Delft University of Technology

Technology Integration Capability in the Oil/Gas Industry

Cross case study of iRing and BIM technologies

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Preface

The research is performed in the faculty of Civil Engineering and Geosciences of the Delft University of Technology, collaborating with the Amsterdam office of Fluor. The subject is related to the master track Construction Management and Engineering (CME).

The research started in December 2015 after several discussions with my supervisors and professionals at Fluor. At first, the direction of my research was just defined as a comparison study between BIM in AEC industry and iRing in Oil/Gas industry. But the scope of this subject is too broad to study clearly within several months time. After that I was thinking about one question: what is the biggest change that technologies have brought to the construction industry or what is the trend that BIM and iRing are developing towards. At last I found the answer, which is integration. Integration is a very appropriate word which can represent the changes in processes and disciplines within the construction field. Having this important word –integration in mind, I was thinking how to break this word down, what values or what compulsory aspects consist of integration, in which common aspects BIM and iRing technologies can be compared and so on. The thinking process and organization process of many thoughts took a very long time and during this period I got a lot of help from very kind engineers at Fluor. Therefore I would like to thank all the engineers who contributed to my research and the interviews.

In addition, I would like to thank my supervisors from the TU Delft and Fluor: Marcel Hertogh, Sander van Nederveen, Jos Vrancken, Anton van der Steege and Arne Siewertsen. Thank you very much for the useful discussions we have had and the advice you gave me.

Furthermore, I would like to thank my family and friends who supported me during this research and my entire study time.

Delft, June 28, 2015

Chulin Xue

Summary

In Architecture, Engineering and Construction (AEC) industry and Oil/Gas industry, there are various ways to realize projects. No matter in which way, the working process and design discipline are the two important components in the planning and design phase of any project. Traditionally, the first component, "working process", is described by the "sequential waterfall model" (Kruchten, 2000). The second component, discipline, can be seen as fragmented parts that lack collaboration between professionals in different areas. With the traditional sequential process and fragmented disciplines, there are a lot of problems arising in both Oil/Gas and AEC industry: progress at a very low speed, miscommunications between different functional teams, too much rework coming at the very end, bad impact on knowledge harvesting and continuous learning, etc (Drejer & Vinding, 2004). With the rapid development of construction projects in the world, such problems are being increasingly recognized nowadays and are on the way to be changed.

Integration is becoming a significant trend in the AEC industry and Oil/Gas industry, helping to change the working process from sequential to iterative and transform design discipline transform from fragmented to collaborative. The driving force of the trend in integration relies much on the technology that we are trying to implement in the industry, the so called Building Information Modeling (BIM) and iRing. Finding out the integration level and capabilities of technology can provide engineering companies with insights into improvement directions and is important for them to find practical problems. The main objective for this research is to propose opportunities for technology improvement in terms of integration capability for an engineering company (e.g. Fluor) through comparing iRing and BIM technologies.

Theoretical Basis

In this research, based on CMM (Paulk et al., 1995), NBIMS (NIOBI, 2007) and discussions with professionals at Fluor, I employed the concept of integration capability for the evaluation of integration levels of the two technologies, BIM and iRing. In terms of the integration capability, considering practical engineering requirements in real projects, we think it should consist of five compulsory parts: visualization capability, collaboration capability, simulation capability, optimization capability and digitization capability. Besides, based on evaluation of these capabilities, the integration levels of technology can be roughly divided into two levels: the inter-disciplinary level (inter-integration level) and the trans-disciplinary level (trans-integration level). Inter-integration indicates that professionals from different specialties, such as architects, structural engineers and MEP (mechanical, electrical and piping) engineers, can work together on the same design platform, sharing information and their specific experiences simultaneously. Trans-integration indicates the collaboration not within design disciplines, but the coordination with other project disciplines. Cost discipline, which is the extra discipline being

further integrated into the platform to enable designers and other professionals making wiser decisions based on more comprehensive considerations, is chosen to be studied in this research. Then, according to different integration level, based on the five compulsory capabilities of integration, the evaluation criteria for interdisciplinary of design and transdisciplinary of design and cost are formulated. The criteria for inter-integration level cover: graphical information, roles, spatial information, change tracking, information accuracy, timeliness and delivery method; the criteria for trans-integration level are composed of graphical information, roles, cost flow, change tracking, reliability of information production, quantification process and built-in standards.

Case Analysis

Two cases, one from each industry, are selected for the research. The KNPC Clean Fuels project is from Fluor, which represents the Oil/Gas part; the new T3A terminal of Chongqing Jiangbei International airport is constructed by China Construction Eighth Engineering Division, which represents the AEC part. The BIM technology and iRing technology applied by these two projects for the purpose of design and estimating are evaluated separately based on the criteria of inter-integration and trans-integration. After that, the cross comparison is performed where the strengths and weaknesses will be analyzed and the opportunities for improving the current positions will be proposed.

Conclusions

As for inter-integration level, the current position of iRing is not lagging behind that of BIM. For some aspects, iRing surpasses BIM, especially for real time data access. iRing supports designers from different disciplines, such as structural, architectural, piping, etc., working on the same model. While for BIM, different design disciplines work separately and their exclusive models are combined manually at a certain time every week. Besides, iRing can support tracking of change history, web-based and secured information distribution, 3D intelligent graphics and coordinates spatially located functionalities.

Overall speaking, iRing possesses very good inter-integration capability, but there is still some space for iRing technology to improve. From this research, for iRing have been found at least the following aspects for improvement: change tracking capability (adding change recording functionality of what: what the exact change is), response information capability (support updating automatically), and spatial information sharing capability (integrating with GIS).

As for trans-integration, BIM stands at a little higher level than iRing. The gap between design and cost estimation in iRing is much larger than BIM. More specifically, iRing works in the following way: quantity take-offs have to be first calculated and exported from design tools and then cost estimators need to import the taken-off quantities into estimating tools for final cost calculation. There has to be a bridge between design tools and cost estimation tools. Whereas, cost estimation software in BIM can directly support 3 dimensional models that are generated from design tools. So BIM is able to perform cost estimation in a more fluent way. In general, the estimation accuracy of iRing depends on how accurate the taken-off quantities are calculated, while accuracy of BIM depends on how accurate the project model is built. Therefore, at present, BIM's integration can realize multiple uses of one model among different disciplines, while iRing's integration is limited to design disciplines.

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Introduction

In Architecture, Engineering and Construction (AEC) industry and Oil/Gas industry, there are various ways to realize projects. No matter in which way, the working process and design discipline are the two important components in the planning and design phase of any projects. Traditionally, the first component "working process" is described by the "sequential waterfall model" (Kruchten, 2000). The second component, design discipline, can be seen as fragmented parts that lack of collaboration between professionals with experiences from different areas. With the traditional sequential process and fragmented disciplines, there are a lot of problems arising in both Oil/Gas and AEC industry: progress at a very low speed, miscommunications between different functional teams, too much rework coming at the very end, bad impact on knowledge harvesting and continuous learning, etc (Drejer & Vinding, 2004). With the rapid development of construction projects in the world, such problems are being increasingly recognized nowadays and are on the way to be changed.

For construction industry, those changes are very welcomed as they are the desired trends of development in the construction industry. While, there is no exception with Oil/Gas industry. Fluor has proposed "integrated solutions" as the next steps for a deliberate and purposeful path for their development, which is very essential for Fluor's future competitiveness (Fluor, 2014). Under this situation, integration of working process and design discipline is becoming a significant trend in both industry, helping working process change from sequential to iterative and design discipline transform from fragmented parts to collaborative team.

In order to achieve an integrated solution, Fluor does apply new technologies in practice, and have a hope that with these technologies, Fluor can work more efficiently and sustainably, said by Anton van der Steege, manager of the Global E&C Cost. He also noticed that in the AEC (Architecture, Engineering and Construction) industry, a very new and effective integration concept arise, which is "Building Information Modeling (BIM)". There are a great number of benefits BIM has brought to the AEC projects. While BIM is specifically centered on building projects as well as infrastructure projects, it cannot be used by Fluor in the oil/gas projects directly. But Fluor does have interest to know more about BIM's integration capability in the AEC industry, and through comparison to see how far they have gone in the integrated direction and what problems they still need to solve.

Therefore, in order to achieve the goal of "integration", we are going to rely much on booming technologies that we are trying to implement in the industry, so called Building Information Modeling (BIM) and iRing.

As the research is carried out at Fluor, a representative Oil/Gas company in the industry, the main evaluation is conducted on the iRing technology utilized by Fluor for most of their projects. Through evaluation, it is helpful to propose opportunities for technology improvement in terms of integration capability at Fluor. In order to do the evaluation as objectively as possible, BIM (Building Information Modeling) technology from AEC industry is chosen for comparison. First of all, knowing more about BIM's application in the AEC industry can help us better understand iRing technology itself and its meaning for Oil/Gas industry. Second, BIM, as a technology that has been systematically researched in the AEC industry, can provide reasonable insight on how well Fluor has been done on the way to integration. It can also give valuable experiences and directions for the improvement in the Oil/Gas industry. Finding out the current position through comparison will not only help the company in recognizing the position it stands at currently, but also helps them in figuring out what functionalities they need and desire and what developing possibilities they can achieve. Moreover, the design tool used by Fluor, namely Smart Plant, is regarded as the most advanced collaboration platform for process plant. Similarly, Revit and several other design software also seen as the most advanced tools for designing buildings. Existence of such tools gives possibility for the comparison of technology, which has embedded in the tools that designers are using in both industries.

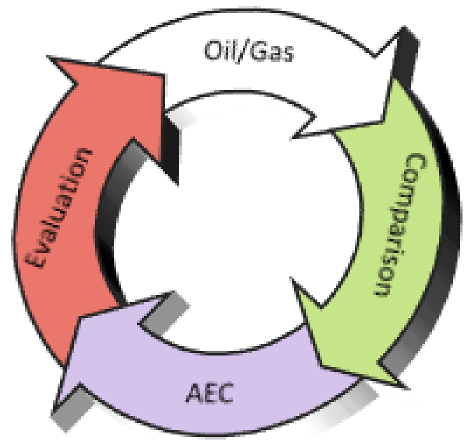


Figure 1 Comparative evaluation

Therefore, the integration level that provided by BIM and iRing technology will be evaluated from both AEC industry and Oil/Gas industry, and also a comparison between them. Through comparison, the strengths and weakness of the current position of Fluor will be discovered and possible opportunities for further improvement can be found.

This research consists of four parts: research context, theoretical analysis, practical analysis and conclusions. In the first part, Chapter 1, the research problem, objective, questions and research approach will be elaborated. In the second part, Chapter 2 will introduce the compare preconditions between AEC industry and Oil/Gas industry; Chapter 3 will be centered on the evaluation model. In the third part, Chapter 4 will carry out the practical analysis: two cases study and cross comparison analysis. In the last part, Chapter 5 will be drawn according to the research question and objective, illustrating the benefits of integration, trends of integration, and recommendations on improving the integration level.

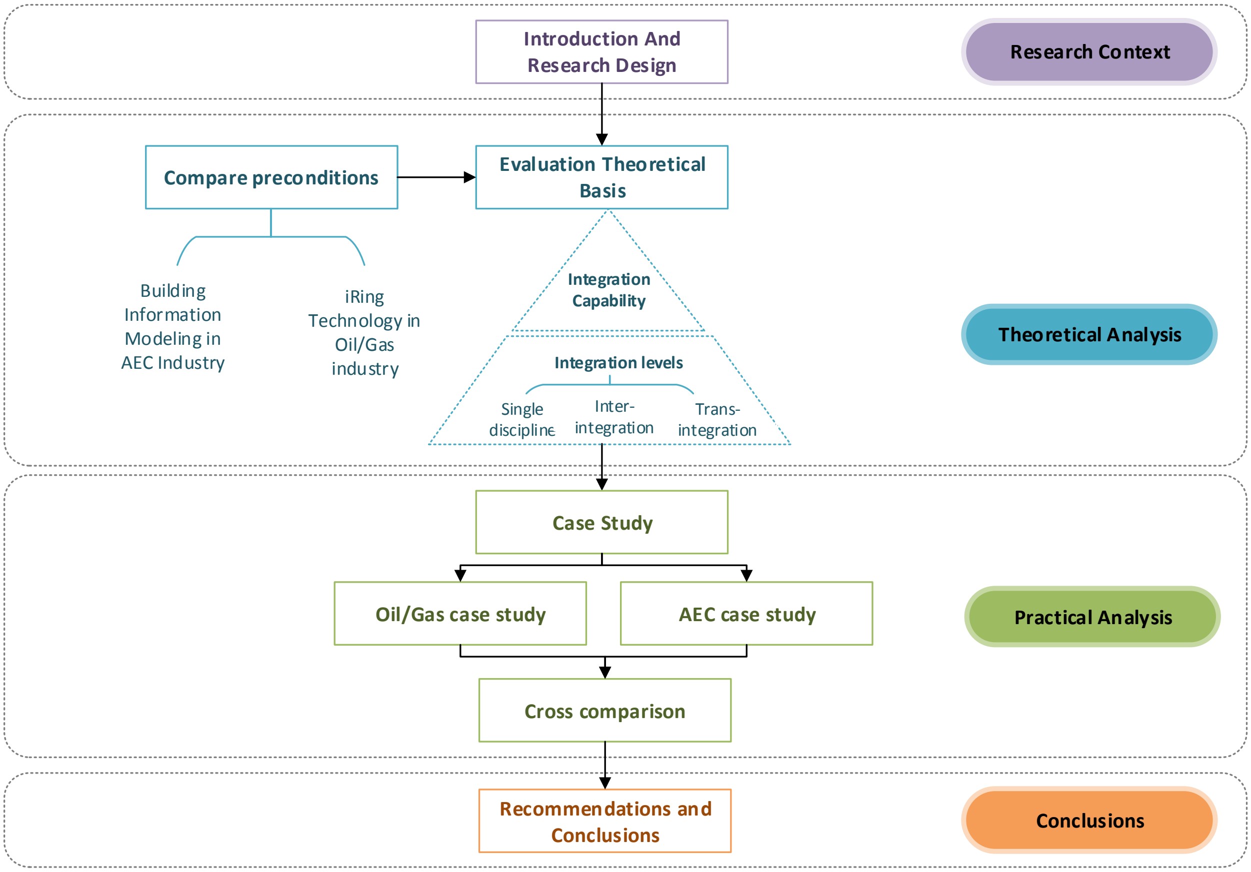


Figure 2 Thesis structure

RESEARCH DESIGN

Chapter 1
Research Design

1.1 Problem Statement

In Architecture, Engineering and Construction (AEC) industry and Oil/Gas industry, there are various ways to realize projects. No matter in what way, the process and discipline are the two important components. Traditionally, the first component "engineering process" is described as "sequential waterfall model". Kruchten pointed out that the traditional process of conducting a construction work complies with a linear project approach, that is "sequential waterfall model"(Kruchten, 2000). The Royal Institute of British Architects (RIBA) described traditional sequential processes as planning, design, financing, construction and continues until takeover and maintenance, which was widely accepted throughout the construction industry (RIBA, 1997). As for the second component, the structure of disciplines is so long described as fragmented (Alashwal, Rahman, & Beksin, 2011), and the fragmented disciplines are usually related with sequential waterfall processes. With the traditional sequential process and fragmented disciplines, there are a lot of problems: progress at a very low speed, miscommunications between different functional teams, too much rework coming at the very end, bad impact on knowledge harvesting and continuous learning, etc (Drejer & Vinding, 2004). Because of tremendous problems recognized, the traditional working approach is desperately needed to be changed. Under this situation, integration is needed so as to drive these changes, where process is changing from sequential to iterative and discipline structure is transforming from fragmented to collaborative. For construction industry, those changes are very welcomed as they are the desired trends of development in the construction industry.

The integrated solution is wanted by every company in the construction field. There is no exception with Fluor. Fluor has proposed "integrated solutions" as the next steps for a deliberate and purposeful path for their development, which is very essential for Fluor's future competitiveness (Fluor, 2014).

Integration means a lot: integration of people across geographical, organizational and disciplinary boundaries, integration of processes in terms of business integration and vendor collaboration and finally; integration in relation to technology: data, sensors, protocols, fiber optics , standardization and others (OLF, 2005a, 2005b). The integration of all technologies discussed in the thesis can be seen as a typical e-field: an instrumented and automated oil and gas field that utilizes people and technology to work efficiently in order to maximize the life value of the field (Filstad & HEPSØ, 2009) In order to achieve "integration", while the hope relies much on technology. As elaborated by Succar, technology is one of the three cornerstones if changes must happen, that is to say technology is indispensible if there is a revolution (Succar, 2009). Kruchten also pointed out that "In the iterative process, it is the software we develop that comes first" (Kruchten, 2000).

In order to achieve an integrated solution, Fluor does apply new technologies in practice, and have a hope that with these technologies, Fluor can work more efficiently and sustainably, said by Anton van der

Steege, manager of the Global E&C Cost. He also noticed that in the AEC (Architecture, Engineering and Construction) industry, a very new and effective integration concept raised, which is "Building Information Modeling (BIM)". There are a great number of benefits BIM has brought to the AEC projects. While BIM is specifically centered on building projects as well as infrastructure projects, it cannot be used by Fluor in the oil/gas projects directly. But Fluor does have interest to know more about BIM's integration capability, and through comparison to see how far they have gone in the integrated direction and what problems they still need to solve.

The comparison approach does not only consider Fluor's wish, but is also supported by the theoretical reasons. The compare object is the technology represented by BIM (Building Information Modeling) in the AEC industry. The first reason for choosing BIM is because some technologies used by Fluor, namely Smart Plant, is regarded as the most advanced design tool for process plant. In order to assess the integration level, a detailed-researched technology with clear developing direction is preferred in order for further improvement. Additionally, another reason for comparing with BIM is because there are comparison basis in terms of process, discipline and norms. The comparison basis will be elaborated in detail in Chapter 2 based on the description of the AEC industry and Oil/Gas industry.

Therefore, the research will be carried out with a comparison approach. The integration level that provided by the technology will be evaluated from both sides, namely AEC industry and Oil/Gas industry. Based on the separate evaluation result, the comparison will be carried out. Through comparison, the strengths and weakness of the current position of Fluor will be discovered and possible opportunities for further improvement can be found.

1.2 Research Objective

As mentioned in the problem statement, learning about the level of integration provided by technology in an organization is important for them to find practical problems. Finding out the current level through comparison will not only help the company in recognizing the position it stands at currently, but also helps them in figuring out what functionalities they need and desire. So the main objective for this research is as follows:

> ***To propose opportunities of technology improvement in terms of integration capability for engineering contractors, through comparing iRing and BIM.***

1.3 Research Question

The formulation of the problem statement and the research objective lead to the formulation of the following research question:

> ***In what aspects, can technology be improved in terms of integration capability for engineering contractors, through comparing iRing and BIM?***

In order to answer this main research question, the following sub questions have to be answered:

- *What is the basis for comparing between BIM in AEC industry and iRing in Oil/Gas industry?*
  This part is answered in Chapter 2. The introduction of AEC industry and relevant BIM technology of is in Section 2.1. The introduction of Oil/Gas industry and relevant iRing technology is in Section 2.2. Following these two sections, the compare basis is illustrated in section 2.3.

- *What does integration mean?*
  The integration refers to the combination of process changing from sequential towards iterative and disciplines changing from fragmented towards collaborative. The changes of process and disciplines are outlined in Section 3.1. And the role of integration provided by technology is elaborated in Section 3.2.

- *What are integration's levels?*
  The integration level consists of inter-integration and trans-integration, which will be elaborated in Section 3.3.

- *What are the compulsory capabilities of integration?*
  The compulsory capabilities and the derivation process are elaborated in Section 3.4. based on the compulsory capabilities, corresponding criteria of evaluation are chosen in Section 3.5.

- *What is the integration level, namely inter-integration and trans-integration, provided by the technology in an Oil/Gas company?*
  This part is mainly answered in Section 4.1 by a case study. In section 4.1.1, the profile about this company and relevant project is elaborated. Section 4.1.2 and 4.1.3 will evaluate the inter-integration level and trans-integration level respectively.

- *What is the integration level, namely inter-integration and trans-integration, provided by BIM at an AEC company?*

This part is answered in Section 4.2 by a case study. In section 4.2.1, the profile about this company and relevant project is elaborated. Section 4.2.2 and 4.2.3 evaluate the inter-integration level and trans-integration level respectively.

- *What are the strengths and weaknesses for the technology at engineering companies?*
  The answer is in Section 4.3.1 and 4.3.2. Based on the separate inter-integration and trans-integration evaluation result two cases, the strength and weakness will be elaborated. Possible opportunities for technology improvement will be introduced based on comparison.

- *What are the difficulties for improving the integration levels at engineering companies?*
  Section 4.3.3 will focus on the difficulties and problems in improving integration levels.

1.4 Research Approach

Literature study is the first step to learn about current status and level of research in similar fields. The second approach is survey, which including interviews targeted at different parties, that will be used to gather information and data. The third approach is case study. Two practical cases will be used to collect relevant information. Besides, exploratory study will be carried out to check the possibilities and feasibilities of the knowledge sharing between the AEC field with Oil & Gas field. Deductive analysis will also be applied, aiming at evaluation and conclusions. Figure 3 shows the main approaches in this research. The details of literature study, interview study, exploratory analysis and deductive method will be elaborated below.

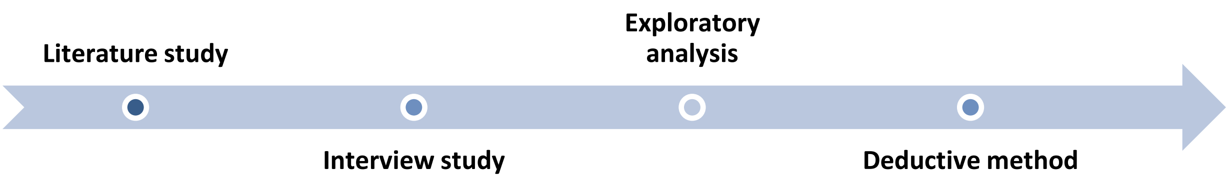


Figure 3 Research Approaches

Literature Study

Literature study is the first step to learn about the AEC industry, Oil and Gas industry, BIM''s current development status, and similar technologies. Thus literature study is one of the most important and basic approaches in this research and it will go through the whole research period.

Interview study

Interviews and questionnaires are carried out in the research, aiming at the professionals from different disciplines in AEC (Architectural, Engineering and Construction) industry and Oil/Gas industry, that is the way to collect relevant information. Based on the interviews, benefits of BIM's applications and technologies in oil and gas industry will be quantitatively analyzed and compared, which helps to know what are the to-be-improved for each industry.

Exploratory Analysis

With all the resources of BIM in AEC industry and technologies in Oil and Gas industry, differences, similarities, benefits and challenges will be firstly analyzed qualitatively and then go to detailed quantitative analysis. Besides, the to-be-improved part and the potential for knowledge sharing will be explored using the relevant methods of exploratory study.

Deductive Method

With the result from all the methods mentioned above, the conclusion of the to-be-improved parts and potential for knowledge sharing will be made with deductive method.

1.5 Research Structure

In order to solve the research questions and achieve the research goal, the research will be done in a structured and organized way. The structure of the research is schematically shown in Figure 2 . The thesis consists of four parts:

Part A: Research Context

In the introduction and chapter 1 research design, the context of this research is described. It gives an introduction to the subject; it points out the research problem, objective, questions and research approach.

Part B: Theoretical Analysis

In the second part, Theoretical Analysis is based on literature study. This part consists of Chapter 2 and Chapter 3. Chapter 2 is focused on the compare basis between AEC industry and Oil/Gas industry. Section 2.1 introduces the AEC industry and relevant Building Information Modeling technology. Section 2.2 introduces Oil/Gas industry and relevant iRing technology. Based on the previous two sections, compare basis is summarized in Section 3.3.

On the other hand, Chapter 3 is centered on the criteria of integration levels. In order to proposing the criteria of integration level, in chapter 3, the changes in process and disciplines are introduced first, from sequential, fragmented to iterative, collaborative (section 3.1). The driving force of these changes lies on the integration capability of technology (section 3.2). The integration capability is defined as consisting of inter-integration and trans-integration (section 3.3). Following that, the criteria in evaluating the level of inter-integration and trans-integration are illustrated (section 3.4).

Part C: Practical analysis

This part, Chapter 4, consists of three main sections: case 1 analysis, case 2 analysis and cross comparison. In Section 4.1, the case from oil/gas perspective will be studied. It contains the background information, namely company profile and project profile in Section 4.1.1. The evaluation of inter-integration and trans-integration will be elaborated in section 4.1.2, and section 4.1.3 respectively.

The second case is from the AEC industry (Section 4.2). The case study procedure is same with the first case study: background information is the first part in Section 4.2.1; the evaluation of inter-integration level is the second part in Section 4.2.2; the trans-integration evaluation is the last part in Section 4.2.3. The evaluation of these two cases is based on interviews.

Based on cross comparison, Section 4.3 is going to propose weakness and strengths of iRing's capability and then analyze the difficulties in improvement.

Part D: Conclusions

In the chapter 5, conclusions regarding research objective will be drawn. Besides, recommendations will be provided in general and towards Fluor and iRing. This part also includes reflections on the possibilities that are created with this research, but as well as limitations

THEORATICAL ANALYSIS

Chapter 2

AEC Industry and Oil/Gas Industry

2.1 BIM in AEC industry

2.1.1 AEC Industry

The Architecture, Engineering and Construction (AEC) industry is one of the most important cornerstones for a nation's economy and development. To some extent, the development of the AEC industry determines the development of a country.

This traditional industry has long sought techniques to decrease project cost, increase productivity and quality, and reduce project delivery time (Azhar, 2011). Many professionals, researchers, governments, scientists are studying on the AEC industry's future. Sawhney pointed out in 1998 that the AEC industry is now developing at a rapid speed with the adoption of new project delivery methodologies, continuous improvement of design of facilities and generation of newer means, methods and construction materials (Sawhney, 1999). Two-dimensional automated drafting is being changed by 3D modeling systems (C Eastman, Wang, You, & Yang, 2005). It can be seen that the AEC industry is in a revolutionary era, running towards more intelligent, efficient and sustainable.

2.1.2 Technology

This section will introduce Building Information Modeling, ISO 15926, TC184/SC4, and Building Smart Alliance. Building Information Modeling (BIM) is a very popular concept involving integration technology in the AEC industry. Open Standard of ISO 15926 is the basic norm supporting BIM's development. TC184/SC4 is the committee who formulated ISO 15926 and has a clear scope of it. As for Building Smart International, it is the organization who shoulders the responsibility to promote BIM's implementation in the AEC industry.

Building Information Modeling

The concept of BIM originated from the 1970s(Charles Eastman, 1974). The terms of Building Information Model and Building Information Modeling (including the acronym "BIM") is becoming popular 10 years later when Autodesk released the white paper entitled "Building Information Modeling" (Autodesk, 2003). Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility, which can provide adopters many benefits and competitive advantages, assisting them to perform projects in a more collaborative manner, throughout the whole engineering life cycle. BIM is increasingly considered as an Information Technology (IT) – enabled approach that allows design integrity, virtual prototyping, simulations, distributed access, retrieval and maintenance of the building data (Fischer & Kunz, 2004).

ISO 16739

ISO 16739, also called IFC, is an open international standard for Building Information Modeling (BIM) data in a building construction or facility management project during the life cycle phases, which allows for data exchanging and sharing among software applications. ISO 16739 consists of conceptual data schema (EXPRESS scheme specification), and reference data (property, quantity names and descriptions). The details of the IFC Data Schema can be found in the Appendix B.

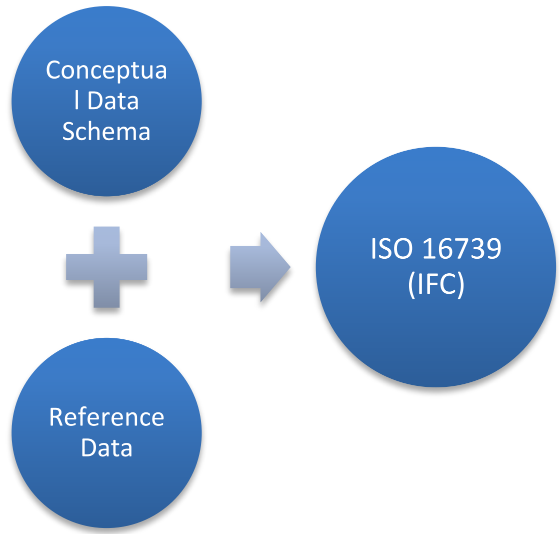


Figure 4 Composition of ISO 16739

IFC is an open vendor-independent neutral file format covering building geometry, topology, spatial structure, building elements, relationships between building elements, building equipment and furniture, as well as people, organizations and project data.

TC 184/SC4

ISO 16739 belongs to the industry standard of sub-committee of ISO TC184/SC4 (See Figure 5). TC184 is the Technical Committee 184 for Industrial Automation System and Integration, in the structure of ISO organization. SC4 is the subcommittee 4 for industrial data under the TC 184, which is aimed at developing standards for industrial automation systems and integration (See Figure 6) (ISO, 2006).

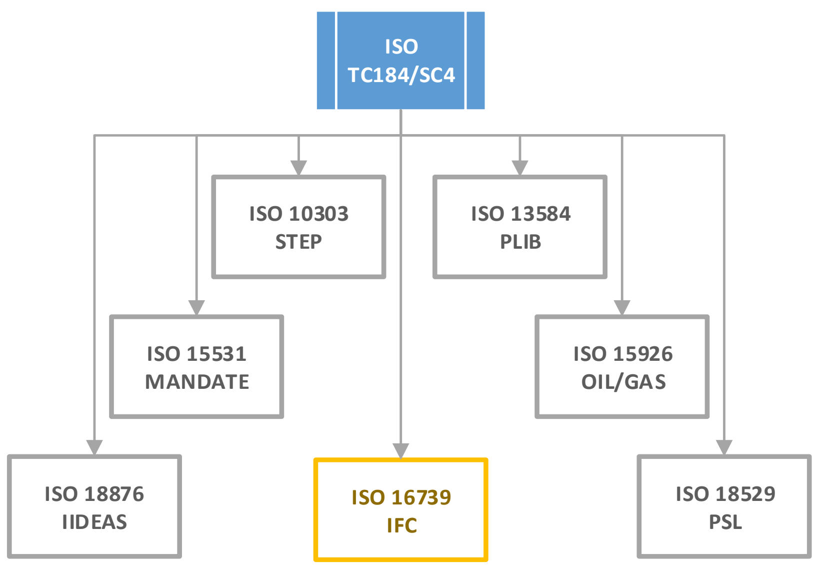


Figure 5 ISO 16739 in ISO Family

As the information society is developing and evolving rapidly, different computer systems, different programs, different program languages, different representation and structure of the data call for a common standard and the voice of this requirement is increasing significantly. There are many reasons lying behind the requirement of common information standards and accelerating the generation of SC4(Chris Kreiler, 2006; ISO, 2006):

1) Quantity and the quality of product information necessary to sell a product are increasing;
2) Product life is increasing because of reuse and recycles;
3) Sometimes the life of the product data last longer than the product itself;
4) Information society has an increasing role in any business;
5) Products have become more complex due to the development of the materials technology and new processes;
6) Automation is spreading in any phase of the product development from the design to the recycling and computers have become essential;
7) Information that refers to the materials gets lost during the different phases of the life cycle product while they are essential for the reuse and the recycling of the product.

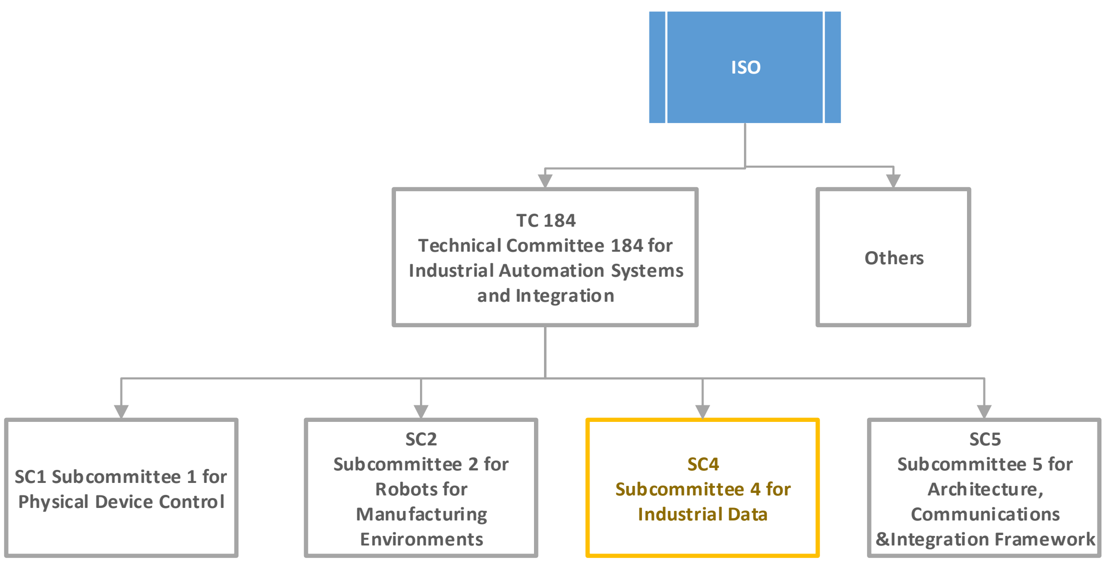


Figure 6 TC184/SC4 in ISO Family

Product Data are generated and preserved on informatics support systems that are often made available to suppliers and the general public. Many companies are compelled to maintain the hardware and software that generated the data because the data cannot be read or used by today's advanced technology systems. In the appendix B, the scope of TC184/SC4 is elaborated.

Building Smart International

Building Smart International, formerly the International Alliance for Interoperability founded in 1996, is the key driving force behind ISO 16739 Industrial Foundation Classes (IFC) and BIM concept, which aims to promote the use of Building Information Models in order to help building industry stakeholders to share highly accurate information throughout a facility or project's life cycle and contribute to a sustainable built environment through smarter information sharing and communication.

In order to completely bring BIM into practice and achieve National BIM Standard ballot item, four sub-goals were defined by building SMART alliance, which are: define the information exchange requirements (IER), complete process maps at each Level of Development (LOD) based on IER, complete the Information Delivery Manual (IDM) for each LOD process map, and initiate the development of Model View Definitions (MVD). After these four sub-goals achieved, the ballot item of NBIMS will be realized (Tamera L. McCuen; Peter R. Bredehoeft, 2013).

Currently, BIM is gaining great acceptance in the AEC industry as a great number of firms are beginning to adapt BIM into their work and establish BIM within their organizations. Below is a list of some events, which shows that BIM is becoming a necessity for the AEC industry gradually (Tamera L. McCuen; Peter R. Bredehoeft, 2012).

1) 2003, U.S. Government Services Administration (GSA) stated formally in the document P-100, Facilities Standards for the Public Buildings Service, requiring Building Information Models being implemented on FY06 projects in support of improving design quality and construction delivery.
2) 2007, GSA requires BIM being implemented on projects of $10 million or greater and for all projects being funded by the US Congress for design.
3) 2008, eight organizations, NIBS[1], AACEi[2], RICS[3], GSA[4], USACE[5], BSA[6] etc., signed a Memorandum of Agreement (MOA) to define the information exchange requirements for cost estimating in BIM.
4) 2008, Estimating in BIM Workgroup was founded with the goal of producing a ballot item for national BIM Standard.

Late 2012, Blue Sky Submission was submitted by Estimating in BIM Workgroup, including defining the estimating data criteria, information exchange process maps, and other information exchange requirements for cost estimating in BIM.

[1] NIBS: National Institute of Building Sciences
[2] AACEi: Association for the Advancement of Cost Engineering International
[3] RICS: Royal Institution of Chartered Surveyors
[4] GSA: Government Service Administration
[5] USACE: United States Army Corps of Engineers
[6] BSA: Building SMART Alliance

As the major private and government owners want to institutionalize BIM's benefits of faster, more certain project delivery and more reliable quality and cost, BIM usage is accelerating greatly, which therefore cause the powerful accelerating of BIM usage. Take North America for example, BIM adoption in North America jumped from 28% to 71% between 2007 and 2012(Construction, 2012, 2014). Figure 7 shows the changes of the level of BIM adoption in North America.

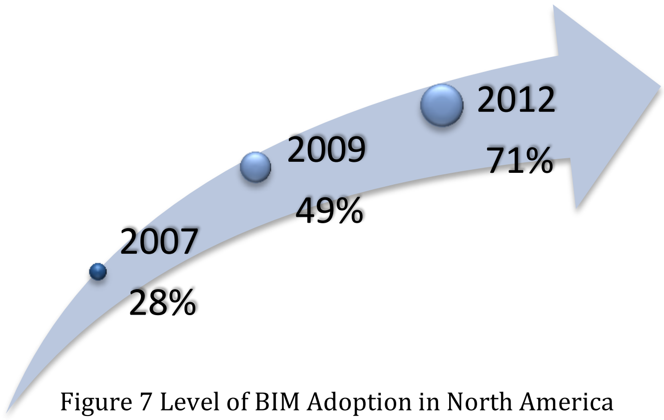


Figure 7 Level of BIM Adoption in North America

Source: McGraw-Hill Construction, 2012

Software

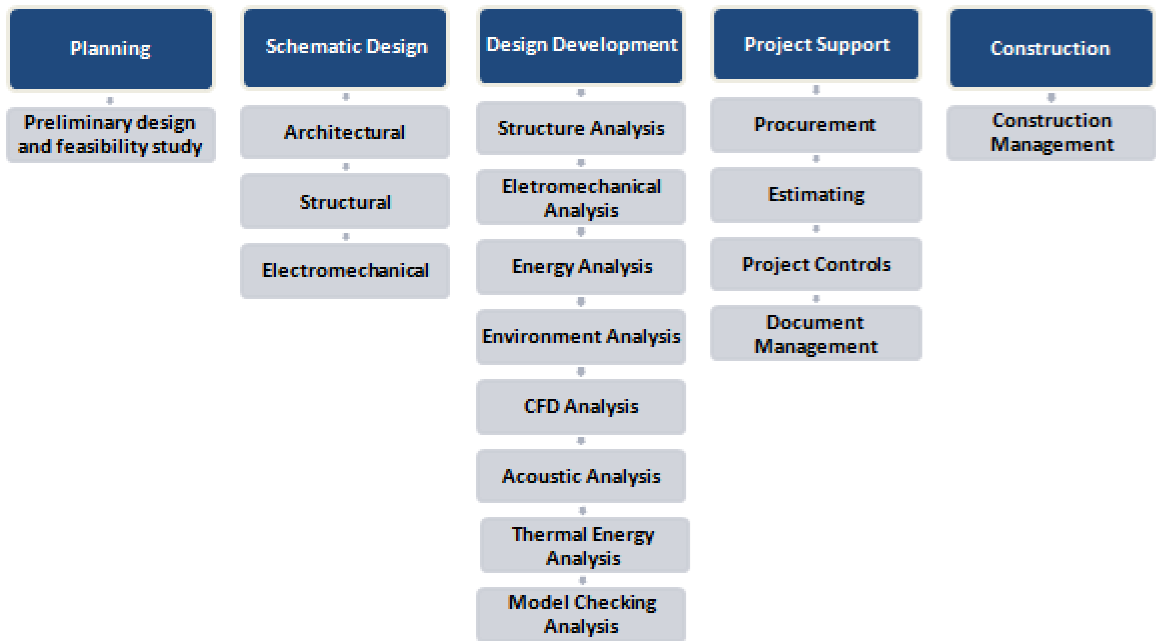


Figure 8 Classification Structure

There are large quantities of IFC-based applications and there are three division approaches to divide the applications, namely AGC (Associated General Contractors of American) Classification (Hardin, 2011), Guanpei He Classification (He, 2010), and Manufacturer Classification. In the thesis, referring to the first two classification methods, BIM's software are divided into 5 groups, namely Planning tools, Schematic Design tools, Design Development tools, Project Support/Construction Design tools, and Construction tools. In more detail, Schematic Design has 3 sub-groups, namely Architectural, Structural and Electromechanical tools. As for Design Development group, it includes 8 sub-groups, namely Structure

Analysis, Eletromechanical Analysis, Energy Analysis, Environment Analysis, CFD (Computational Fluid Dynamics) Analysis, Acoustic Analysis, Thermal Energy Analysis, and Model Checking Analysis. In the group of Project Support, the sub-groups are Procurement, Estimating, Project Controls and Document Management. According to the classification structure, the table below shows the relevant BIM software for each group and sub-group.

Table 1 BIM software

Classification		**Software**	**Manufacturer**
1 Planning	Preliminary Design and Feasibility Study	SketchUP	Google
		ArchiCAD	Graphisoft
		Vectorworks Designer	Nemetschek
		Tekla Structures	Tekla
		Affinity	Trelligence
		Vico Office	Vico Software
		Revit Architecture	Autodesk
		Bentley Architecture	Bentley
		D-Profiler	Beck Technology
2 Schematic Design	Architectural	Revit Architecture	Autodesk
		Bentley Architecture	Bentley
		ArchiCAD	Graphisoft
		Vectorworks Designer	Nemetschek
		Digital Project	Gery Technology
	Structural	Revit Structure	Autodesk
		Bentley Structural	Bentley
		Digital Project	Gery Technology
		Tekla Structures	Tekla
		Fastrak	CSC
		SDS/2	Design Data
		RISA	RISA Technologies
	Electromechanical	Revit MEP	Autodesk
		Bentley Mechanical Systems	Bentley
		Digital Project MEP	Gery Technology
		Cadpipe HVAC	AEC Design Group
		MEP Modeler	Graphisoft
		Fabrication for ACAD MEP	East Coast CAD/CAM
		CAD-Duct	Micro Application Packages Ltd
		Duct/Pipe Designer 3D	QuickPen International
3 Design Development	Structural Analysis	Robot	Autodesk
		RISA	RISA Technologies
		Digital Project	Gery Technology
		GTSTRUDL	Georgia Institute of Technology
	Electromechanical Analysis	Apache HVAC	IES
		Carrier E20-II	Carrier
	Energy Analysis	Green Building Studio	Autodesk
		Ecotect	Autodesk

		VE-Pro	IES
		Energy Plus	DOE and LBNL
	Environment Analysis	VE-Pro	IES
	CFD Analysis	FloVent	Mentor Graphics
		Fluent	Ansys
	Acoustic Analysis	Apache HVAC	IES
	Thermal Analysis	TRNSYS	University of Wisconsin
	Model Checking	Solibri Model Check	Solibri
	Estimating	QTO	Autodesk
		Dprofiler	Beck Technology
		Visual Applications	Innovaya
		Vico Takeoff Manager	Vico Software
	Project Controls	Navisworks Simulate	Autodesk
		ProjectWise Navigator	Bentley
		Visual Simulation	Innovaya
		Tekla Structures	Tekla
		Vico Control	Vico Software
	Document Manage	Buzzsaw	Autodesk
		Digital Exchange Server	ADAPT Project Desivery
		Constructware	Autodesk
		SharePoint	Microsoft
		Project Center	Newforma
		Doc Set Manager	Vico Software
5 Construction	Construction Manage	Navisworks Manage	Autodesk
		ProjectWise Navigator	Bentley
		Digital Project Designer	Gery Technology
		Solibri Model Check	Solibri
		Synchro Professional	Synchro
		Tekla Structures	Tekla
		Vico Office	Vico Software

2.2 iRing in Oil and Gas industry

2.2.1 Oil and Gas Industry

Oil and gas provide the world's 7 billion people with 60 percent of their daily energy needs. Oil and gas are not only fuels for generating electricity and power, but also used as raw materials to manufacture plastics and many other products.

Oil and Gas are both strategic materials and they are very critical to all countries. Firstly, from a business perspective, oil and gas stand for worldwide commerce on large scale. World energy markets are continually expanding, and companies spend billions of dollars annually to maintain and increase their oil and gas production. Second, from a geopolitical perspective, large amount of oil and gas flow from "exporting" regions to "importing" regions, which creates political, trade, economic and even national security concerns on both sides. Maintaining a steady supply of oil and gas is vital to a country's long-term economic growth. What's more, both exporting and importing countries are faced with major policy decisions related to oil, gas and other energy resources. These issues have major long-term impacts, both within individual countries and on the world at large, even affecting such fundamental issues as war and peace. Therefore, the oil and gas business is clearly a multifaceted, global industry that has impacts on many aspects of our lives.

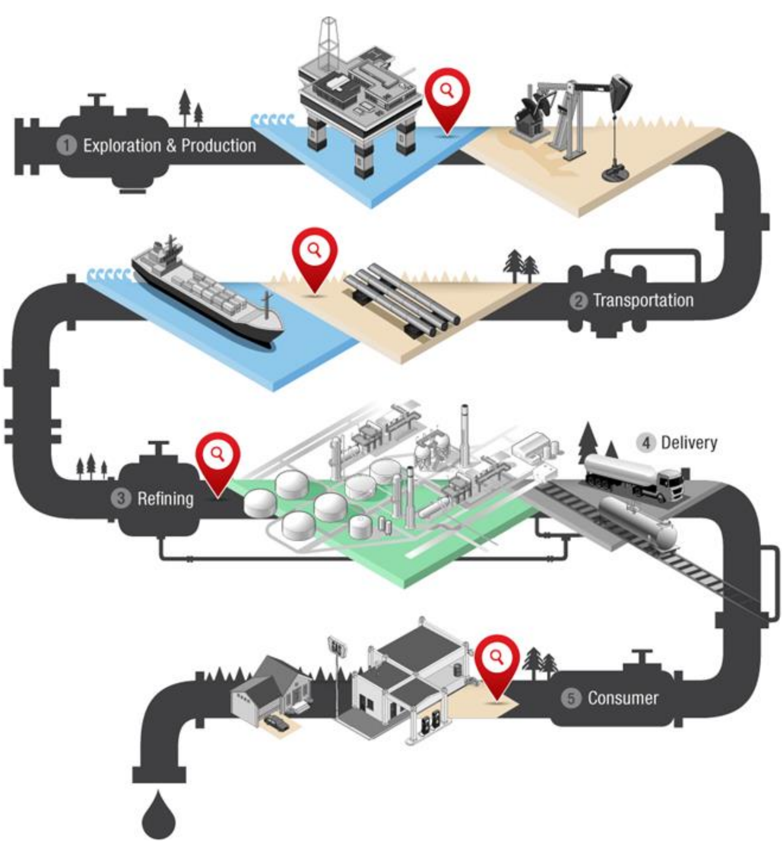


Figure 9 Main Processes in Oil and Gas Industry

The petroleum industry includes the global processes of exploration, extraction, refining, transporting and marketing products. Given the above processes, the industry is usually divided into three major sectors:

1) Upstream, commonly known as exploration, development and production (E&P) sector of crude oil or natural gas;
2) Midstream, composed of processes and operations of gathering, transportation, storage, and sometimes classified within downstream sector;
3) Downstream, mainly refers to the refining of petroleum crude oil and the processing and purifying of raw natural gas, as well as marketing and distribution of products.

While, according to The American Petroleum Institute, their division method is a little different that petroleum industry is sorted into five sectors: upstream, downstream, pipeline, marine and service and supply(API, 2008). Although the division methods are little different, but all processes are included. Figure 9 shows the main processes in the Oil and Gas industry.

Oil & Gas industry is extremely complex and owns significant characteristics, which distinguish it from the AEC industry. The characteristics include: (Song, 2007)

1) Concentration of high risks in each stage, from design, construction to installation. Although Oil & Gas projects are commonly based on EPC contract, which will transfer much more risks from clients to contractors, but high risks still exist.
2) Huge investment, especially on equipments. The equipments will usually serve for about a couple of years, but meanwhile face a severe natural environment, such as typhoon, high acid, high pressure oil and gas flow, etc. This situation results in the high quality and high cost equipments.
3) High and complex technical requirements.
4) Professionals from multi disciplines and many interfaces.

To a large extent, Modern oil and gas industry is a knowledge- and information-industry, and techniques from computer science and informatics can make significant contributions to productivity and environment protection (Thorsen & Rong, 2008).

Holst and Nystad also pointed out that it is new technologies that build the premises for oil and gas industry's developing and enable new ways of organizing work, particularly the utilization of real-time data and allowing tighter integration (Holst & Nystad, 2007). The software tools, such as CAD/CAE packages and simulators, together with knowledge-based engineering (KBE) paradigms facilitate a daily engineering practice, and integrate different types of information and knowledge typical for engineering applications (Sheremetov, Batyrshin, Chi, & Rosas, 2008). Although some technologies occurred and are assisting development, but Mohaghegh and Shahab hold the opinion that oil and gas industry still awaits the commercialization of software applications that can realize the implementation of integrated intelligent systems (Mohaghegh, 2005).

There is one research by Jinghua Yao, Yuan Fang and Ying Jia, which is carried out between BIM and marine engineering, rather than the construction engineering. This research indicates that BIM based Building Lifecycle Management (BLM) is of significance for marine projects(Jinghua, 2011; Yongkui, 2007), as BIM has the ability to bear and relate various information together digitally, so if BIM's concept can be explored to some extent into marine and offshore engineering, especially platform structure design, BIM based BLM technology can solve many practical difficulties, such as low work efficiency, poor visualization, design mistakes, design changes, high load information management, etc. This research shows that there are possibilities for the knowledge sharing between the AEC industry and oil and gas industry.

2.2.2Technology

Based on the introduction of oil and gas industry, this part will introduce ISO 15926, iRing and its promoting organizations. ISO 15926, set by ISO TC 184/ SC4, is the open standard of process plant for oil and gas industry, from which the concept of "iRing" is generated from and currently under further promotion.

ISO 15926

ISO 15926, belonging to ISO TC184/SC4, is a standard aimed at recording lifecycle data for process plant, which is increasing in maturity and becoming an open standard for interoperability and collaboration between complex data models of all types. ISO 15926 requires the data warehouse should contain the information about:

1) The requirement for a process plant and changes to the requirements;
2) The design for a process plant and changes to the design;
3) The physical objects in a process plant and changes to these.

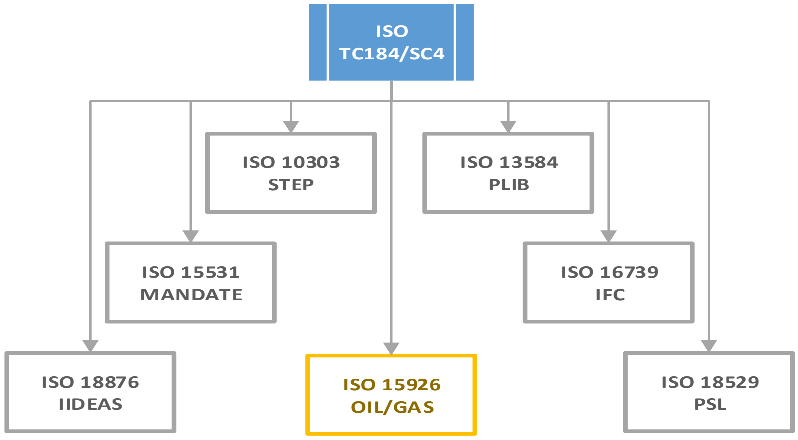


Figure 10 ISO 15926 in ISO family

The scope of ISO 15926 includes all plant lifecycle phases from conceptual design, operation and maintenance, in which two components are (see Figure 11):

1) Generic data models in conjunction with reference data library (RDL) represent the lifecycle information for process plants.
2) The object classes of RDL include piping, valves, electrical, instrumentation, heat transfer and also organizations, activities and documentation types.

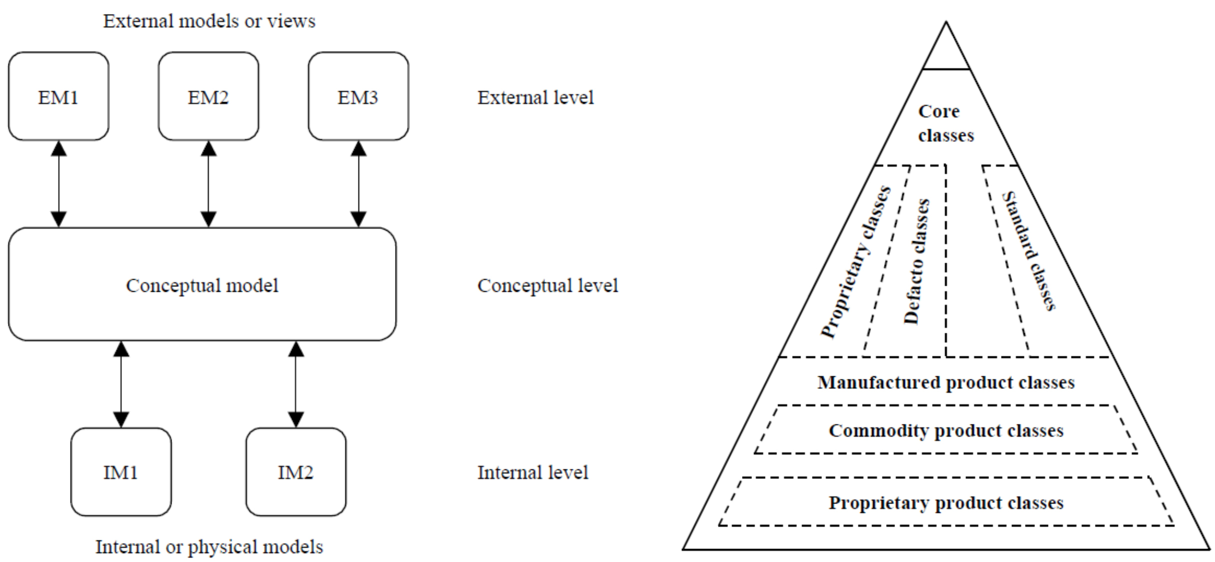


Figure 11 Generic Data Models and Types of Classes in RDL

IRing

Like BIM to ISO 16739, ISO 15926 is also developing similar concepts representing its theories and ideologies. IRing is a new concept whose goal is to expedite the adoption and pragmatic use of the ISO 15926 standard to improve data interoperability across the capital projects industry, resulting in vastly improved supply chain efficiency (iRingToday, 2015).

The "i" represents ISO 15296 and RING is the metaphor that represents a continuous flow of information in a peer-to-peer networking architecture over the Internet. A unified brand name provides the wider community a more complete and comprehensive story for interoperability services and solutions for all facets from the executive and business level to the technical and implementation level. iRING embraces all legacy ISO 15926 efforts including XMplant, Proteus, Gelish and others (Today, 2015).

Other concepts are also used by different organizations, government, software vendors, etc, like Next Generation, and at present there is no unified concept representing the theory of ISO 15926 as well as PLM for oil and gas industry. In this thesis, "iRing" is the concept being used.

Promoting organizations

For oil and gas industry, POSC Caesar and Det Norske Veritas are the principle organizations contributing to the creation, implementation and promotion of ISO 15926. POSC Caesar Association was founded in 1997 in Norway, whose goal is to promote the development of open standards for the interoperability of data, software, etc (PCA). Det Norske Veritas is a free-standing, autonomous and independent foundation whose purpose is to safeguard life, property and the environment.

More recently, the FIATECH consortium joined, whose purpose is to accelerate adoption of this standard. Fiatech is an international community of passionate stakeholders working together to lead global development and adoption of innovative practices and technologies to realize the highest business value throughout the life cycle of capital assets.

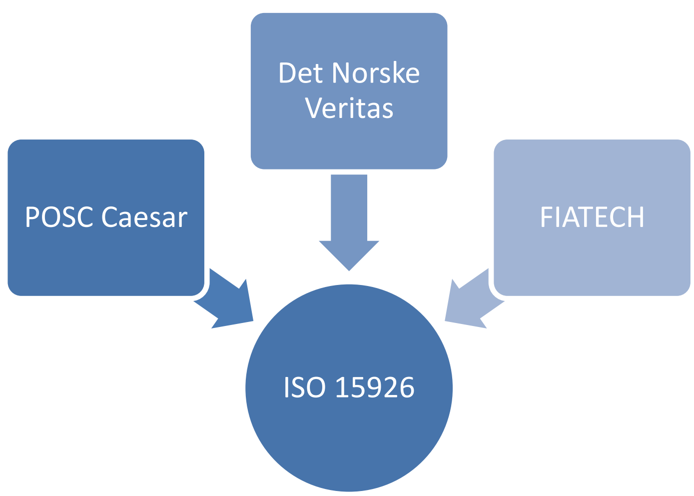


Figure 12 Promoting Organizations of ISO 15926

Software

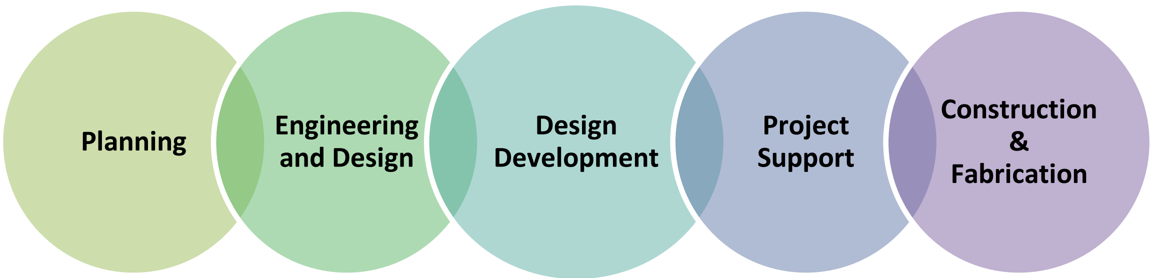


Figure 13 5 Groups of iRing Application

iRing is a relatively new generation concept. There are not as many ISO 15926 based iRing applications as BIM available in the market. But technology does have a lot of development in the oil and gas field as the incredible advantages it bears and the corresponding requirements are growing greatly.

Like the classification of BIM applications in the AEC industry, iRing applications, in theory, can also be classified into five groups, conceptual engineering, engineering & design, design development, project support, construction & fabrication (see Figure 13). Ideally iRing applications can cover all phases of projects, but at present it is in the exploration stage, there are not a series of iRing applications seamlessly connecting with each other and running through projects.

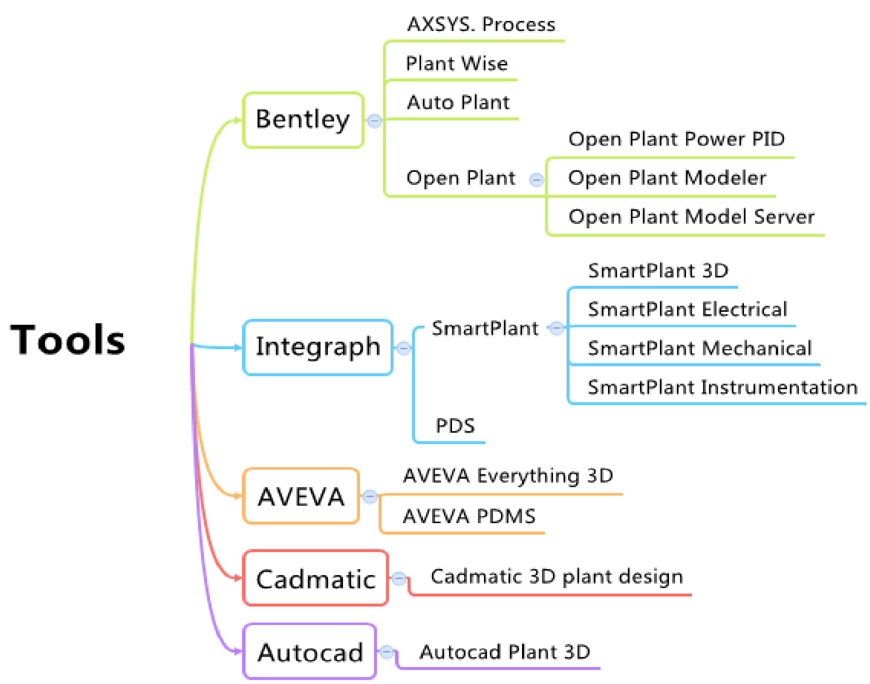


Figure 14 iRing Design Tools

But it is fortunate that there is great progress in the development of technology regarding the design phase. Onshore projects in oil and gas industry are usually adopting EPC (Engineering, Procurement and Construction) contract. Design has no doubt to be the most important starting step in the whole system. The figure below shows the related ISO 15926 based design applications.

2.3 Preconditions for Comparison

Eurostat[7] gives a clear definition of Construction, which refers to the structures connected with the ground which are made of construction materials and components and/or for which construction work is carried out (Eurostat, 1997). Eurostat published the statistical classification of economic activities in the European Community in NACE Rev. 2 in 2008, which imposes the use of the classification uniformly within all the Member States. In the standard aggregations of NACE, Construction is categorized into the section "F". In appendix A, there are two tables which show the high-level aggregation and intermediate aggregation respectively according to the standards of ISIC and SNA (Rev, 2008).

In the section F, NACE Rev.2 gives a detailed structure of construction, namely division, group and class (see Table 1). There are three divisions of construction, construction of buildings (41), civil engineering (42), and specialized construction (43). In the thesis, the first two divisions are the main focus: "construction of residential and non-residential buildings (41.20)", which representing building industry; and "construction of utility projects for fluids (42.21)", which representing oil and gas industry. Both AEC industry and Oil/Gas industry belong to construction industry, which is the first comparison basis.

Under the same construction industry, the disciplines in AEC industry and in Oil/Gas industry are similar. The structure of disciplines is

Division	Group	Class	
			SECTION F — CONSTRUCTION
41			Construction of buildings
	41.1		Development of building projects
		41.10	Development of building projects
	41.2		Construction of residential and non-residential buildings
		41.20	Construction of residential and non-residential buildings
42			Civil engineering
	42.1		Construction of roads and railways
		42.11	Construction of roads and motorways
		42.12	Construction of railways and underground railways
		42.13	Construction of bridges and tunnels
	42.2		Construction of utility projects
		42.21	Construction of utility projects for fluids
		42.22	Construction of utility projects for electricity and telecommunications
	42.9		Construction of other civil engineering projects
		42.91	Construction of water projects
		42.99	Construction of other civil engineering projects n.e.c.
43			Specialised construction activities
	43.1		Demolition and site preparation
		43.11	Demolition
		43.12	Site preparation
		43.13	Test drilling and boring
	43.2		Electrical, plumbing and other construction installation activities
		43.21	Electrical installation
		43.22	Plumbing, heat and air conditioning installation
		43.29	Other construction installation
	43.3		Building completion and finishing
		43.31	Plastering
		43.32	Joinery installation
		43.33	Floor and wall covering
		43.34	Painting and glazing
		43.39	Other building completion and finishing
	43.9		Other specialised construction activities
		43.91	Roofing activities
		43.99	Other specialised construction activities n.e.c.

Figure 15 Classification of Construction Activities (Rev, 2008)

[7] Eurostat is the Statistical Office of the European Communities and its mission is to provide the European Union with high-quality statistical information.

composed of engineering group and project support group. Under engineering group, there are process, architecture, structural, mechanical, electrical, piping disciplines. As for project support group, disciplines of procurement, estimating, project controls, document management are involved. Construction work, for both AEC projects and Oil/Gas projects, refers to the structures connected with the ground which are made of construction materials and components and/or for which construction work is carried out. Besides, the process for those two fields is changing from sequential towards cycling type. (Eurostat, 1997)

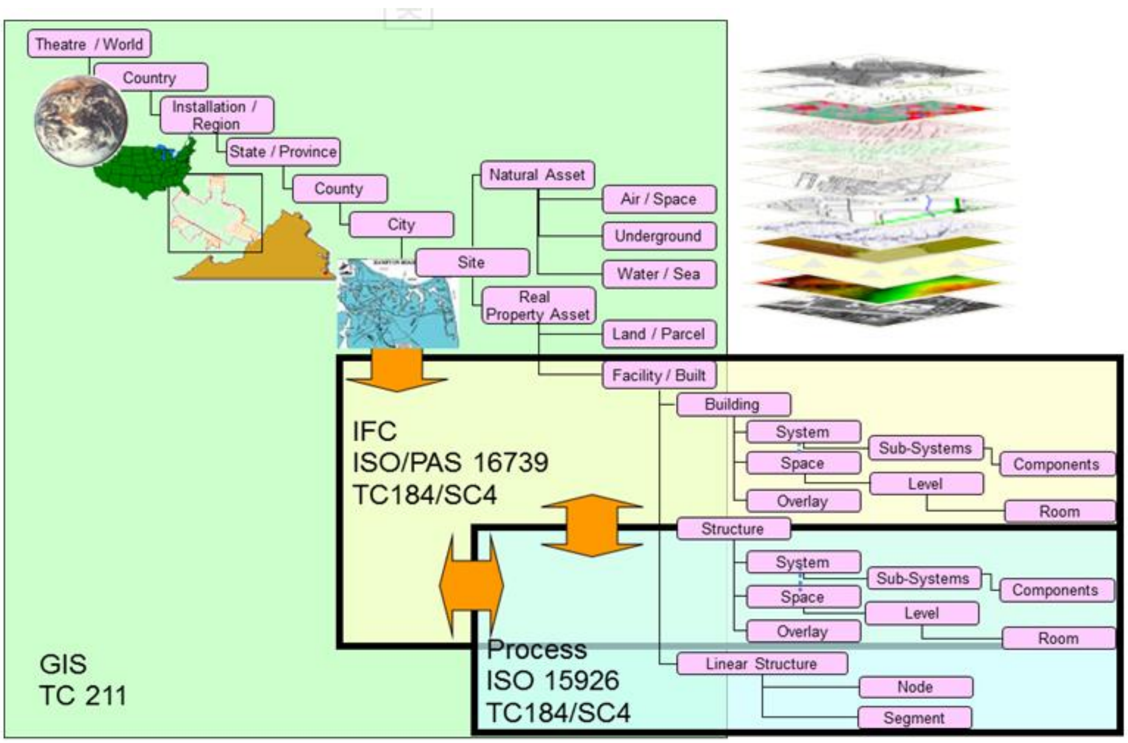


Figure 16 Scope of ISO 16739 and ISO 15926

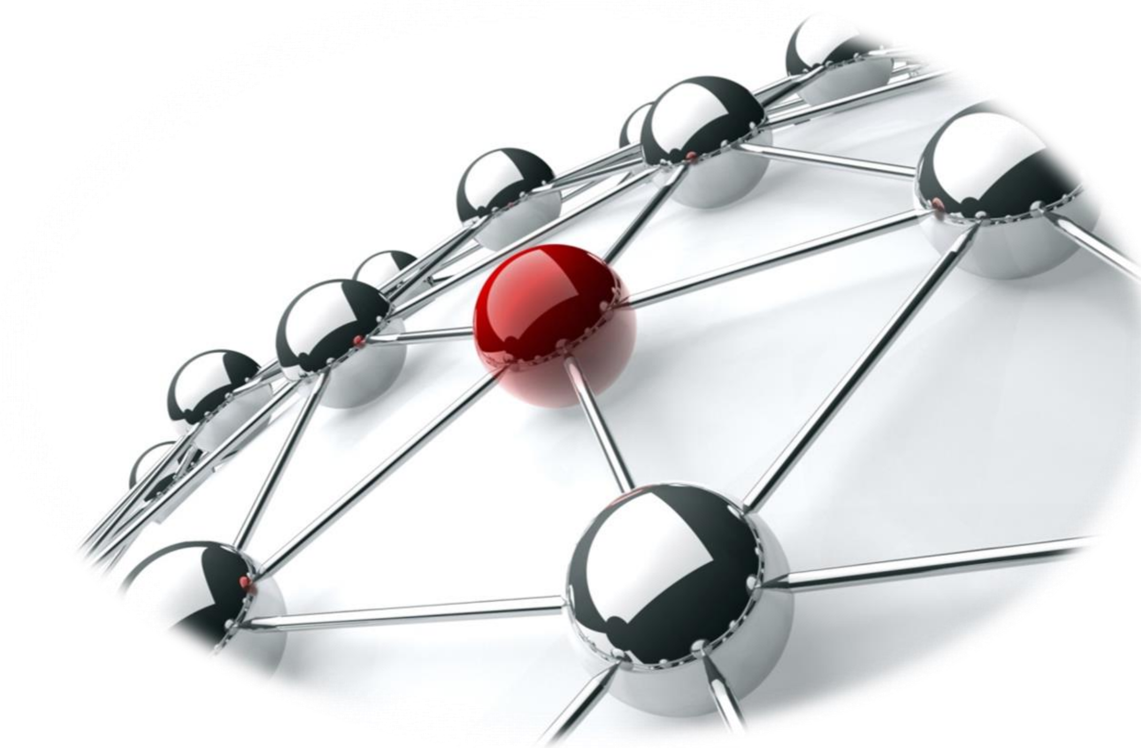
What's more, there are also similarities in terms of technology. BIM is the new trend in the AEC industry, which is based on the IFC data formats and complies with ISO 16739. IRing is not much used in the Oil/Gas industry, but it is starting to represent the new technology applied in the Oil/Gas industry complies with ISO 15926. Comparing ISO 15926 and ISO 16739 can also shows the motivation to evaluate these two fields together and draw lessons from each other. As showed in Figure 16Figure 16, the whole world can be breakdown to country level, region level, state or province level, county level, city level, site level, real property and natural asset level, etc. In the category of real property, land/Parcel and Facility/Built are the components. ISO 15926 and ISO 16739 are both focused on the Facility/Built aspect, while the emphasis is different but still have overlaps. For BIM, it mainly considers the building and structure parts, while iRing is centred on aspects of structure and linear structure.

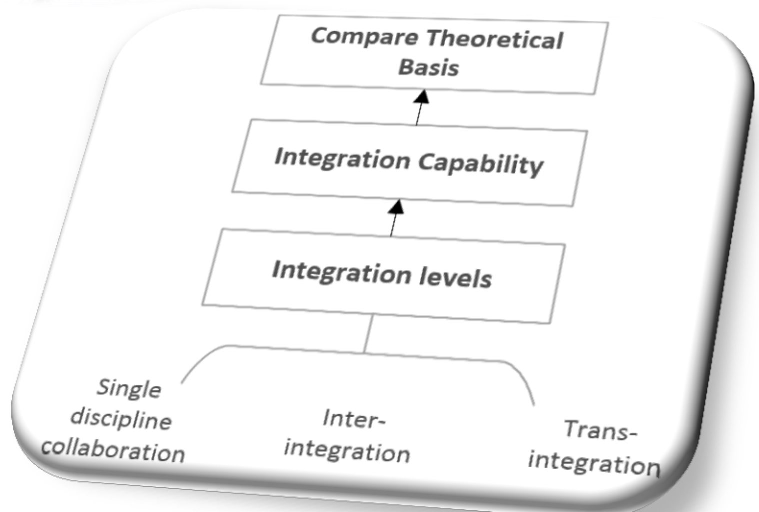
Norms	ISO 15926/iRing	ISO 16739/BIM
Scope	Process plant related	Facilities related
Phases	Life-cycle	Life-cycle
Size	Large scale	Human scale
Objects	Process pants, like units, utilities, facilities	Buildings
Components	Generic Data Model (GDM), Reference Data Library (RDL) and Types of Classes	Conceptual Data Schema (EXPRESS schema specification) and Reference Data
Participants	Oil & Gas related Manufacturers and suppliers starting to participate	Manufacturers and suppliers starting to participate
Software vendors	Supported by major software vendors	Supported by major software vendors

Table 2 Comparison between ISO 15926 and ISO 16739

ISO 16739 is applied to most buildings and many structures related to smaller scale projects; while, ISO 15926 is related to process industry including large infrastructure projects. In Table4, the main characters of ISO 15926 and ISO 16739 are listed below. ISO 15926 is related with process plant, large scale structures and infrastructures, while ISO 16739 is facilities related, human scale structures and buildings. ISO 15926 is towards design and analysis, but IFC is designed for objects. However, both these two international standards are designed for lifecycle, and supported by major software vendors.

In summary, the AEC industry and Oil/Gas industry have solid comparison basis in terms of process, disciplines, technology. The need to improve the communication between those two groups is now increasing greatly (Laud, 2013). Under these compare basis, the integration capability of technologies in both AEC industry and Oil/Gas industry will be evaluated based on two projects in the following chapter.





Chapter 3
Comparison Theoretical Basis

3.1 Changes in Process and Disciplines

In order to realize projects, working processes are significant both in the AEC industry and Oil/Gas industry. A construction project cannot be realized successfully without a proper working process. Working processes are described as a system of producing products (Rev, 2008).

The traditional working process in the construction industry has been researched and defined by many professionals and organizations. The Royal Institute of British Architects (RIBA) described traditional working process as planning, design, construction, takeover and maintenance, which is widely accepted throughout the construction industry (RIBA, 1997). According to Kruchten, the traditional process of conducting a construction work complies with a "sequential waterfall model", which is a linear approach (Kruchten, 2000). The sequential waterfall method in the construction field is also called as "over the wall" approach (Evbuomwan & Anumba, 1998; RIBA, 1997). Usually, the working process starts with problem definition, requirements definition, then conceptual design, preliminary design, detailed design, design communication, and final design, construction, operation and maintenance (Dym, Little, Orwin, & Spjut, 2004).

However, there are a lot of problems with the traditional working process. One of the biggest problems is the trouble of rework. According to Kruchten, too much rework comes at the very end when following the "sequential waterfall model", as an annoying and often unplanned consequence of finding nasty bugs will occur during the final testing and integration phase (Kruchten, 2000).

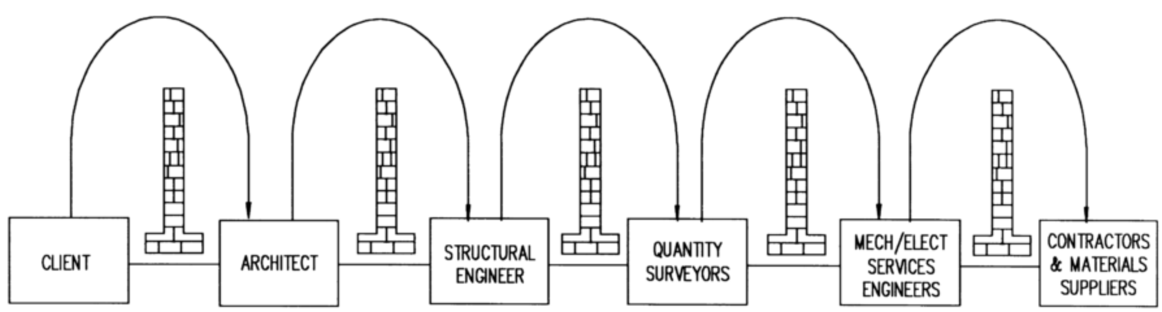


Figure 17 Over the wall approach

Therefore, the working process is being changed and tends to become more iterative (see Figure 18). The iterative process is a cyclic approach to realize a project. The iterative process can bring a lot of efficiency and sustainability into the construction industry. With an iterative approach, "you simply acknowledge upfront that there will be rework, and initially a lot of rework: as you discover problems in the early architectural prototypes, you need to fix them" said by Kruchten (Kruchten, 2000). The iterative process can involve all elements of the whole life cycle for a construction work, taking quality, cost, schedule and user requirements into account for each engineering phase (Winner, Pennell, Bertrand, & Slusarczuk, 1988) .

Besides working process, people are indispensible in the construction industry as it is the people that participate in and operate the working process. In the construction industry, people belong to different disciplines, which perform different functionalities in the whole team. For example, the design disciplines are responsible for designing products and the estimating discipline is responsible for calculating the cost of projects.

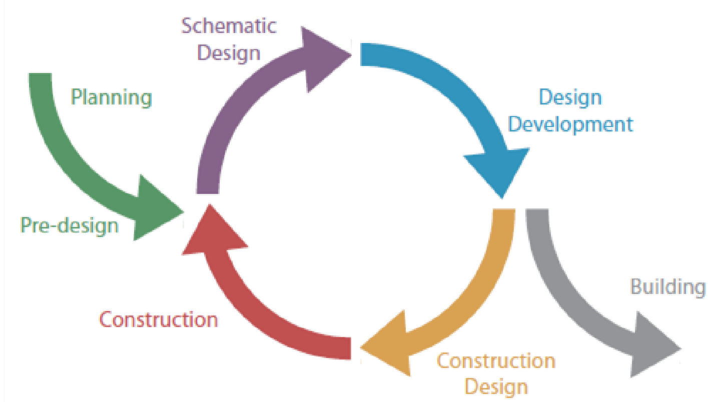


Figure 18 Iterative Process

There are many complaints about the traditional structure of disciplines. Traditionally, the structure of disciplines is often described as fragmented (Alashwal et al., 2011). The Building Research Establishment (BRE) also characterized the disciplines' structure as "a completely fragmented mess" (BEC, 2007). The fragmented disciplines can result in a serious problem in knowledge harvesting and continuous learning (Drejer & Vinding, 2004).

With problems of fragmented structure being recognized by people, the collaborative structure is becoming the trend in the construction industry. In a general sense, Roschelle and Teasley said that collaboration will occur when more than one person works on tasks (Roschelle & Teasley, 1995). Collaboration is defined by Roschelle and Teasley as a coordinated, synchronous activity that is the result of a continuing attempt to construct and maintain a shared conception of a problem (Roschelle & Teasley, 1995). A collaborative structure for various disciplines is quite necessary to carry out a project and facilitates, knowledge sharing and continuous learning.

Disciplines and processes are closely related to each other. That means, every process needs a discipline to operate and every discipline needs to follow a certain form of process to realize projects. The fragmented situation usually follows a sequential waterfall process, like Figure 17. An iterative process provides a solid foundation for realizing a collaborative structure for disciplines. Currently, the process is changing from sequential to iterative and discipline structure is transforming from fragmented to collaborative. The driving force for those changes lies mainly in technology, which will be elaborated in Section 3.2.

3.2 The Role of Technology in Integration

As introduced by Succar, Technology, Process and Policy (TPP) are the three aspects if changes must happen (Succar, 2009). Technology means the application of scientific knowledge for practical purposes, for instance computer technology (Oxford, December 2009). Process is a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action (Davenport, 1992). Policy is written principles or rules to guide decision-making (Clemson, 2007).

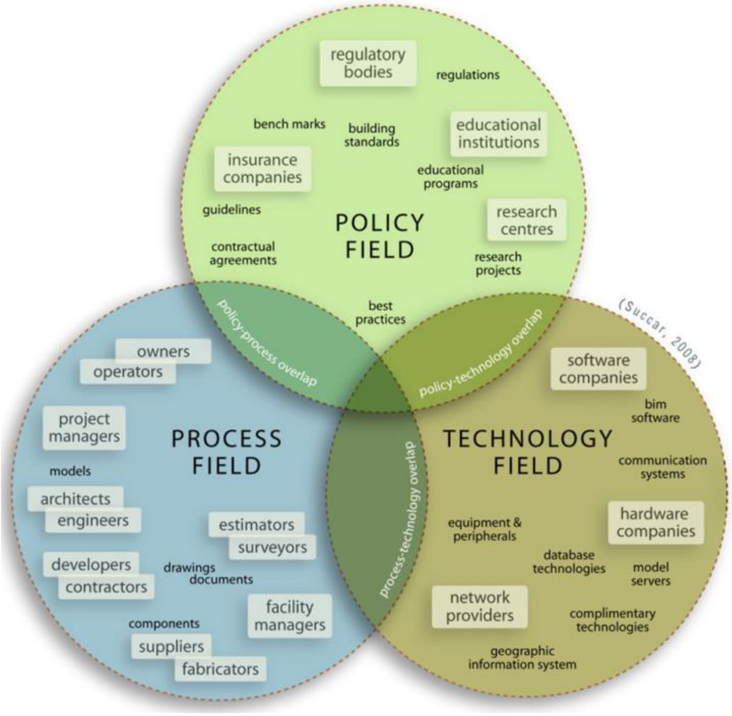


Figure 19 Venn diagram of TPP

The development level of each direction affects each other closely and they three together determine whether a transformation can happen. Figure 19 is the Venn diagram of TPP, which shows the interlocking relationships, contents, and the height of development.

The changes from a traditional waterfall process to an iterative process and from fragmented to collaborative structure depend greatly on technology. Kruchten pointed out that "in a waterfall approach, there is a lot of emphasis on "the specs" (i.e., the problem-space description) and getting them right, complete, polished and signed-off. In the iterative process, the software we develop comes first"(Kruchten, 2000). Brookes and Backhouse depicted the framework of the relationship between technology with goals, objectives, strategy (see Figure 20): goal can be divided into detailed objectives; strategy is focused on how to achieve each objective; tools and techniques are the rooted foundation supporting the realization of the whole framework (Brookes & Backhouse, 1998). Khalfan and Anumba also pointed out that there are two aspects that need to be considered in the construction: the managerial and human aspect is the first, and the technological aspect is the second (Khalfan, Anumba, & Carrillo, 2001). The process and disciplines belong to the aspect of Managerial and Human, which are supported by the technology aspect. The details of these two aspects are listed below:

1) Managerial and human aspect:
    a. the use of cross-functional, multi-disciplinary teams to integrate the design of products and their related processes;
    b. The adoption of a process-based organizational philosophy;
    c. Committed leadership and support for this philosophy;
    d. Empowered teams to execute the philosophy.
2) Technological aspect:
    a. The use of computer aided design, manufacturing and simulation methods (i.e. CAD/CAM/CAE/CAPP) to support design integration through shared product and process models and databases;
    b. The use of various methods to optimize a product's design and its manufacturing and support process;
    c. The use of information sharing, communication and co-ordination systems;
    d. The development and/or adoption of common protocol, standards, and terms within the supply chain.

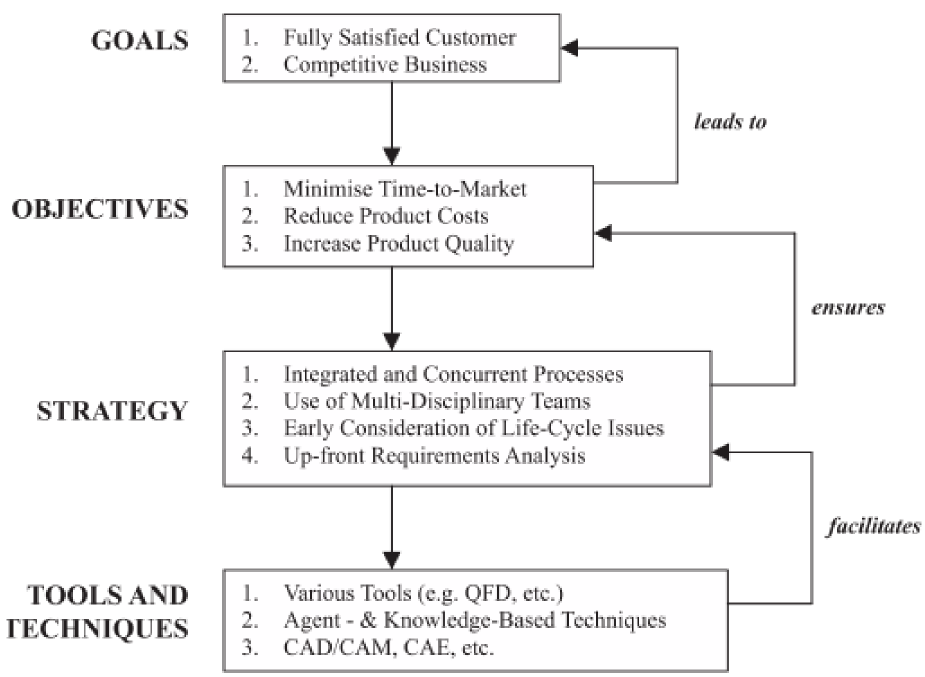


Figure 20 Relationship of goals, objectives, strategy and techniques

Ameri, Dutta, Kiritsis, Bufadi and Xirouchakis elaborated the concept of Product Lifecycle Management (PLM) as the process of managing the entire lifecycle of a product, which integrates people, data, processes and business systems and provide a product information backbone (Ameri & Dutta, 2005; Kiritsis, Bufardi, & Xirouchakis, 2003). PLM contains many layers. From outer to inner, layers are:

people, process, tools, methods, technology, and data. It can be seen that technology is also standing at the core when implementing a new approach. Building lifecycle management (BLM) is the adaptation of product lifecycle management (PLM), which proposes to organize all heterogeneous processes of civil engineering lifecycle in a uniform way (Bonandrini, Cruz, & Nicolle, 2005). Techniques to the design, construction, and management of engineering work is also recognized as the key to involve various phases and participants of a project, integrating AEC industry into a cycling system (Vanlande, Nicolle, & Cruz, 2008). It can be seen that it is technology that supports the change from sequential, fragmented to iterative and collaborative. To be more specific, it is the integration capability of technology that processes drives the transformation. Computer-Aided Design technology owns supper integration capability, so it can provide a collaborative platform enabling the operation of iterative process greatly. Most complex engineering projects involve multi-disciplinary collaboration, complex structure and the exchange of large data sets, technology's integration capability is the efficient solution(Singh, Gu, & Wang, 2011).

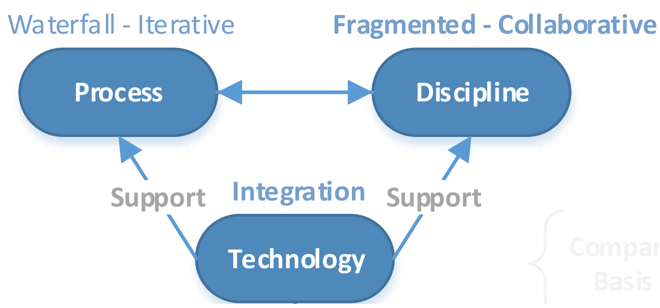


Figure 21 Integration Capability of Technology

3.3 Integration Level

The integration capability of technology is developing from a very low level, as every new thing cannot be perfect level when just developed. The integration capability of technology also goes through a development process, where the insufficient aspects need to be found and improved in order to achieve complete functionalities. According to Succar, the maturity developing path of technology (see Figure 22) should start from object-based modeling, to model-based collaboration, and then goes to network-based integration (Succar, 2009). Marilyn Stember gave a very clear definition of different levels of collaboration among different disciplines (Stember, 1991):

Figure 22 Maturity Path of Technology

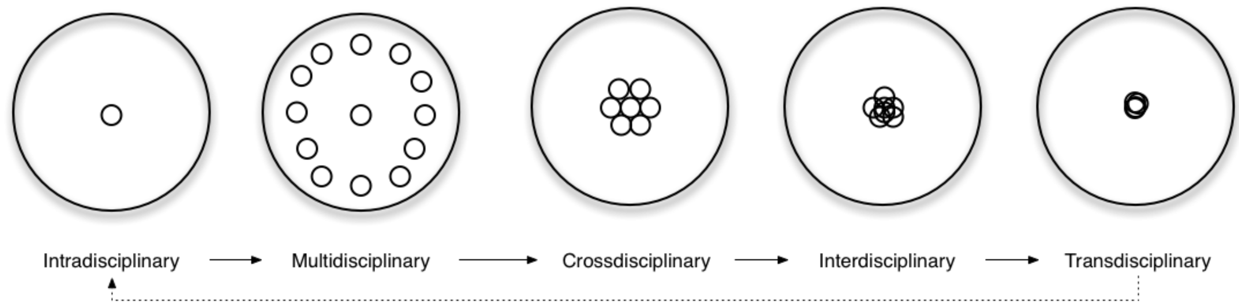


Figure 23 Intra, multi, cross, inter and trans

- Intradisciplinary: working within a single discipline.
- Crossdisciplinary: viewing one discipline from the perspective of another.
- Multidisciplinary: people from different disciplines working together, each drawing on their disciplinary knowledge.
- Interdisciplinary: integrating knowledge and methods from different disciplines, using a real synthesis of approaches.
- Transdisciplinary: creating a unity of intellectual frameworks beyond the disciplinary perspectives.

In 2012, according to Marilyn Stember's theory, Alexander Refsum Jensenius sketched the figure of intra, multi, cross, inter and trans-disciplinary (see Figure 23) (Jensenius, 2012). The newly developed technologies, BIM and iRing are aimed at interdisciplinary and transdisciplinary.

Figure 24 Inter-integration level

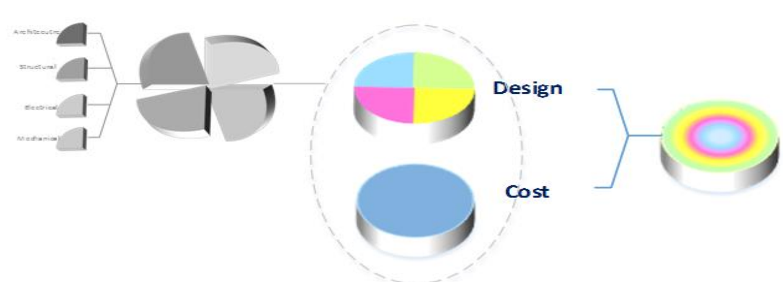


Figure 25 Trans-integration level

Based on the above theories, the integration level in the thesis is divided into inter-integration and trans-integration. Inter-integration means collaboration within design disciplines. For example, in both AEC industry and Oil/Gas industy, design includes many branches, like architecture design, structure design, electrical design, piping design, etc. Not long ago, each branch developed individually, so it is hard to say that there were any possibilities for information sharing among the design disciplines. But things are changing with the development of technology. The separate design branches are starting to collaborate with each other, which enable real time information sharing among the inter-design discipline. The inter-discipline integration is the first step being realized (see Figure 25).

After the inter-integration of design discipline, it becomes the foundation for extra disciplines to be integrated in. This will change towards trans-integration. Trans-integration indicates the collaboration not only within design discipline, but also the coordination with other project disciplines, like cost estimation, procurement and project scheduling. Extra disciplines are being further integrated into the platform to enable designers and other professionals make wiser decisions based on more comprehensive considerations.

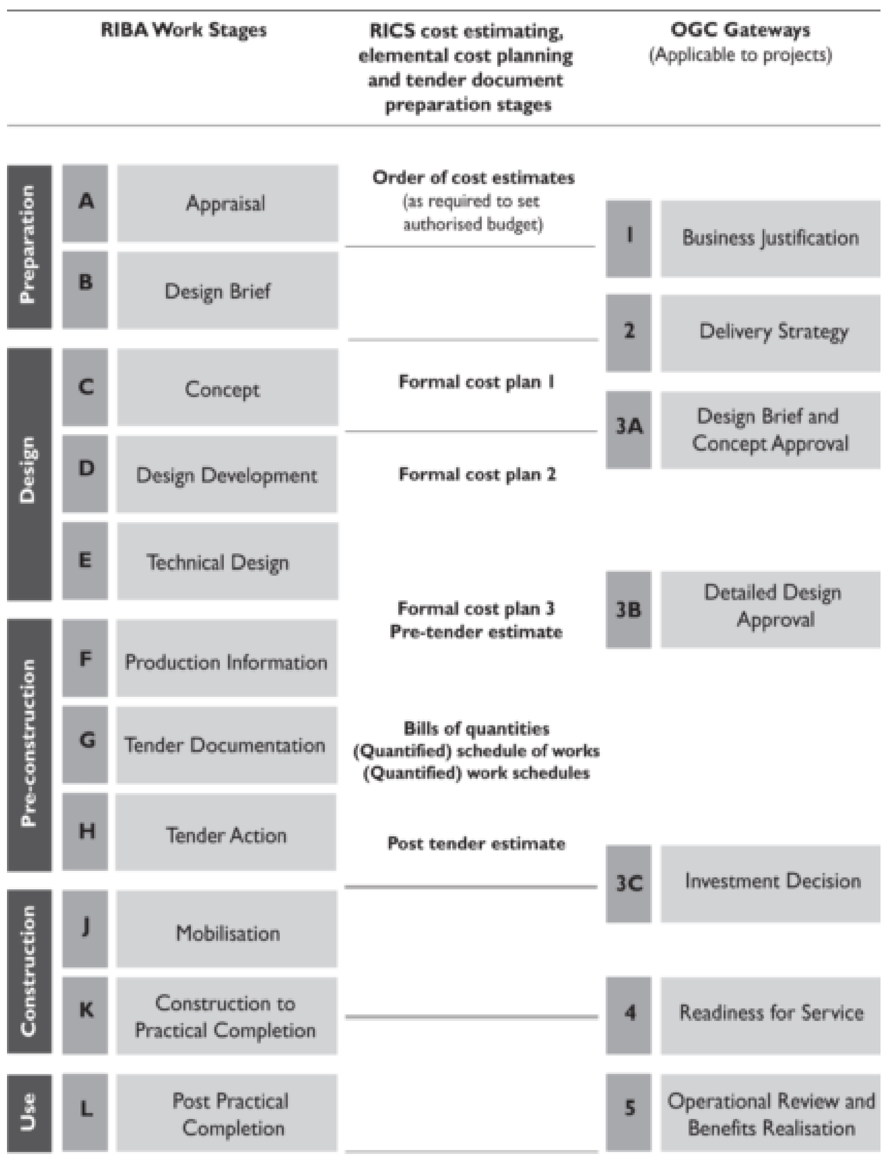


Figure 26 Relationship between design and cost (RICS, 2012)

In the report, the discipline of cost estimating is the new element selected to be studied in the trans-integration, see Figure 24, the first reason is the close relationship between design and Cost. The Figure 26 depicts this relationship clearly. The left column of Figure 26 is defined by the RIBA (Royal Institute of British Architects) as the Work Stages in construction industry. The theory of RIBA Work Stages is commonly accepted by the professionals as the model of the construction process. It shows five main work stages: preparation, design, pre-construction, construction and use. In the first two stages, there are a series of processes belonging to design, which starts from design brief, concept design, design development, technical design and so on. Along with the design process, cost estimates with different accuracy are being developed, from concept estimation into detailed tender documents, shown in the middle column of Figure 26. The right column is the project gateways between the two contiguous work stages, which is developed from the OGC (Office of Government Commerce) Gateways. The meaning of design for cost engineers is the potential for predictability. A good design method or tool can help cost team increase working efficiency, avoid surprises and improve the quality of information from data.

From a general sense, three-dimensional (3D) can specify any point within an object so that it can depict the space for the objects. Time is recognized as the fourth-dimension based on the three-dimensional. But the research does not choose schedule to be the first new element of trans-integration. The second reason is listed below. The question can be asked by why 4D refers to time. The first time we got to know 4-dimensional is from Albert Einstein. Albert Einstein proposed a famous theory of special relativity, where he treats the time as the component of four-dimensional. The theory of special relativity and the concept of "time as the fourth dimensional" are generally accepted by people. Therefore, after people have completed 3 dimensional models in BIM or iRing, time is in the first place in their mind to describe the schedule property of the built 3D model. But in reality, to some extent, time and cost, these two dimensional are relatively independent in terms of software capability. It cannot be denied that in practical construction works, they do have influence on each other, but in terms of software capability, the sequence of these two functions does not matter a lot. This can be proved by software vendors. The software vendors are developing separate applications which can provide schedule functionality or cost functionality, like Navisworks for schedule control, and QTO for cost control. Software vendors are also developing applications which include both schedule and cost control capabilities, like Vico, but the users have the choice to choose if using schedule functionality first or cost functionality first. So schedule and cost are two relatively independent and in this report, cost is selected as the first to be analyzed in the trans-integration level. The third reason that cost is selected into the analysis of trans-integration is because of the research is conducted in the cost department at Fluor. There are a lot of resources for cost. Besides, cost is the very important term for the engineers working there. They do also care about schedule, but cost for them means a lot: cost can determine whether they can get a contract from clients, cost means whether they can earn profit and how much percentage they can get. It cannot be denied that schedule is also very important perspective, so further researches can focus on the perspective of schedule to analyze the its trans-integration level.

In summary, the integration capability is composed of two levels: the inter-integration level (integration of design discipline) and the trans-integration level (integration between design and cost).

3.4 Derivation of Integration Capability

According to National BIM Standard (NBIMS) (NIOBS, 2007), there is a Capacity Maturity Model (CMM) which is used to assess the developing level of Building Information Modeling (BIM). But actually CMM is a root theory in software development path. In 1993, Paulk, Weber, Curtis and Curitis firstly elaborated the Capacity Maturity Model in the technical report of "Capability Maturity Model for Software" (Paulk et al., 1995). There are five levels in CMM: initial, repeatable, defined, managed, and optimizing (see Figure 27). The details of each level are listed below:

1) Initial: the software process is characterized as ad hoc, and occasionally even chaotic. Few processes are defined, and success depends on individual effort.

2) Repeatable: Basic project management processes are established to track cost, schedule, and functionality. The necessary process discipline is in place to repeat earlier successes on projects with similar applications.

3) Defined: the software process for both management and engineering activities is documented, standardized, and integrated into a standard software process for the organization. All projects use an approved, tailored version of the organization's standard software process for developing and maintaining software.

4) Managed: Detailed measures of the software process and product quality are collected. Both the software process and products are quantitatively understood and controlled.

5) Optimizing: continuous process improvement is enabled by quantitative feedback from the process and from piloting innovative ideas and technologies.

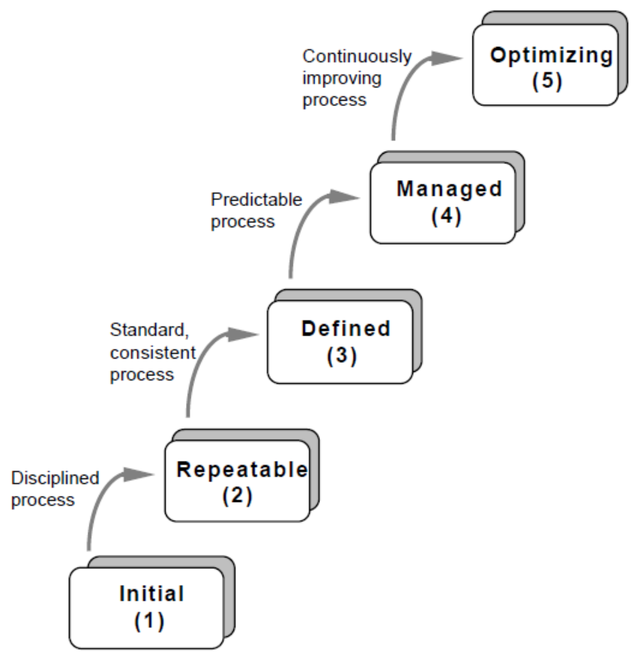


Figure 27 Five levels of software process maturity
Source: The Capability Maturity Model Guidelines for Improving the Software Process

CMM can be seen as the standards guiding technologies' development, also applicable for the technologies of BIM and iRing in AEC and Oil/Gas industries. Referring to NBIMS and CMM, one of the senior engineers at Fluor and I adapted the concept of development levels in CMM and derived the evaluation criteria of inter-integration level and trans-integration level together, taking criteria's applicability for both industries into account. When deriving the criteria, we considered the minimum use of BIM and iRing, as the new generation of technology, to be the rationale.

After discussing with professionals at Fluor about the requirements for technologies they want, we conclude that both of technologies should provide five added values, which can also be regarded as compulsory capabilities, to designers and cost estimators. Details about the five capabilities are listed below:

1) **Visualization capability**: the capability to conjunctively present various views of design results into 3 dimensional (3D) models with certain quality. Traditionally, 2D drawings are commonly used to present design ideas of designers. Such type of idea presentation makes it difficult to understand, requiring relatively high imaging ability to abstract the designed configuration from lines and polygons. As current design is becoming more and more complex, it is being less possible to have exact understanding of the design via 2D representations. 3D representations or even those with more dimensions are required for understanding and communication of design results. If processing the 3D visualization capability, the results from architecture, structural engineers, MEP engineers or even estimating engineers can be integrated together.
2) **Collaboration capability**: the capability to serve as a common platform for players from different design disciplines and other departments. This capability has been regarded as the most important one within the AEC industry, as well as within Oil/Gas industry. Collaboration happens everywhere among different stakeholders. With the traditional approach, collaboration, or more precisely speaking revision, only happens when problems happen. For example, as structural engineers and MEP (mechanical, electrical and piping) engineers work separately in traditional design process, there will always be clashes among pipes and structural components. While the problem often can only be found during real installation in construction phase. So time waste on correcting such kind of mistakes would be undesirably high. Therefore, collaboration on a common platform, that enables resolving problems before they happen, is extremely important to improve design efficiency and effectiveness.
3) **Simulation capability**: the capability to do simulations based on design results, such as project spatial environment simulation, cost flow simulation, energy simulation or even emergency situation simulation. Nowadays, deliverables required by designers are more than drawings. The more simulation functionalities that the platform has, the more factors could be considered during design, therefore more comprehensive and reliable integrated solutions can be generated. Simulation capability can help people consider more factors that may have influence on the projects, based on the integration platform.

4) **Optimization capability**: the capability to optimize efficiency of working process, diminishing unnecessary conflicts and recording updated changes, etc, which is important in integrated solutions because various results or processes from different parties cannot only be stiffly combined together, but need certain optimizations after combination, which is a way to achieve better integration of results or processes.
5) **Digitization capability**: the capability to store, retrieve and analyze all information generated during the project lifecycle. As the nature of both BIM and iRing is 'information', it is important to evaluate the information processing capability of each platform.

Another possible capability, namely 2D drawings generation, is often mentioned between the design disciplines and the construction discipline. Although designers are making efforts to change their design tools from 2D (CAD) to 3D (BIM and iRing), constructors are still at the stage of using 2D drawings to guide their construction processes. Reasons for this phenomenon cannot be explained only by several sentences. One reason that designers must provide 2D drawings is that 2D drawings are still regarded as official deliverables for most construction projects. If the platform used by designers can only support 3D output, which is though helpful for understanding design ideas, designers will have to redo 2D design works separately in order to make official deliverables.

However, we are not going to name 2D drawings generation capability as the sixth capability in this research Firstly, as the development of 3D information technology goes further in the future, 2D drawings may not be needed any more in any projects. And secondly, the most important reason is that we regard this capability as one part of the optimization capability, help designers to minimize their working processes and make the design work as convenient as possible.

3.5 Evaluation Criteria

Based on capabilities developed in the last section, key evaluation criteria can be further generated. For each capability, at least one criterion is generated for emphasizing each aspect. From discussions with company professionals, several factors are found to be commonly considered by them when choosing design and cost estimation platforms. In order to make the factors more complete with our aim of evaluation of technology integration, we adjust some of the factors by adding and diminishing exact meanings of each factor. Then the factors are further categorized into subsets of integration capabilities, according to their characteristics for supporting technology integration. As a result, 8 key criteria for the inter-integration level are formulated as: graphical information, roles, spatial information, change tracking, information accuracy, timeliness and delivery method. Also 8 key criteria for trans-integration level are formulated as: graphical information, roles, cost flows, change tracking, reliability of information production, quantification process and built-in standards. The description of each criterion and details of capability they emphasize will be elaborated in this section.

Evaluation Criteria of Inter-Integration of Design

Table 3 Criteria of inter-integration level

Capability	Criteria
Visualization	Graphical information
Collaboration	Roles
Simulation	Spatial information
Optimization	Change tracking
	2D drawings generation
Digitization	Information accuracy
	Timeliness
	Delivery method

Criteria of inter-integration level:

1) Graphical Information: The advent of graphics helps to paint a clearer picture of all involved elements. Graphical information belongs to visualization capability, which can assess the specific and intelligent degree of integrated results from architecture, structural engineers, MEP engineers.
2) Roles: Roles belongs to collaboration capability, referring to the number different disciplinary designers, who can work on the integration platform to conduct design process.
3) Spatial information: Understanding where something is in space is significant to simulation capability, which is also a way to improve the richness of the information for the integration platform. Spatial information means whether the designed models can be placed in the real spatial environment, showing the streets, terrain, etc.
4) Change tracking: tracking the exact changes, the people who made these changes, and when the changes were made are important steps in the optimization process, which can give designers who are using the integration platform clear ideas in what directions their designs are being changed.
5) 2D drawings generation: it refers to the capability of design software to generate 2D design drawings directly from 3D design results. With this functionality, it would be much more convenient for designers to conduct their work on a 3D integration platform, without concerning about 2D deliverables for construction purposes.
6) Information accuracy: Information Accuracy, belonging to digitization capability, refers to the level of accuracy of polygons which are located and used to compute space and volume and to

identify what areas have been identified. Integrated platform needs to be exactly accurate in space and volume in order to ensure the efficiency and effectiveness of construction.

7) Timeliness: Timeliness, another criterion of digitization capability, refers to the speed of response information. While some information is more static than other information, it all changes and up to the minute accuracy may be critical in emergency situations. The closer to accurate real-time information you can be, the better quality the decisions that are made. Some of those decisions may be lifesaving in nature. Therefore timeliness should be incorporated by the integration platform
8) Delivery method: Data delivery, which is one of criteria for digitization capability, is critical to the success of integrated solutions. If data is only available on one machine then sharing cannot occur other than by email or hard copy. In a structured networked environment if information is centrally stored or accessible then some sharing will occur. If the model is a service oriented architecture (SOA) in a web enabled environment the net centricity will occur and information will be available in a controlled environment to the appropriate players. Information assurance must be engineered into all phases.

For each criterion, five levels of maturity scoring from one to five are used during the evaluation process (Table 4). This scoring framework, which briefly represents the development direction of each aspect of technology integration, is adopted from a similar scoring methods in NBIMS.

Table 4 Capability Evaluation Table

Criteria	1	2	3	4	5
Graphical Information	Primarily Text - No Technical Graphics	2D Non-Intelligent Data	2D Intelligent Data	3D - Intelligent Graphics	3D - Current And Intelligent
Roles	No Single Role Fully Supported	Only One Role Supported	Two Roles Partially Supported	Two Roles Fully Supported	All Design Roles Supported
Spatial Capability	Not Spatially Located	Spatially Located	Located Spatially with Info Sharing	Part of GIS	Integrated into a complete GIS
Change Tracking	No CT Capability	Element can be changed easily	Includes Limited Change Recording Capability	Includes Change Recording Full Capability, what/who/when	Full CT Capability Including comparison with Previous Version
2D Drawings Generation	Not possible	Substandard Support	Support for limited design works with passable accuracy	Support for most design works with good accuracy	Fully supported

Information Accuracy	No Ground Truth	Ground Truth - Int Spaces	Ground Truth - Int & Ext Spaces	Computed Areas & Ground Truth	Computed Ground Truth & Full Metrics
Timeliness/ Response	Response Info manually re-collected	Response Info Available Manually	Response Info Available Automatically & Timely	Response Info Available Automatically & Timely	Real Time Access
Delivery Method	Single Point Access	Network Access	Web Enabled Services	Web Enabled Services - Secure	Netcentric Access

Evaluation Criteria of Trans-Integration of Design and Cost

Table 5 Criteria of trans-integration level

Capability	Criteria
Visualization	Graphical information
Collaboration	Roles
Simulation	Cost flow simulation
Optimization	Change tracking
	Report generation and export
Digitization	Reliability of information production
	Quantification process
	Built-in standards

From design to cost estimating, there are mainly four resources required: design software, cost estimating software, an accurately built design model, and cost data (McCuen, 2009). Traditionally, with accurate design models built in design tools, precise quantities can be generated. With the generated quantities, cost data can be added in the cost tools in order to generate cost estimates. This process can be depicted by the figure below. From the figure, it can be seen that there is an overlap between design tools and cost tools, which enables the information exchange between these two different platforms. If the overlap becomes larger, the compatibility of information would become better, and the trans-integration level would become higher. Assuming that design tools and cost tools can be seamlessly integrated, then the five capabilities of design tools should be processed by cost tools. Based on the five capabilities and cost estimating process, 8 key criteria are formulated to assess the trans-integration level between design and cost.

Criteria of trans-integration level (integration with cost estimation):

1) Graphical information: whether the models from design tools can be supported by the cost tools and whether the users can navigate, manipulate, toggle or highlight the objects or building elements within the model when preparing estimates. This criterion can equip the cost tools with visualization capability of design models built in design tools, which is an important step towards trans-integration between design and cost.
2) Roles: Roles refer to how many disciplines can work on the common platform simultaneously. In this part, it specifically means the integration within cost estimating discipline and with design discipline. It assesses how well cost tools can support co-working between design team and cost estimation team.
3) Cost flow simulation: cost flow refers to the amount of money that has been spent throughout the whole construction process. Simulation of such process can help the engineers and cost estimators fully utilize integration platform to forecast the need of monthly and weekly capital, materials and labors beforehand, thereby changing their construction plan or even the design.
4) Change tracking: the capability to recognize and record changes accurately, and whether the tools can highlight changes of new revisions and allow users to make comparison with previously estimated versions. Tracking the exact changes, the people who made these changes, and when the changes were made is an important step in the optimization process, which can give estimators, who are using the integration platform, clear ideas in what directions their projects are being changed.
5) Report generation and export: the ability to process the output of cost estimates into reports and export them into users' desired file format and structure, e.g. excel, pdf, txt, etc. With this functionality, it would be much more convenient for estimators to conduct their work on a 3D integration platform, without concerning about 2D deliverables for construction purposes.
6) Reliability of information production: capability of tools to extract information from models with a minimum loss of valuable object properties or data. This digitization criterion assesses the accuracy degree and efficiency degree during integration among designers and estimators.
7) Quantification process: The level of simplicity and speed of the tools in generating quantity take-offs or cost estimates can affect the accuracy and effectiveness of the integration platform between design and cost. This criterion examines whether the tool provides users the necessary flexibility to choose which information to take-off from the model along with the ability to produce accurate outcomes.

8) Built-in standard: the availability of built-in standards, measurement rules or parameters within the tools can bridge design discipline with cost discipline in order to enable users to generate quick quantity take-offs and cost estimates.

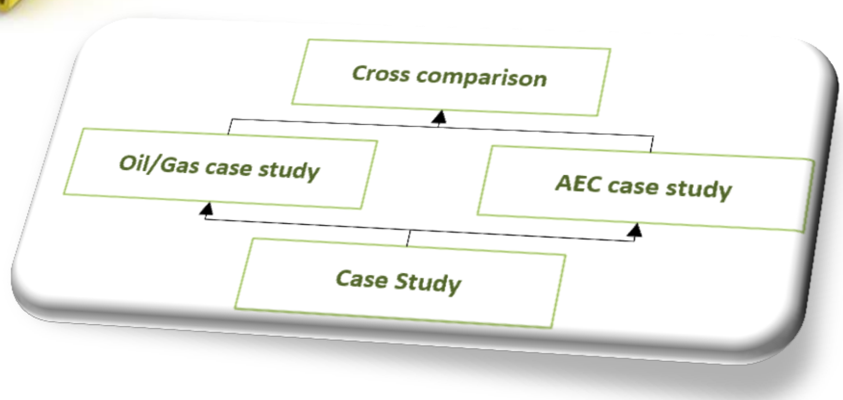
Also, for each criterion at the trans- integration level, four levels of maturity are used during the evaluation process.

Table 6 Evaluation Table of Integration Level between Design and Cost

Criteria	Options			
Graphical information	Absent	Limited	Mostly	Full Ability
Roles	Absent	Limited	Mostly	Full Ability
Cost flow simulation	Absent	Limited	Mostly	Full Ability
Change tracking	Absent	Limited	Mostly	Full ability
Report generation and export	Absent	Limited	Mostly	Full ability
Reliability of information production	Absent	50% loss	20% loss	within 10% loss
Quantification process	Absent	Complex	Simple	Very simple
	Absent	Slow	Fast	Very fast
	Absent	Able/Limited accuracy	Able/ Mostly accuracy	Able/ Accurate
Built-in Standards	Absent	Little available	Mostly available	Full available

Based on the above criteria, the inter-integration level and trans-integration level will be evaluated in the next chapter based on two cases chosen from each of the two industries.

PRACTICAL ANALYSIS



Chapter 4
Integration Evaluation

Based on the theories in the previous chapters, this chapter will evaluate the inter-integration level and trans-integration level of two cases, which are from the AEC industry and oil/gas industry respectively. After evaluating the two cases separately, the results will be compared together.

4.1 Case 1：Clean Fuels project in Kuwait

4.1.1 Background

Company Profiles：Fluor

Founded in 1912, Fluor is a global Fortune 500 firm that designs and builds some of the world's most complex projects. The century-old company delivers engineering, procurement, fabrication, construction, maintenance and project management services worldwide. Fluor serves clients in the energy, chemicals, government, industrial, infrastructures, mining and power market sectors. The company consistently ranks on FORTUNE Magazine's Most Admired Companies list as well as Ethisphere Institute's World's Most Ethical Companies list.

Figure 28 Company's logo of case 1

Fluor's business is comprised of five business groups serving diverse industries: Oil & Gas, Industrial & Infrastructure, Government, Global Services and Power. Oil and Gas segment is the largest business for Fluor. For 2014, the segment profit of Oil and Gas is 673 million dollars, taking up 67% of the total revenue. The Oil & Gas group designs and builds some of the world's largest and most complex upstream, downstream and petrochemical projects in remote and challenging locations around the globe. The group provides design, engineering, procurement, construction, fabrication and project management services for processing plants, refineries, pipelines, offshore facilities and other energy assets.

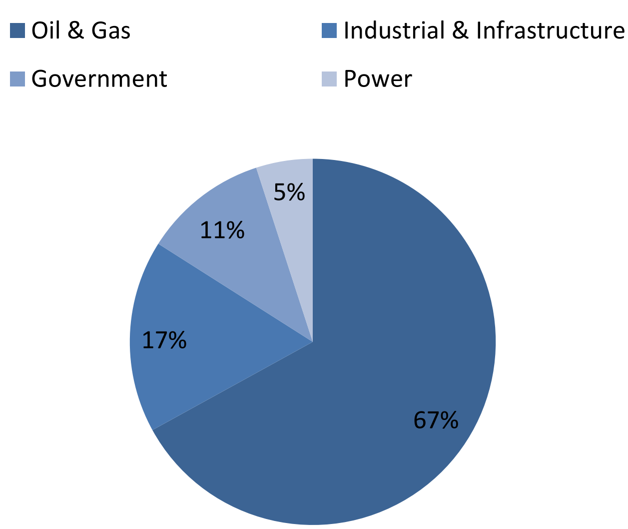


Figure 29 Revenue percentage of service markets

Fluor fully leveraged the wave of gas monetization projects which led to new awards in LNG, large petrochemical complexes and pipelines. The geographic strength and ability to partner with other firms led to new mega-project awards in Asia, the Middle East and North America. In the near term, lower oil prices may cause producers to reassess the timing and capital intensity of some projects. But in the long term, increased energy consumption will certainly drive growth.

Project Profiles：KNPC

The Kuwait National Petroleum Company (KNPC) is the national oil refining company of Kuwait. Mina Abdullah Refinery (MAB) is one of their assets located approximately 60 km to the South of Kuwait City, directly on the Arabian Gulf. The total area covered by Mina Abdullah Refinery installations is 7,935,000 m2. The refinery was first built in 1958 during the rule of the late Sheik Abdullah Al-Salem Al-Sabah, by the American Independent Oil Company “AMINOIL”. It was at that time a simple refinery that contained one crude oil distillation unit with a capacity of approximately 30,000 bpd. Following several expansion projects between 1962 and 1967 its refining capacity rose to approximately 145,000 bpd. KNPC wants to increase productivity at the facility while delivering products that comply with state-of-the-art environmental standards. KNPC’s Clean Fuels Project involves upgrading the Mina Abdulla and Mina Al-Ahmadi refineries to increase capacity. This Clean Fuels Project (CFP) is being executed on the three KNPC owned and operated refineries in Kuwait: Mina Al Ahmadi (MAA), Mina Abdullah (MAB) and Shuaiba (SHU), all within 10 kilometers apart. As part of CFP, KNPC plans the retirement of the processing facilities at SHU and a major upgrade/expansion of MAA and MAB to integrate the refining system into one complex with full conversion operation. Overall process capacity will increase from 736,000 BPSD (after SHU retirement) to 800,000 BPSD.

Figure 31 Project Rendering

Figure 30 Project Location

Main features of Mina Abdulla Refinery are listed below (KNPC, 2011):

- Established in 1958 and Expanded in 1988
- Located in southern Kuwait about ≈ 60 KM from Kuwait City

- Occupies an Area of 7.9 sq. KM
- Besides the Crude processing capacity of 270 MBPD, has the following process units :
- Atmospheric Residue Desulfurization units
- Delayed Coking Units to upgrade vacuum residue
- Hydrocracker unit to upgrade Vac. Gas oil
- Distillate Hydrotreaters (for Naphtha, Kerosene & Gas Oil) (Along with a host of supporting units (Hydrogen Production, Sulfur Recovery, Utilities, etc)

Project Organization

A joint venture was selected in a public tender as the most competitive bidder, to design, construct, and commission KNPC's Mina Abdulla Package 2 Clean Fuels project. The joint venture is composed of three companies: Fluor, Daewoo and Hyundai. Fluor's three offices joined in this project, namely Amsterdam office, New Delhi office, Kuwait and AI Khobar office, where Amsterdam office being the lead office and other Fluor offices perform substantial part of the works. For Daewoo and Hyundai, their Seoul offices participate in this project.

The large KNPC project is split within the three companies according to the strength and experience of each Joint Venture partner and also considers the availability of the resources. Fluor is responsible for more engineering Process and Utilities aspects, while Daewoo and Hyundai focus more on tank farm, buildings and construction aspects. The detailed organization structure of the joint venture is shown in Figure 32.

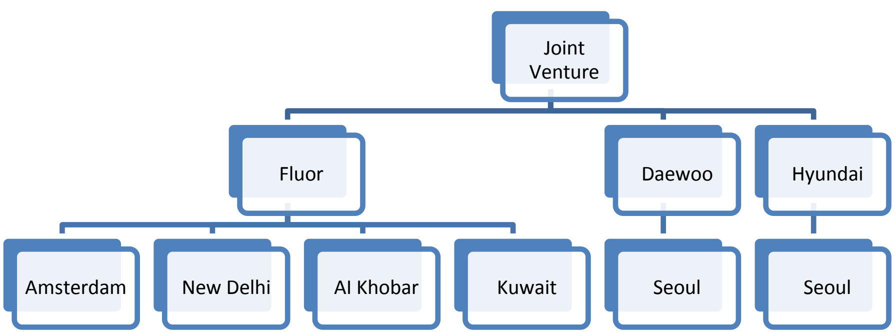


Figure 32 Project organization

Fluor began detailed engineering and design in 2014 and started construction in 2015, with expected delivery of the completed facility in 2018. During construction the anticipated peak construction force is 15,000 on site.

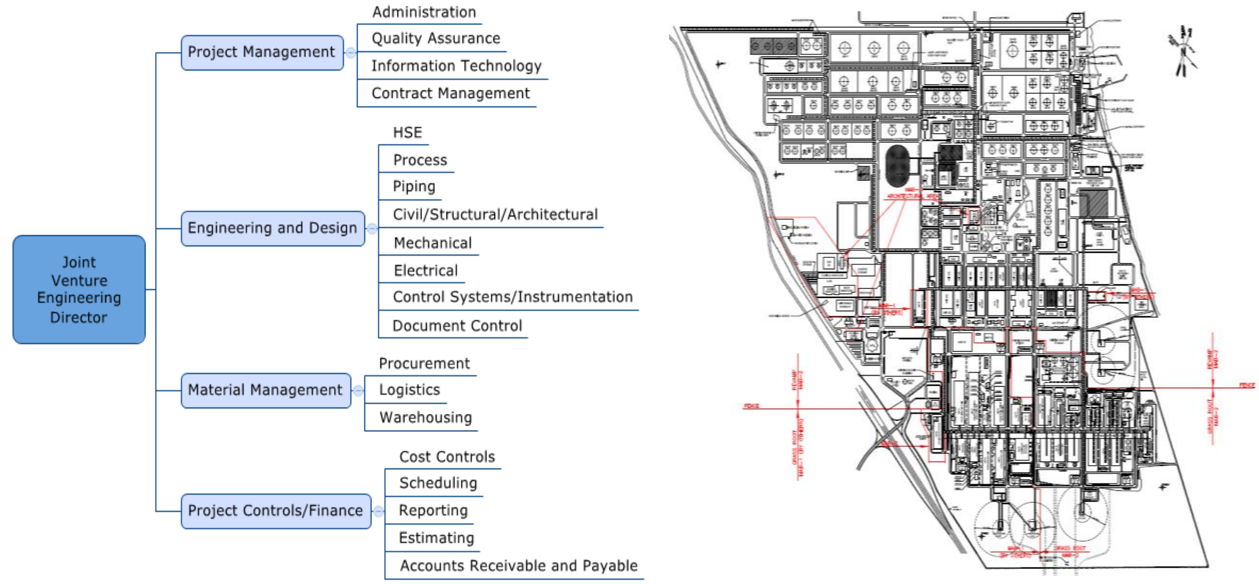


Figure 33 Organization Structure (left) and Overall Plan of Case 1 (right)

The MAB package is comprised of a world-scale hydrogen plant (steam reformers), sulfur block (SWS, ARU, SRU) and utilities, off-sites and non-process buildings. It also covers modifications to the existing Mina Abdulla refinery units. The figure below is the work breakdown structure of MAB.

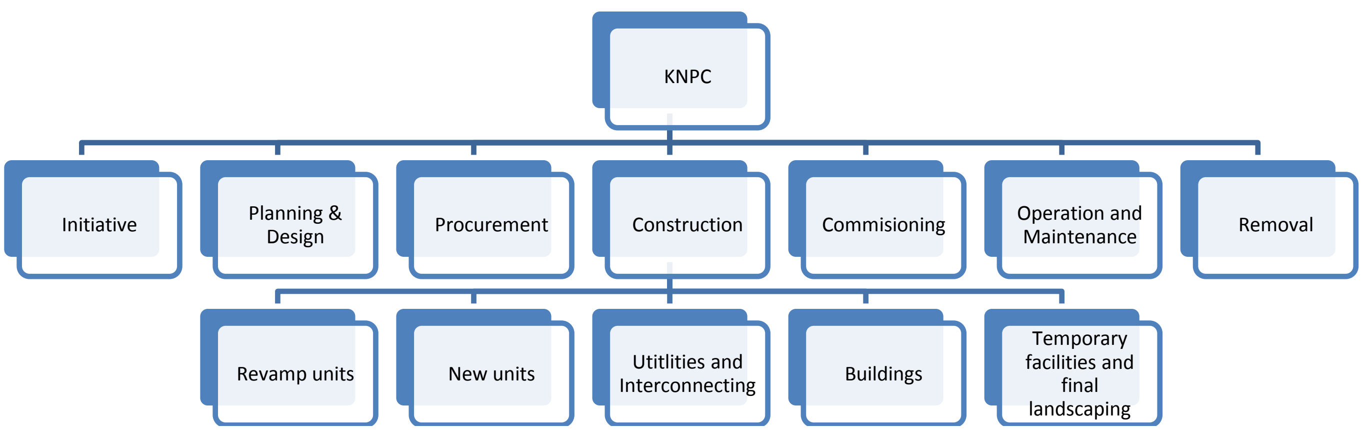


Figure 34 Work Breakdown Structure

4.1.2 Evaluation of Inter-Integration Level

Design Technology： Intergraph SmartPlant

Intergraph SmartPlant 3D is a professional design software for process plant, offshore, shipbuilding and mining industries. As for the project of KNPC, Fluor applied Intergraph SmartPlant in design phase. Intergraph software is used by Fluor for more than 30 years, which is an integrated solution suite that provides full design, construction and engineering data management capabilities for the creation, maintenance and safe operation of large-scale process projects. The ARC Advisory Group, a leading industry analyst firm, ranked Intergraph the No. 1 overall engineering design 3D software and process engineering tools (PET) provider worldwide according to its "PET Worldwide Outlook Market Analysis and Forecast through 2015" (Advisory, 2011).

Except Intergraph SmartPlant, Fluor does have other options, like AVEVA PDMS, AVEVA Everything, TEKLA, Bentley's AutoPlant and OpenPlant, etc. There are several reasons for Fluor to choose SmartPlant. One of the most important reasons is the interoperability in SmartPlant. As the format of object properties in SmartPlant is XML and 3D graphic file format is VUE, which two are the most basic data representation languages, SmartPlant possesses the 3D interoperability, supporting the models from TEKLA, AVEVA, AutoCAD, PDS, etc. With this super-interoperability, there are several super-benefits:

- Larger pool of potential project participants to draw from;
- Eliminates many barriers in multi-tool projects;
- More choices in how a project can be split up.

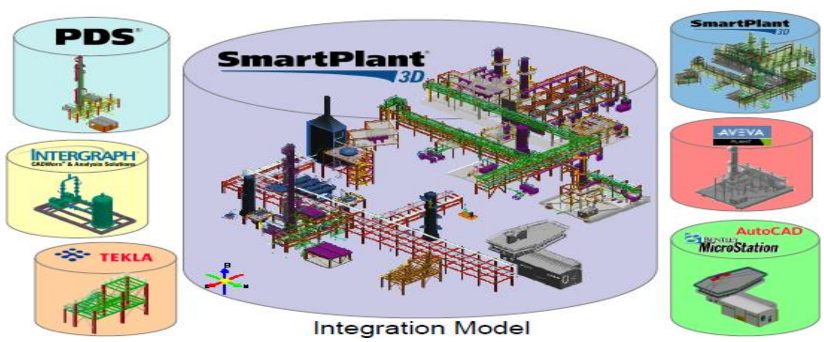


Figure 35 3D interoperability in SmartPlant

The products of Intergraph have been used by Fluor for more than 30 years for engineering and design. Besides, Fluor has also applied other tools in other disciplines. SmartPlant does have more or less direct relationships with those tools. Specifically speaking, in the conceptual engineering phase, OptimEyes and QuickPlant are the two main tools for conceptual design. The result from these two tools will be the foundation for the further development of detailed designs. SmartPlant is based on those results to create further detailed designs. The drawings and models built in the SmartPlant are the basis for the procurement aspect, where Material Manager is applied for material management, SmartSource is for strategic sourcing, and CMSi is for contract management. Following design and procurement is the construction phase. In this phase, InVision, In sequence, NEWs, and MCPlus are applied under the basis of models built in SmartPlant. As for the models from SmartPlant, UpFRONT and MCPlus are applied on the construction phase.

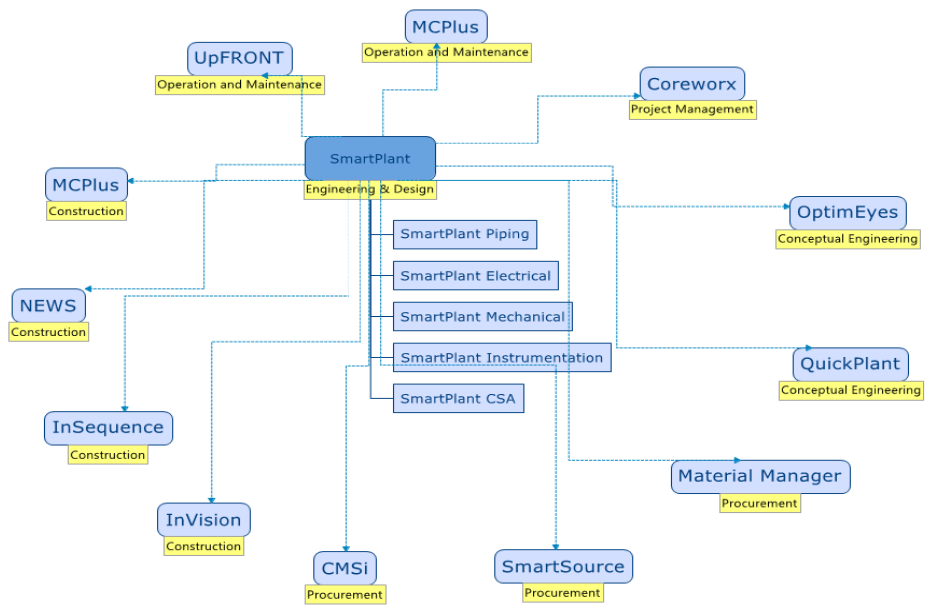


Figure 36 SmartPlant relationships with other tools

Various designers can use SmartPlant at the same time. Various designers get permissions from the Information Technology (IT) support department before using the tool. During designing, they are only allowed to build models in the permitted scope and area. IT department is also in charge of SmartPlant

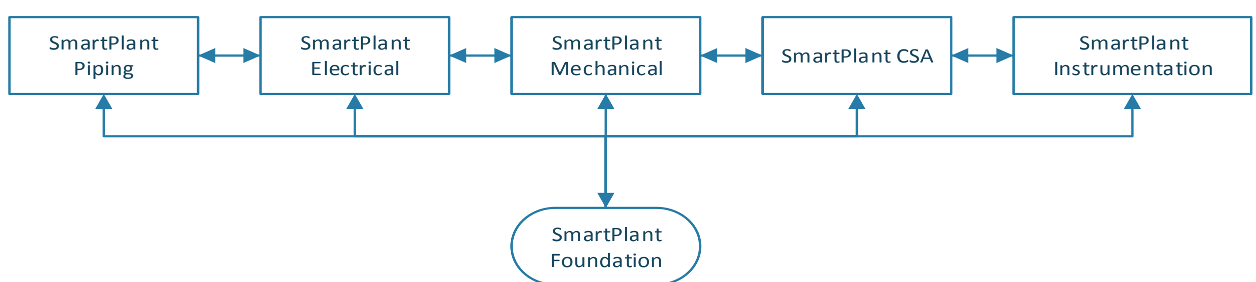


Figure 37 Data flow of SmartPlant

foundation, which is significant in real-time data sharing and model combining, i.e. the designs created by piping, electrical, mechanical, CSA designers can be combined and shared near real time.

Interview Content

The evaluation work has been carried out with interviews. The interviews have been held with a variety of design disciplines and actors who took part in the process, to outline a complete overview of the project. The interviews followed the evaluation criteria, which are set in Section 3.4.1. The questions for all participants were more or less the same. In this way, the answers can be compared with each other and used to get a specified view of the inter-integration capability of SmartPlant applied by Fluor in this project.

The participants had to describe their function and role in this project. Then the interviews continued with interview questions. The interview questions were focused on the criteria derived in Chapter 3: graphical information, roles, spatial information, change tracking, information accuracy, timeliness and delivery method. With these questions, answers can contribute to various ratings for each criterion. The higher the rating, the better the inter-integration capability.

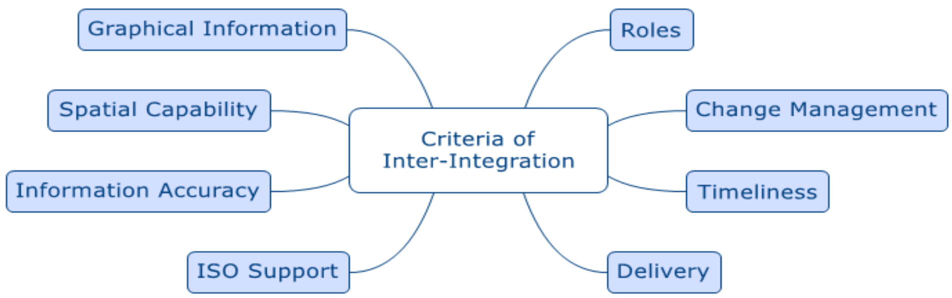


Figure 38 Inter-integration evaluation criteria

Seven experienced engineers participated in the interview. Within Fluor, the interviews involve various design disciplines of Civil/Structural/Architectural, Piping, Electrical and Mechanical. One engineering manager also participated in the interview as he has an overview for coordinating various designers on the common design platform. These design disciplines compose the design department and each of them plays a significant role in practice.

Table 7 Case 1 inter-integration interviewees

Name	Function	Software program
Jack Snijders	Senior Piping	SmartPlant
Dino Bradarac	CSA	SmartPlant
Martin Gonzala	Piping	SmartPlant
Dirk van der Reep	CSA	SmartPlant
Luis Bonito	Electrical	SmartPlant
Eric Drio	Mechanical	SmartPlant
Leon Voogd	Engineering Manager	SmartPlant

Interview Results

For the criterion of graphical information, all engineers agree that SmartPlant can provide 3 dimensional intelligent graphics, which can be exactly allocated in space without clashes between different components. For the criterion of roles, all the answers from the interviewees showed that SmartPlant is a very good design platform, which can support all design disciplines working simultaneously. That means various designers do not need work separately or individually as SmartPlant provides them a good collaboration platform, where they can perform piping, electrical, mechanical, civil, structural and architectural designs, i.e. everything regarding the project can be modeled in SmartPlant. As for spatial capability, with SmartPlant, the project models cannot be moved to a real environment and surroundings, but instead, a kind of artificial background for purpose of presentation will be made sometimes. One good thing for this criterion is that the coordinates can be moved. The zero coordinate can be moved to the place where the project is. In terms of change tracking, changes can be made very easily in the tools and other people can also view the changes which happened in the whole model. The software can also show all designers who made changes just now and what time the changes were made. However the exact changes cannot be recorded or tracked by SmartPlant. From this perspective, Dino and Dirk said "we have discussed a lot on this tool about the change tracking capability and we both think SmartPlant is not a very good tool in this aspect". As SmartPlant serves as a common platform for worldwide designers, every change matters a lot for them and can influence the following changing processes, so with the limited change tracking capability, SmartPlant needs to be improved a lot. In terms of 2D drawing generation criterion, SmartPlant performs very well; the degree of accuracy is recognized by all the interviewees. As for information accuracy, every designer agreed that SmartPlant can provide accurate information to them, which is very important for designers as "we need to be exact in space being allocate to avoid clashes between different components". In SmartPlant environment where all the designers are modeling the whole project, the timeliness response is very quick. In other words, it means that the updated information can be accessed less than one second and nearly real-time. In order to retrieve the updated information, a simple operation of pressing "refresh" button is needed. So every time you press the "refresh" button, the models can be updated. However, engineering manager said he cannot receive real-time updated information and he thought that the timeliness is not that good in terms of SmartPlant. As for delivery method, SmartPlant has centralized pool which can store all projects' data and the data about this project can be accessed very easily and quickly through the data center. The distribution process is a web based and secured approach. Besides the above formulated questions, interviewees were also asked about ISO 15926. Most of them know that ISO 15926 is an effective way to ensure the interoperability of information between different applications and they think that SmartPlant is one of the supporters for ISO 15926.

Table 8 Case 1 inter-integration evaluation result

Maturity Level	*Rating*	*Score*
Graphical Information	3D intelligent graphics	4
Roles	All design roles are supported	5

Spatial Capability	Spatially located	1
Change Tracking	Limited change recording ability	3
2D Drawings Generation	Full supported	4
Information Accuracy	Computed ground truth and full metrics	5
Timeliness	Response info available timely but manually	2.5
Delivery Method	Secured web enabled services	4
ISO 15926/16739 Support	Partly/Yes	3.5

4.1.3 Evaluation of Trans-Integration Level

Fluor is using Aspen Capital Cost Estimator and RiB for cost estimating. Aspen Capital Cost Estimator is a cost estimating software that is capable of generating AACE (Association for the Advancement of Cost Engineering) Class IV through Class II estimates for capital projects in the oil and gas, refining, and chemicals industries. While RiB is aimed at provide Class II estimates based on the details of quantities.

American Society for Testing and Materials (ASTM) and Association for the Advancement of Cost Engineering (AACE International) have published the cost estimate classifications, from Class 5 to Class 1 (AACE, 2011; ASTM, 2011). The U.S. Department of Energy and many others use these five classes of estimates in practice. The table below shows these five classes, including purpose and corresponding project definition level.

Table 9 Estimate classifications

Estimate class	Purpose	Project definition level
Class 5	Screening or feasibility	0% to 2%
Class 4	Concept study or feasibility	1% to 15%
Class 3	Budget, authorization, or control	10% to 40%
Class 2	Control or bid/tender	30% to 70%
Class 1	Check estimate or bid/tender	50% to 100%

Interview Content

The evaluation work had been carried out through interviews. The interviews were held with experienced estimators involved in the KNPC project. The interviews followed the formulated evaluation criteria, which are set in Section 3.4.2. The questions for all participants were more or less the same. In this way, the answers can be compared with each other and used to get a specified view to the trans-integration capability between design and cost within Fluor.

The participants had to describe their function and role in this project. Then the interview continued with interview questions. The interview questions, based on evaluation criteria, were focused on graphical information, roles, cost flow simulation, change tracking, report generation, reliability of information production, quantification process and built-in standards. With these questions, answers can contribute to the ratings for each criterion.

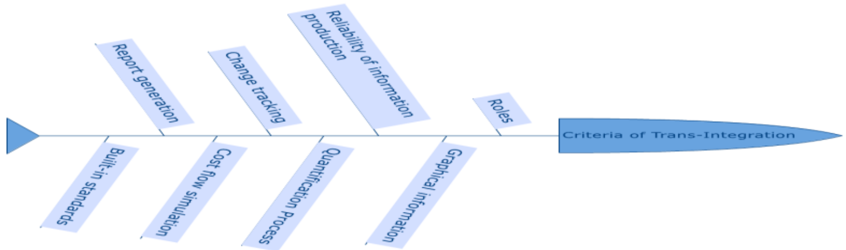


Figure 34 Trans-integration evaluation criteria

Three experienced engineers of KNPC project participated in the interview. All of them have working experience in estimating. Sven Hukriede is the senior estimator at Fluor, having worked in estimating field for more than 13 years. Maurits de Rooij has more than 13 years working experience in civil/structural/architectural design and moved to estimating department in 2014, so he can provide his feeling and ideas on the interface between design and estimating. Carl Gilding is mainly focused on project controls for KNPC project, so he has a holistic point of view on estimating.

Table 10 Case 1 trans-integration interviewees

Name	Function
Maurits de Rooij	CSA, Estimator
Sven Hukriede	Senior Estimator
Carl Gilding	Estimating, Project controls

Interview Results

Table 11 Case 1 trans-integration evaluation result

Criterion	Rating	Score
Graphical information	Absent	-
Roles	Most estimators	++
Cost flow	Absent	-
Change tracking	Limited	+
Reliability of information production	Within 10% loss	+++
Quantification process	Simple, slow, most accurate	++
Built-in standards	Mostly available	++

The estimating process at Fluor is limited in the level of extracting quantities from design tools into spreadsheet and then importing the spreadsheet into estimating tools. The estimating tools applied by Fluor do not have the capability of supporting original models generated from design tools directly, i.e. design models cannot be shown in the estimating tools. There is no direct exchange capability of model information. As the estimating tool does not have the ability to support model input, the model visualization capability is absent, the same with the capability for users to navigate, manipulate, toggle or highlight the objects or building elements within the model when preparing estimates.

As for the criterion of roles, the tools support that estimators working at the same project simultaneously. They have a clear division in the estimating team: some people are responsible for estimating civil part, some for mechanical, and some for piping, electrical, etc. They can work simultaneously with the quantities from models but cannot really see the working content from each other.

Besides, when many estimators work at the same platform, the changes they made cannot be tracked. That means that the tools have limited capability in recognizing and recording changes. Correspondingly, the tools cannot highlight the differences between new updated version and original version so as to allow users to make comparisons easily. One estimator said that “he think it is not necessary to have this capability. As the price they selected for each quantity is based on the analysis from procurement and materials engineers. So the prices are seldom changed during preparing estimating”.

As for the criteria of information reliability, quantification process and built-in standards, the results are positive. Specifically, three estimators and six designers pointed out that the process of generating quantity take-offs and cost estimates is simple, but the generating speed is not that fast from their perspective. The tool can provide users the capability to choose which information to take-off from the model. The accuracy of extracted quantities from models is mostly accurate with less than 10% loss in data properties. Within the tool, the built-in standard measurement rules or parameters within the tools are mostly available.

4.2 Case 2: Chongqing Airport Phase IV Expansion Project

4.2.1 Background

Company profile

China Construction Eighth Engineering Division (CCEED), subordinate to China State Construction Engineering Corporation, which is a large state-owned backbone construction enterprise. It was established in 1952.

Figure 35 Company's logo of case 2

As a member of the first group of experiment enterprises of China construction management comprehensive reform and one of the general contractors of class A state qualification, CCEED owns four building construction companies, one industrial installation company, one civil construction company, one mechanized construction company, and one decoration company totally eight subsidiaries with state class A construction qualification (note: All these eight subsidiaries have got ISO9000 quality system certificate). Besides eight subsidiaries, CCEED also has six branch companies, one design institute, one supervision company and one property development company. It has the capacity of a general contractor for the design, construction, scientific research, and material equipment supply of large industrial and civil buildings. In recent years, it has continuously ranked as one of top-10 good construction enterprises in China. CCEED owns 5.3 billion yuan RMB fixed assets, more than 2,600 sets of construction equipment, and 13,788 employees, of whom 268 employees are senior engineers, 1853 employees are engineers, and 4898 employees are technicians. The total annual construction value is more than 5 billion yuan RMB. CCEED can provide construction service for a great variety of professions, such as petrochemical, communication, electronic, traffic, automobile, building material, machinery, textile, pharmacy, military industries and space-flight, national defense works etc. Its business scope has spread to more than 20 provinces in China and further to southeast of Asia, Middle East of Asia and north Africa.

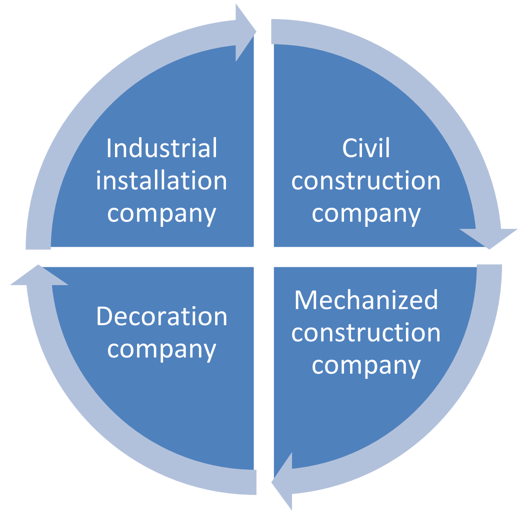


Figure 36 Joint Venture structure

Project profile

Chongqing Jiangbei International Airport is ranked 9th (22 mln) in Chinese airports PAX in 2012. It is located 21km of Chongqing, China. After 3-phase expansion the airport currently has 3 terminals (T1, T2A and T2B) 180,000 sqm and 2 runways. Phase IV expansion project has started in 2011. The new expansion includes the construction of a new runway (3800m), a

Figure 37 Rendering of T3A terminal

new terminal T3A (500,000sqm), a transportation hub (300,000sqm), 94 new parking aprons and warehouses. For long term plan a terminal T3B and the 4th runway will be built in Phase V expansion project.

Figure 38 Interior rendering of T3A project

Phase IV expansion project focuses on the new terminal 3, whose 550,000 sqm area is designed to handle 30 million passengers per year. This will increase the airport's capacity to 45,000,000 passengers per year by 2020.

The new T3A terminal of Chongqing Jiangbei International airport is located in the east of the existing terminal area. The terminal consists of the main building and A, B, C, D four galleries. The terminal has four floors above ground and the main building has two layers of basement. Most part of the whole building foundation is independent column foundation, and there are some parts are mechanical rotary digging pile foundation. For the building structure, the roof of the building is large steel structure and the rest are reinforced concrete frame structure. The project is based on BIM full professional modeling, which includes every discipline's collision check, design optimization, construction simulation, optimization of construction process and 3 dimensional construction coordination platforms.

This project is a turnkey project, which is mainly performed by three parties: CCEED is the general contractor; Jiangbei Airport Group co., ltd is the client; Chongqing University provides consultancy service. BIM is implemented in this project by CCEED as required by the client, under supervision of the consultant.

In CCEED, design team is mainly responsible for the BIM model design, involving the designers from architectural, structural and MEP (mechanical-electrical-piping) groups. Project controls team is responsible for cost estimating, procurement, logistics, permitting and legal matters. Construction team conducts construction at the site. The organization structure is showed in Figure 40.

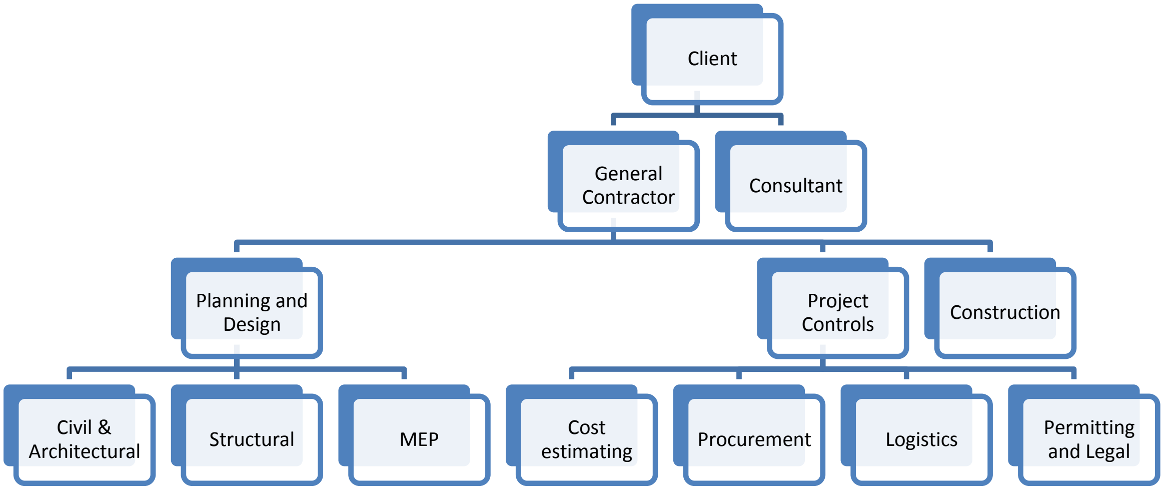


Figure 39 Organization structure of case 2

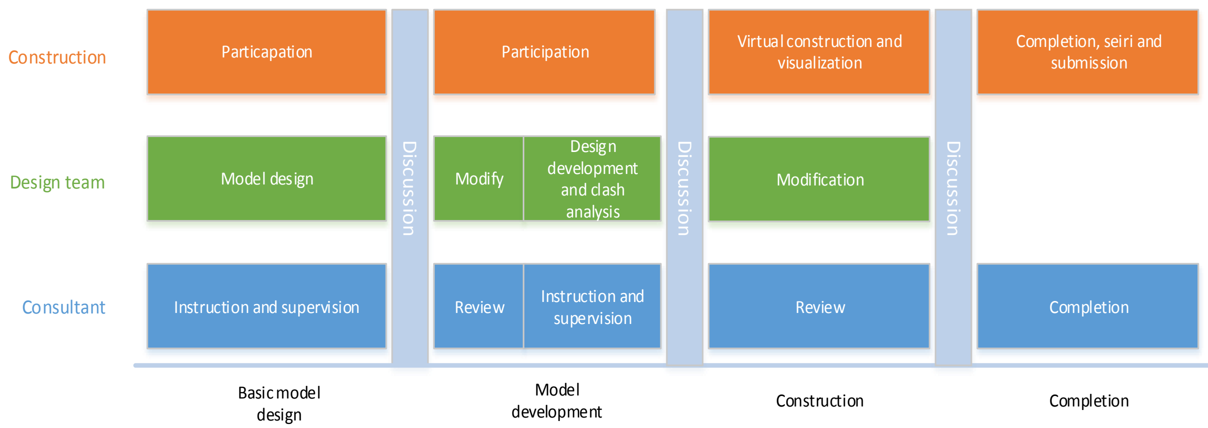


Figure 40 BIM implementation process

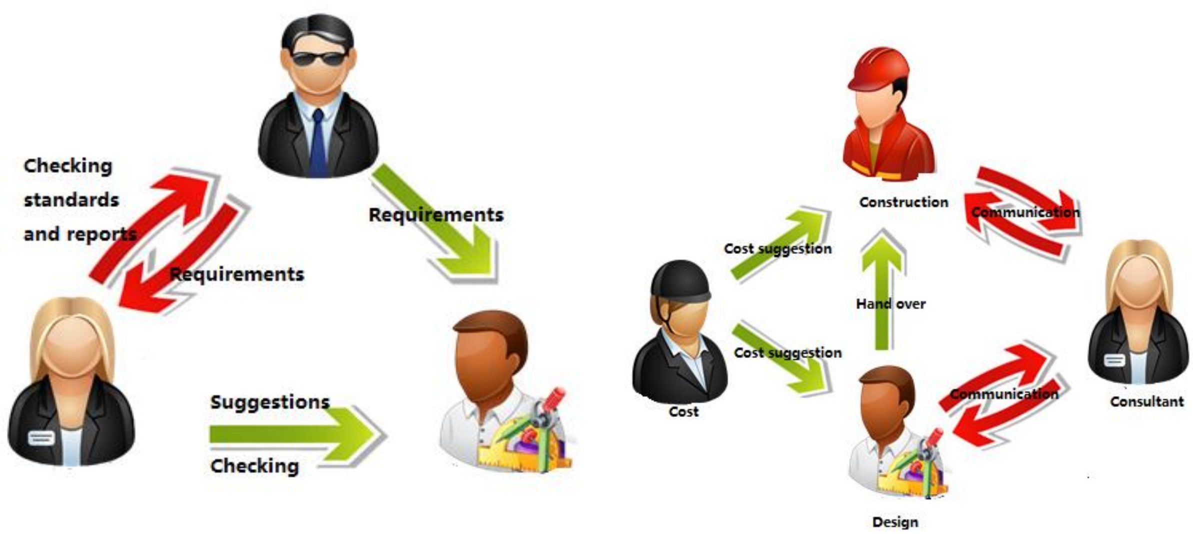


Figure 41 Relationship in design stage and design development stage

BIM'S implementation process is mainly composed of four stages: basic model design stage, model development stage, construction stage and completion stage. During the four stages, there are daily meetings, including coordination, difficulties communication, regular meetings, etc. Between the neighboring stages, there are key meetings when the involved parties can discuss the progress matters. Figure 40 shows the four stages and the main participants, design team, construction team and consultant.

In the basic model design stage, it is firstly that the client described their requirements to the design and the consultant. Based on the requirements, design team of general contractor starts basic model design. Consultant is responsible for providing checking standards and reports to the clients. The relationship among these three parties is show in Figure 41. In the design development stage, the consultant is the link between client and contractor. Representing the client, the consultant checks the basic model with design team, communicates with the client and provide detailed requirements for model development. Based on the developed design, the work will be handed over to the construction team. The relationship is shown in Figure 41.

4.2.2 Inter-Integration Evaluation

Design Technology：Autodesk Revit

Revit series is one of the most popular products invented by the Autodesk Company. Revit series is specifically built for Building Information Modeling (BIM), which can help engineering companies design, construct and maintain the high quality and energy efficient projects. In this project, Revit is used by the design team.

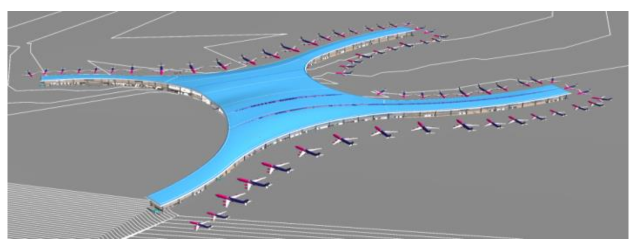


Figure 42 Architectural model

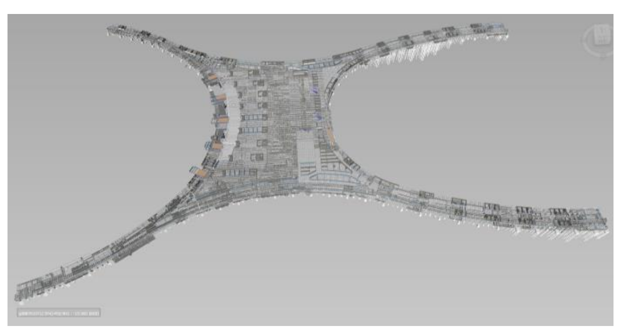


Figure 43 Structural model

While there do have alternatives of Revit, like Bentley, AchiCAD, Digital Project, etc. One of the most important reasons for this project choosing Revit is because that Autodesk Revit is the dominating design software in the AEC industry (Monteiro & Martins, 2013). The other reason is that Revit provides excellent collaboration capability with cost software, which will be elaborated in detail in the next Section.

Autodesk Revit provides features for architectural design, structural design and MEP (mechanical-electrical-piping) design. With this tool, different designers can design easily according to their way of thinking. Architectures can perform the following activities with the tool: site planning, energy analysis and lighting analysis with the purpose of making sustainable design decisions; 3D visualization and connecting with laser scans so as to explore, validate and communicate designs. As for structural engineers, with the tool, they can conduct: gravity analysis in order to determine vertical loads transmitted from top to bottom; static analysis in the cloud; structural analysis, etc. MEP engineers create designs for electrical system, mechanical system and plumbing system.

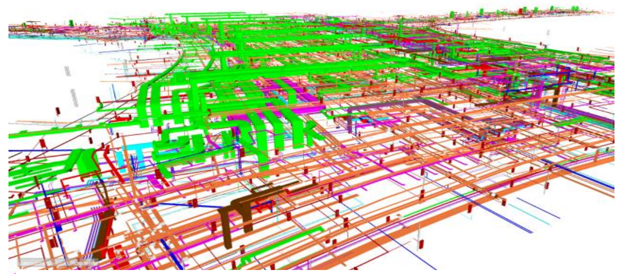


Figure 44 MEP model

In the project of T3A airport terminal, Autodesk Revit is applied by the design team, among architectures, structural engineers and MEP engineers. Civil and architectural engineers, structural engineers and MEP engineers build models in the Revit software and at some certain times, the models will be combined together. Figure 45 shows the relationship between revit and other BIM tools in the project.

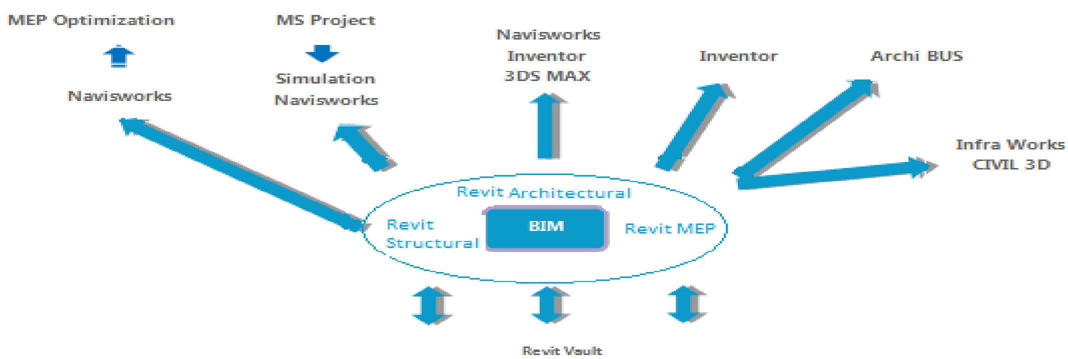


Figure 45 Revit relationships

Interview Content

Same with case 1, the evaluation work has been carried out with interviews. The interviews have been held with 5 designers from various design disciplines. The interviews followed the evaluation criteria, which are set in Section 3.4.1. The questions for all participants were more or less the same. In this way, the answers can be compared with each other and used to get a specified view of the inter-integration capability of Revit applied in this project.

The participants had to subscribe their functions and roles in this project. Then the interview continued with interview questions. The interview questions were focused on the criteria derived in Chapter 3: graphical information, roles, spatial information, 2D drawings generation, change tracking, information accuracy, timeliness and delivery method. With these questions, answers can contribute to various ratings for each criterion.

Five experienced engineers participated in the interview and they are responsible for structural design, architectural design, and MEP (mechanical, electrical, and plumbing) design respectively. These design disciplines compose of the design team for the Chongqing Airport project.

Table 12 Inter-integration Interviewees of Case 2

Name	Function	Software program
Xiangyu Chen	Architecture	Revit Architecture
Yawei Li	Architecture	Revit Architecture
Xing Liu	Structure	Revit Structure
Tao Wang	Structure	Revit Structure
Shiyao Gao	MEP	Revit MEP

Interview Results

For the criterion of graphical information, the specific and intelligent degree of graphical data is very high for Revit. In Revit, the graphical information consists of geometrical properties and non-geometrical properties. These two categories of properties compose of the rich graphical information and make each element in the tool into intelligent graphics. Roles: For the criterion of Roles, all designers said that "Revit is a good platform for all different design disciplines to work and collaborate together. Architectural, structural, mechanical, electrical and piping design can be created in the Revit software". But they do mention that if the project has a steel structure, Revit will not be applied, which does not mean that Revit does not have the steel design capability, but means Revit is not good at steel designing. If the project is a steel structure, the product of Benteley will be used instead of Revit in practice. In terms of spatial capability, Revit does not have the capability of projecting the model in the real environment. However, the BIM model can be located spatially under help of other tools, like BIM360, which is in the beginning stage. Chen said the obstacle for placing BIM model in spatial environment is the data format: BIM model contains geometrical and non-geometrical properties, but geographical system only can read geometrical properties. If the non-geographical properties can be deleted from BIM model, then it is easier to spatially locate BIM models. As for change management capability, changes can be made easily in Revit software. And changes can also be updated quickly. But Revit lacks the change recording capability, which means that who made the change, when the change was made and what exact the change cannot be tracked in Revit. The change management capability is less than limited. Li said that he hopes the tool can have change tracking capability, as many changes can happen one day, there should be a functionality to help every designer remember and know about what changes are being made by whom and when. Otherwise, the information cannot be synchronized and conflicts may occur. Revit is developed based on CAD, so it has no problems to support 2D drawings generation. For the criterion of information accuracy and timeliness, the opinions are positive. Every designer thinks that Revit is a good tool which can provide the most accurate design, much more super than previous 2D design software. In the environment of Revit, all designers modeling the whole project can access the updated information timely and automatically. Designers do not need to take any action to update their model. The process of accessing updated information is like real time. Besides, the delivery approach is web-enabled and secured. With the secured web distribution service, there is a structured network environment where the information is centrally stored and accessible by every designer, which can ensure information sharing within the whole design group. The additional question regarding ISO 16739 is also asked. Most of them know this norm and IFC, but Chen said that Revit partly supported ISO 16739 in 2013 as there were some incompatibilities. But for Revit 2015, the tool used in the airport project, he thinks it can support IFC completely.

Table 13 Case 2 evaluation result of inter-integration

Maturity Level	*Rating*	*Score*
Graphical Information	3D intelligent graphics	4
Roles	All design roles are supported	4
Spatial Capability	Spatially located	1
Change Tracking	Limited change recording ability	3
2D drawings generation	Supported, but rechecking needed	4
Information Accuracy	Computed ground truth and full metrics	5
Timeliness	Response info available timely but manually	2.5
Delivery Method	Secured web enabled services	4
ISO 15926/16739 Support	Partly/Yes	3.5

4.2.3 Evaluation of Trans-Integration Level

Glodon is the cost estimating software used by the estimating department for the CA project. Glodon Bill of Quantities (TBQ) is one of the most popular costs estimating software in China. Glodon Software Co. Ltd. is the producer of TBQ and is a leading Chinese AEC IT company. On September 11, 2014 Glodon signed the memorandum of understanding (MoU) with Autodesk Software Company, a world leader in 3D design, engineering and entertainment software and services. The goal is to jointly promote the further adoption and application of Building Information Modeling (BIM) technology in the construction industry.

Interview Content

Based on the cost software they used, the evaluation assessed the trans-integration level between design and cost the estimating tools. The evaluation has been carried out with interviews. The interviews were held with experienced estimators who were involved in the CA project and based on the evaluation criteria to get a specified view of the trans-integration level between design and cost. The evaluation criteria are described in detail in Section 3.4.2.

Table 14 Trans-integration Interviewees of Case 2

Name	Function
Lihua Su	Estimator
Xiaoyuan Yuan	Estimator
Yang Du	Estimator

Same with case1, to begin the interview, the participants had to describe their functions and roles in this project. Then the interview continued with interview questions. The interview questions were based on evaluation criteria, namely visualization, quantification process, reliability of information production, change management and report generation. With these questions, answers can contribute to the ratings for each criterion.

Three experienced engineers of CA project were contacted via Skype for interview. All of them have rich working experience in cost estimating. Lihua Su has specialized in BIM cost field for more than 5 years since she graduated from Chongqing University. She has participated in many BIM projects, like Chongqing Airport, Vanke commercial projects, government projects at Huxi district. Xiaoyuan Yuan specialized in structural design three years ago and then changed to estimating department. Until now he has 3 years estimating experience.

Interview Results

The level of cost estimating is in the level of importing BIM graphical models into estimating tools. The estimating tools can support the original Revit model importing into its system and the estimators can navigate, manipulate, toggle and highlight the objects and building elements within the model when preparing estimates. The importing process for Glodon is not based on the original Revit file format, but relies on a self-developed new format, Global Fundation Classes (GFC), which is developed by Glodon and Autodesk. With the conversion of format, Glodon can realize the idea of "one model multiple usages", which can decrease the working complexity. As for the criterion of Roles, Su said that estimators work

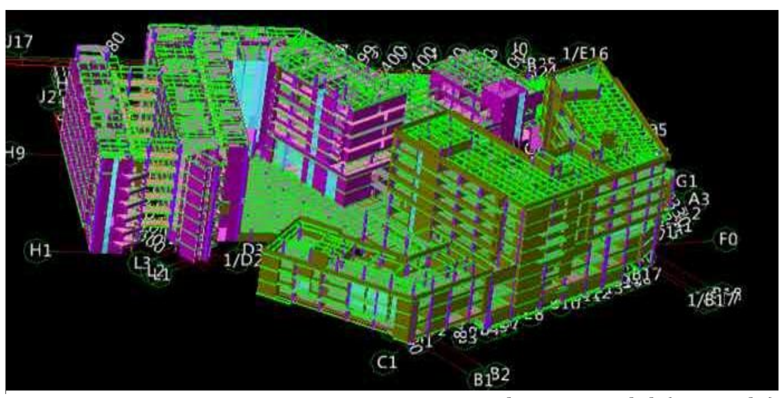


Figure 46 Imported Revit model (example)

individually, based on the pre-division of working content. Glodon does not support cost flow simulation if no support from dynamic schedule. As for the quantification process, Glodon is able to measure the entire BIM model automatically. As said by Lihua, the difference between traditional quantity take-off and direct model take-off is nearly zero, which have been tested by them. But at the first time, they do need some manual operations, like define the measurement types, select assembly objects, etc. After that, the process of quantity take-off can run automatically. They can generate quantity take-offs and based on that to generate cost estimates. The level of simplicity in this process is moderate, as it needs manual operations, but only one time. And the speed of generation quantity take-offs and cost estimates are largely depended on the size of project. From the perspective of the three interviewees, the speed is fast compared to the previous tools. The tools also allow users to choose which information to take-off from the model. The transferred and extracted information from the model have good performance in the reliability of information production, less than 10% loss. Regarding the criterion of change tracking, the tools do not support change recording capability, change recognizing capability, so that the comparison between different versions cannot be realized. The capability to export the cost estimates into files and into users' desired file format and structure is owned by the tools.

Table 15 Case 2 trans-integration evaluation result

Criterion	Rating	Score
Graphical information	Mostly available	++
Roles	Only one estimator	-
Cost flow	Absent	-
Change tracking	Limited	+
Reliability of information production	Within 10% loss	+++
Quantification process	Simple, slow, most accurate	++
Built-in standards	Mostly available	++

4.3 Cross Case Comparison

4.3.1 Inter-Integration Comparison

After the separate evaluation of the design tools of BIM and iRing, the results from these tools will contribute to BIM and iRing's inter-integration level. As SmartPlant and Revit both are advanced tools within their own field, therefore to some extend the results from these two technologies can represent iRing's and BIM's inter-integration level in design discipline. Based on the separate results, strengths and weaknesses of BIM and iRing will be compared in this section. The comparison is based on the evaluation criteria: graphical information, roles, spatial information, change tracking, information accuracy, timeliness, and delivery method. According to the comparison, the opportunities to improve the inter-integration level will be provided especially for iRing.

Intergraph SmartPlant

- SmartPlant 3D
- SmartPlant Electrical
- SmartPlant Piping
- SmartPlant Mechanical
- SmartPlant Instrumentation

Autodesk Revit

- Revit Architectural
- Revit Structural
- Revit MEP

Figure 47 Design Modules of BIM and iRing

Strengths and Weaknesses Comparison

Table 16 Inter-integration Strenghs Comparison

iRing	BIM
Supporting all design roles	Supporting all design roles
Change recording of who and when	Response info timely and automatically, real-time
Web based info distribution system	Network access
Secured info transmission environment	3D intelligent graphics with manual updating
3D intelligent graphics	Located spatially with info sharing
Coordinates spatially located	Coordinates spatially located
Computed ground truth and full metrics	Computed ground truth and full metrics
ISO support	ISO support

Table 17 Inter-integration Weaknesses Comparison

iRing	BIM
Limited change recording ability	Design seperately
Response info manually	Not good at steel design
No spatial info sharing	No built-in spatial location capability
No connecting with GIS	No connecting with GIS
	No change recording capability

Information sharing is significant to the design's integration. SmartPlant and Revit both support all design roles to collaborate in the system. But the difference is that in Revit the design disciplines work in their individual models. Only at a certain time, like at 4pm every Friday, the models from architectural, structural and MEP designers will be combined together. In this way, architectural designers, structural designers and MEP designers do not have a real time information sharing during the whole week. But for SmartPlant, it is more superior than Revit. SmartPlant can support different designers working at same time on the same model.

As for the change tracking capability, although there are some limits in SmartPlant, as it can only record who made the changes and when the changes were made, not any recordings of what the exact changes are. But this level already exceeds that of Revit. For Revit, there is no recording capability of what has been changed by whom at when, so the change tracking capability that Revit can provide is almost zero. But change tracking capability is very important in change management and in the collaborative environment. As more transparent the working environment is the more value and effectiveness the designers can contribute.

For timeliness, this criterion, they stay almost at the same level but Revit is a little bit over SmartPlant. SmartPlant is good at timely responding, but need to press "refresh" manually before updating the model. As for Revit, the response is timely and automatically, and no extra operation is needed. For designers at Fluor, they do prefer automatically updating model, but the current situation is not bad, as the system receives and sends out data very quickly. Pressing "refresh" button is not a big thing for them.

In terms of delivery method, SmartPlant has a secured web environment. The broad web environment ensures that different offices of Fluor located in different placed can work together. As the coverage of web service is very broad, Fluor has a professional IT support team who are responsible for the security and stability of the web. On the other hand, for Revit, it is worked in the Network environment. That means that only the people who can join the local network area can share files with each. The network access limits the size and location of the whole design group.

For the criterion of spatial capability, BIM develops to a little more mature level than iRing. The model of BIM can be placed in real environment. Although this capability is not owned by Revit, there are several software can help Revit realize this capability. Professionals of BIM and GIS are attempting to find the possibilities to integrate BIM models with the Geographic Information System (GIS) now. If this is achieved, more valuable data of geological conditions can be used to rich the 3D model and the model can be tested in realistic surroundings. SmartPlant and Revit both support 3D intelligent graphics, computed ground truth with full metrics and ISO standards.

SmartPlant and Revit both have disadvantages. These disadvantages impact the inter-integration level they can provide to the AEC industry and Oil/Gas industry. The disadvantages of SmartPlant have: Limited change recording ability (what exactly the change is); Response info manually; No spatial info sharing; No connecting with GIS. The weaknesses of Revit have: No change recording capability; Not good at steel design; No current data updating automatically; No built-in spatial location capability; No connecting with GIS.

Current positions of iRing and Opportunities for improvement

Table 18 iRing current position of inter-integration

Inter-Integration Criteria	Ratings					Current position
Graphical information	1	2	3	4	5	Mostly achieved
Roles	1	2	3	4	5	Achieved
Spatial information	1	2	3	4	5	Not achieved
Change tracking	1	2	3	4	5	Partly achieved
2D drawings generation	1	2	3	4	5	Mostly achieved
Information accuracy	1	2	3	4	5	Achieved
Timeliness	1	2	3	4	5	Limited achieved
Delivery method	1	2	3	4	5	Mostly achieved
ISO support	1	2	3	4	5	Mostly achieved

Table 19 Opportunities for iRing

	Capability	Criteria	Opportunities
Inter-Integration Capability	Visualization	Graphical information	Mostly achieved. Connecting with current info flow to update material pool and element properties.
	Collaboration	Roles	Achieved
	Simulation	Spatial information	Not achieved. Adding spatially located model capability for realistic simulation.
	Optimization	Change tracking	Partly achieved. Including change recording of exact changes, not only available in the program, but also can be chosen to export into files, showing on the printed-out drawings.
	Optimization	2D drawings generation	Mostly achieved.
	Digitization	Information accuracy	Achieved
	Digitization	Timeliness	Limited achieved. Response info updated automatically, not only available for designers but also for the clients and public.
	Digitization	Delivery method	Mostly achieved. Adding cloud technique to realize full netcentric access.
	Collaboration	ISO support	Mostly achieved/Achieved.

SmartPlant is a representative design tool of iRing. It helps the Oil/Gas industry achieve two inter-integration criteria: Roles and Information Accuracy. For the criteria of Delivery Method, Graphical Information and ISO Support, iRing mostly achieved, but there is still some room for improvement. If

SmartPlant can include change recording capability of exact changes, and these recordings not only available in the applications, but also can be exported out into files and shown on exported drawings, the change management capability can be fully achieved. As for the delivery method, connecting with cloud technique is a way to realize full netcentric access thus the data distribution can be centrally controlled. Connecting with latest material pool, element pool, properties pool will help iRing fulfill the graphical information criterion. Spatial capability is in the lowest level. If the model can be integrated with GIS system, it will help the model information communicate with the information from surroundings and environment.

4.3.2 Trans-Integration Comparison

After the separate evaluation of trans-integration level in BIM and iRing, the strengths and weaknesses will be compared in this section. The comparison is based on the seven evaluation criteria: Graphical information, roles, cost flow, change tracking, reliability of information production, quantification process and built-in standards. According to the comparison, the opportunities to improve the inter-integration level and trans-integration level will be provided especially for iRing part.

Strengths and weaknesses

Table 20 Trans-integration Strength Comparison

iRing	BIM
Quantity take-off process simple	Quantity take-off process simple
Quantity take-offs accurate	Quantity take-offs accurate
Loss of information is less than 10%	Loss of information is less than 10%
Most measurement rules and parameters standards built-in	Most measurement rules and parameters standards built-in
Report can be exported into users' desired file format and structure	Report can be exported into users' desired file format and structure
	Support BIM model
	Allows users to operate the model

Table 21 Trans-integration Weakness Comparison

iRing	BIM
Quantity take-offs speed moderate	Quantity take-offs speed moderate
30% Quantity take-offs manually	Limited capability to record changes
Limited capability to recognize changes	Original BIM model is not supported
No capability to record changes	No capability to record changes
No capability to compare between two versions	No capability to compare between two versions
No model supporting capability	
No model visualization capability	

Both iRing and BIM have strength and weakness in terms of the integration between design and cost. For the strengths, both iRing and BIM perform very well in the quantity take-offs process: the process is simple, the results are mostly accurate and the loss of information is limited. The built-in measurement standards and rules are available for both sides, which can secure the accurate take-off result. Users also have flexibility to choose which file format and structure they would like to use if generating reports. But the difference is that BIM cost tools can support the model input and allow users to navigate, manipulate, toggle and highlight the objects when preparing estimates. This capability narrows the gap between design and cost estimating, as the quantities do not need to be extracted out first and then be passed to the estimators. If the model can be imported into the cost tools directly, there is no big interface which can cause the inconsistency of information during the transmission procedures. Equipping the cost tools with capability to import models and generating quantities is a step towards trans-integration between design and cost. BIM is starting to achieve this goal, but iRing needs more efforts in this aspect.

As for the weakness, iRing has more than BIM. 30% of the total quantity of iRing has to be take-off manually. iRing does not have change recording capability and comparison capability. 3 dimensional models cannot be input into the iRing estimating tools in order to allow the users to survey quantities and calculate cost directly on the model.

From an overall perspective, the gap between design and cost of iRing is larger than that of BIM. iRing is in the level of extracting quantities to estimating software, while BIM is in the level of integrating model with quantification tools. BIM's integration level between design and cost is higher than iRing's.

Current position of iRing and Opportunities

Overall, iRing is lagged a lit behind terms of the seven criteria of trans-integration. iRing is standing at a stage where the quantities need to be taken-off to a spreadsheet first, and then passed to estimators, estimators import the quantities into their tools and then do the pricing work. This is the beginning stage for the collaboration between design and cost where the gap between them is very big. iRing should learn from BIM in terms of trans-integration between design and cost, because the interface between design and cost for BIM is very small so that much easier to manage.

Table 22 iRing current position of trans-integration

Trans-Integration Criteria	Current position				
Graphical information	-	+	++	+++	Absent
Roles	-	+	++	+++	Mostly achieved
Cost flow	-	+	++	+++	Absent
Change tracking	-	+	++	+++	Absent
Reliability of information production	-	+	++	+++	Mostly achieved

Quantification process	-	+	++	+++	Mostly achieved
Built in standards	-	+	++	+++	Mostly achieved

Specifically speaking, the aspects of graphical information, cost flow and change tracking need to be improved most as there are nearly no capability in iRing. For iRing tools, adding the capability of supporting models can diminish the interfaces between design and estimating a lot, which is welcomed by estimators. In this way, the information contained by design models can be directly used by the estimator. The traditional way of extracting quantities out of the model and then importing quantities into the estimating tools can cause many problems as the quantity is the sole link between design and cost. If this link has some problems or is not accurate enough, the estimates based on the quantities can be influenced greatly. If deleting the process of extracting quantities and importing quantities, just give the tools capability to support the design model, the link between design and cost is not just quantity, but unlimited accurate elements in the model. In this way, the trans-integration can be realized on design and cost completely without the interface between each other.

Table 23 iRing opportunities of trans-integration

	Capability	**Criteria**	**Opportunities**
Trans-Integration Level	Visualization	Graphical information	Not achieved. Adding model support capability in the estimating tools which can allow estimators to get quantities directly from the model and pricing the items directly on the model.
	Collaboration	Roles	Mostly achieved. Can be further developed towards supporting real-time updates
	Simulation	Cost flow	Not achieved. Can be achieved by adding schedule.
	Optimization	Change tracking	Not achieved. Adding change recording capability so as to support users compare two versions together before making decisions on the final estimates.
	Digitization	Reliability of information	Mostly achieved.
	Digitization	Quantification process	Partly achieved. The speed of quantification process depend much on the computer performance and project size, so this cannot have much improvement from the vendor and user sides.
	Digitization	Built in standards	Mostly achieved.

4.3.3 Analysis and Discussions

Comparison is a kind of knowledge sharing process. Brown et al. and Easterby-Smith et al. claimed that knowledge is the property of individual but regenerated when a group of individuals are tightly knit (Brown & Duguid, 1998; Easterby-Smith & Lyles, 2011). From Esra Bektas' perspective, in essence, knowledge has both an objective character (based on factual information) and subjective character (personal experiences differing by different backgrounds and skills of individuals). Knowledge represents a dynamic and organically growing asset rather than a 'stationary' object (Bektas, 2013). And Esta proposed there are two types of knowledge sharing processes:

1) Indirect knowledge sharing through tools and artifacts,
2) Direct knowledge sharing through social interaction.

The thesis is based on the comparison between BIM and iRing tools in design and cost disciplines, which is an indirect knowledge sharing format. While during the research being carried out, the process includes social interactions with different groups of people from AEC and Oil and Gas fields, which is a direct knowledge sharing format. No matter direct or indirect knowledge sharing or comparison, the goal is "integration". All the efforts are paid on the research question: "In what aspects, can the technology be improved in terms of iRing integration capability for Fluor".

The interviews provide a diversity of information in which level that BIM and iRing is standing at. Based on interview results and cross comparison, this part will focus more on the reasons or difficulties for why some aspects are weak in terms of iRing or iRing lagging behind.

Inter-integration level

Firstly for inter-integration level, there are mainly three weak aspects: spatial information (simulation capability), change tracking (optimization capability) and timeliness (digitization capability).

Spatial capability

As elaborated in the previous section, the model built in iRing cannot be directly transferred to geographical information systems at Fluor. But this aspect is seen as one of intelligent representatives and future trend by the five designers. They expressed their hope of placing model in real environment "just imagine when change piping lines, you can simulate the piping lines at the real location; when you build utilities, you can see what influence they have on environment directly; when you arrange instrumentations, you can see the situations of sites. How wonderful it is." With the spatial information, like the situation of streets, terrain, can help designers, decision makers, clients make more comprehensive and accurate decisions. To improve this capability, much effort relies on the connections between iRing and GIS. But from one senior designer's perspective, iRing and GIS are the two different worlds, like two "parallel universes". This means that the standards, techniques are largely different. Jack Snijders said that as far as he knows that there are two ways to attempt integrating iRing with GIS: one is that professionals from GIS (GISer) utilize the developed and available GIS techniques and standards to change the oil/gas projects into a type of geographical data in space; the other one is that the professionals from iRing (iRinger) side utilize the design tools to design as much as possible of the surroundings, like streets, terrain, underground pipings, etc. These two ways are the integration of GIS and iRing. But he thinks these two ways don't work very much in practice. In the first way, iRing will become the basic data source for constructing environment by GISer; while in the second way, GIS is regarded by the key spatial data source by iRinger. The essence of GIS and iRing doesn't change, leave alone spatial information sharing. For iRing, the models contain a great amount of information from designing to construction, including detailed architectural, structural, mechanical, electrical, piping and so on information. And that information is mainly used to support construction. Whereas in the field of GIS, it is mainly focused on geographical information and how to use the 3 dimensional approach to spatially model the entire city. Therefore bridging iRing and BIM seems lacking of a common standard language which can help the data information share between iRing and GIS. This standard language cannot be developed by one organization, like Fluor, they do not have enough specialists from these two fields. But what Fluor can do is to provide researchers with feedbacks after using such functionally and tell the researchers what functionalities they desire for the next generation tools in the future. Enhancing spatial simulation capability needs mutual efforts and close collaborations from professionals of GIS and iRing.

Change tracking

Several engineers said that SmartPlant is not a good tool because of no change tracking functionality. But change tracking is important for them to record what have been changes by their peers. Although SmartPlant can track who make changes at when, no valuation information regarding the real changes can provide them. Especially when they generate 2D drawings, they hardly see the differences between the new and old drawings when putting them together. Sometimes, misuse of drawings can happen according to their experience. One designer thinks that the change tracking problem is the responsibility of software vendors but the field service team leader said they did not notice this is a big problem and nobody tell them to improve this aspect. The aspect can be improved by software vendors and more communications between Fluor and Intergraph are needed, not only limited within design leaders but all disigners' opinions matter.

Timeliness of Updated information

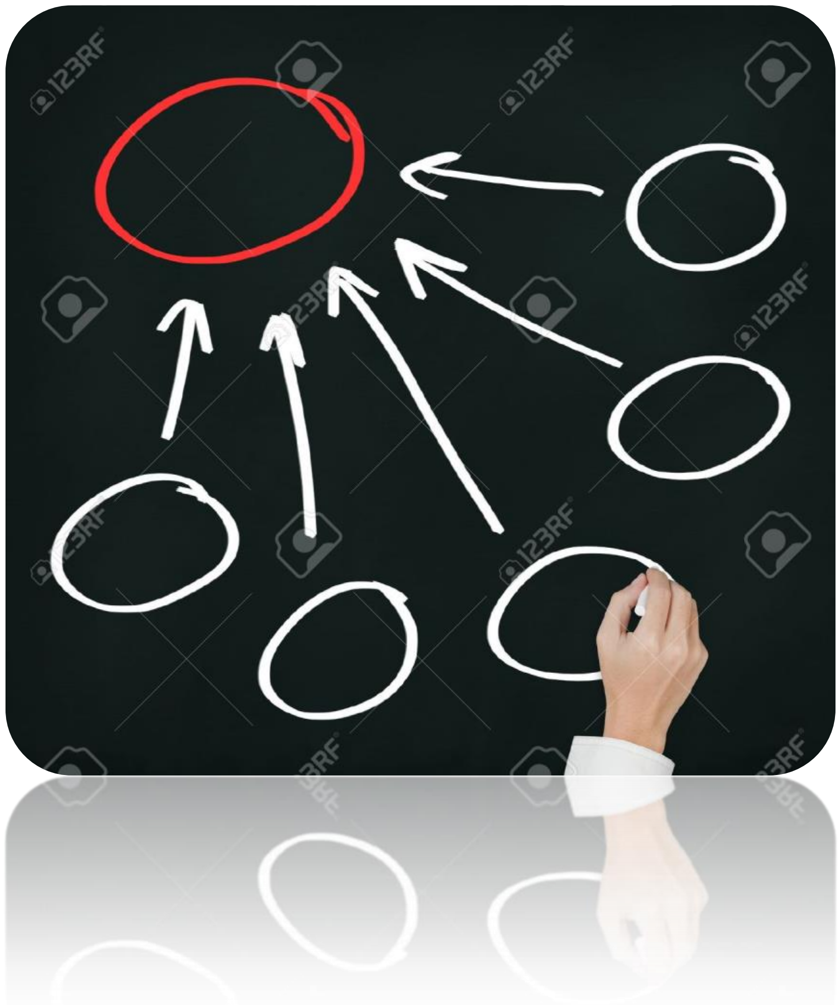
Real-time updated information for designers is of great importance to make decisions. From the interviews, it can be seen that the real-time updated model can be only viewed by designers, but not available for the client and the public. The reason for this is explained a little bit by one of the engineers from IT support department, he said that "the reason is designers use SmartPlant 3D, but the public and client use SmartPlant review. These two tools are separated and different". SmartPlant 3D is directly related with the data center, which is secured by the IT department. The data center receives information from users, update its current data pool, and then send out the updated data to all the end users. This process is nearly real-time and automatically. IT engineers are mainly responsible for the security of the distribution process, the performance of equipment, etc. As for SmartPlant Review, it is controlled by IT department directly. The control process is like placing a valve in the pipe. During the whole day, the valve is usually in the off position. But at some certain time, 5pm at Fluor every day, the valve will be turned on manually by IT engineers. After this operation, the updated model can be received by the public users. The first reason for controlling the information updating is because of the great amount of complex information SmartPlant contains. Besides, the users of the SmartPlant are not only from one location, but from various locations worldwide. For the KNPC project, the designers of four offices from four different locations, namely Amsterdam, New Delhi, AI Khobar and Kuwait, work together in the SmartPlant environment. The transition distance of information can cause many challenges. There are several ways to deal with such challenges: open access, control the number of end users, upgrade hardware and the storage of data center. But before taking these actions, more surveys can be carried out with clients and the public in order to check if their desire is strong or not and then determine the necessity.

Trans-integration level

Besides, as for trans-integration level, iRing needs to be radically changed as it is at a relatively low level, namely extracting quantities to spreadsheet and then import into estimating software. For this aspect, iRing can learn from BIM as BIM is realizing the concept of "multiple uses of one model", that means the model created in design tools can be imported into estimating tools to instruct cost estimating. The process of extracting quantities into the estimating tools can cause many problems as the quantity is the sole link between design and cost, therefore if this link has problems or is not accurate enough, the estimates based on the quantities can be influenced greatly. Another problem is the risk of rework. That means if any changes occurred in design models, new quantities have to be recalculated, exported and then imported into estimating tools again. This reworking risk is always existing within the estimating group.

Cost estimation is an essential process in both the construction and Oil/Gas industry, which is to predict the costs of a project based on the required materials, labor and time constraints. Results of cost estimation can affect much on both budgeting and scheduling for most projects. Although the competitiveness of industry is becoming more and more fierce, iRing, which is proposed to be able to greatly reduce estimating time and expenses, was not ready to implement for cost estimating in Oil/Gas industry, or at least at Fluor Company. Up to now, Fluor has set up an internal roadmap for the development of nD modeling, the first step of which intends to fully integrate cost estimation functionality into current design tools. Currently at Fluor, the wish of fully automated cost estimation has not been realized yet. About 30% of estimating work, which are so detailed elements that cannot be modeled within SmartPlant, have to be calculated manually by estimators. So in real projects it often takes up to several weeks for cost consultants to generate exact estimation results. Since for each phase of the design process, at least four estimations should be done, the delays caused by estimating could be considerable large. Besides, for cost estimating using SmartPlant, quantities take-offs have to be firstly calculated in and exported from design tools and then cost estimators need to import the taken-off quantities into estimating tools for final cost calculation. There have to be a bridge between design tools and cost estimation tools. So if unfortunately there is a change in the design, whole estimating process has to be repeated again to generate a new estimating result. While fully integration of cost estimating has the potential to make estimating more detail and accurate, while with less time and expenses needed. Therefore, benefits of Fluor’s integration roadmap are obvious. However, multiple factors are preventing the transition from traditional estimation processes to fully model-based estimation. First of all, the most challenging aspect for the implementation is the cultural switch within the company. People in the cost estimation department all feel much more comfortable with current estimating approach. They have deeply influenced and got used to current estimating processes. There is no motivation for the company employees to change. Moreover, even some of the employees get to know the benefit of nD modeling, mainly through normal workshops at company, most of them only have very abstract concepts, rather than a clear vision of what nD modeling exactly is relating to their daily job. The second aspect that is very important to implementing is the confidence of the estimator in the automation. Any new estimating software will have to undergo a thorough examination with several cross-checks. Estimators require one to two months of training with newly integrated software before the company will save time and costs on a project.

CONCLUSIONS



Chapter 5
Conclusions

Conclusions

Integration is becoming a significant trend in the construction industry and the Oil/Gas industry, helping working processes change from sequential to iterative and design disciplines transform from fragmented to collaborative. The driving force of the trend in integration relies much on the technology that we are trying to implement in the industry, the so called Building Information Modeling (BIM) and iRing. Finding out the integration level and capabilities of technology can provide engineering companies with insights into improvement directions and is important for them to find practical problems. The main objective for this research is: *to propose opportunities for technology improvement in terms of integration capability for engineering companies through comparison of the iRing and BIM technologies.*

In this research, based on CMM (Paulk et al., 1995), NBIMS (NIOBI, 2007) and discussions with professionals at Fluor, I employed the concept of integration capability for evaluation of integration levels of the two technologies, BIM and iRing. In terms of the integration capability, considering practical engineering requirements in real projects, there are five compulsory parts:

- Visualization capability; Collaboration capability; Simulation capability; Optimization capability; Digitization capability.

Besides, based on evaluation of these capabilities, the integration levels of technology can be roughly divided into two levels:

- Inter-disciplinary level (inter-integration level);
- trans-disciplinary level (trans-integration level).

Inter-integration indicates that professionals from different specialties, such as architects, structural engineers and MEP (mechanical, electrical and piping) engineers, can work together on the same design platform, sharing information and their specific experiences simultaneously. Trans-integration indicates the collaboration not only within design discipline, but also the coordination with other project disciplines. Cost discipline, which is the extra discipline being further integrated into the platform to enable designers and other professionals making wiser decisions based on more comprehensive considerations, is chosen to be studied in this research.

Based on the five compulsory capabilities of integration, the evaluation criteria for interdisciplinary integration of design and transdisciplinary integration of design and cost are formulated.

- The criteria of inter-integration level have: graphical information, roles, spatial information, change tracking, information accuracy, timeliness and delivery method;
- The criteria of trans-integration level are composed of graphical information, roles, cost flow, change tracking, reliability of information production, quantification process and built-in standards.

Based on the theories above, two cases are selected in the chapter on practical evaluation. The evaluation results and cross comparison results show that the inter-integration level of iRing at Fluor performs very well in visualization capability and collaboration capability, for example iRing can support all design roles working simultaneously, accurate change recording of who and when, web-based and secured information distribution, 3D intelligent graphics, coordinates spatially located. But there is room for iRing to improve further. The room for iRing's improvement in terms of inter-integration level relies on the simulation capability, optimization capability and digitization capability:

- *Simulation capability: adding spatial information*
  - finding ways to simulate the model in the real location with real surroundings;
  - integrate with Geographical Information System;
- *Optimization capability: enhancing change tracking*
  - adding change recording of what exact change is;
  - adding pre-change and post-change comparison capability;
  - supporting change histories exporting functionality.
- *Digitization capability: improving timeliness*
  - supporting information updating automatically
  - real-time information can be seen by other disciplines
- *Ameliorating distribution method*
  - connecting with cloud techniques
  - enabling the information of the models can be viewed from multiple kinds of equipment

The possible factors which limit the inter-integration level of iRing are listed below:

- Performance of hardware
- Storage of data center
- Distribution distance
- Time difference
- Large quantity and complexity of model data
- Data incompatibilities
- Number of users

As for the trans-integration level, iRing needs to be radically changed as it is in a relatively low level, namely extracting quantities to a spreadsheet and then import into estimating software. For this aspect, iRing can learn from BIM as BIM is realizing the concept of "multiple uses of one model", which means the model created in design tools can be imported into estimating tools to do cost estimating. The process of extracting quantities into the estimating tools can cause many problems as the quantity is the sole link between design and cost, therefore if this link has problems or is not accurate enough, the estimates based on the quantities can be influenced greatly. Another problem is the risk of rework. That means if any changes occurred in design models, new quantities have to be recalculated, exported and then imported into estimating tools again. This reworking risk always exists in the estimating group. If equipping the tools with a capability to support design mods, the link between design and cost is not just quantity, but unlimited accurate elements. The accuracy degree can be improved first. As for reworking risk, it will be decreased a lot as models are dynamically connected with design, any changes occurred can be shown at the estimating side. Therefore the first step for iRing to overall change relies on the visualization capability:

- supporting design models can be imported into cost tools
- supporting design models can be navigated, manipulated, toggled and highlighted by estimators when preparing estimates

The possible challenges for improving trans-integration level of iRing are listed below:

- company culture's acceptance
- limited recognition
- commitment at the client and project partners

Recommendations

The recommendations (in general and towards Fluor and iRing) are part of the evaluation of this research. It includes reflections on the possibilities that are created with this research, but as well as limitations.

For Fluor, if they want to improve further in terms of inter-integration level and trans-integration level, several things should be noticed:

- Create an appropriate soft- and hardware environment
- Ensure homogeneous and plural software environment
- Control the number of users
- Active commitment at construction industry's trend
- Recognitions from engineers, staffs and relevant clients and partners
- Necessary training and education for the current staff
- Possible collaboration with leading companies, knowledge institutes, software vendors and even government.

As it cannot be denied that technology should be improved together with policy and process, so technology's improvement is on one hand, but on the other hand managerial aspect matters greatly as well. Further research can focus on how to operate or manage iRing in practice.

The research mentioned ISO 15926 and ISO 16739, which are two standards supporting interoperability of BIM and iRing. The research did not dive deeply into these two standards. Further research could go into depth to check whether BIM and iRing applications can meet the expectations of ISO 15926 and 16739 and if ISO standards can meet practical expectations.

Cost is the extra discipline integrated with design in this research and the reasons have been elaborated in the Chapter 3. As it is known that scheduling is also a new dimension in addition to 3D, further research can be conducted to evaluate the trans-integration level of design and scheduling, or even design, scheduling and cost at the same time.

In the research, evaluation criteria are derived according to the five compulsory integration capabilities. In a further evaluation study, except the current criteria, some new aspects can be formulated in order to evaluate more comprehensively.

Another limitation is that only two cases are selected in the research, so the conclusions are mainly centered on Fluor's iRing and CCEED's BIM. The results are not enough to draw conclusions on the whole industry's inter-integration level and trans-integration level. Therefore further research can select more cases among BIM or iRing so as to make relatively comprehensive conclusion for the whole industry, but this must be a long term evaluation.

Reflection

During the research, the most difficult part for me is to find an evaluation approach. When thinking about how to evaluate the integration level, many thoughts and many words occurred in my mind at the same time. Some ideas and some words can be very useful, but some of them can be very confusing. At this time, looking back to the research objective is very helpful, which can help to identify which idea is right and which idea is beyond the research direction. After figuring out and picking up the useful ideas, finding a way to logically organize these ideas is the next step.

There are many limitations in this research. However from my perspective, the five compulsory capabilities can be continuously used in further researches. If I would have a change to redo this research, I would also rely on these five capabilities, but generate more criteria to evaluate more cases from the construction industry. And if possible, I would like to have contact with the relevant software vendors to see their situations and difficulties.

I have to say that research is a “bittersweet time”. But it is also a process for forming good habits. I think no matter what researches I am going to do next, there are several things I would like to keep in mind:

- Schedule time properly;
- Break long term objective down into monthly, weekly and even daily objectives;
- Control progress regularly and adjust your plan accordingly;
- Write down all ideas I can think of even if there is no logic;
- Be brave to hold on my idea;
- Keep a recorder at hand which can be useful during interviews;
- Keep records of all regular meetings which were held with any supervisor, professional or colleague;
- Keep records of the revised thesis which can help think of many original ideas.

Appendix A: High and Intermediate Level of Aggregation

	ISIC Rev. 4/ NACE Rev. 2 sections	Description
1	A	Agriculture, forestry and fishing
2	B, C, D and E	Manufacturing, mining and quarrying and other industry
2a	*C*	*Of which: manufacturing*
3	F	Construction
4	G, H and I	Wholesale and retail trade, transportation and storage, accommodation and food service activities
5	J	Information and communication
6	K	Financial and insurance activities
7	L	Real estate activities*
8	M and N	Professional, scientific, technical, administration and support service activities
9	O, P and Q	Public administration, defence, education, human health and social work activities
10	R, S, T and U	Other services

* which includes imputed rents of owner-occupied dwellings

Table 24 High level aggregation (NACE, 2008)

	A*38 code	ISIC Rev. 4/ NACE Rev. 2	Divisions
1	A	Agriculture, forestry and fishing	01 to 03
2	B	Mining and quarrying	05 to 09
3	CA	Manufacture of food products, beverages and tobacco products	10 to 12
4	CB	Manufacture of textiles, apparel, leather and related products	13 to 15
5	CC	Manufacture of wood and paper products, and printing	16 to 18
6	CD	Manufacture of coke, and refined petroleum products	19
7	CE	Manufacture of chemicals and chemical products	20
8	CF	Manufacture of pharmaceuticals, medicinal chemical and botanical products	21
9	CG	Manufacture of rubber and plastics products, and other non-metallic mineral products	22 + 23
10	CH	Manufacture of basic metals and fabricated metal products, except machinery and equipment	24 + 25
11	CI	Manufacture of computer, electronic and optical products	26
12	CJ	Manufacture of electrical equipment	27
13	CK	Manufacture of machinery and equipment n.e.c.	28
14	CL	Manufacture of transport equipment	29 + 30
15	CM	Other manufacturing, and repair and installation of machinery and equipment	31 to 33
16	D	Electricity, gas, steam and air-conditioning supply	35
17	E	Water supply, sewerage, waste management and remediation	36 to 39
18	F	Construction	41 to 43
19	G	Wholesale and retail trade, repair of motor vehicles and motorcycles	45 to 47
20	H	Transportation and storage	49 to 53
21	I	Accommodation and food service activities	55 + 56
22	JA	Publishing, audiovisual and broadcasting activities	58 to 60
23	JB	Telecommunications	61
24	JC	IT and other information services	62 +63
25	K	Financial and insurance activities	64 to 66
26	L	Real estate activities*	68
27	MA	Legal, accounting, management, architecture, engineering, technical testing and analysis activities	69 to 71
28	MB	Scientific research and development	72
29	MC	Other professional, scientific and technical activities	73 to 75
30	N	Administrative and support service activities	77 to 82
31	O	Public administration and defence, compulsory social security	84
32	P	Education	85
33	QA	Human health services	86
34	QB	Residential care and social work activities	87 + 88
35	R	Arts, entertainment and recreation	90 to 93
36	S	Other services	94 to 96
37	T**	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	97 + 98*
38	U**	Activities of extra-territorial organisations and bodies	99*

* including imputed rents of owner-occupied dwellings

** All of U and part of T (division 98) are outside the SNA production boundary, and will be empty for SNA data reporting, but are included for completeness.

Table 25Intermediate Level Aggregation (NACE, 2008)

Appendix B: IFC Data Scheme

IFC data schema contains four categories: domain schemas, shared schemas, core schemas and resource schemas. The top layer is the domain specific data schemas. Entities defined in this layer are self-contained and cannot be referenced by any other layer. The domain specific layer organizes definitions according to industry discipline. The second layer, interoperability layer is the shared element data schemas, which contain intermediate specializations of entities. Entities defined in this layer can be referenced and specialized by all entities above in the hierarchy. The shared element layer provides more specialized objects and relationships shared by multiple domains. The core data schemas are in the most general layer within the IFC schema architecture. Entities defined in this layer can be referenced and specialized by all entities above in the hierarchy. The core layer provides the basic structure, the fundamental relationships and the common concepts for all further specializations in aspect specific models. All entities defined in the core layer, having unique identification, name, description, and change control information. The resource definition data schema is in the bottom, consisting of supporting data structures. Entities and types defined in this layer can be referenced by all entities in the layers below (ISO, 2013).

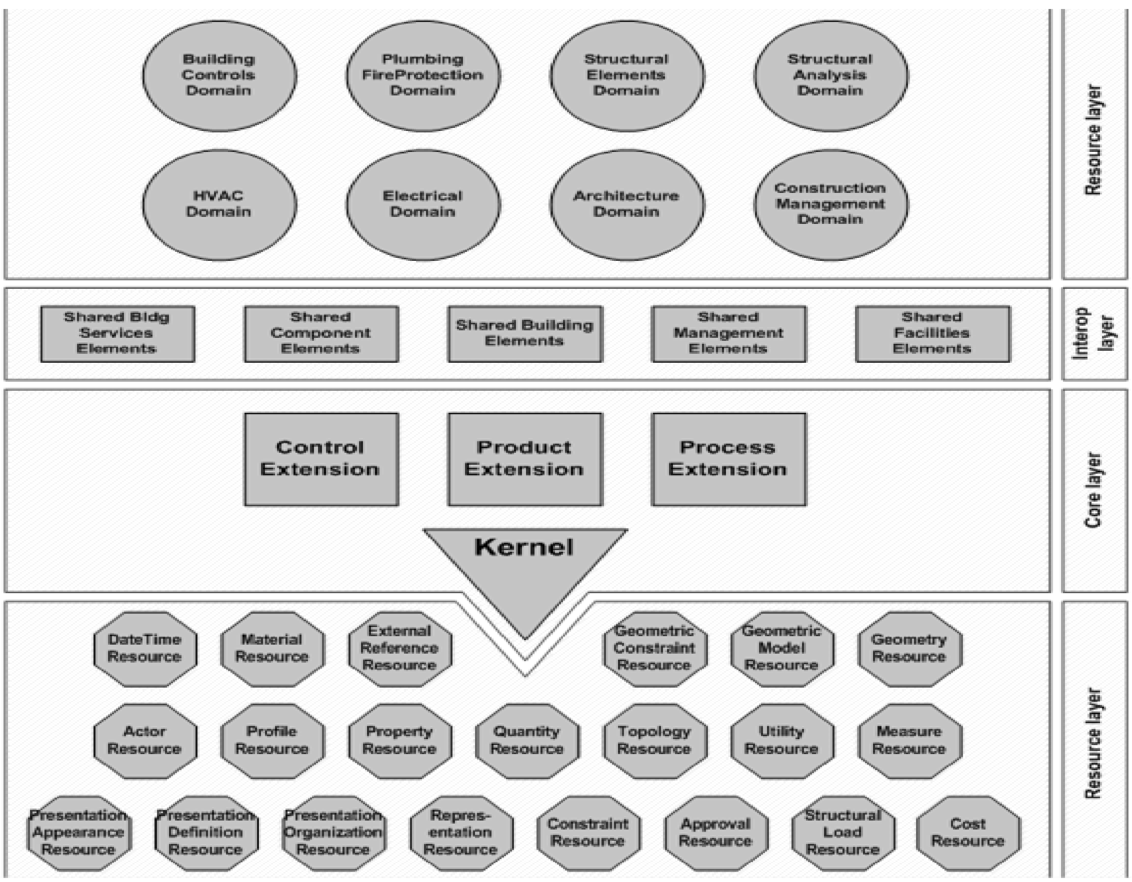


Figure 48 IFC Data Schema (ISO, 2013).

Appendix C: Scope of TC184/SC4

TC184/SC4 Scope

1) includes all industrial data related to discrete products including, but not limited to:

- geometric design and tolerance data;
- material and functional specifications;
- product differentiation and configuration;
- process design data;
- production data (including cost);
- product support and logistics;
- life cycle data;
- quality data;
- Disposal planning data.
- organizational data such as the relationship between enterprises
- personnel data to the extent of identification of approvals

2) Excluded:

- business planning data such as profit projections, cash flow, etc., and any other personnel data or organizational data

Appendix D: SC4 Standards Family

SC4 Families of Standards:

Name	ISO number	Title
STEP	ISO 10303	Standard for the exchange of product model data
PLIB	ISO 13584	Parts Library
MANDATE	ISO 15531	Industrial manufacturing management data exchange, in the annex the titles of the standards delivered
OIL & GAS	ISO 15926	Integration of Life-cycle Data for Oil and Gas Production
PSL	ISO 18629	Process specification language
IIDEAS	ISO 18876	Technical Specifications: integration of industrial data for exchange, access, and sharing
OTD	ISO 22745	Open technical dictionary
	ISO 20542	Reference model for systems engineering
	ISO 22720	ASAM Open Data Services
IFC	ISO 16739	Industry Foundation Classes
EXPRESS	ISO 20303	Technology Parts (reserved number)

Appendix F: Glossary of Terms

AEC industry: Architecture, Engineering and Construction industry

SNA: System of National Accounts

SITC: Standard International Trade Classification of the United Nations

NACE: European Classification of Economic Activities

ISIC: International Standards Industrial Classification

Inter-integration: interdisciplinary integration, meaning collaboration within design discipline.

Trans-integration: transdisciplinary integration, meaning collaboration with design discipline, cost estimation discipline, procurement discipline and scheduling discipline, etc.

IFC: industrial foundation classes

CMM: capability maturity model

HVAC: heating, ventilating, and air conditioning

MEP: mechanical, electrical and plumping

NBIMS: National Building Information Modeling Standard

ISO: International Organization for Standardization

BIM: Building Information Modeling, an intelligent model-based concept based on the ISO 16739 standard with the purpose of improving data interoperability across AEC industry.

iRing: a new concept with the goal of expediting the adoption and pragmatic use of the ISO 15926 standard and improving data interoperability across the oil/gas industry.

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