises all the functions required to satisfy the owner's needs and communicate it to the constructor by turning the program and the execution plan into construction documents, while at the same time enforcing the project

controls and constraints. While the traditional design process relies on the expertise of specialists who work in their respective specialties somewhat isolated from each other, the “Integrated Design Process” (IDP) relies heavily on the input and involvement of all project team members including owner, end users, and constructors to be working side by side while defining the design and how it would be realized bounded by the project constraints. This approach helps them to identify and resolve potential design conflicts that traditionally may not be discovered until construction

The IDP requires the integration of the knowledge of the designers and all stakeholders to continually interact and work together across the life cycle of the project, from defining the need for a building, through planning, design, construction, building occupancy, and operations to develop and evaluate the design for cost, quality-of-life, future flexibility, efficiency; overall environmental impact; productivity, creativity; and occupants comfort. (International Initiative for sustainable build environment, [www.iisbe.org](http://www.iisbe.org)). Figure 4-3 below is a graphic representation of the integrated design process developed by the international initiative for sustainable built environment.

The design documents developed by a discipline consultant should be easily interpreted and understood by other trade specialists. So, these design documents can be used to either increase their knowledge about the project or to build upon this knowledge to execute a certain sub-process in the development process. Utilizing IT- tools (model-based technology) such Building information Model (BIM) to generate design documents can serve this purpose.



**Figure 4-5 Integrated Design Process---** adopted from the international initiative for sustainable built environment

To measure the level of IT-based integration in the design process, the author first, looked at the major tasks of the traditional design process in section 4.3, identified actions and mechanisms related to the organization, process, product and information technology that need to be taken to satisfy the ITDCI requirements. Also, the desired characteristics of the end product of this phase (integrated design) have been listed.

**Anticipated outcomes of an integrated phase:**

- Better coordinated design documents with minimum or no design errors and omissions

- Coordinated and integrated building systems and performance requirements.
- Resolved or min. constructability issues.
- Harmonized design that fits perfectly into the campus architectural style and master plan.
- Regulatory compliant & campus standards compliant design documents.
- Validated target cost through continuous integration.(GC & subs input)
- Validated targeted schedule through continuous integration.(GC and subs input)

#### **4.4.2.1 ITDCI mechanisms in the design phase**

1. Effective involvement and contribution of the owner in the design process in a timely manner.
2. Assigning someone in the project (design facilitator) to identify in a timely manner potential conflicts among different design disciplines and acquire design specialists inputs as required.
3. Continuous inter-disciplinary collaboration between architects, engineers, cost engineers, operation staff and other relevant actors right from the beginning of the design process.
- 4- Establishing procedures to ensure that all design decisions that require multi-disciplinary input are made in a timely manner.
- 5- Setting an agreement between the owner and the designers upon the relative importance of the various performance issues.
- 6- Considering the harmonization of the facility with other campus facilities.

- 7- Identifying and emphasizing the project constraints in terms of time and cost continuously while developing the design.
8. Continuous testing of the conformance of the design to the design functional requirements according to the university codes and standards.
- 9- Communicating and understanding the developed design to/by all design professionals.
10. Evaluating different alternatives for cost/schedule and logistics constraints.
11. Evaluating alternatives against fabrication and lead time constraints.
12. Evaluating different alternatives for operability and maintenance.
13. Identifying specific dates for reviewing key submissions and deliverables for compliance with program goals and design objectives.
14. Using BIM to develop the design documents.
- 15- Using BIM as a reliable database for communication and collaboration.
16. Using coordinated information network for designers to ensure the availability of the required knowledge related to the design intent, procedures and options in a timely manner.
17. Creating a central file repository to post /store and access the different materials or systems catalogues and brochures.
18. Using software packages like Navisworks® or any similar one to detect clashes and interferences between different design disciplines.

#### **4.4.3 IT-based integrated procurement process:**

Traditional procurement process is the solicitation and selection process enabling the acquisition of goods or services from an external source. It is also defined as the process

from the completion of design to the successful commissioning of the assembly of the building.

In order to reach a decision and to determine the winning bid, there are some steps that have to be followed such as: request for proposals (RFP), invitation for bids (IFB) and bids awarding (BA). The traditional form of procurement is where the designer does not have direct link with the vendors and suppliers and all communication is via the main contractor. The owner appoints independent consultants, on a fee basis, who fully design the project and prepare bid documents upon which competitive bids are obtained from contractors.

Whilst in the integrated procurement method, there is a direct involvement of the trade contractors and vendors from the early beginning of the planning phase to integrate their knowledge in the process by continuously incorporating their feedback in terms of the viability of the perceived design. The decision making process in the integrated process differs from the traditional in a way that key decisions need to be made early to avoid expensive alteration to the design. This also allows early procurement of the different work packages especially those packages that necessitate long lead times, custom or prefabricated items (AIA, IPD guide). The use of this system of procurement enables the commencement of the project to be accelerated, which in turn, should enable earlier completion to be achieved than when using conventional procurement systems.

Until early last decade, public school districts and institutions of higher education were required to utilize competitive bidding with the “lowest price” for the award of their construction contracts. (Construction and procurement Handbook)

The S.D.I departed from that traditional basis for awarding contracts by allowing school districts to use a variety of different contracting methods to obtain the "best value" for the school district. With this change, school districts are now permitted to consider other evaluation factors in determining to whom to award a contract rather than the "lowest price" such as: the reputation of the vendor; the quality of the vendor's goods or services; the extent to which the goods or services meet the district's needs, the vendor's past relationship with the district; and any other relevant factor that a private business entity would consider in selecting a vendor. However, the new legislation did not provide adequate guidance to the school districts on what procedures should be utilized to select the evaluation factors to obtain the best value for the school.

The "best value" concept goes well with the integrated procurement process since they both mandate the inclusion or integration of the necessary knowledge related to the participants, process and the product which is the bid in this phase.

In the following section, the author will list the desired outcomes of the integrated procurement process then identifies the actions and mechanisms that have to be activated while executing each task to maintain the integration of the three components: Organization, Process and Product with the support of IT-tools.

**Anticipated outcomes of an integrated procurement phase:**

- Continuous and seamless interaction between the design system and the suppliers to enable detailed and accurate design.
- Optimized and coordinated work packages.



- Selected products, qualified suppliers, and best products procured at the best prices with complete confidence and ability to deliver on time and within budget.
- Orchestrated resources for optimal construction efficiency.
- It-based accurate and complete electronic procurement packages including 3D product definitions, product specifications, procurement format standards, and supporting analytical models.

#### **4.4.3.1 ITDCI mechanisms in the procurement phase**

- 1- Incorporating of the vendors and suppliers expertise regarding the constructability, materials availability while preparing the bids documents.
- 2- Certification of the bidder to the owner that each engineer or architect of its team was selected based on demonstrated competence and qualifications.
- 3- Consideration of the owner or his representative of the bidder's experience, technical competence, capability to perform and the past performance of the bidder's team members.
- 4- Evaluating the bidders on the basis of the safety and long-term durability of the project.
- 5- Evaluating the different alternatives to optimize and orchestrate the involved resources.
- 6- Considering the design output performance specifications (bill of materials, schedule, cost targets, delivery requirements to solicit and evaluate bids, make source selection recommendations and place orders.

7- Establishing procedures to ensure the integration and compatibility of the different work packages.

8- Accommodating and communicating all of the implemented site changes to all of the affected parties and packages.

9- Using BIM to extract quantities for procuring the different work packages.

10- Deploying the appropriate IT-tools in place to identify and solicit qualified bidders and support evaluation of source capabilities and ability to deliver.

11- Setting a reliable way of communication to ensure proper and standardized means of representing information/knowledge to support project management, project controls, material and labor tracking, engineering and procurement functions.

12- Creating a central file repository to post /store and access the subcontractors/vendors quotations of different materials or systems to maintain on-line knowledge bases coupled with performance specifications.

#### **4.4.4 IT-based integrated construction process:**

The construction process of any facility involves all the activities needed to translate the available resources into a completed facility. The four major activities in the construction process are: acquire construction services, plan and control the work, provide the needed resources and execute the field operation.

The successful execution of the construction process is critical to the overall success of the project [110]. This is because according to Lim and Mohamed [109], the construction phase is the phase where all the project goals like time, cost, quality, safety and the like are put to the test. Whilst this may be true in many cases – certainly in the traditional

approach – it is not the case in the integrated process where it extends to the pre-construction phase.

In the integrated construction process, the designers and other members of the team project must remain fully involved. Decisions previously made may require clarification; suppliers' information must be reviewed for compliance with the contract documents; and alterations must be evaluated. It is extremely important that the user/clients also stay involved. Any changes to the original design and necessitate changes in the building must be thoroughly investigated and discussed among all of the project team members.

For IT-based construction integration, information technology tools should be utilized to support the integration of the process and help the construction team to model, analyze and evaluate the performance of the desired facility. Besides, it also supports the knowledge transfer process between the project team members in a timely manner.

Constructing a well structured and integrated university facility necessitates the capturing of all aspects of the integrated construction process as discussed above to best fit the institute or the university targeted goals and produce a sustainable facility that lasts for decades. Following, is a list of the desired outcomes or results when executing the construction process in IT- based environment.

**Anticipated outcomes of an integrated construction phase:**

- Minimum field changes and better information flow among the design and construction teams.
- Better interpretation of the design intent during construction based on the utilization of BIM visualization capabilities.

- Better constructability based on parametric models to see the project components and how they work together.
- Fewer errors and corrections in the field due to the ability to produce look ahead virtual construction models to illustrate the crowdedness of the site at any given time, utilize available space efficiently, detect conflicts between different construction trades early and accordingly resolve them
- More sophisticated site logistics by executing “what if” scenarios to look at various sequencing options and associated cost.
- Better visualization of the actual construction schedule versus the planned schedule allowing identifying better ways to accelerate the construction process

#### **4.4.4.1ITDCI mechanisms in the construction phase:**

1. Executed constructability review sessions to ensure compatibility between the different systems of the building.
2. Developed standards to enhance the accuracy of the shop drawings.
3. Streamlined standard process to shorten shop drawings submittal/approval time.
4. Discussed and optimized work sequencing among the trade contractors.
5. Revised and coordinated the delivery of materials and equipments according to the construction schedule to ensure efficient flow of work.
6. Scheduled meetings on a regular basis between the design and construction teams to discuss the actual conditions of the construction process to minimize or eliminate field changes.
7. Used the BIM to execute what if scenarios for site logistics studies.

8. Tied the construction schedule to the BIM to reflect the project progress.
9. Used the BIM to generate 3-week look-ahead virtual construction views to help optimize the construction activities and better track the construction progress.
10. Continually updated the BIM according to the “as built” conditions.

#### **4.4.5 IT-based integrated O&M process:**

The operation and maintenance phase of the development process is very crucial in the life cycle of educational facilities. All of the information related to the design, construction, and management has to be well documented to ensure efficient operability. Since this information is contained in a number of formats which include paper drawings, digital CAD files, owner’s manuals, design specifications, and maintenance records. It is often difficult to manage due to different formats and lack of standardization; it cannot be easily combined into a single repository of information that is useful for managing a facility. New emerging IT tools such as BIM can play a distinctive way in organizing, storing, and maintaining information about the physical nature of a building. Not only that but when using BIM, a facility manager can click on a component in the computer model and see information about that item including manufacturer, model, serial number, specifications, and even maintenance history. The model could also allow more complex analysis, such as simulations of smoke propagation during a fire or how the facility would fare in severe weather.

#### **Anticipated outcomes of an integrated operation& maintenance phase:**

- Integrated warranties, brochures and operation and maintenance information.

- Updated BIM with all of the “as built” information.

#### **4.4.5.1 ITDCI mechanisms in the operation & maintenance phase:**

1- Obtaining and updating the BIM model with the 'as built" information.

2- Gathering and documenting all the information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components of the building.

3- Linking and incorporating the previous information (information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components) in the BIM model.

## **Chapter 5 Academic survey**

### **5.1 Objectives**

An online survey was conducted to collect data from the colleges and universities community segment of the construction industry. The main purpose of the survey was to validate the model by exploring the extent to which the ITDCI actions and mechanisms identified by the researcher were involved in the development of new or renovation of an existing capital investment facilities at colleges and universities. The survey was also used to assess the extent to which the participants were relying on IT-tools to facilitate this integration. The targeted respondents were asked to answer this survey in the context of a recently completed project (not more than five years ago) with the following characteristics:

- The project met the expected objectives.
- There was a positive experience in collaborating and communicating with the project participants.
- Information Technology was used to any extent to support and facilitate communication and collaboration.

### **5.2 Survey design**

The survey targeted facility owners represented by the facility planners for higher education institutions in the United States. The respondents of the survey were reached through the assistance of the Society for College and University Planning (SCUP) membership via their weekly newsletter which is delivered electronically to their members.

The survey consisted of 6 parts: the first five parts (A, B, C, D & E), and the final part (F) which was optional and asked the respondents to provide their personal contact information for future contact to provide them with the research results. Each of the first five parts related to one phase of the ITDCI process: planning, design, procurement, construction and operation and maintenance. For each part, the phase was defined and a set of questions related to the phase followed. Table 5-1 shows the number of questions in each part with a total of 78 questions.

**Table 5-1 shows the number of questions in each part**

Part	# of Qs
Part A	34
Part B	18
Part C	12
Part D	11
Part E	3
Total	78

The survey form was created and made available online using the Survey Monkey website. Survey Monkey is an intelligent survey software to create professional online surveys quickly and easily on a designated Internet address.

[\(http://www.surveymonkey.com/\)](http://www.surveymonkey.com/)

The survey was approved for public distribution by the WPI Institutional Review Board (IRB). A hard copy of the survey form is in Appendix C.



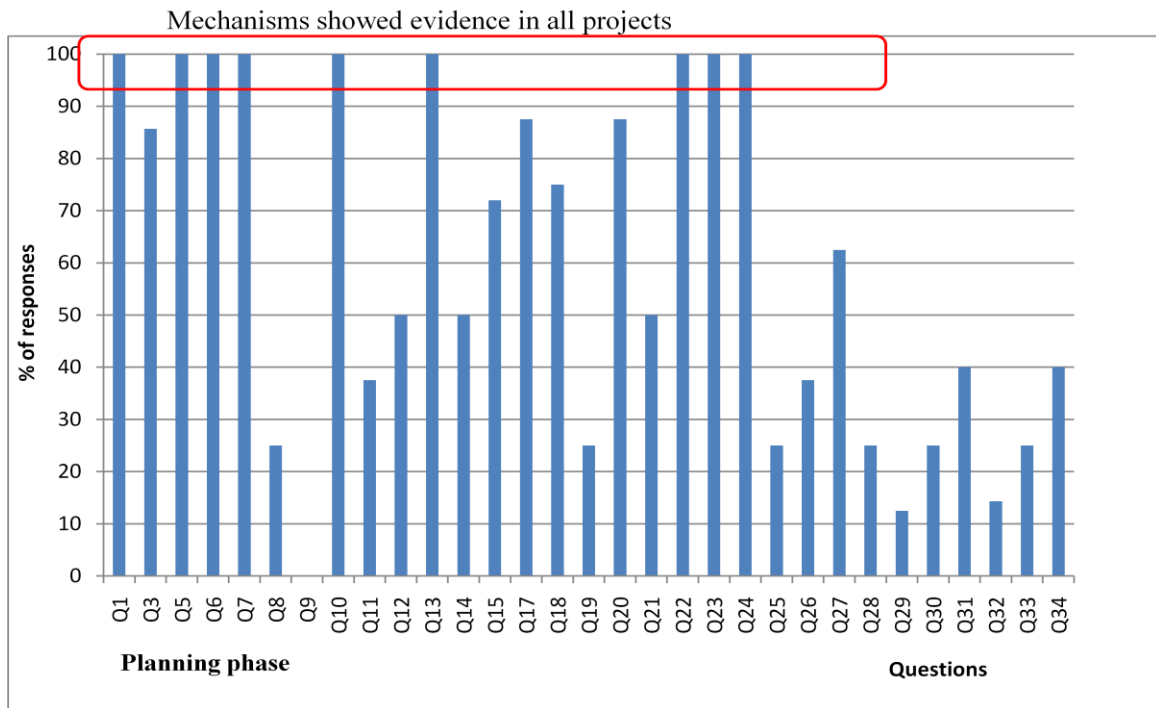
A glossary of the most important terms used in the survey was made available to the respondents at the second page of the survey after a brief introduction to the research in the first page.

### **5.3 Survey Results**

The survey was released on September 23, 2008. The SCUP members were asked to submit their answers within three weeks period. After one week, another follow-up message was sent to remind the members about the deadline on the survey. Eight survey responses were collected through Survey Monkey database and transferred to Microsoft Excel spreadsheet. The data were sorted and filtered in accordance with the purpose of this work.

*In Part A, the responders were asked to assess* the extent to which the mechanisms that promote the integrated development were incorporated during the planning phase in their projects.

Figure 5-1 shows the percent of responses received for each of the 34 questions included in this part except questions no. 2, 4 and 16. While thirty one of the questions represented one ITDCI, questions (2, 4 and 16) were asked to capture in more detail how the ITDCI mechanisms were introduced. Ten out of the thirty one questions capture the extent to which IT-tools were involved to leverage the level of integration. The graph shows that nine of those mechanisms were 100% present in all of the projects.



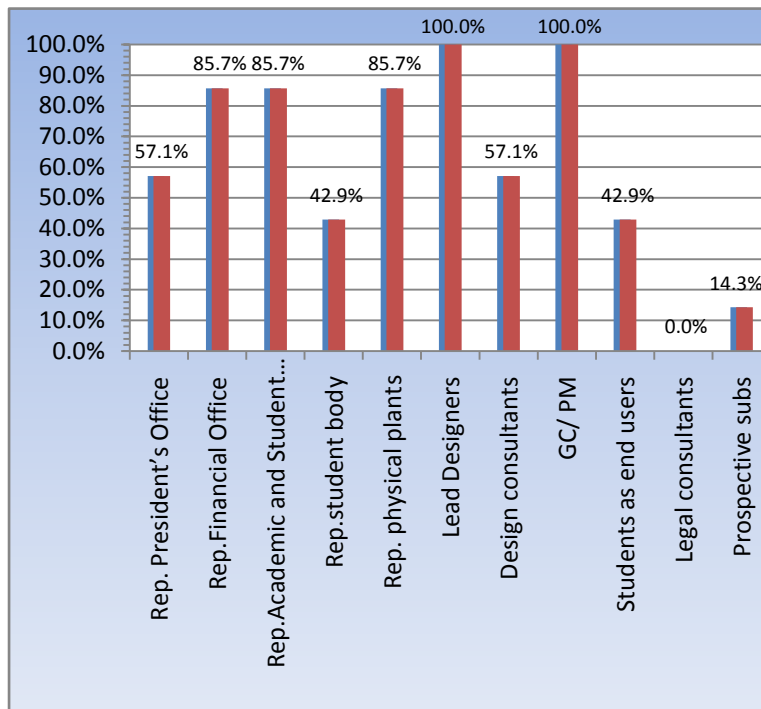
**Figure 5-1 Overall responses to the ITDCI mechanisms in the planning phase**

Five mechanisms were there in 70% - 90% of the projects (Q3, Q15, Q17, Q18 and Q20), while 7 mechanisms were evident in 30-70 % of the projects (Q11, Q12, Q14, Q21, Q26, Q31 and Q34). The remaining 10 mechanisms existed in 30 % of the projects. The mechanisms that were present in all of the projects were:

- Holding an initial kick off meeting to bring the project team together.
- Expressing the Owner’s plans and expectations clearly to all project team members.
- Ensuring a compatible and shared culture among all project team members.
- Establishing a timely and clear objectives and communicate them to all project team members.

- Allocating competent key personnel by the owner who are capable of making decisions in a timely manner.
- Committing and dedicating representatives from the different parties involved to the project.
- Considering the current/future operation conditions in the planning phase.
- Incorporating the builders' perspective in the planning phase.
- Establishing procedures and actions to solve technical issues that might arise in a timely manner.

The three questions which were asked to explain in more details how the ITDCI were introduced were questions no.2, 4, and 16. Question no.2 asked the respondents to list who was involved in the kick off meeting. Figure 5-2 shows the percentage of the involvement of the different project parties in the kick off meeting. The lead designers and the general contractors were involved in all of the projects, the institutional representatives of the student life , physical plants and the financial office were involved in 85% of the projects, the institutional representatives of the student body and the institutional representative were there in almost 50% of the project. The prospective sub-contractors and the legal bodies were not there in almost all of the projects. However it is very important that they should be there to provide their feedback and contribute their knowledge early in the process.



**Figure 5-2 Percentage of the different project parties involvement in the kick off meeting**

In Question no.4, the respondents were asked to specify the type of actions that they took to set the tone for cooperation and collaboration throughout the project. Three choices were given to them to choose from. They also had the choice to specify any other actions they considered. In 40% of the responses, the respondents introduced training programs and incentives to encourage more collaboration among the project team. Partnering agreement was introduced in one project. Each of the remaining responses, respondents took different actions like:

- Discussion of individual and group talents and experience, commitment to shared vision of the quality of the end product.
- Inviting presence and tone of collaboration set by the Owner and Designer when CM joined the team.
- Owner's challenge to finish the project by certain date.

- Running Design Forums or Design "Tapedowns" during the planning phase.

**Part B** of the survey was intended to assess the extent to which the ITDCI mechanisms were incorporated during the design phase. It consisted of 18 questions. 5 out of the 18 questions were asked to capture the extent the IT-tools were involved during the design phase. Figure 5-3 below shows that 4 out of the 13 mechanisms were present in all of the responders selected project. These mechanisms were:

- Identifying and emphasizing the project constraints in terms of time and cost continuously while developing the design.
- Evaluating different alternatives for cost/schedule and logistics constraints.
- Evaluating alternatives against fabrication and lead time constraints.
- Identifying specific dates for reviewing key submissions and deliverables for compliance with program goals and design objectives.

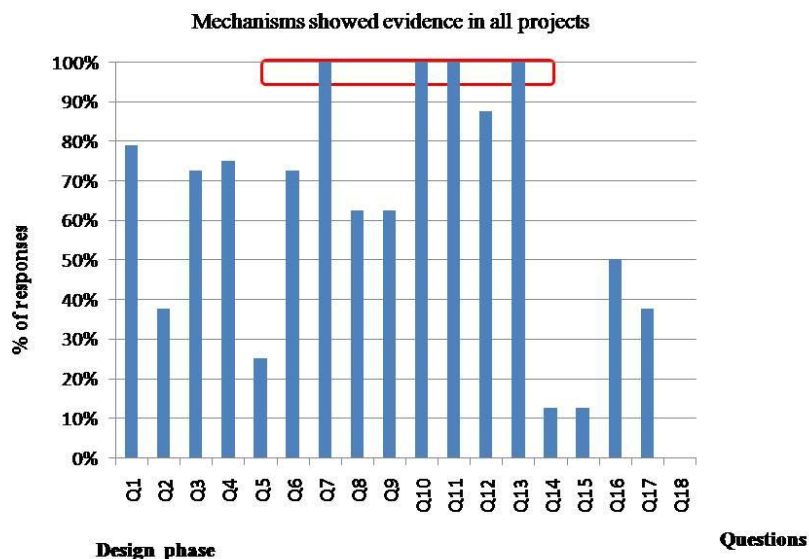


Figure 5-3 Overall responses to the ITDCI mechanisms in the design phase

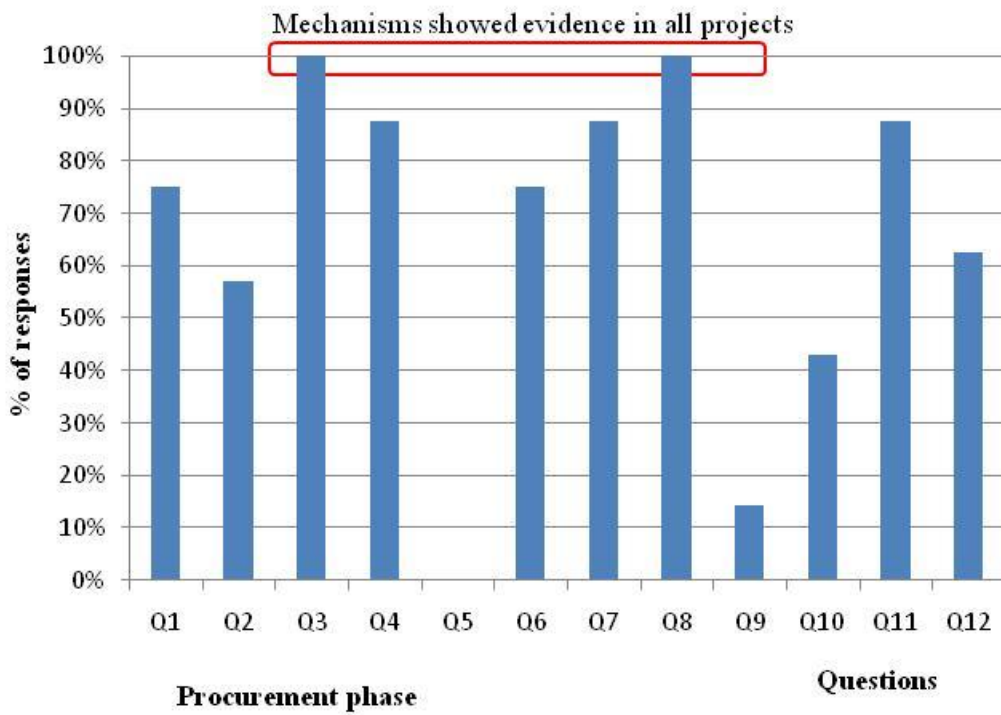
The answers of the responders showed that 6 of the mechanisms were present in 70%-90% of the projects. These are:

- Addressing the design decisions that require multidisciplinary input in a timely manner.
- Testing the design conformance to the university design functional requirements in terms of codes/standards.
- Communicating and understanding the developed design by all design professionals.
- Evaluating the different design alternatives against fabrication and lead time constraints.
- Evaluating the different design alternatives for operability and maintenance.
- Providing a coordinated information network for different design consultants to ensure the availability of the knowledge related to the design intent, procedures and options in a timely manner.

As far as the rest of the mechanisms, 5 of them existed in 50% of the projects while the last 4 mechanisms were present in less than 30% of the projects.

*In Part C, the responders were asked to assess* the extent to which the mechanisms that promote the integrated development were incorporated during the procurement phase in their projects.

Figure 5-4 shows the overall replies of the responders to the questions that represents ITDCI mechanisms (12 questions). 2 out of the 12 questions capture the extent to which IT-tools were involved to leverage the level of integration. The graph shows that two of those mechanisms were present in all of the projects. Five mechanisms were present in 70%-90% of the projects, while three mechanisms existed in 40%-60% of the projects.



**Figure 5-4 Overall responses to the ITDCI mechanisms in the procurement phase**

One of the mechanisms showed in only one project (represented by Q9) while the remaining mechanism didn't show in any of the projects (represented by Q5). This mechanism was:

- Executing a study to optimize and orchestrate the involved resources.

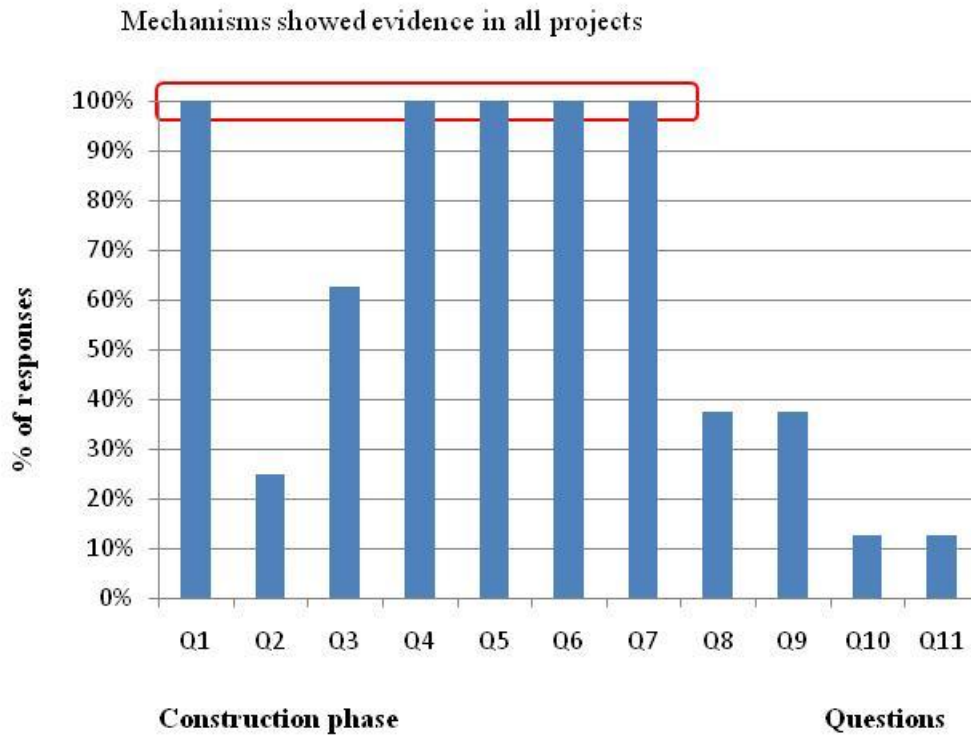
The two mechanisms that were there in all of the projects were:

- Consideration of the owner or his representative of the bidder's experience, technical competence, capability to perform and the past performance of the bidder's team members.
- Accommodating and communicating all of the implemented site changes to all of the affected parties and packages.

*Part D* of the survey was structured to assess the extent to which the ITDCI mechanisms were incorporated during the construction phase. It consisted of 11 questions. Four out of the 11 questions were asked to capture the extent to which the IT-tools were involved during the construction phase. Figure 6-5 below shows that 5 out of the 11 mechanisms were present in all of the projects. These mechanisms were:

- Conducting constructability review sessions to ensure computability between the different systems of the building.
- Discussing and optimizing the work sequencing among the different trade contractors.
- Coordinating the delivery of the materials and equipments according to the construction schedule to ensure efficient work flow.
- Scheduling meetings on a regular basis between the design and construction team to discuss the actual conditions of the construction process in order to minimize or eliminate field changes.
- Considering and coordinating the required information for testing and inspection with the regulatory agencies.





**Figure 5-5 Overall responses to the ITDCI mechanisms in the construction phase**

As far as the other responses, mechanism no. 3 (represented by question no. 3) was present in 62.5% of the projects. Mechanism no. 2: structuring procedures to enhance the accuracy of the shop drawing showed in only 25% of the responders' project.

Mechanisms no.8, 9, 10, and 11 represented by questions no. 8, 9, 10, and 11 were introduced in 12.5%-37.5% of the projects. These mechanisms were:

- Using BIM to execute what/if scenarios for site logistics.
- Tying the construction schedule to the BIM model to visualize and understand the construction progress.
- Using the BIM model to generate 3-week look-ahead construction views to help optimize the construction activities and better track the construction progress.

- Updating the BIM model according to the “as built” conditions.

*Finally in part E, the responders* were asked only two questions (each question represents one mechanism) to assess the extent to which the mechanisms that promote the integrated development were incorporated during the operation and maintenance phase in their projects. The responses showed that the first mechanism was present in 62.5% of the project. That mechanism was:

- Documenting and maintaining all of the information about manufacturer, model, specs and the maintenance history for each component or most of the components of the building.

After considering all of the responses in each part of the survey at which each part represented one phase of the ITDCI process, each response was considered separately. For each response, the total number of ITDCI mechanisms was summed to calculate the overall score. Table 5-2 below shows the ITDCI score in all of the responses. Although the highest possible score was 75 points, none of the responses reached it. Response no. 4 achieved the highest score with 61.1 points while response no.2 had the lowest score with 35.2 points.

**Table 5-2 Overall ITDCI score on all responses**

Response	ITDCI score
Response 1	37.9
Response 2	35.2
Response 3	45.5
Response 4	61.1
Response 5	40.9
Response 6	47
Response 7	43.8
Response 8	36.2

Comparing the results of the responses of the highest and the lowest score, it was found that:

- ITDCI mechanisms were highly introduced in response no. 4, because of the high awareness of the project team members to promote ITDCI. They pre-structured some actions and procedures to maintain ITDCI in the planning phase of the process. This was represented by the presence of the following mechanisms:
  - Enforcing a prequalification criteria by the owner to assess the ability of the designer to integrate multi-disciplinary aspects of the facility with the institution short and long term needs and objectives
  - Establishing procedures to ensure the sufficiency between the personnel and the role they perform. (The right knowledge, etc.)

- Putting mechanisms (contractual agreements) in place to enforce mutual respect and open/honest communication flow amongst the different parties involved
- Setting Standard protocols and format for communication between all project team members.
- Setting a contingency plan to manage possible breaching of the previously identified mechanisms.
- Developing format to integrate the expertise from the design and operation of other campus facilities to the design and construction of this facility?
- Creating a central file repository to post and store the entire project related documents and information
- Deciding upon the software that is going to be used in the planning stage to support budget preparation and cost control and ensuring that it is operable with other CAD software that is being used by the designer.
- Establishing pre-qualifications or selection criteria established to ensure that all project professionals are equipped with IT- tools that support their provided services and in the time disseminate their knowledge.
- Addressing the issue of technology interoperability to cross-pollinate their products-related knowledge. (share and co-produce electronic files)
- Pre-setting specifications to address the required BIM level of detail for different areas and disciplines of the project.
- Using the Building Information Model to evaluate the different alternatives. (Sensitivity analysis).

- Considering the design output performance specifications (bill of materials, schedule, cost targets, delivery requirements to solicit and evaluate bids, make source selection recommendations and place orders.
  - Using BIM to extract quantities for procuring the different work packages.
  - Setting a reliable way of communication to ensure proper and standardized means of representing information/knowledge to support project management, project controls, material and labor tracking, engineering and procurement functions.
  - Structuring procedures to force the sub-contractors to enhance the accuracy of the shop drawings. (incentives, penalties, standards, etc.)
  - Developing a standard process to shorten shop drawings submittal/approval time.
  - Tying the construction schedule to the BIM model to visualize and understand the construction progress.
  - Using the BIM model to generate 3-week look-ahead construction views to help optimize the construction activities and better track the construction progress.
  - Updating the BIM model continually according to the “as built” conditions
- On the other hand, in response no.2, the project team members collaborated together but without considering any pre- structured actions. This could be concluded by the absence of the above mentioned mechanisms and the presence of the following mechanisms:

- An initial kickoff meeting held to bring the project team together? (Owner, Chief of Officer, dean of students, director of students affairs and campus life, director of physical plants, designers and contractors and students as end users)
- Specific actions taken to set the tone for cooperation throughout the project toward a common goal. (Training programs, incentives, etc.)
- Owner's (Board of trustees, President) plans and expectations expressed and understood by all team members. (Characteristics of the desired facility, constraints, etc.)
- All team members share a compatible philosophy with the owner for this project. (culture, vision and goal congruence)
- Clear and complete objectives established and communicated to all project members.
- Committing and dedicating representatives from the different parties involved to the project.
- Establishing procedures to allow the owner and designers exchange the information in a continuous manner.
- Scheduling meetings on a regular basis between the design and construction teams to discuss the actual conditions of the construction process to minimize or eliminate field changes.
- Considering and coordinating the required information for testing and inspection with the regulatory agencies.

- Another reason for the big difference between the ITDCI in both responses is the absence of the IT tools in response no.2 while it was extensively introduced in response no.4.

By looking at all of the eight responses, it was found that some mechanisms were there in all of the projects as expected by the author which were necessary to promote a collaborative work environment for integration. Some of those mechanisms were managerial actions to leverage the level of integration by holding an initial kick off meeting to bring the project team all together and discuss the owner's plan expectation and to promote a tone of cooperation and setting protocols for enhancing communication. From the technical point of view, there were some mechanisms which were considered to maintain integration between the design documents and construction. Examples of these mechanisms were: incorporating the builders' perspective in the design process, evaluating the different design alternatives against cost/schedule/ fabrication.

Important mechanism such as setting a contingency plan to manage possible breaching of the ITDCI mechanisms was absent in 80 % of the projects. However, it should be clearly stated in the contract.

As far as the IT mechanisms that were put in place to assess the extent to which the project participants were utilizing the IT-tools effectively to promote integration, they showed very little involvement in all of the projects. In only one project, (response no.4) BIM was utilized in all phases to act a basis for collaboration and knowledge sharing. This was an expected outcome because the IPD method (Integrated Project Delivery) was used as a delivery method. Table 5-3 shows the distribution of both the IT and non-IT mechanisms in each response and the ITDCI score in both cases. Although there were 26

IT mechanisms, none of the responses scored more than 6 points (almost 25%) except for response no.4 which received 21.5 points (80%).

Figure 5-6 below shows the total ITDCI score that was involved in the responses side-by-side with the ITDCI score with and without the IT mechanisms.

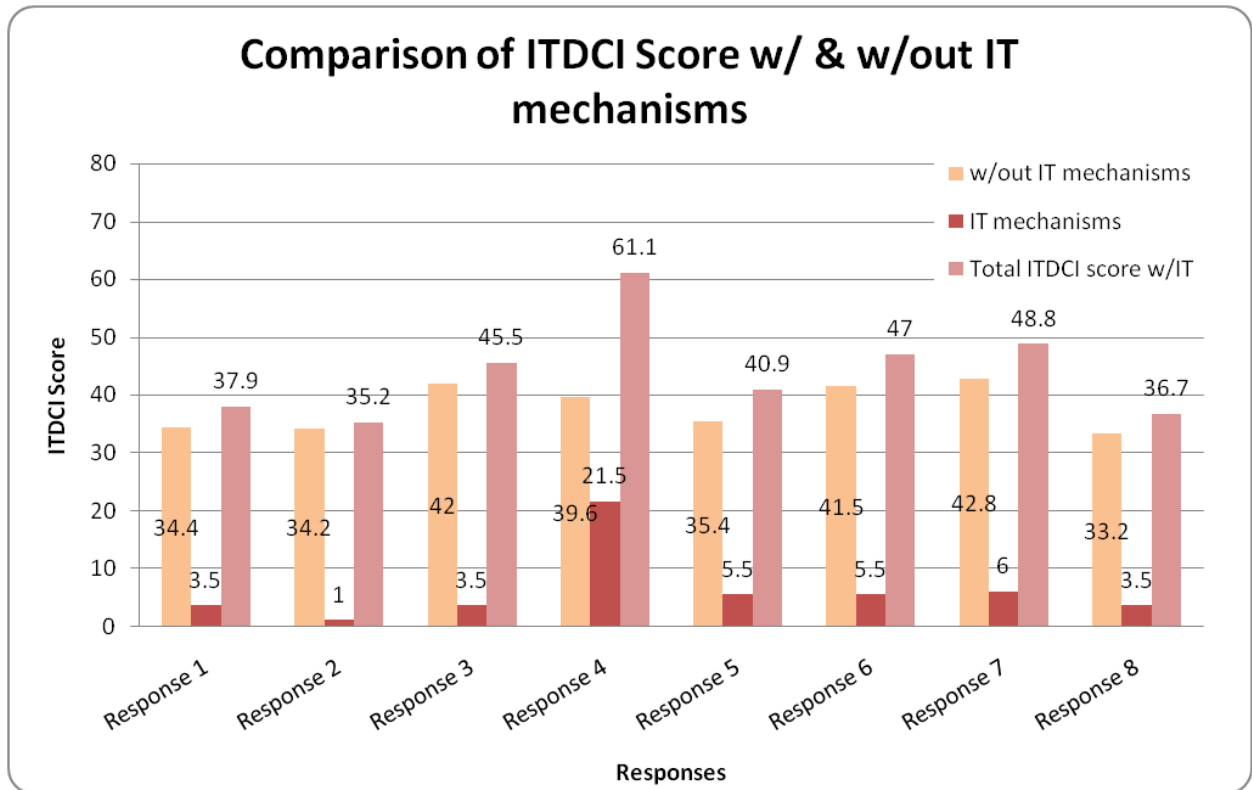


Figure 5-6 ITDCI score w/& w/out IT mechanisms

## 5.4 Discussion

The above results reflected the responders' replies to the survey published by the author to capture the extent to which the ITDCI mechanisms were present in their projects.

After analyzing the survey results, the author was able to observe and find out the trends that were present in the responses of the survey participants. From the managerial point of view, all of the projects experienced open, clear, standard and timely communication



evidenced by the responders' responses to the related questions. Technically, in all of the responses all of the projects had considered the integration and harmonization of the different disciplines and work packages involved. All of the projects utilized more than 50 % of the integration mechanisms (more than 6 points out of 12) in the procurement phase. Also, the evaluation of the different alternatives for cost, schedule, fabrication lead time and operability and maintenance were considered in all of the involved projects. The vendors and the end users perspectives were also involved. However, in the procurement phase none of the responses replied that there was a consideration for the evaluation of the different alternatives to orchestrate the involved resources.

Recommended mechanisms that were missing in most of the projects were for example: presetting actions and standard protocols for communication and collaboration, setting an agreement between the owner and the designers upon the relative importance of the various performance issues. Another important missing but needed mechanism in 5 out of the 8 responses was assigning somebody (design facilitator) to identify in a timely manner potential conflicts among different design disciplines and acquire design specialists inputs as required. It was even absent in response no.4 at which the project team used the Integrated Project Delivery.

As far as the technology is concerned to support collaborative team work, information technology tools were not introduced properly enough. This was evidenced by the absence of the IT mechanisms in almost all of the projects. Recommended actions include: enforcing a contractual agreement to enforce the use of use of IT-tools to support the communication and coordination process; ensuring an IT infrastructure is in place starting from the beginning of the planning phase by implementing any necessary

organizational changes to enable effective utilization of information technology; Setting up a central file repository to post and store all of the project related documents and make it available for all participants; and, using appropriate software for planning and budgeting that is interoperable with the design software. Finally, the project task force must be well equipped and trained with IT- tools that support their provided services and in same time help them to disseminate their knowledge in a timely manner.

More attention should be directed to utilize IT-tools such as project websites and BIM as a basis for collaboration and exchanging the knowledge of the different parties involved and leverages the level of integration among them.

In terms of model validation, the author concluded that the model is significantly important to be used to measure the level of ITDCI involved in the project. Although all of the survey respondents were asked to select projects that experienced a high level of IT-based integration based on extensive level of knowledge transfer and the use of it-tools, the results obtained by using the model showed a discrepancy. There was a difference between the levels of ITDCI obtained for each response. Minimum ITDCI score response was 35.2 points while the maximum score was 61.1. Using the model provided a baseline or a standard way for the responders to assess the extent to which the ITDCI were present in their projects which enabled the quantification of the ITDCI level by using the developed ITDCI model.

Comparing the ITDCI model with the model developed by Mitropoulos and Tatum (2003), it can be concluded that the ITDCI model is considered an expansion of Mitropoulos and Tatum's model. In their model they recommended that project participants should adopt global integration mechanisms to foster integration:

1) Contractual mechanism such as design/build contracts or joint ventures; 2) Organizational mechanisms such partnering or cross-functional units; and 3) Technological mechanisms electronic linkages between involved organization. They did not go beyond these suggestions. However in the IITDCI model, the integration mechanisms were developed to a high degree of detail. The author considered the ITDCI mechanisms that have to be activated in all of the tasks needed to execute each phase of the development process of the project.

## **Chapter 6. Case Study: WPI New Residence East Hall**

In this chapter the author used the WPI new residence East Hall project to validate and experiment with the ITDCI model that was developed. The chapter starts with a background of the project followed by a description of the different phases of the development process. The analysis of the integration was first performed with help of an undergraduate student. In her Major Qualifying Project (MQP), she conducted an integration analysis of the new WPI Residence Hall building. In her analysis, the student used the driving/deterring factors of integration developed by Rahman and Kumaraswamy in 2005. The Project integration factors were ranked according to their usage and importance levels and compared through a Pearson Correlation [58]. Also, she identified the areas to increase integration. The author further gained some insights regarding the project integration level based on the interpretation of the project team with the aid of the meeting minutes. The ITDCI model was then used to assess the level of ITDCI that was involved. A comparison of the two scenarios was conducted and a summary of the results was then followed.

### **6.1 Background**

Worcester Polytechnic Institute (WPI) decided that it wanted to provide more upper-classmen housing in order to draw students back to campus and to accommodate future growth. In the summer of 2006, the school hired Cannon Design to start to develop a study for an existing building site on campus. Cannon Design, out of Boston, MA, is a

renowned design firm demonstrating proficiency in educational building. The project is located next to Founders' Hall facing Boynton Street and involves new residence halls and a new parking garage.



**Figure 6-1 Aerial view of WPI Residence Hall on Boynton Street**

Figure 6-1 shows an aerial view of the project. WPI wanted to achieve its goals for new residential space while being environmentally sensitive, respectful of the surrounding Worcester community, and also incorporate an arts walk into the arts section of Worcester. In order to maintain environmentally safe the WPI Residence Hall wanted to achieve a silver ranking from the Leadership in Energy and Environmental Design LEED. LEED is a program administered by the US Green Building Council to promote sustainable building practices. The WPI Residence East Hall project was a fast-track Construction Management Project.

## **6.2 Goals of Project**

The goals of the new WPI Residence Hall Project as outlined by WPI are:

- Provide upper-class housing to draw students back to campus
- Maximize use of the site
- Relate to and respect the Worcester community
- Design a project that is environmentally sensitive
- Accommodate the Arts walk to the south, adjacent to Founders Hall

[14].

## **6.3 Design Stages**

This section provides a brief description of the three stages of the design phase of the WPI Residence Hall Project: conceptual design, design development and construction documents.

### **6.3.1 Conceptual Design**

The conceptual design phase is the first phase of design where drawings are the dominant tool and product. Usually, drawings in this phase are composed of simple, single-line floor plans, building sections, elevations, and site plans. After two months of investigation and deliberation on different design schemes for the building, WPI decided on the design scheme shown in figure 6-2. This scheme provides 232 beds and a 5-levels building facing Boynton Street next to Founders and abutting the Church of Our Saviour. In addition to the residential building, a 150 car external parking garage structure is also included in the project. The construction estimate performed by both Gilbane and

Cannon Design indicated that there were \$31.5 million in construction costs for the building and \$2.5 for the garage and the project was carrying around \$4.5 million in contingencies. The conceptual design phase of the New WPI Residence Hall was completed on November 17, 2006.

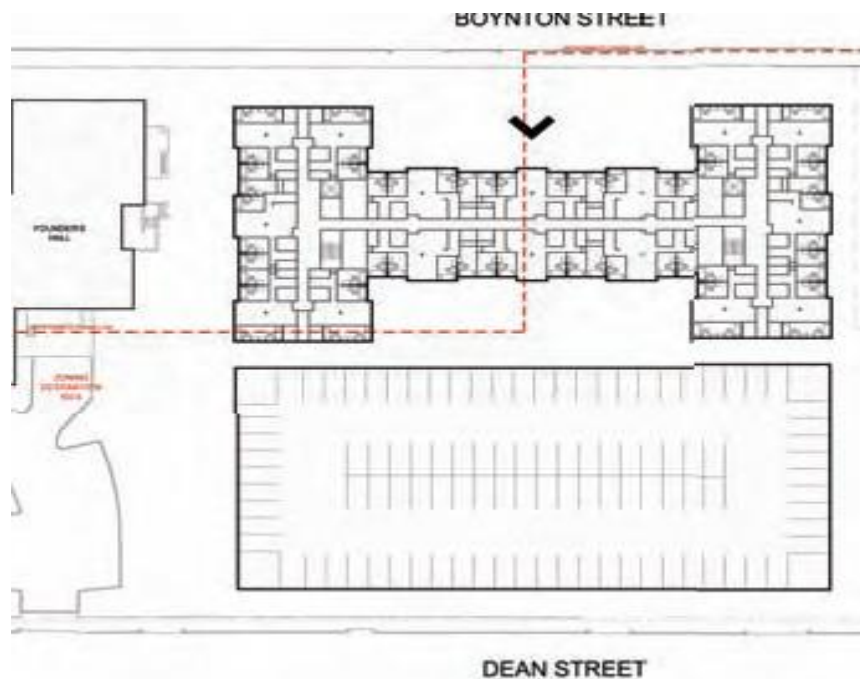


Figure 6-2 Design Scheme [14 ]

### 6.3.2 Design Development

The design development is the second stage of design during the design phase which represents the period where all questions about the project are identified and general concepts are refined in order to represent the ultimate design. Design development is not specifically detailed; instead; it merely just identifies details that require further study. It does however offer the first understandable look at the building and shows the ultimate form and character of the building. The design development phase of the New WPI

Residence Hall was completed as of January 31, 2007. Figure 6-3 below shows a rendering of the perception of the design development.



**Figure 6-3 3-D Design Development Perception [14]**

### **6.3.3 Construction Documents**

The construction documents (CD) stage is the last phase in the design process and is where the design reaches 100% complete. The construction documents of the New WPI Residence Hall were released on Friday, April 20, 2007.

Since the WPI New Residence East Hall was a fast track project, construction for the project had started and began before the construction documents stage was complete. The information obtained from the schematic and design development stages provided enough information to allow the project to proceed to construction. Cannon Design met with the WPI Residence Hall Committee (listed in section 6.4.1) bi-weekly to discuss final program requirements, building standards, and finishes in order to confirm the layout, size, and adjacencies of each element, fixture, and finish. Below is a picture of the new WPI Residence Hall from the perspective along the arts walk.





**Figure 6-4 : Rendering along Arts Walk [14]**

## **6.4 Parties involved**

The Project Team consisted of three main parties: Worcester Polytechnic Institute, Cannon Design, and Gilbane Company. An overview, description, and the role of each party are provided below.

### **6.4.1 WPI**

Worcester Polytechnic Institute is the owner of the project. WPI members who were involved with the project represented the different interests and aspects of the WPI community. That included the student body, residential services, financial representative, plant services, students conducting research on the project, and the dean of students. The

individuals and their association are explained in detail in the investigation and analysis section of this project.

#### **6.4.2 Cannon Design**

Cannon Design is an architecture, engineering, planning, interior design, and project delivery firm headquartered in Boston, MA with other locations at various spots in the US. The firm was established in 1945, has around 700+ employees, and currently grosses \$104.2 million dollars in revenue each year. They have performed projects at other colleges and universities including the John Hancock Student Village at Boston University, buildings at USC, UC-Berkeley, Tufts, University of Maryland, and SUNY Oswego [27]. Cannon Design was selected as the designer for the WPI Residence Hall.

#### **6.4.3 Gilbane Building Company**

Gilbane Building Company is a well-established building company that offers construction services, turnkey services, and facilities management. Gilbane was brought onto the WPI Residence Hall Project as Construction Manager of the project. Gilbane was founded in 1873 by Thomas and William Gilbane as a family run carpentry and general contracting shop out of Providence, Rhode Island. The company is now in its fourth generation of leadership and is still a privately owned and family run business. The company is pulling in over \$3 billion dollars in revenue each year and employing over 1800 employees across the country and US territories. They have been involved with building a variety of projects over the company's history including the 1980 Olympic Venues in Lake Placid, NY, the Vietnam War Memorial, and even the

President's House at Brown University in Providence. Gilbane has a previous work relationship with WPI through the construction of its new administration building (Bartlett center) [39].

## **6.5 Project integration analysis using Rahman and Kumaraswamy factors**

In order to estimate the extent to which the project was integrated, the driving/ deterring factors for integration developed by Rahman and Kumaraswamy in 2005 were used to estimate the level of integration. A questionnaire concerning promotional and deterring factors of project integration was prepared and used to determine which factors were evident in the WPI Residence Hall Project.

A statistical analysis of the findings was produced and computed to demonstrate (1) the usage and importance level of each factor of integration of the project; (2) the usage and importance level of each category of factors; (3) the correlation between the usage and importance levels; and (4) determine areas of where to increase integration.

Before proceeding with the analysis, both the project work environment and the project organization structure were explored.

### **6.5.1 Project work environment**

The WPI Residence Hall Project was based on a Construction Management project delivery system. The owner (WPI) was highly involved with the process and only enlisted one agent outside of the organization, a civil engineer from Cardinal Construction, as an addition to their project team to monitor construction cost and project production. All parties involved in the project were using Primavera<sup>®</sup> software to

produce schedules for the project. The cost estimates for the project were produced by Gilbane Building Company using Timberline® Precision Estimating.

The project committee typically met every Wednesday at 2pm on WPI's campus center and almost all the meetings were attended by WPI, Cannon Design, and Gilbane Building Co. Decisions needed to be taken involved the input of all the different parties of the project in a timely manner. Responsibility for certain decisions was placed on individuals within each party but the committee as a whole over the period of analysis had demonstrated an integrated and collaborated approach to confronting issues, making decisions, and solving problems.

As far as the information technology tool that the project team was using for communication, the team created a website on mywpi website for committee member to post and access to the documents for the project.

### **6.5.2 Project Organizational Structure**

WPI is the owner of the project and has contracted Cannon Design from Boston, MA as the Architect for the project; the Construction Manager for the Project (selected after a series of meetings between WPI and Cannon) was Gilbane. Within WPI there were different parties that acted on behalf of WPI. Those were WPI Plant Services, Chief Financial Officer, Dean of Students, a WPI Student, Director of Residential Services, Current Residential Advisor of a WPI Dorm (RA), Head of Academic Technology Services, WPI Academic Participant, and three various project teams from Civil Engineering who were tracking the project. Cannon, the Architectural Designer of the project had different representatives including Project Managers, Project Designers,

Design Principal, and Project Planners. Table 6-1 below shows the breakdown of the project organization.

**Table 6-1: WPI Residence Hall Organizational Breakdown**

<b><u>Organization</u></b>	<b><u>Job Title</u></b>	<b><u>Name of Person</u></b>
<b>WPI (Owner)</b>	Chief Financial Officer	Jeffrey F. Solomon
	Dean of Students	Philip Clay
	President	Dennis Berkey
	Vice President of Student Affairs & Campus Life	Janet Richardson
	Associate Director of Physical Plant	Christopher Salter
	Director of Physical Plant	John E. Miller
	Director of Residential Services	Naomi B. Carton
	Director of ATC	Mary Beth Harrity
	Academic ,Professor of Civil Engineering	Guillermo Salazar
	Executive Director of Corporate & Foundation Relations, WPI Development	Denise Rodino
	WPI Student	Heather M. LaHart
	WPI Student	Jennifer Arellano
	WPI Student	Christine Conron
	WPI Student	Ryan Young
	WPI Student	Krystal Parker
	WPI Student	Jonathan Bourque
	WPI Student	Nathalia Arenas
<b>Cannon Design (Architect)</b>	Project Manager	Lynn Deninger
	Project Planner	Peter Hourihan
	Project Designer	Antoni Borgese
	Design Principal	John Berchert
	Project Principal	Bob Peterson
	Planning Principal	Peter Hourihan
	Engineer Principal	John Swift
	Plumbing & Fire Protection Engineer	Ron Furbish
	Electrical Engineer	Brian Pineau
	Mechanical Engineer	Fletcher Clarcq
<b>Gilbane Co. (Construction Manager)</b>	Project Executive	Bill Kearney
	Project Manager	Neil Benner
<b>Brown Sardina (Landscape)</b>	Design Principal	Bill Brown

Architect)		
<b>Cullinan Engineering Owner's Agent</b>	Vice President, Chief Engineer	Ken Hodgson

### **6.5.3 Data Collection**

The data for the analysis was collected through the attending some of the project meetings and distributing a questionnaire ranking the usage and importance levels of promotional and deterrent factors of integration. [58] The description of the meetings is provided in Appendix C

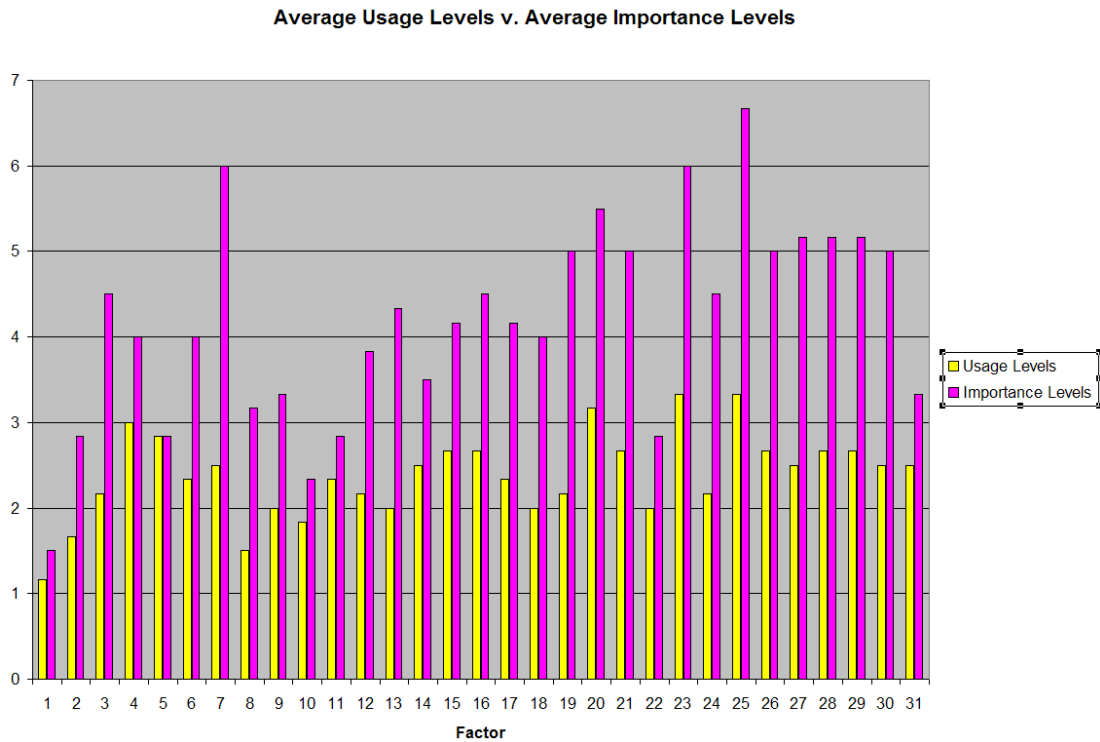
#### **6.5.3.1 Questionnaire on Integration Factors**

A questionnaire was prepared and distributed to all parties involved on the WPI Residence Hall Committee. This questionnaire asked the participants to conjecture his/her personal opinion on the usage level and importance level of identified driving and deterrent factors of integration. There were 31 driving factors and 31 deterring factors identified in Rahman and Kumaraswamy research study. A list of these factors was presented in Chapter 2. The specific questions have been removed from the chart and just referred to by the corresponding number. The responses were recorded individually and then organized according to their associated group of designers, construction managers, or owner.

#### **6.5.3.2 Data analysis**

The collected data from the questionnaire distributed to the WPI Residence Hall Committee was analyzed to investigate the extent to which the integration was involved. 50% of the questionnaires (six out of the twelve questionnaires handed out) were returned.

The six returned questionnaire forms were filled out by three members from the WPI committee, two from the construction manager Gilbane, and one from the designer Cannon Design. The researcher followed the approach used by Rahman and Kumaraswamy to perform the analysis of the returned questionnaire. Both the usage and the importance level of each factor were extracted from the responses. The average of each driving factor's usage level versus the average importance level is shown below in figure 6-5. The graph provides a comparison of the usage levels compared to the importance levels ranked by the responses. The driving factors range from 1 to 31 because there are 31 different driving factors of integration. The usage levels of each factor seen in yellow was ranked on a seven points Likert scale (y-axis) where 1 indicates a very strong usage level of that factor and 7 indicates no usage level of the factor. The corresponding importance levels of each factor are shown in magenta and are ranked the same Likert scale (y-axis) where 1 indicates the highest importance and 7 indicates the least importance of the factor to project integration. The closer that the average usage and importance levels are to 1, the more they are being used and the more importance they hold and vice versa for least usage and importance.



**Figure 6-5 Usage levels and importance levels of the integration driving factors.**

The top factors that were mostly used are:

- Factor #1, “enlightened and enthusiastic client.
- Factor #8, “willingness/enthusiasm of involved parties.”
- Factor #2, “knowledgeable client about project processes & integration.”
- Factor #10, “adequate resources and technical skills.”

The top factors which were mostly important

- Factor #1, “enlightened and enthusiastic client.
- Factor #10, “adequate resources and technical skills.”
- Factor #2, “knowledgeable client about project processes & integration.”
- Factor #5 “cooperative learning with project organization”



- Factor #11 “previous performance records on hard factors like time, quality, and safety.”
- Factor #22, “group combined responsibility instead of individual.”

From the above results, it was found that the three factors: 1, 10, and 2 were common having the highest usage and most importance.

In order to determine if there is any correlation between the two variables a further analysis needed to be considered, which was a Pearson Correlation. A Pearson Correlation is a measure of correlation between two variables of measure on one object and determines if the two variables have a tendency to decrease or increase with one another. The correlation ranges from -1 to 1, and an answer of 1 means that a linear equation describes the relationship perfectly with all the data points lying on the same line and as variable 1 increases variable 2 increases and vice versa. A value of 0 indicates that there exists no linear relationship amongst the variables and they are not correlated with one another. The linear equation which represents this relationship can be generated from linear regression, and this equation can be used to best predict the value of one measurement through the knowledge of the other. The answer provided by the  $r$  value (the Pearson correlation coefficient) is the ratio of explained variation to total variation, and is provided by the following equation:

$$r = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

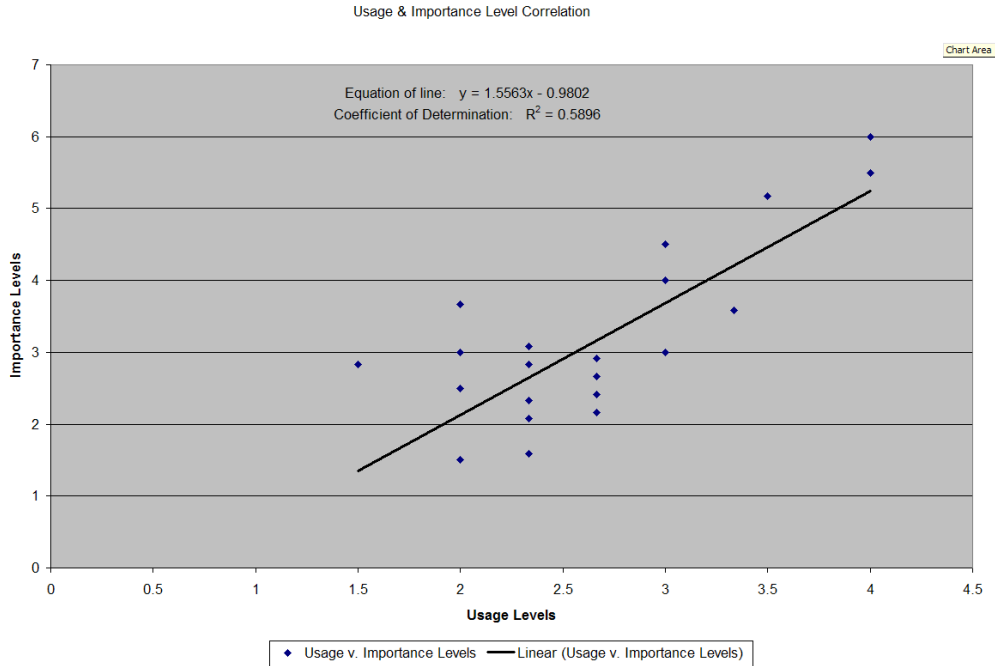
**Equation 2 Correlation Coefficient between the highest usage and most importance**

The variables  $x$  and  $y$  are the sample means and  $\bar{x}$  and  $\bar{y}$  are the sample variable entries. By squaring  $r$  the coefficient of determination can be determined which demonstrates the proportion of variability in a data set. Thus  $r^2 = 1$  means that the fitted model explains all variability in  $y$  where as  $r^2 = 0$  means that there is no explanation available through a linear model.

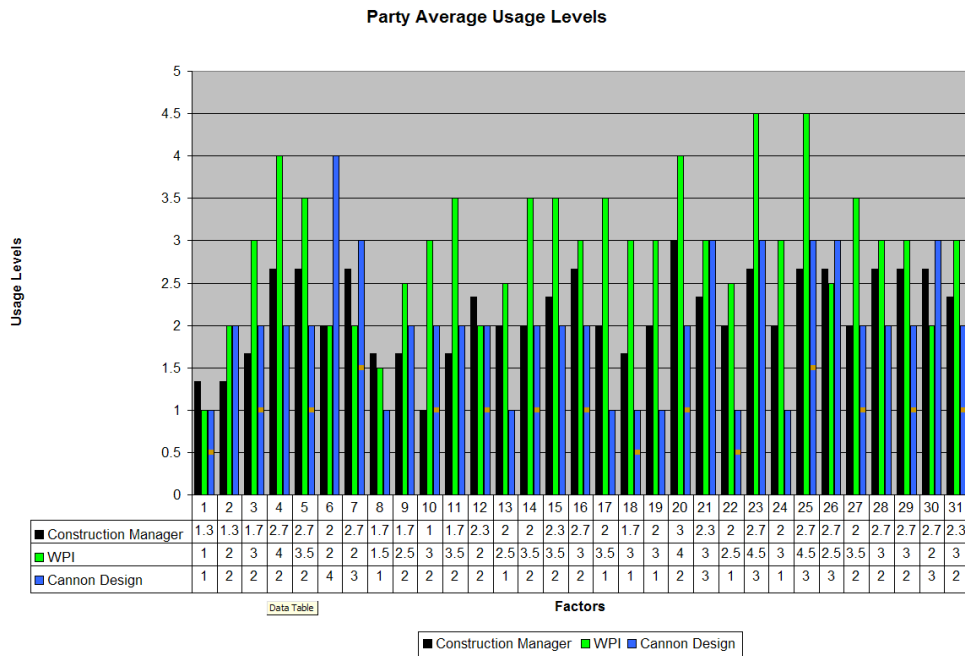
From the information obtained through the questionnaire a correlation between the usage levels and importance levels of the integration driving factors was derived. The Pearson correlation (correlation coefficient), line of regression, and coefficient of determination were useful tools which helped to explain whether the two variables were correlated or not. The correlation coefficient calculated was determined to be 0.7678, which means that there was a 76.78% correlation. As  $x$  increases or decreases  $y$  will also increase or decrease along with it or vice versa. The graph that demonstrates the regression line of the correlation between usage and importance levels is seen below in Figure 6-6. The coefficient of determination was evaluated to be 0.5896. If the two axes were switched the variation would not change even though the equation of the line would.

The optimal scenario for the project integration would occur when all of the driving factors of integration are both very strongly used and have the highest importance level. Not every party in a project holds the same opinion in relation to these concepts. In the sample population there were three different parties which the samples could be categorized according to. Because each party has a different role and perspective of the project, there was a possibility that there could be certain biases amongst the parties. To determine if there were biases among the different parties, the responses were grouped according to their role in the project, whether as an agent of the owner (WPI), designer,

or construction manager. A graph which shows the different levels indicated by each group is shown below in figure 6-7.



**Figure 6-6 Usage and importance level correlation**

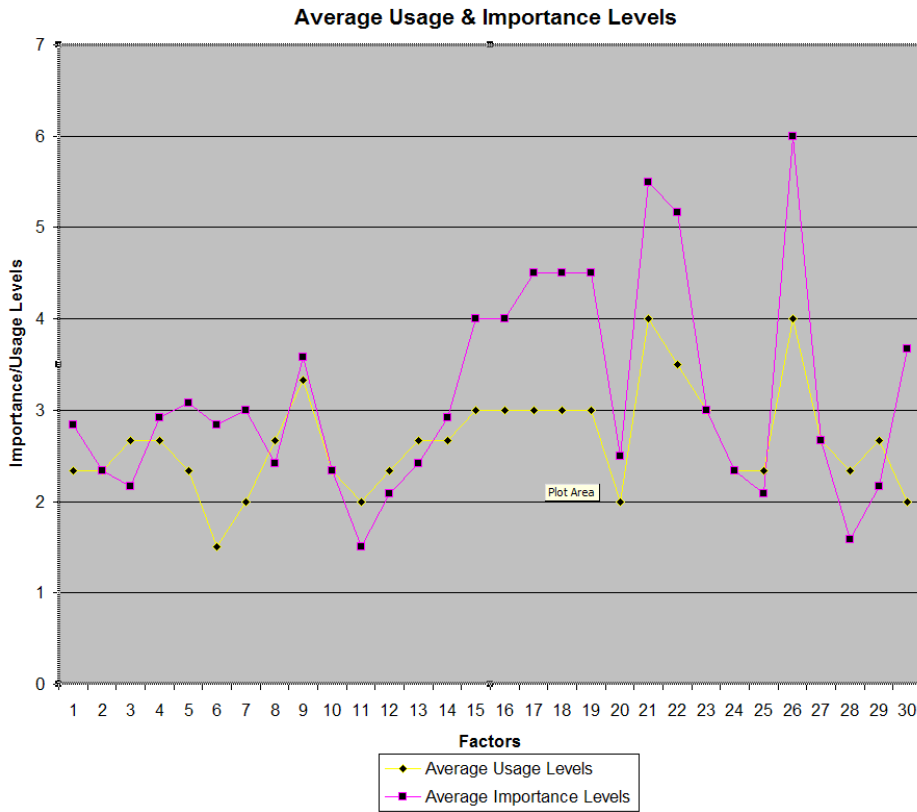


**Figure 6-7 Parties involved average usage levels**

It can be seen that WPI ranked the usage levels for certain factors slightly lower than both Cannon and Gilbane. In order to see if there was a correlation between the usage levels as indicated by the different sample groups of Cannon and Gilbane, a Pearson correlation was used. The results provided that the coefficient of correlation for Cannon and Gilbane was 0.4295, for Gilbane and WPI was 0.4127, and for WPI and Cannon was 0.2280.

An additional study was conducted to maximize areas where driving factors of integration can be increased and deterrent factors of integration can be decreased. In order to determine areas of where integration in the project could be increased, the average usage levels of the factors were compared with their corresponding average importance levels. If there existed a factor that was ranked of high importance but had low usage levels, by increasing the usage levels of the driving factor, the level of integration of the project could be increased.

As shown in the above graph 6-8, there existed eight areas that indicated that the importance level was closer to 1 than the usage level. These were factors 3, 8, 11, 12, 13, 25, 28, and 29. Since the responses determined that these areas had higher importance than their level of usage, these were areas at which the usage levels of driving factors of integration could be increased. If the usage level of driving factors increased, then the project integration can be increased. Considering the deterrent factors, the closer the usage levels and the importance levels were to 7, the less likely that the deterrent factors indicated in the questionnaire are deterring the project integration.



**Figure 6-8 Deterrent Factor Importance & Usage Level Integration Evaluation**

By looking at the high ranked usage levels of deterrent factors it demonstrates which factors are deterring integration with the project. The graph indicated that factor 6, factor 20, and factor 30 had usage levels that are relatively higher than their corresponding importance levels. If the usage levels of those factors can be reduced, the project integration could increase.

Using the driving factors/detering factors for analyzing integration evidenced that the project experienced a certain level of integration due to the existence of some of the driving factors of integration such as the enthusiasm of the project participants to share their knowledge, their high technical skills, their knowledge about the project processes

and integration and their previous performance records. However, there were some factors that deter integration.

## **6.6 Project integration using the meeting minutes of the project**

Some of the meeting minutes of the WPI Residence Hall Committee meetings were used to assess the project integration supported by with above provided analysis of the driving and deterring factors of integration. Example of the used meeting minutes are provided in Appendix C. The project experienced integration between the different parties involved. They were continuously meeting every Wednesday to discuss all different issues. All of the participants were sharing a compatible vision and unified goal to execute the project successfully. This was supported by Cannon's Project Manager note: that the amount of involvement that WPI had in the project (from students, students doing projects, teachers, ATC, and other administrators) added greatly to the development of the project. He added that "it is not usual to find such a highly integrated amount of people from the owner side" [14]. He thought that was provided the best building for the school. He also said that the collaboration between WPI and Cannon has been very effective.

On the other hand, there were some issues that reflected lack of integration due to the non existence of the needed person with the sufficient level of authority in a timely manner. That was concluded from an event related to the preliminary design of the building. While Cannon developed the design based upon the information that WPI administrators had already supposedly agreed on. WPI's administrators did not communicate the design to President Berkey (WPI president) in a timely manner. President Berkey did not like any of the building design schemes that Cannon had developed. Cannon's Project

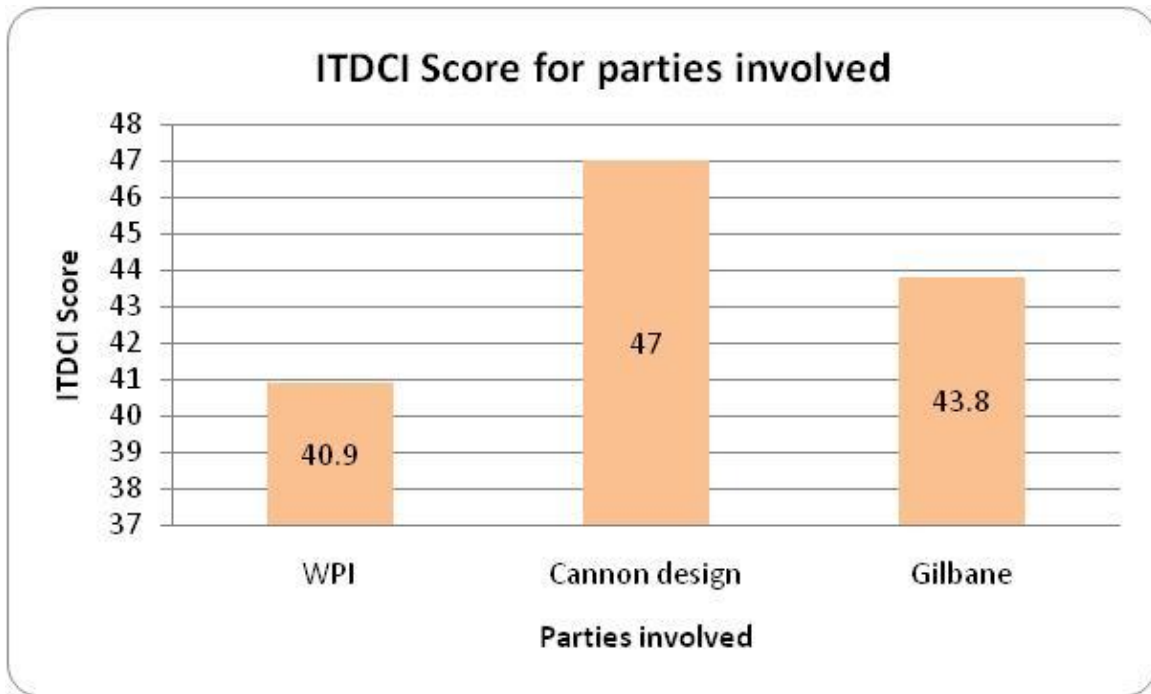
Manager said that if President Berkey's involvement was greater towards the beginning of the design phase it may have reduced the possibility of redesign and time could have been saved

After exploring the New WPI Residence Hall meeting minutes and attending some of the meeting by the undergraduate student who helped with this case study, it can be concluded that all the factors that affect the integration of the project could be witnessed firsthand. The project was moving smoothly and with a fair amount of integration and collaboration from all parties.

## **6.7 Project integration using the ITDCI model**

Lastly, the developed ITDCI model was used to explore the level of integration that was involved in the project. The model was sent to representatives of the three parties involved in the form of survey using the Survey Monkey website: Frederick Di Mauro, WPI, Eddie Mellow, Cannon Design, and Neil Banner, Gilbane.

The returned survey responses yielded an ITDCI scores as represented in the below graph. Figure 6-6 shows that WPI had an ITDCI score of 40.9 points out of 75 points; Cannon Design had 47 points out of 75 points; and Gilbane had a score of 43.8 points out of 75 points.



**Figure 6-9 ITDCI score for parties involved in the project**

It can be concluded that the ITDCI model helped the three parties of the project to interpret the level of integration in consistent way. Both the mean and the standard deviation were calculated for the obtained ITDCI scores. The ITDCI score obtained by the parties involved yielded consistent results with a mean of 43.9 and a standard deviation SD with 3.09.

The three parties almost used the same exact metrics to determine the level of integration that was involved in their project. The survey forms of their responses are provided in appendix D

## **6.8 conclusion**

By comparing the results of the integration analysis in both scenarios: the first scenario using the driving/deterring factors developed by Rahman and Kumaraswamy in 2005



with the help of the project meeting minutes and the second one using the ITDCI model, it was found that:

Although the first scenario helped to evidence integration of the participants of the project due to the existence of the driving factors of integration, it was not possible to quantify the exact level of integration involved in the project. Additionally, these factors used did not capture the specific aspects of the different phases of the development process. The first scenario could not capture the extent to which the project participants were relying on the appropriate IT tools to facilitate and promote the integration.

However it was determined from the meeting minutes that the participants created a website on my WPI website to exchange project information but it did not imply the frequency that they were using it or whether they were depending on other way of communications.

Using the ITDCI model enabled the project parties to quantify the integration in each phase while developing the project in consistent manner. Moreover, the model helped to quantify the extent to which the project participants were using IT tools to promote integration. This data was achieved by answering the IT-related questions in each phase of the project.

Finally, the ITDCI model provided well structured guidelines to capture the level of integration that was involved in WPI new residence hall accurately and consistently.

The responses of the survey results sent to the project participants yielded a consistent ITDCI score of the project with a standard deviation of 3.09.

## **Chapter 7 Conclusions & Future work**

This chapter provides the conclusions, contributions and limitations of this research. A discussion of future research in the quantification of the ITDCI is also presented

### **7.1 Conclusions**

The main objective of this research was to develop a formal model to measure the different levels of ITDCI during the facility development process within colleges and universities.

ITDCI is a collaborative knowledge-based activity in which each participant continuously and timely contributes and shares his/her knowledge to realize a specific goal, bonded by a unified and cohesive culture with the use of the supportive IT-tools. Executing the project in an ITDCI fashion requires the satisfaction of these conditions. This research developed a formal model that consists of 75 ITDCI mechanisms distributed over the different phases of the facility development process within colleges and universities to enable the knowledge transfer process and achieve the highest level of integration. The level of ITDCI involved in a particular project can be then measured by quantifying the number of ITDCI mechanisms introduced.

The research methodology included the following activities: reviewing the related literature, developing and validating a scenario for the facility development process of a typical college or university through literature review and interviews, providing a definition for each phase of the process to be executed in an ITDCI fashion, and finally identifying actions or mechanisms that have to be activated to obtain the highest level of ITDCI. The model was validated through an online survey that targeted the members of

the Society of Colleges and Universities (SCUP) and a case study. WPI's new East Hall residence facility was used as a case study to validate the model.

The survey results reflected the extent to which the ITDCI mechanisms were present in the respondents' projects. The responses to the survey were analyzed to observe and find out the trends that were presented.

From the managerial point of view, all of the projects experienced open, clear, standard and timely communication evidenced by the responders' responses to the related questions. Technically, all of the projects had considered the integration and harmonization of the different disciplines and work packages involved. All of the projects utilized more than 50 % of the integration mechanisms (more than 6 points out of 12) in the procurement phase. Also, the evaluation of the different alternatives for cost, schedule, fabrication lead time, and operability and maintenance were considered in all of the involved projects. The vendors' and the end users' perspectives were also involved. However, in the procurement phase none of the responses replied that there was a consideration for the evaluation of the different alternatives to orchestrate the involved resources.

Recommended mechanisms that were missing in most of the projects were for example: presetting actions and standard protocols for communication and collaboration, and setting an agreement between the owner and the designers upon the relative importance of the various performance issues. Another important missing but needed mechanism in 5 out of the 8 responses was assigning somebody (design facilitator) to identify in a timely manner potential conflicts among different design disciplines and acquire the input of the

design specialists as required. It was even absent in response no.4 at which represents a project team that used the Integrated Project Delivery.

As far as the technology is concerned to support collaborative team work, information technology tools were not introduced properly enough. This was evidenced by the absence of the IT mechanisms in almost all of the projects. Recommended actions include: enforcing a contractual agreement to enforce the use of IT-tools to support the communication and coordination process; ensuring IT infrastructure is in place starting from the beginning of the planning phase by implementing any necessary organizational changes to enable effective utilization of information technology; setting up a central file repository to post and store all of the project related documents and make it available for all participants; and using appropriate software for planning and budgeting which is interoperable with the design software is also necessary. Finally, the project task force must be well equipped and trained with IT- tools that support their provided services, at the same time help them to disseminate their knowledge in a timely manner.

More attention should be directed to utilize IT-tools such as project websites, BIM as a basis for collaboration and exchanging the knowledge of the different parties involved and leveraging the level of integration among them.

In terms of model validation, the author concluded that the model is significantly important to be used to measure the level of ITDCI involved in the project. Although all of the survey respondents were asked to select projects that experienced a high level of IT-based integration based on extensive level of knowledge transfer and the use of IT tools, the results obtained by using the model showed a different result. There was a

difference between the levels of ITDCI obtained for each response. Minimum ITDCI score response was 35.2 points while the maximum score was 61.1. Using the model provided a baseline and a standard way for the responders to unify the different interpretation of the AEC industry practitioners while assessing the ITDCI mechanisms that were presented in their projects.

Comparing the ITDCI model with the model developed by Mitropoulos and Tatum's [65], it was concluded that the ITDCI model can be considered an expansion of Mitropoulos' and Tatum's model. In their model they recommended that project participants should consider global integration mechanisms to foster integration: 1) Contractual mechanisms such as design/build contracts or joint ventures; 2) Organizational mechanisms such partnering or cross-functional units; and 3) Technological mechanisms electronic linkages between involved organization. They did not go beyond these suggestions. However in the IITDCI model, the integration mechanisms were developed to a high degree of detail. The author considered the ITDCI mechanisms that have to be activated in all of the tasks that are needed to execute each phase of the development process of the project.

WPI's new residence facility East Hall was used as a case study to validate the model. An integration analysis of the project was conducted using two different scenarios: the first scenario using the driving/deterring factors developed by Rahman and Kumaraswamy in 2005 with the help of the project meeting minutes and the second one using the ITDCI yielded from this research.

The first scenario evidenced the integration of the project participants due to the existence of the driving factors of integration and also from the way the project parties

were collaborating as provided in the meeting minutes of the project. However, the exact level of integration involved in the project could not be quantified. In addition, the integration factors used did not capture the specific aspects of the project involved in the different phases of the development process. Also, the driving factors for integration could not capture the extent to which the project participants were relying on the appropriate IT tools to facilitate and promote the integration. However it was provided in the meeting minutes that the participants created a project website on myWPI to exchange the project information but the minutes did not imply the frequency with which they were using it or whether they were depending on other ways of communication. Using the ITDCI model enabled the project parties to quantify the integration in each phase while developing the project in consistent manner. Moreover, the model helped to quantify the extent to which the project participants were using IT tools to promote integration. That was achieved by answering the IT-related questions in each phase of the project.

In conclusion, the ITDCI model provides well structured guidelines for the project participants to capture the level of integration that is involved in their project in an accurate and consistent manner. Additionally, it captures the different aspects of the processes and organizations involved. The integration mechanisms developed in each phase ensure the knowledge transfer process among the different project participants. However, different weights should be added to the different phases to reflect the level of importance of the integration of each phase on the overall score of integration. More weight should be considered in the planning phase since it represents the most important

phase that has a significant impact on the cost and other decisions being made at this early stage.

## **7.2 Research Contributions**

This model is considered an advancement of the current industry practices. It adds a contribution to the construction industry because it acts as a measuring tool to assess the corresponding level of ITDCI in the facility development process within colleges and universities. It also helps to develop a common understanding among the industry practitioners on what is required to achieve a desired level of ITDCI in their project. This comprehension would guide them to a better recognition of the benefits and consequences of each specific level of IT-based integration on their project outcomes. It will also enable them to execute more accurate cost/benefit analysis and eventually opt for the optimum ITDCI level.

## **7.3 Future Research**

In this research, the ITDCI model was developed for colleges and universities.

For future work, the model could be experimented and refined by testing more projects. Different weights should be added to the different phases to reflect the level of importance of the integration in each phase of the development process. More weight should be considered in the planning phase due its significant impact on the project performance.

Finally, the model could be expanded to include other types of facilities such as: residential, healthcare, and commercial facilities to achieve wider adoption by the AEC industry.



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# Appendices

## Appendix A Interviews

The main purpose of the interviews was to identify new issues that were not identified during the literature review. The interview included three main questions as follows:

- *In your definition, what is Design and construction integration?*
- *How to recognize that a project is a well integrated or not? What indicators should one look for to identify integration in a project?*
- *What is the role of those emerging information technologies such as: OCPM, BIM and others in promoting design and construction integration?*

In addition to the previous questions, the author gathered the interviewees view on the potential benefits of integration based upon their experience from integrated projects

### 1. In your definition, what is Design and construction integration?

#### **Bill Kearney:**

Design and construction integration can occur in the different phases of the project at different levels. From the preconstruction phase with the early version of the design all project parties start looking at the same design from different point of views. The CM look at the cost estimate, Builders look at the buildability or the constructability of the design, schedules and the materials availability. They continually contact each others to revise and update the project documents and sometimes find more feasible construction methods in terms of time and cost. Also, the owner works closely with the designers and the builders for better planning and circulation.

**Rob Taylor:**

The industry is pretty fractious and need to be integrated. Everybody should look for models to help them better understand and integrate the different phases of design and construction.

DCI is that the design and construction teams are working together from day one in a parallel track. The constructors don't wait for the designers to finish the design but they are working together from the beginning to investigate different design alternatives in terms of workability, feasibility, etc.

He hopes that the systems that are being used to design the building can be used later in monitoring the performance of the building in the operation and maintenance phase.

He believes that IT tools can do this.

Design Build approach imposes more involvement of the owners to give their ideas and feedback. The owner involvement in the process is taken for granted, but it should be structured in a way that benefits the project.

One of the problems that they are facing and it impedes the integration is that the owner doesn't have the same tools they are using.

**John Miller:**

Integration means that you hire the contractor right away from the conceptual phase to discuss design ideas and to figure out some other ways to build the building faster and cheaper.

**2. How to recognize that a project is a well integrated or not? What indicators should one look for to identify integration in a project?**

**William Kearney**

- Good Communication.
- Working together as one unit or company not for each one own interest.(shared profit and loss.
- Decision making in a timely manner by all project parties.
- Well organized site, equipments, trades, and logistics.
- Good flow of information. (can be achieved using prolog, everyone can log into).

**Rob Taylor**

If we have an integrated project: `that means that the cost, schedule and quality of the project are not surprising all over the project life cycle. (consistent CSQ).

The success of the multi-layered building process is heavily influenced by the degree of integration of all components

May be those are markers of project success, but project integration??

Some indicators are:

- Time to respond to RFI's.
- Time to take decisions.

**John Miller:**

- Less change orders.
- Less RFIs.
- No surprises.
- Less changes to the original scope.

**3. What is the role of those emerging information technologies such as: OCPM, BIM and others in promoting design and construction integration?**

**William Kearney:**

Lot of IT tools can promote integration by enabling long distance communication.

- Webinar is an example at which 20 people can communicate together remotely with the help of a moderator. Project parties can point at the screen, chat, and discuss several issues without being physically in the same place.
- Video teleconferencing.
- BIM—Cost estimating or clash detection.
- E-Mails.
- Prolog website: computer generated documents are all put on the website to coordinate between them

**Rob Taylor**

The current IT tools are becoming more user's friendly and can definitely promote integration.



They are using Microstation, ADT, Microsoft project for project scheduling , Timberline for estimating, and Prolog for project management.

One problem is that they are using timberline which is not compatible with the BIM software. He added that ArchiCAD® ignored timberline and created their own estimating module.

**John Miller:**

Common websites for the project can really help to share all related and necessary information.

**In general, how do you see the Potential benefits of integration?**

A summary of the benefits of integration according to the three interviewees replies were as follows:

- More detailed design information.
- Designers and constructors are responsible for the project equally.
- Open and more trust worthy communication between designers and builders.
- More complete design. (Buildable design).
- Shorter duration as a result of good communication and enhanced information flow.
- More effective schedule.

After analyzing the results of the interviews, the author got better insight on the definition of the design and construction integration, all of them agreed that for integration to be exists: “all project participants should be working together and sharing their information, knowledge and responsibility seamlessly from the early phases of the project.” As far as the indicators that one should look for to identify integration, they suggested: more effective communication, less RFIs, less time to take decisions and less change orders. As for the new emerging IT tools that promote integration, they all replied that they have been exploring a variety of those tools like: Webinar which allows people to communicate together remotely, BIM for modeling, cost estimating and clash detection. The interviewees also added that using IT-tools such as Prolog or project websites can promote collaboration and integration to a big extent.

## Appendix B Hardcopy of the survey

### Measuring Design and Construction Integration with the use of

#### 1. Introduction

The main purpose of this survey is to explore the extent to which the actions and mechanisms identified by the researcher to promote a continuous and interdisciplinary sharing and integration of knowledge, goals and information were involved in the development of new or renovation of capital investment facilities at colleges and universities. And to what extent were the participants relying on Information Technologies to facilitate this integration. We ask you to answer this survey in the context of a recently completed project (no more than five years ago) with the following characteristics:

- The project met the expected objectives
- There was a positive experience in collaborating and communicating with the project participants.
- Information Technology was used to any extent to support and facilitate communication and collaboration.

This survey should take 15-20 minutes to be completed. It consists of 6 parts: the first five Parts (A, B, C, D & E). Each of the five parts represents one phase of the building development process. The author will first provide a definition of the phase followed by the related questions. And finally part F which is optional and requires that you enter your personal contact information for future contact to provide the research results.

Confidentiality: Please read carefully and review the following before responding to the survey:

- a. Your participation in the survey is voluntary. You may decline to answer any question(s), but the researcher appreciate if you kindly answer each question.
- b. There is no particular benefit to your participation in this survey, but you may find the research results useful. If you choose to provide contact information at the end of the survey, we will share the study results with you.
- c. No personal information about you or information about your organization will be published as a part of this research. The information to be published will only include the aggregate data obtained from all the survey participants.
- d. SurveyMonkey (Website used to host the survey) has policies on privacy and confidentiality which you may wish to review before completing this survey. See (link). SurveyMonkey will not re-publish the information you provide and will not disclose your identity.
- e. The only foreseeable risk of participation is that you may disclose information that is potentially embarrassing; however the investigator will not have access to your identity unless you provide us with that information.
- f. There is no compensation being offered for your participation in this research.
- g. Should you have any questions about the research or your participation in this survey, please contact me: Hala Mokbel (hnmokbel@wpi.edu). You may also contact the WPI IRB which has approved this research at irb@wpi.edu.

For your reference, a glossary of terms used in this survey is provided in the second page.

# Measuring Design and Construction Integration with the use of

## 2. Glossary

Below is a glossary of some of the terms that are going to be used in this survey.

IT-based Design and Construction Integration(ITDCI):

IT- based Integration is a knowledge driven activity at which each participant continuously and timely contributes and shares his/her knowledge to build up common knowledge that is needed to execute the process to realize an integrated product that capture both knowledge with the support of the IT-tools.

Building Information Model (BIM):

Eastman describes BIM as "the provision of rich, integrated information—from conception through design to construction and demolition of a building over its life cycle. It relies on object based, information rich 3-D modeling as the design of record and for as-constructed, as-built, and as-operated information. The benefits enabled by BIM will greatly change the ways buildings are designed, fabricated, and operated.

Virtual Design and Construction:(VDC)

Is the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public buisness objectives.(CIFE, 2004)

Online Collaboration Project Management software:

Emerging information technology tools to help construction projects participants to execute and manage their jobs and processes collaboratively. With the assistance of those IT tools, construction project teams can become more flexible, adaptive, and competitive by improving their performance (Björk, 2003). Extranets and model-based 3D and 4D collaboration tools for information sharing, storing, and communication are some examples of these technologies.

## Measuring Design and Construction Integration with the use of

### 3. Part A: Integrated Planning phase

This part contains questions to assess the extent to which the mechanisms that promote the integrated development were incorporated during the planning phase.

#### 1. Was an initial kickoff meeting held to bring the project team together?

- Yes  
 No

#### 2. Who was involved in the kick off meeting?

- Institutional Representative of the President's Office  
 Institutional Representative of the Financial Office.  
 Institutional Representative of Academic and Student life.  
 Institutional Representative of student body.  
 Institutional Representative of physical plants  
 Lead Designers  
 Design consultants.  
 General Contractors/ Project managers.  
 Students as end users  
 Legal consultants.  
 Prospective subcontractors.

Others (please specify)

#### 3. Were there any actions taken to set the tone for cooperation and collaboration throughout the project?

- Yes  
 No

#### 4. If your answer to question 3 was yes, please specify what kind of actions were put in place:

- Training programs  
 Incentives  
 Partnering agreement

Others (please specify)

## Measuring Design and Construction Integration with the use of

**5. Were the owner's plans and expectations clearly expressed and understood by all team members? (Characteristics of the desired facility, constraints, etc.)**

Yes

No

**6. Did all team members share a compatible philosophy with the owner for this project? (culture, vision and goal congruence)**

Yes

No

**7. Were timely, clear, and complete objectives established and communicated to all team members?**

Yes

No

**8. Was there a contractual agreement (or otherwise) requirement set by the owner for the use of IT tools to support the communication coordination process? (project websites, e-mail, BIM, etc.)**

Yes

No

**9. Were there any organizational changes to enforce effective utilization of information technology? (hiring of new staff members to specifically serve this purpose)**



**10. Did the owner allocate competent key personnel who are capable of making decisions in a timely manner?**

Yes

No

**11. Was a prequalification criteria formally established by the owner to assess the ability of the designer to integrate multidisciplinary aspects of the facility with the institution's short and long term needs and objectives?**

Yes

No

## Measuring Design and Construction Integration with the use of

**12. Were procedures established to ensure the sufficiency between the personnel and the role they perform? (The right knowledge, etc.)**

Yes

No

**13. Were the representatives of the different parties involved fully committed to the project?**

Yes

No

**14. Were there mechanisms (contractual agreements) put in place to enforce mutual respect and open/honest communication flow amongst the different parties involved?**

Yes

No

**15. To what extent was the building program generated by the designers conveyed in clear and concise terms? (to clear and minimize uncertainties)**

extremely clear

clear

somehow clear

not clear

vague

**16. Which of the following performance-based objectives considered in the planning phase, please check what applies:**

Safety

Quality

Cost/schedule control

Value Engineering

Team building

Community relationships

**17. Were procedures established to allow the owners and designers exchange information about the project in a continuous manner?**

Yes

No

**18. Were there standard protocols established for the communication between all project team members?**

Yes

No

## Measuring Design and Construction Integration with the use of

**19. Was there a contingency plan in place to manage possible breaching of the previously identified mechanisms that promote collaboration?**

Yes

No

**20. Have time schedules been established and agreed to by everyone affected, and have campus schedule-related contingency plans been established?**

Yes

No

**21. Has a format been developed to integrate the expertise from the design and operation of other campus facilities to the design and construction of this facility?**

Yes

No

**22. Were there actions and measures for solving technical issues in the area of equipment reliability, configuration control, performance monitoring, etc. in a timely manner?**

Yes

No

**23. Was the builder's perspective incorporated during the planning process?**

Yes

No

**24. Were the current/future operational conditions considered in the planning phase?**

Yes

No

**25. Was there a central file repository created to post and store the entire project related documents and information?**

Yes

No

**26. Was there an agreed upon interoperable file format for exchanging information and support feedback mechanism/ (DWG,PDF,DWF,...)**

Yes

No



## Measuring Design and Construction Integration with the use of

**27. Part1: Was there a software application used to support budget preparation and cost control in the planning stage? Part 2:If yes, was that software interoperable with the CAD software that is being used by the designers?**

	Yes	No
Part 1	<input type="checkbox"/>	<input type="checkbox"/>
Part 2	<input type="checkbox"/>	<input type="checkbox"/>

**28. Were there any pre-qualifications or selection criteria established to ensure that all project professionals are equipped with IT- tools that support their provided services and in the same time disseminate their knowledge?**

- Yes  
 No

**29. Was the issue of technology interoperability among different organizations involved to cross-pollinate their products-related knowledge taken into consideration? (share and co-produce electronic files)**

- Yes  
 No

**30. Had the BIM technology been involved to evaluate the different alternatives? (sensitivity analysis)?**

- Yes  
 No

**31. If you answered yes to the previous question, did you set specifications to address the required BIM level of detail for different areas and disciplines of the project?**

- Yes  
 No

**32. Had the AutoCAD Civil 3D been used to develop the site analysis?**

- Yes  
 No

**33. Was there a GIS map of the campus?**

- Yes.  
 No.

## Measuring Design and Construction Integration with the use of

**34. If your answer to the previous question was yes, was that map used for understanding the spending cycle, monitoring and analyzing different alternatives to optimize the planning process?**

Yes.

No.

# Measuring Design and Construction Integration with the use of

## 4. Part B Integrated Design phase

This part contains questions to assess the extent to which the mechanisms that promote the integrated development were incorporated during the design phase

**1. On a scale from 1 to 10, 1 being least involvement and 10 being the most, please rate the contribution of the owner in the design process?**

Degree of owner's involvement

1	2	3	4	5	6	7	8	9	10
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**2. Was someone in the project team explicitly assigned to identify, in a timely manner, potential conflicts among different design disciplines?**

- Yes  
 No

**3. On a scale from 1 to 5, 1 being very low and 5 being very high, how would you rate the inter-disciplinary collaboration among all project participants (architects, engineers, cost engineers, operation staff and other relevant members of the project team) during the design process?**

inter-disciplinary collaboration

1	2	3	4	5
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**4. Were design decisions requiring mutidisciplinary input made in a timely manner?**

- Yes  
 No

**5. Was there an agreement between the owner and the designer on the relative importance of various performance issues?**

- Yes  
 No

**6. To what extent was there a consideration to harmonize architecturally the design of this project with other facilities of the university campus?**

Design harmonization

very strong	strong	Normal	little	very little
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**7. Were the project constraints in terms of time and cost continuously identified and emphasized to be applied consistently while developing the design?**

- Yes  
 No

## Measuring Design and Construction Integration with the use of

**8. Was there a continuous testing of the conformance of the design to the design functional requirements according to the university codes and standards?**

Yes

No

**9. Was the developed design understandable and communicated by all design professionals?**

Yes

No

**10. Were different alternatives for cost/schedule and logistics plans considered?**

Yes

No

**11. If your to te previous question was yes, were these alternatives evaluated against fabrication and lead time constraints?**

Yes

No

**12. Were all design alternatives evaluated for operability and maintenance?**

Yes

No

**13. Have you identified specific dates for reviewing key submissions and deliverables for compliance with program goals and design objectives?**

Yes

No

**14. Was BIM used to develop the design documents in this project?**

Yes

No

**15. If your answer to the previous question was yes, was it used as a reliable database for communication and collaboration?**

Yes

No

## Measuring Design and Construction Integration with the use of

**16. Was there a coordinated information network for different design consultants to ensure the availability of the required knowledge related to the design intent, procedures and options in a timely manner?**

Yes

No

**17. Was there a central file repository to post /store and access the different materials or systems catalogues and brochures?**

Yes

No

**18. Was there any software used to detect clashes and interferences between different design disciplines?**

Yes

No

## Measuring Design and Construction Integration with the use of

### 5. Part C: IT- based integrated procurement phase

This part contains questions to assess the extent the ITDCI mechanisms were present during the procurement phase.

**1. Was the vendors and suppliers expertise incorporated regarding the constructability, materials availability while preparing the bids documents?**

Yes

No

**2. Had the bidder certified to the owner that each engineer or architect of its team was selected based on demonstrated competence and qualifications?**

Yes

No

**3. Had the owner or its representative considered and evaluated the following aspects: bidder's experience, technical competence, and capability to perform, the past performance of the bidder's team and members of the team, and other appropriate factors submitted by the team or firm in response to the request for qualifications?**

Yes

No

**4. Were the bidders evaluated on the basis of considerations of the safety and long-term durability of the project?**

Yes

No

**5. Was there a study to optimize and orchestrate the involved resources?**

Yes

No

**6. Were the design output performance specifications such as: bill of materials, schedule, cost targets, delivery requirements considered to solicit and evaluate bids, make source selection recommendations and place orders?**

Yes

No

## Measuring Design and Construction Integration with the use of

**7. Was there a consideration for the integration and compatibility of the different work packages?**

Yes

No

**8. If any: were the implemented site changes efficiently accommodated and communicated to all affected parties and packages?**

Yes

No

**9. If applicable, was BIM used to extract quantities for procuring the different work packages?**

Yes

No

**10. Was Information Technology involved in identifying, soliciting and evaluating qualified bidders?**

Yes

No

**11. Was there a reliable way of communication set to ensure proper and standardized means of representing information/knowledge to support project management, project controls, material and labor tracking, engineering and procurement functions?**

Yes

No

**12. Was there a central file repository to post /store and access the subcontractors/vendors quotations of different materials or systems?**

Yes

No

## Measuring Design and Construction Integration with the use of

### 6. Part D: IT- based integrated Construction phase

This part contains questions to assess the extent the ITDCI mechanisms were present during the Construction phase.

**1. Were there constructability review sessions to ensure compatibility between the different systems of the building?**

Yes

No

**2. Were there procedures structured to force the sub-contractors to enhance the accuracy of the shop drawings?(incentives, penalties,...)**

Yes

No

**3. Was there a standard process to shorten shop drawings submittal/approval time?**

Yes

No

**4. Was the work sequencing discussed and optimized among the different trade contractors?**

Yes

No

**5. Was there a Coordination of the materials and equipments delivery according to the construction schedule to ensure efficient flow of work?**

Yes

No

**6. Were there scheduled meetings on a regular basis between the design and construction teams to discuss the actual conditions of the construction process to minimize or eliminate field changes?**

Yes

No

**7. Were the required information and documentation for testing and inspections considered and coordinated with the regulatory agencies?**

Yes

No



## Measuring Design and Construction Integration with the use of

**8. Was BIM used to execute what/if scenarios for site logistics studies?**

Yes

No

**9. Was the construction schedule tied to the model to better understand the construction progress?**

Yes

No

**10. Was BIM used to generate a look head virtual construction views to help optimize the construction activities and better track the construction progress?**

Yes

No

**11. If applicable, Was the BIM updated according to the "as built" conditions?**

Yes

No

## Measuring Design and Construction Integration with the use of

### 7. Part E: IT- based integrated operation and maintenance phase

This part contains questions to assess the extent the ITDCI mechanisms were present during the operation and maintenance phase.

**1. Was all the information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components of the building?**

Yes

No

**2. If applicable, was all of the previous information incorporated in the BIM model?**

Yes

No

N/A

# Measuring Design and Construction Integration with the use of

## 8. Part F: Contact Information

This part contains questions related to your contact information, organization and market segment

### 1. Your name (Optional)

### 2. Your Organization name(Optional)

### 3. What kind of services does your organization offers for its clients?

- Pre-construction services
- Architecture
- Engineering
- Construction
- Construction Management
- Others

### 4. What type of contracting method does your organization usually use?

- Design bid build
- Design- build
- Partnering
- Other(please specify)

specify

### 5. What is your organization market segment? (select all that apply):

- Educational facilities
- Residential facilities

## **Appendix C WPI new residence hall meeting minutes**

### **Meeting #1 Description**

The agenda for this meeting was to review prioritized program goals, review of the building program, design explorations, and miscellaneous issues such as the Construction Manager selections, schedule, and the strategy for review with the building inspector.

The beginning of the meeting started with the WPI Residence Hall Committee Architects and WPI Committee members talking with the Founders Cafeteria Manager and their Architect for the new Pub/Restaurant in Founders. They wanted to make sure that any of the improvements or changes that they were making in Founders how it could affect the new residence hall and if there are anything that they need to take into consideration when renovating. The WPI Residence Hall Committee talked with the Founders Renovation team and tried to figure out how the building will face in order to gear the Pub/Restaurant to coordinate well with the new Residence Hall. One of the main topics of discussion was the 4 ½ foot grade change from the building floor to ground elevation and how this may be encompassed to work well with the new Residence Hall. Another topic of discussion was a Courtyard area that would be developed between the new WPI Residence Hall and Founders. It was noted by both parties that this was an important factor to consider when building but that there was lots of flexibility for creating this space. After talking for 15 minutes it was concluded that the Founders

project was to continue as planned and that everything looks good and that it will work with the new Residence Hall.

The Founders Project Team left the room and the meeting moved onto the focus of the meeting, the new WPI Residence Hall. The Project Manager from Cannon started off the meeting with discussing the agenda for the meeting and what the key issues for discussion were. The first subject that was addressed was the selection of a Construction Manager (CM); Cannon said that they will be interviewing three potential candidates (Gilbane, Walsh, & Bar & Bar) and by Monday they should have a contract to show WPI. The next topic discussed was the problem that WPI was having acquiring the Police Station Property (as this property is currently not owned by WPI but needs to be acquired in order for the construction for the Residence Hall to begin because the building will lie on that property once it is built). Everyone agreed that it was a work in progress and the project and schedule will continue on as if it has already been acquired.

The Project Manager for Cannon gave positive feedback to WPI about the goals that they gave Cannon and they believed that they addressed everything and met all their requirements for the project and welcomed any further comments or feedback that they had.

Moving on the Project Manager for Cannon brought up the discussion of the Building Review Program: where will the Police Station be relocated and what is the amount of space and requirements that the Police Station requires. The Project Manager next spoke about the way that the information of the project will be available to all electronically. The WPI ATC said that it will exchange names so that the Project Manager can have access to add and change things on the my.wpi site.

The next main topic on the agenda was the Development of the Plans. One of the main concerns is the height of the building and the requirements that the City of Worcester may have for the building and how their authority on the project will affect the design. It was said by WPI that the requirements for the building will not be anticipated as a major obstacle.

The Design Principle and Project Designer for Cannon then put drawings up and went over the design of the building with the committee addressing parking, building orientation, design of building in respect to levels, the location of the WPI Police Station and whether to use an elevated courtyard. It was noted that the location for the WPI Police Station was in a good area but there was flexibility where it could be moved to. The WPI Chief Financial Officer (CFO) stated that the setback for the building was only 10 feet back from the property line and that the City of Worcester might not like that too much, and Cannon responded that it maximizes the amount of building space and if it were to be moved farther inwards from the property line it would take away from available space in the potential courtyard between Founders and the new Residence Hall.

Although probably one of the largest design considerations was brought up by WPI Plant Services was snow removal. Some of the designs that Cannon presented showed considerable difficulties with snow removal for the parking garage. Certain designs showed better prospect on this issue.

Cannon and WPI interacted back and forth considering the different designs orientations that could be used interchanging the levels, the way the building would face, and the various designs for the parking garage. It was noted that depending on how the

building was oriented it would affect different issues and requirements of the project such as the height, length, access, Campus Police location, and zoning variance.

One of the key issues in construction was brought up to WPI by Cannon, cost. Janet talked about how she met with the President and he said spend what you need to spend because the students want parking and they want a new residence hall. A number was not discussed at this time but was said that it would be provided in the near future. One of the reasons that cost was brought up by Cannon designers was because they wanted to consider the possibility of a courtyard option on top of the parking garage and noted that it would be considerably more costly, estimated around \$1.5 million. WPI said to keep it open as an option but had not given a definite yes to the idea.

WPI next noted that they wanted to get the CM involved as soon as possible to start working with them to get costs for the project estimated and start engaging with the CM so that structural systems and issues can be taken into consideration. WPI said that it was estimating the cost of the project, Cannon noted that they have an in-house estimator and that they would possibly hire an outside estimator also, and it was also noted that the students tracking this project and performing research would also be completing estimates along with the CM once on the project, so there would be anywhere from 4-6 estimates for the project. The Project Manager addressed the committee and told them that aerial photos for the project were complete and the survey of the area was also complete.

WPI Plant Services brought up another consideration of the dumpster location, activity at that area, the service entrance and how the location of all these should be taken into consideration when determining the orientation of the building.

After the meeting had been going on for two hours the meeting came to a conclusion with WPI saying to Cannon to develop a more Architecturally Developed Scheme. It was noted that the project is still on a fast track schedule and that the meetings are still on a 2 week schedule. The last minutes of the meeting Cannon and WPI were interacting saying that they both understand one another and that there is quite a lot of room for flexibility within the project and it looks like things are progressing quite well with the project.

## **Meeting #2 Description**

The meeting started out with Cannon Project Manager opening the meeting talking about the previous building design schemes that were looked at. He also mentioned that they (meaning Cannon) met with President Berkey and presented to him the various different design options they had for the residence hall. President Berkey had certain recommendations that he wanted the design to have:

- 4 – 5 stories max
- More green space surrounding the building
- All parking to be hid underground
- Relocated Police station to another location
- Be more respectful to our neighbors; be more courteous to the appearance of the building on Dean St.
- Look at providing double beds (about 30%)
- The travel distance to the elevator needed to be reduced. 200 ft was too far for student to travel to the elevator.



- The amount of cars in the parking lot needed to be reduced from 200 cars to 150

A cost was also mentioned amongst the Gilbane, who is the Construction Manager, the CFO for WPI, and the Cannon Project Manager, and was said to be estimated at about \$265-\$285/square foot (including just the construction costs).

After talking for a half hour about the meeting Cannon had with President Berkey, Cannon representatives preceded to tell us that the new design they came up with in the past 30 hours since they had with the president hopefully will meet the majority of recommendations he provided for the design of the building.

There were five different new building schemes that were presented. There was constant interaction between Cannon and WPI affiliates about choosing the right scheme based off of the new recommendations from President Berkey. It had been determined that having a garage underground could cost around \$50,000 a parking space compared to \$15,000 a parking space for an above ground two story parking garage. At this point cost has become the limiting factor to the type of scheme that will ultimately be chosen.

The Cannon Project Manager moved on to say that because of the design delay and no decision yet, the conceptual design is about a week behind, but the point of conclusion with the design submitted and estimated should be completed in two weeks from the date of the meeting (subsequent to Cannon's meeting with the President).

ATC services said that they could provide a computer and project for the project presentation if it was easier or more convenient for them. Cannon took the advice but did

not seem extremely excited about it; they seemed almost timid to accept the idea of presenting their material in a different way than on paper.

Moving back to the building design scheme, Philip (Dean of Undergrad Students) said that Option A and Option E seemed to be the best, but ultimately Option E was the best. At this point the question of when the City preliminary review would occur, which was determined to be within 2 weeks? The school is still trying to acquire the Police Station.

# Appendix D Survey responses for case study analysis

## Survey responses for case study responses (Gilbane)

ITDCI metrics		Metrics for measuring IT-based Design and Construction Integration In the development process of colleges & Universities				
<b>Y/N</b>	<b>It-based integrated planning phase</b>	<b>Total points = 34</b>	<b>Y/N</b>	<b>It-based integrated design phase</b>	<b>Total points = 18</b>	
	1- An initial kickoff meeting held to bring the project team together? (Owner, Chief of Officer, dean of students, director of students affairs and campus life, director of physical plants, designers and contractors and students as end users)	1		1. Effective involvement and contribution of the owner in the design process in a timely manner.	1	
	2- Specific actions taken to set the tone for cooperation throughout the project toward a common goal. (Training programs, incentives, etc.)	1		2. Assigning a some one in the project (design facilitator) to identify in a timely manner potential conflicts among different design disciplines and acquire design specialists inputs as required.	1	
	3- Owner's (Board of trustees, President) plans and expectations expressed and understood by all team members. (Characteristics of the desired facility, constraints, etc.)	1		3. Continuous inter-disciplinary collaboration between architects, engineers, cost engineers, operation staff and other relevant actors right from the beginning of the design process (up stream).	1	
	4- All team members share a compatible philosophy with the owner for this project. (culture, vision and goal congruence)	1		4- Establishing procedures to ensure that all design decisions that require multidisciplinary input are made in a timely manner.	1	
	5- Clear and complete objectives established and communicated to all project members.	1		5- Setting an agreement between the owner and the designers upon the relative importance of the various performance issues.	1	
	6- Enforcing a contractual agreement (or otherwise) requirement set by the owner for the use of IT-tools to support the communication coordination process. (Project website, webinars, e-mail, BIM, etc.)	0		6- Considering the harmonization of the facility with other campus facilities.	0.8	
	7- Implementing organizational changes to enable effective utilization of information technology. (creation of a customized job to serve this service)	0		7- Identifying and emphasizing the project constraints in terms of time and cost continuously while developing the design.	1	
	8- The owner allocate competent key role people who are capable of taking decision in a timely manner.	1		8. Continuous testing of the conformance of the design to the design functional requirements according to the university codes and standards.	1	
	9- Enforcing a prequalification criteria by the owner to assess the ability of the designer to integrate multi-disciplinary aspects of the facility with the institution short and long term needs and objectives	1		9- Communicating and understanding the developed design to/by all design professionals.	0	
	10- Establishing procedures to ensure the sufficiency between the personnel and the role they perform. (The right knowledge, etc.)	0		10. Evaluating different alternatives for cost/schedule and logistics constraints.	1	
	11- Committing and dedicating representatives from the different parties involved to the project.	1		11. Evaluating alternatives against fabrication and lead time constraints.	1	
	12- Putting mechanisms (contractual agreements) in place to enforce mutual respect and open/honest communication flow amongst the different parties involved	0		12. Evaluating different alternatives for operability and maintenance.	1	
	13- Conveying the program developed by the designer in clear and concise terms to clear and minimize uncertainties.	1		13. Identifying specific dates for reviewing key submissions and deliverables for compliance with program goals and design objectives.	1	
	14- Considering most or all of the performance-based objectives in the planning phase. (Quality, cost/schedule control and Value Engineering)	1		14. Using BIM to develop the design documents.	0	
	15- Establishing procedures to allow the owner and designers exchange the information in a continuous manner.	1		15- Using BIM as a reliable database for communication and collaboration.	0	
	16- Setting Standard protocols and format for communication between all project team members.	1		16. Using coordinated information network for designers to ensure the availability of the required knowledge related to the design intent, procedures and options in a timely manner.	0	
	17- Setting a contingency plan to manage possible breaching of the previously identified mechanisms.	1		17. Creating a central file repository to post/store and access the different materials or systems catalogues and brochures.	0	
	18- Establishing and approving the time schedules and campus schedule-related contingency plans by every affected party.	1		18. Used any software package (like Navis work) or any similar one to detect clashes and interferences between different design disciplines.	0	
	19- Developing format to integrate the expertise from the design and operation of other campus facilities to the design and construction of this facility?	1		<b>Total points</b>	<b>11.8</b>	
	20- Establishing procedures and actions to solve technical issues that might arise in a timely manner. ( equipments reliability, configuration control, etc.)	1		<b>Y/N</b>	<b>It-based integrated construction phase</b>	<b>Total points = 11</b>
	21- Incorporating the builder's perspective. (construction methods)	1		1. Executing constructability review sessions to ensure compatibility between the different systems of the building.	1	
	22- Considering current/future operational conditions of the facility.	1		2- Structuring procedures to force the sub-contractors to enhance the accuracy of the shop drawings. (incentives, penalties, standards, etc.)	0	
	23- Creating a central file repository to post and store the entire project related documents and information	1		3. Developing a standard process to shorten shop drawings submittal/approval time.	0	
	24- Setting an interoperable file format for exchanging information and support feedback mechanisms/ (DWG, PDF, DWG...)	0		4. Discussing and optimizing the work sequencing among the different trade contractors.	1	
	25- Deciding upon the software that is going to be used in the planning stage to support budget preparation and cost control and ensuring that it is operable with other CAD software that is being used by the designer.	0		5. Revising and coordinating the delivery of materials and equipments according to the construction schedule to ensure efficient flow of work.	1	
	26- Establishing pre-qualifications or selection criteria established to ensure that all project professionals are equipped with IT-tools that support their provided services and in the time disseminate their knowledge.	1		6. Scheduling meetings on a regular basis between the design and construction teams to discuss the actual conditions of the construction process to minimize or eliminate field changes.	1	
	27- Addressing the issue of technology interoperability to cross-pollinate their products-related knowledge. (share and co-produce electronic files)	0		7- Considering and coordinating the required information for testing and inspection with the regulatory agencies.	1	
	28- Pre-setting specifications to address the required BIM level of detail for different areas and disciplines of the project.	0		8. Using BIM to execute what if scenarios for site logistics studies.	0	
	29- Using the Building Information Model to evaluate the different alternative. (sensitivity analysis)	0		9. Tying the construction schedule to the BIM model to visualize and understand the construction progress.	0	
	30- Using the AutoCAD Civil 3D to develop site analysis.	0		10. Using the BIM model to generate a look ahead construction views to help optimize the construction activities and better track the construction progress.	0	
	31- Developing a GIS map of the campus to better understand spending cycle, monitoring and analyzing the trends to optimize the planning process.	1		11. Updating the BIM model continually according to the "as built" conditions	0	
	<b>Total points</b>	<b>19</b>		<b>Total points</b>	<b>5</b>	
<b>Y/N</b>	<b>It-based integrated procurement phase</b>	<b>Total points = 12</b>	<b>Y/N</b>	<b>It-based integrated operation &amp; maintenance phase</b>	<b>Total points = 3</b>	
	1- Incorporating of the vendors and suppliers expertise regarding the constructability, materials availability while preparing the bids documents.	1		1- All the information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components of the building is gathered and well documented.	1	
	2- The bidder certified to the owner that each engineer or architect of its team was selected based on demonstrated competence and qualifications.	0		2- Obtained and updated the BIM model with the "as built" information.	0	
	3- Consideration of the owner or his representative of the bidder's experience, technical competence, capability to perform and the past performance of the bidder's team members.	0		3- Tied and incorporated the previous information (information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components) in the BIM model.	0	
	4- Evaluating of the bidders on the basis of the safety and long-term durability of the project.	0		<b>Total points</b>	<b>1</b>	
	5- Evaluation of different alternatives to optimize and orchestrate the involved resources.	0		<b>Overall score</b>	<b>43.8</b>	
	6- Full consideration of the design output performance specifications (bill of materials, schedule, cost targets, delivery requirements to solicit and evaluate bids, make source selection recommendations and place orders.	1				
	7- Establishing procedures to ensure the integration and compatibility of the different work packages.	1				
	8- Accommodating and communicating all of the implemented site changes to all of the affected parties and packages.	1				
	9- Using BIM to extract quantities for procuring the different work packages.	0				
	10- IT was in place to identify and solicit qualified bidders and support evaluation of source capabilities and ability to deliver.	1				
	11- Setting a reliable way of communication to ensure proper and standardized means of representing information/knowledge to support project management, project controls, material and labor tracking, engineering and procurement functions.	1				
	12- Creating a central file repository to post/store and access the subcontractors/vendors quotations of different materials or systems to maintain on-line knowledge bases coupled with performance specifications.	1				
	<b>Total points</b>	<b>7</b>				

## Survey responses for case study responses (Canon design)

ITDCI metrics		Metrics for measuring IT-based Design and Construction Integration In the development process of colleges & Universities	
<b>Y/N</b>	<b>It-based integrated planning phase Total points = 34</b>	<b>Y/N</b>	<b>It-based integrated design phase Total points = 18</b>
	1- An initial kickoff meeting held to bring the project team together? (Owner, Chief of Officer, dean of students, director of students affairs and campus life, director of physical plants, designers and contractors and students as end users)		1. Effective involvement and contribution of the owner in the design process in a timely manner.
	2- Specific actions taken to set the tone for cooperation throughout the project toward a common goal. (Training programs, incentives, etc.)		2. Assigning a some one in the project (design facilitator) to identify in a timely manner potential conflicts among different design disciplines and acquire design specialists inputs as required.
	3- Owner's (Board of trustees, President) plans and expectations expressed and understood by all team members. (Characteristics of the desired facility, constraints, etc.)		3. Continuous inter-disciplinary collaboration between architects, engineers, cost engineers, operation staff and other relevant actors right from the beginning of the design process.(up stream).
	4- All team members share a compatible philosophy with the owner for this project. (culture, vision and goal congruence)		4- Establishing procedures to ensure that all design decisions that require multidisciplinary input are made in a timely manner.
	5- Clear and complete objectives established and communicated to all project members.		5- Setting an agreement between the owner and the designers upon the relative importance of the various performance issues.
	6- Enforcing a contractual agreement(or otherwise) requirement set by the owner for the use of IT-tools to support the communication coordination process. (Project website, webinars, e-mail, BIM, etc.)		6- Considering the harmonization of the facility with other campus facilities.
	7- Implementing organizational changes to enable effective utilization of information technology. (creation of a customized job to serve this service)		7- Identifying and emphasizing the project constraints in terms of time and cost continuously while developing the design.
	8- The owner allocate competent key role people who are capable of taking decision in a timely manner.		8. Continuous testing of the conformance of the design to the design functional requirements according to the university codes and standards.
	9- Enforcing a prequalification criteria by the owner to assess the ability of the designer to integrate multi-disciplinary aspects of the facility with the institution short and long term needs and objectives		9- Communicating and understanding the developed design to/by all design professionals.
	10- Establishing procedures to ensure the sufficiency between the personnel and the role they perform. ( The right knowledge, etc.)		10. Evaluating different alternatives for cost/schedule and logistics constraints.
	11-Committing and dedicating representatives from the different parties involved to the project.		11. Evaluating alternatives against fabrication and lead time constraints.
	12- Putting mechanisms (contractual agreements) in place to enforce mutual respect and open/honest communication flow amongst the different parties involved		12. Evaluating different alternatives for operability and maintenance.
	13- Conveying the program developed by the designer in clear and concise terms to clear and minimize uncertainties.		13. Identifying specific dates for reviewing key submissions and deliverables for compliance with program goals and design objectives.
	14- Considering most or all of the performance-based objectives in the planning phase. (Quality, cost/schedule contro and Value Engineering)		14.Using BIM to develop the design documents.
	15- Establishing procedures to allow the owner and designers exchange the information in a continuous manner.		15- Using BIM as a reliable database for communication and collaboration.
	16- Setting Standard protocols and format for communication between all project team members.		16. Using coordinated information network for designers to ensure the availability of the required knowledge related to the design intent, procedures and options in a timely manner.
	17- Setting a contingency plan to manage possible breaching of the previously identified mechanisms.		17. Creating a central file repository to post /store and access the different materials or systems catalogues and brochures.
	18- Establishing and approving the time schedules and campus schedule-related contingency plans by every affected party.		18. Used any software package ( Like Navis work) or any similar one to detect clashes and interferences between different design disciplines.
	19- Developing format to integrate the expertise from the design and operation of other campus facilities to the design and construction of this facility.		<b>Total points</b>
	20- Establishing procedures and actions to solve technical issues that might arise in a timely manner.( equipments reliability, configuration control, etc.)		<b>12.8</b>
	21- Incorporating the builder's perspective. (construction methods)	<b>Y/N</b>	<b>It-based integrated construction phase Total points = 11</b>
	22- Considering current/future operational conditions of the facility.		1. Excuting constructability review sessions to ensure compatibility between the different systems of the building.
	23- Creating a central file repository to post and store the entire project related documents and information		2- Structuring procedures to force the sub-contractors to enhance the accuracy of the shop drawings. (incentives, penalties,standards, etc.)
	24- Setting an interoperable file format for exchanging information and support feedback mechanisms/ (DWG, PDF,DWF,...)		3. Developing a standard process to shorten shop drawings submittal/approval time.
	25- Deciding upon the software that is going to be used in the planning stage to support budget preparation and cost control and ensuring that it is operable with other CAD software that is being used by the designer.		4. Discussing and optimizing the work sequencing among the different trade contractors.
	26- Establishing pre-qualifications or selection criteria established to ensure that all project professionals are equipped with IT- tools that support their provided services and In the time disseminate their knowledge.		5. Revising and coordinating the delivery of materials and equipments according to the construction schedule to ensure efficient flow of work.
	27- Addressing the issue of technology interoperability to cross-pollinate their products-related knowledge. (share and co-produce electronic files)		6. Scheduling meetings on a regular basis between the design and construction teams to discuss the actual conditions of the construction process to minimize or eliminate field changes.
	28- Pre-setting specifications to address the required BIM level of detail for different areas and disciplines of the project.		7- Considering and coordinating the required information for testing and inspection with the regulatory agencies.
	29- Using the Building Information Model to evaluate the different alternative.' (sensitivity analysis)		8. Using BIM to execute what if scenarios for site logistics studies.
	30- Using the AutoCAD Civil 3D to develop site analysis.		9. Tying the construction schedule to the BIM model to visualize and understand the construction progress.
	31- Developing a GIS map of the campus to better understand spending cycle, monitoring and analyzing the trends to optimize the planning process.		10. Using the BIM model to generate a look ahead construction views to help optimize the construction activities and better track the construction progress.
	<b>Total points</b>		11. Updating the BIM model continually according to the "as built" conditions
	<b>17.2</b>		<b>Total points</b>
			<b>8</b>
<b>Y/N</b>	<b>It-based integrated procurement phase Total points = 12</b>	<b>Y/N</b>	<b>It-based integrated operation &amp; maintenance phase Total points =3</b>
	1- Incorporating of the vendors and suppliers expertise regarding the constructability, materials availability while preparing the bids documents.		1- All the information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components of the building is gathered and well documented.
	2- The bidder certified to the owner that each engineer or architect of its team was selected based on demonstrated competence and qualifications.		2- Obtained and updated the BIM model with the 'as built' information.
	3- Consideration of the owner or his representative of the bidder's experience, technical competence, capability to perform and the past performance of the bidder's team members.		3-Tied and incorporated the previous information (nformation about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components) in the BIM model.
	4- Evaluating of the bidders on the basis of the safety and long-term durability of the project.		<b>Total points</b>
	5- Evaluation of different alternatives to optimize and orchestrate the involved resources.		<b>1</b>
	6- Full consideration of the design output performance specifications (bill of materials, schedule, cost targets, delivery requirements to solicit and evaluate bids, make source selection recommendations and place orders.		<b>Overall score</b>
	7- Establishing procedures to ensure the integration and compatibility of the different work packages.		<b>47</b>
	8- Accommodating and communicating all of the implemented site changes to all of the affected parties and packages.		
	9- Using BIM to extract quantities for procuring the different work packages.		
	10- It was in place to identify and solicit qualified bidders and support evaluation of source capabilities and ability to deliver.		
	11- Setting a reliable way of communication to ensure proper and standardized means of representing information/knowledge to support project management, project controls, material and labor tracking, engineering and procurement functions.		
	12- Creating a central file repository to post /store and access the subcontractors/vendors quotations of different materials or systems to maintain on-line knowledge bases coupled with performance specifications.		
	<b>Total points</b>		
	<b>8</b>		

### Survey responses for case study responses (WPI)

ITDCI metrics		Metrics for measuring IT-based Design and Construction Integration	
In the development process of colleges & Universities			
<b>Y/N</b>	<b>It-based integrated planning phase</b>	<b>Total points = 34</b>	
	1- An initial kickoff meeting held to bring the project team together? (Owner, Chief of Officer, dean of students, director of students affairs and campus life, director of physical plants, designers and contractors and students as end users)	1	
	2- Specific actions taken to set the tone for cooperation throughout the project toward a common goal. (Training programs, incentives, etc.)	0	
	3- Owner's (Board of trustees, President) plans and expectations expressed and understood by all team members. (Characteristics of the desired facility, constraints, etc.)	1	
	4- All team members share a compatible philosophy with the owner for this project. (culture, vision and goal congruence)	1	
	5- Clear and complete objectives established and communicated to all project members.	1	
	6- Enforcing a contractual agreement (or otherwise) requirement set by the owner for the use of IT-tools to support the communication coordination process. (Project website, webinars, e-mail, BIM, etc.)	0	
	7- Implementing organizational changes to enable effective utilization of information technology. (creation of a customized job to serve this service)	0	
	8- The owner allocate competent key role people who are capable of taking decision in a timely manner.	1	
	9- Enforcing a prequalification criteria by the owner to assess the ability of the designer to integrate multi-disciplinary aspects of the facility with the institution short and long term needs and objectives	0	
	10- Establishing procedures to ensure the sufficiency between the personnel and the role they perform. (The right knowledge, etc.)	0	
	11-Committing and dedicating representatives from the different parties involved to the project.	1	
	12- Putting mechanisms (contractual agreements) in place to enforce mutual respect and open/honest communication flow amongst the different parties involved	1	
	13- Conveying the program developed by the designer in clear and concise terms to clear and minimize uncertainties.	0.7	
	14- Considering most or all of the performance-based objectives in the planning phase. (Quality, cost/schedule contro and Value Engineering)	0.6	
	15- Establishing procedures to allow the owner and designers exchange the information in a continuous manner.	0	
	16- Setting Standard protocols and format for communication between all project team members.	0	
	17- Setting a contingency plan to manage possible breaching of the previously identified mechanisms.	0	
	18- Establishing and approving the time schedules and campus schedule-related contingency plans by every affected party.	1	
	19- Developing format to integrate the expertise from the design and operation of other campus facilities to the design and construction of this facility?	1	
	20- Establishing procedures and actions to solve technical issues that might arise in a timely manner.( equipments reliability, configuration control, etc.)	1	
	21- Incorporating the builder's perspective. (construction methods)	1	
	22- Considering current/future operational conditions of the facility.	1	
	23- Creating a central file repository to post and store the entire project related documents and information	0	
	24- Setting an interoperable file format for exchanging information and support feedback mechanism) (DWG, PDF,DWF, ..)	0	
	25- Deciding upon the software that is going to be used in the planning stage to support budget preparation and cost control and ensuring that it is operable with other CAD software that is being used by the designer.	0.5	
	26- Establishing pre-qualifications or selection criteria established to ensure that all project professionals are equipped with IT- tools that support their provided services and in the time disseminate their knowledge.	0	
	27- Addressing the issue of technology interoperability to cross-pollinate their products-related knowledge. (share and co-produce electronic files)	0	
	28- Pre-setting specifications to address the required BIM level of detail for different areas and disciplines of the project.	0	
	29- Using the Building Information Model) to evaluate the different alternative.' (sensitivity analysis)	0	
	30- Using the AutoCAD Civil 3D to develop site analysis.	0	
	31- Developing a GIS map of the campus to better understand spending cycle, monitoring and analyzing the trends to optimize the planning process.	0	
	<b>Total points</b>	<b>13.8</b>	
<b>Y/N</b>	<b>It-based integrated design phase</b>	<b>Total points = 18</b>	
	1. Effective involvement and contribution of the owner in the design process in a timely manner.	0.9	
	2. Assigning a some one in the project (design facilitator) to identify in a timely manner potential conflicts among different design disciplines and acquire design specialists inputs as required.	1	
	3. Continuous inter-disciplinary collaboration between architects, engineers, cost engineers, operation staff and other relevant actors right from the beginning of the design process.(up stream).	0.6	
	4-Establishing procedures to ensure that alldesign decisions that require multidisciplinary input are made in a timely manner.	1	
	5-Setting an agreement between the owner and the designers upon the relative importance of the various performance issues.	1	
	6- Considering the harmonization of the facility with other campus facilities.	0.6	
	7- Identifying and emphasizing the project constraints in terms of time and cost continuously while developing the design.	1	
	8. Continuous testing of the conformance of the design to the design functional requirements according to the university codes and standards.	0	
	9- Communicating and understanding the developed design to/by all design professionals.	0	
	10. Evaluating different alternatives for cost/schedule and logistics constraints.	1	
	11. Evaluating alternatives against fabrication and lead time constraints.	1	
	12. Evaluating different alternatives for operability and maintenance.	0	
	13. Identifying specific dates for reviewing key submissions and deliverables for compliance with program goals and design objectives.	1	
	14.Using BIM to develop the design documents.	0	
	15- Using BIM as a reliable database for communication and collaboration.	0	
	16. Using coordinated information network for designers to ensure the availability of the required knowledge related to the design intent, procedures and options in a timely manner.	0	
	17. Creating a central file repository to post /store and access the different materials or systems catalogues and brochures.	0	
	18. Use any software package ( like Navis work) or any similar one to detect clashes and interferences between different design disciplines.	0	
	<b>Total points</b>	<b>9.1</b>	
<b>Y/N</b>	<b>It-based integrated construction phase</b>	<b>Total points = 11</b>	
	1. Excuting constructability review sessions to ensure compatibility between the different systems of the building.	1	
	2-Structuring procedures to force the sub-contractors to enhance the accuracy of the shop drawings. (Incentives, penalties,standards, etc.)	0	
	3. Developing a standard process to shorten shop drawings submittal/approval time.	1	
	4. Discussing and optimizing the work sequencing among the different trade contractors.	1	
	5. Revising and coordinating the delivery of materials and equipments according to the construction schedule to ensure efficient flow of work.	1	
	6. Scheduling meetings on a regular basis between the design and construction teams to discuss the actual conditions of the construction process to minimize or eliminate field changes.	1	
	7- Considering and coordinating the required information for testing and inspection with the regulatory agencies.	1	
	8. Using BIM to execute what if scenarios for site logistics studies.	1	
	9. Tying the construction schedule to the BIM model to visualize and understand the construction progress.	1	
	10. Using the BIM model to generate a look ahead construction views to help optimize the construction activities and better track the construction progress.	0	
	11. Updating the BIM model continually according to the "as built" conditions	0	
	<b>Total points</b>	<b>8</b>	
<b>Y/N</b>	<b>It-based integrated procurement phase</b>	<b>Total points = 12</b>	
	1- Incorporating of the vendors and suppliers expertise regarding the constructability, materials availability while preparing the bids documents.	1	
	2- The bidder certified to the owner that each engineer or architect of its team was selected based on demonstrated competence and qualifications.	1	
	3- Consideration of the owner or his representative of the bidder's experience, technical competence, capability to perform and the past performance of the bidder's team members.	1	
	4- Evaluating of the bidders on the basis of the safety and long-term durability of the project.	1	
	5- Evaluation of different alternatives to optimize and orchestrate the involved resources.	0	
	6- Full consideration of the design output performance specifications (bill of materials, schedule, cost targets, delivery requirements to solicit and evaluate bids, make source selection recommendations and place orders.	1	
	7- Establishing procedures to ensure the integration and compatibility of the different work packages.	1	
	8- Accommodating and communicating all of the implemented site changes to all of the affected parties and packages.	1	
	9- Using BIM to extract quantities for procuring the different work packages.	0	
	10- IT was in place to identify and solicit qualified bidders and support evaluation of source capabilities and ability to deliver.	1	
	11- Setting a reliable way of communication to ensure proper and standardized means of representing information/knowledge to support project management, project controls, material and labor tracking, engineering and procurement functions.	1	
	12- Creating a central file repository to post /store and access the subcontractors/vendors quotations of different materials or systems to maintain on-line knowledge bases coupled with performance specifications.	1	
	<b>Total points</b>	<b>10</b>	
<b>Y/N</b>	<b>It-based integrated operation &amp; maintenance phase</b>	<b>Total points =3</b>	
	1- All the information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components of the building is gathered and well documented.	0	
	2- Obtained and updated the BIM model with the 'as built" information.	0	
	3-Tied and incorporated the previous information (information about manufacturer, model, serial number, specifications, and the maintenance history for each component or most components) in the BIM model.	0	
	<b>Total points</b>	<b>0</b>	
	<b>Overall score</b>	<b>40.9</b>	