MASTER

Creating an information delivery manual to facilitate future cost estimations

a BIM-based approach to create more transparency in the quotation process regarding the installation of large medical equipment in existing hospitals

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Creating an Information Delivery Manual to facilitate future cost estimations

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Preface

The research “creating an Information Delivery Manual to facilitate future cost estimations” is the start of a larger research with the purpose to set up a cost-engineering structure to get more understanding of the costs related to building works project in existing hospitals. The start of this research is also my graduation research, which I worked on for six months in corporation with a medical equipment supplier. The thesis forms my final work for the master Construction Management and Engineering at the Technical University Eindhoven.

This research gave me the change to step outside of my comfort zone when it comes to the subjects discussed during my study. It was interesting to dive into a completely new topic and to experience this period in a non-construction industry company. Next to this I had the chance to position myself in a large company and find my way in it. It was a great learning experience in the final stage of my master program.

Hereby I would like to thank the project team of the medical equipment supplier I was part of during my research, and all other people of this company who were so grateful to help me during my research, even outside the boarders of the Netherlands. I would like to thank the company for the great opportunity and learning experience. Next to that I am very grateful that I had the chance to experience parts of the interesting world of the healthcare industry. Finally, I would like to thank Jakob Beetz, Jan Dijkstra and Bauke de Vries for their support and feedback during my research.

Eindhoven, August 2015

Nicole van Riel

Summary

The decision making process of a construction project now a days takes more and more place in the early project phase. The main focus for decision making are the profit margins and cost control of the project. Therefore effective cost estimation in the early phase of a project is favorable. Nevertheless the construction industry is an industry which knows a high level of customization, which makes every project unique. But a distinction can be made within certain types of project. Building works projects are one of these projects that can be captured as a group with high similarities. This type of project involves all the alterations to an existing hospital room necessary in order to make installation of large medical equipment possible. This type of project is defined by construction works, mechanical- and electrical installations, and fixed- and movable facilities. The cost calculation process conducted by a contractor during the tender process, is currently not transparent, which sometimes results in extremely high expenses for the hospital and the medical equipment supplier, due to lack of knowledge about these building works activities. The purpose of this research therefore is "*Improvement of the insight and creation of more knowledge around costs related to building works activities for the installation of medical equipment in existing hospital rooms"*. This research is the start of a larger research to creating a cost engineering infrastructure for building works projects.

First a literature review was conducted in order to get an overview of the already established research in the field of state-of-the-art cost estimation techniques, cost influencing factors, and information management within the construction industry related to cost calculations. The literature review forms the basis for the research model in order to gain more insight in the costs related to building works activities.

The research model in this research includes a qualitative part and a quantitative part. First the quantitative analysis is conducted to collect input for the qualitative research. A dataset of projects carried out in Egypt is collected on which some statistical analyses are based in order to find cost influencing factors for the construction costs. Analysis that have been conducted are a missing value analysis of the dataset, a deviation of the mean in percentage test, normalization of the cost to cost per square meter room, and the development of several multiple regression analysis (MRA).

In total 4 different MRAs were built with the following dependent variables: Total costs, Construction works, Mechanical installations, Electrical installations. The independent variables were the same for all 4 models: *Hospital Type*, *Location*, *Building Month*, *Number of Tenders* and *Gross Floor Area* (*GFA)*. The model with Mechanical installations as dependent variables was not significant and therefore excluded from further research. The main outcome of this analysis is that the *GFA* is an influencing factor for all 3 MRA models. Next to this, *Hospital Type* is assumed to influence the costs for only electrical installations, *Location* is influencing when discussing the costs related to Electrical installations. *Building Month* is influencing when calculating costs for engineering work. And the last independent variable, *No. Tenders* shows a significant value when discussing costs related to Electrical installations. Nevertheless, the analysis are based on 11 projects. When testing 5 independent variables, some researchers recommend "5 * independent variables" as a

dataset. Next to this, the literature study showed more influencing factors when it comes to construction costs.

The second part of the research design is a qualitative analysis, which involves interviews with stakeholders of the process and a questionnaire which was distributed among project managers of all different markets of one multinational in the healthcare industry. This together with the literature study and the outcomes of the quantitative analysis formed the basis for the development of an Information Delivery Manual (IDM). The purpose of the IDM is trying to formulate a standard way of working and exchanging information and with that standardization of the processes related to a building works project. The IDM suggest a BIM-based approach for quantity take-off, necessary to ask different contractors for a bid. This BIM-based approach requires an Industry Classification system for codification of the different attributes in the Industry Foundation Class (IFC) model. The development of a cost-database is also part of the IDM. This database prescribes a structured way of information storage, in such a way that different project are comparable to each other. In order to get a complete picture of the construction costs, the last step of the IDM, creating a revised IFC model, also known as an as-built model. This model includes the actual building costs and actual materials used.

When completing projects regarding the several steps indicated in the IDM, more transparency will be created within the project. This is also required due to the changing funding of hospitals in the near future for example in the Netherlands. Standardization of the processes and the way of storing data allows projects to be compared with each other. When using the cost-database for several years, it could be used as a reference database of historic projects to do future cost calculations. Nevertheless, one thing that should always be kept in mind when collecting cost data of historic projects is that the costs provided by the contractor are influenced by the economic market conditions, which are related to the work available. This makes that the data retrieved from competitive bids from contractors will always be a bit subjective.

Another important remark for this research is the fact that it describes a BIM-based approach for already existing real-estate. Sometime hospital buildings are more than 20 years old which will most of the time result in the absence of a BIM-model. When this is the case, it is suggested to only model the room subject to the project and the direct surrounding rooms. Nevertheless, difficulties could occur when designing the electrical and mechanical installations for the room that are connected to the already existing installation infrastructures in the hospital.

Samenvatting

Het besluitvormingsproces in de constructie industrie van deze dag verplaatst zich steeds meer naar de eerdere fasen van het project. De belangrijkste focus voor de besluitvorming zijn de winstmarges en de beheersing van de kosten van het project. Daarom is effectief kostenraming in de vroege fase van een project gunstig. Toch is de bouwsector een sector waarbij veel maatwerk komt kijken gerelateerd aan de vraag van de klant, wat elk bouwproject uniek maakt. Echter kan er een onderscheid worden gemaakt binnen bepaalde soorten projecten. Bouwwerkzaamheden in bestaande ziekenhuizen zijn een van deze projecten die kunnen worden vastgelegd als een groep met een hoge vorm van gelijkenissen. Deze projecten omvat de verbouwing van een bestaande ziekenhuis kamer, noodzakelijk voor de installatie van grote medische apparatuur. Dit soort projecten wordt bepaald door bouwkundige werkzaamheden, mechanische- en elektrische installaties, en vaste en verplaatsbare faciliteiten. Het kostenramingsproces uitgevoerd door een aannemer om tot een bod voor het werk te komen, is momenteel niet transparant, wat soms leidt tot extreem hoge kosten voor het ziekenhuis en de medische apparatuur leverancier. Dit is te wijten aan een gebrek aan kennis bij de medische apparatuur leverancier over deze bouwwerken activiteiten. Het doel van dit onderzoek is daarom "meer inzicht verkrijgen in de kosten gerelateerd aan de bouwwerkzaamheden benodigd voor de installatie van medische apparatuur in de bestaande ziekenhuizen". Dit onderzoek is het begin van een grote onderzoek naar het opzetten van een cost engineering infrastructuur voor deze type projecten.

Eerst een literatuurstudie werd uitgevoerd om meer inzicht te krijgen in het reeds gedane onderzoeken op het gebied van state-of-the-art kostenramingstechnieken in de bouw. Daarnaast in gekeken naar onderzoek gerelateerd aan kost bepalende factoren in de bouw en het gebruik van informatie management in de bouwsector gerelateerd aan kostenraming. De literatuurstudie vormt de basis voor het onderzoek model met als doel meer inzicht te krijgen in de kosten gerelateerd aan de bouwkundige werkzaamheden in bestaande ziekenhuizen.

Het onderzoek model in dit onderzoek bestaat uit een kwalitatief deel en een kwantitatief deel. Eerst wordt de kwantitatieve analyse uitgevoerd om input te verzamelen voor het kwalitatieve onderzoek. Een dataset van projecten afkomstig uit Egypte wordt verzameld om een aantal statistische analyses op uit te voeren om zo kost bepalende factoren te achterhalen. Analyses die zijn uitgevoerd zijn een “ontbrekende waarde analyse” van de dataset, een “afwijking van het gemiddelde in percentage test”, “normalisering van de kosten naar kosten per vierkante meter ruimte”, en de ontwikkeling van verschillende “multiple regressie modellen”.

In totaal werden 4 verschillende multiple regressie modellen gebouwd met de volgende afhankelijke variabelen: (1) totale bouwkosten, (2) totale kosten voor bouwkundige werken, (3) totale kosten voor mechanische installaties, en (4) totale kosten voor elektrische installaties. De onafhankelijke variabelen waren hetzelfde voor alle 4 de modellen: *ziekenhuis type*, *locatie* van het ziekenhuis, *maand van afgaven offerte*, *aantal tenders* ingeschreven op de opdracht, en het *bruto vloeroppervlak*. Het model met de totale bouwkosten voor mechanische installaties als afhankelijke variabelen was niet significant en is dus niet verder meegenomen in het onderzoek. Het belangrijkste resultaat van deze

analyse is dat de bruto vloer oppervlak een bepalende factor is voor alle 3 de modellen. Daarnaast is voor het model met de kosten voor elektrische installaties als afhankelijke variabele, het bruto vloeroppervlak een bepalende factor.

Wanneer de kosten gerelateerd aan bouwkundige werken wordt besproken is de maand van afgaven offerte bepalen. De laatste onafhankelijke variabele, aantal tender inschrijvingen, is significant voor het model met de totale kosten voor elektrische installaties. Echter is deze analyse op 11 project gebaseerd, terwijl er 5 onafhankelijke variabelen worden getest. Volgens sommige onderzoekers is het raadzaam om “5 × onafhankelijke variabelen” als dataset aan te houden. Dat zou inhouden dat voor deze analyse 25 projecten nodig zijn. Daarnaast toonde de literatuurstudie meer bepalende kost factoren dat de factoren die hier getest zijn.

Het tweede deel van het onderzoek is gebaseerd op kwalitatieve analyses in de vorm van interviews met experts op het gebied van de verkoop van grote medische apparatuur aan ziekenhuizen. Daarnaast is er een enquête afgenomen tijdens een project managers bijeenkomst. Project managers uit verschillende landen van dezelfde medische apparatuur ontwikkelaar waren hier aanwezig. Deze informatie, samen met de informatie uit de literatuurstudie vormt de basis voor de ontwikkeling van een Information Delivery Manual. Het doel van dit Information Delivery Manual is het proberen om een standaard werkwijze te formuleren, samen met een standaard uit te wisselen informatie behoefte gerelateerd aan de verschillende processen in het project. De Information Delivery Manual suggereert een BIM-gebaseerde benadering voor de hoeveelheid extractie, die nodig is om de verschillende aannemers te vragen om een offerte op te stellen. Deze BIM-benadering vereist een classificatie systeem uit de bouwindustrie voor de codering van de verschillende attributen in de Industry Foundation Class (IFC) model. De ontwikkeling van een kosten-database is ook onderdeel van deze Information Delivery Manual. Deze database schrijft een gestructureerde manier van informatieopslag voor, zodanig dat de projecten met elkaar vergeleken kunnen worden. Om een volledig beeld van de bouwkosten te krijgen is de laatste stap in het information delivery manual opgenomen, het creëren van een herziende versie van het IFC-model, ook bekend als een als-gebouwd model. Dit model omvat de werkelijke bouwkosten en de werkelijke materialen die gebruikt zijn tijdens de bouw.

Bij het doorlopen van dit soort type projecten volgens de stappen die in het information delivery manual zijn voorgeschreven, zal meer transparantie gecreëerd worden binnen het project en voornamelijk omtrent de kostenraming van deze projecten. Dit is interessant vanwege de veranderende middelen die ziekenhuizen tot hun beschikking hebben voor de financiering van projecten. Standaardisatie van de processen en de voorgeschreven manier van data collectie en opslag, maakt dat projecten vergeleken kunnen worden met elkaar. Bij gebruik van de kost-database gedurende meerdere jaren, zal de database uiteindelijk gebruikt kunnen worden als een referentiedatabase die is gebaseerd op historische projecten. Toch zal altijd in gedachten gehouden moeten worden dat bij het verzamelen van gegevens over de kosten van historische projecten de kosten opgegeven door een aannemer altijd worden beïnvloed door de economische marktomstandigheden, die gerelateerd zijn aan het beschikbare werk.

Abstract

Graduation research: *"Improvement of the insight and creation of more knowledge around costs related to building works activities for the installation of medical equipment in existing hospital rooms"*

The purpose of this research is to develop an Information Delivery Manual (IDM) to prescribe a structured way of working and set rules for information management in order to make the tender process related to the installation of large medical diagnostic equipment in existing hospital rooms more transparent. The insight in the process subject to this research is gained by conducting interviews with several stakeholders, sending out a questionnaire and conducting case studies. Next to this a literature review to already established research sets the basis for the IDM development. The literature review highlights research related to state-of-the art cost estimation techniques used in the construction industry, but also provides an overview of cost influencing factors in the construction industry as found by other researchers. The IDM consist of a process map and 4 exchange requirements that prescribe a standardized approach for collecting information related to the cost calculations process of a project installing large medical equipment in existing hospital rooms.

Practical information

This research will be accomplished from the perspective of Philips Healthcare, Eindhoven. This research is also a final and graduation project of the master Construction Management and Engineering at the Eindhoven University of Technology.

Keywords

Cost estimation, State-of-the-art estimation techniques, Historic data, Database, Information Delivery Model, Process Map, Exchange Requirements, IFC

Table of Contents

Chapter 1. Introduction to cost estimating in the construction industry

1.1. Cost estimation in construction projects

Cost estimations for building projects have always been a complicated assignment, due to the fact that every building project in unique and therefore it is a challenge to standardize the cost estimation process. Every construction project is defined by the scope of the project, the type of building, quality, cost and duration of the project (Ahn et al., 2014). Cost management can play a very important role in building projects, which can provide insights into the cost related to the resources needed to fulfil the project. Hence, early cost estimation is one of the key parameters when it comes to defining project success (Ahn et al., 2014). Even though every project is unique, are there activities within the project that can be standardized?

Related to cost estimations is the decision making process for construction projects, which can be related to the different phases within a construction project. The first phase is the initiative phase, which includes the development of an idea of the client about a project or facility, where after translation into a real concept is conducted in the next phase. After the project has been defined, the execution and realization of the project can start. The final phase of the construction process is the maintenance phase, which involves all the processes to keep the building running in such a way that it can fulfil its function. Related to these project life cycle phases are the type of calculations which can be classified as pre-calculations, intermediate calculations and post-calculations (Caputo & Palagagge, 2008).

Every construction project has their own characteristics which are related to some parameters, for example type of building, quality, cost and duration. One of the most important factors these days when discussing a construction project are the cost involved. The cost should be as low as possible, but the requirements of the clients should be met at the same time. Some researchers agree that the success of a project highly depends on the accuracy of the early cost estimations (Ahn, et al., 2014). Nevertheless, cost estimations during the whole project life cycle is very important. To define the reliance of the cost estimations, Frank Freiman, who was the head of the FAST cost-estimating system (Daschback & Apgar, 1988), developed a graphical representation of cost estimations, which is called the Freiman curve (Figure 1.1). This curve shows that there are three types of estimations, under-estimate, realistic estimations and over-estimations (Daschback & Apgar, 1988). Under-estimation most of the time results in cost that were not calculated within the original budget, caused by for example an initial planning that is not achievable. Contrary to this is overestimation, which results in greater profits and the change that Parkinson's Law arises (Dashback & Apgar, 1988). This law prescribes that when money is available it must be spent.

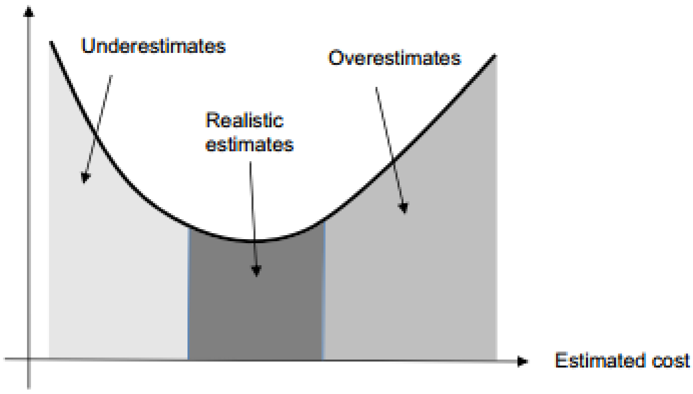

Figure.1.1 Freiman Curve (Chang, 2013)

Figure 1.2. also shows the relevance of good cost estimations. This curve shows that when early cost estimations are done, 70-80% of the total product cost could be determined in an early stage. This is mainly caused by the fact that cost can be better influenced during the design phase than during the execution phase of the project. During the design phase only 1-2% of the project is already established. Another important parameter is the modification cost, which are smaller in the design phase than in the execution phase of the project life cycle (Chang, 2013).

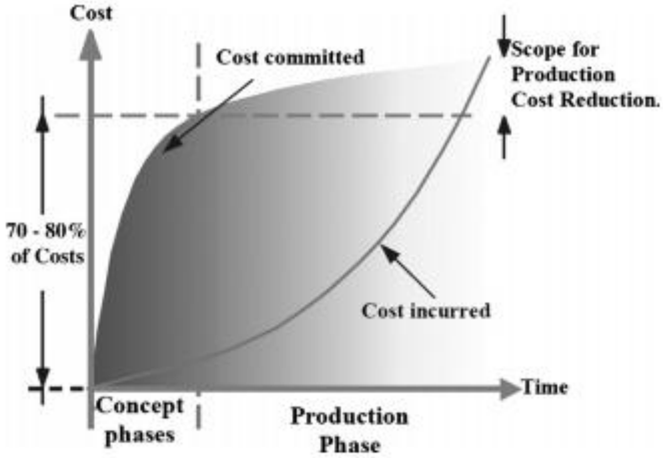

Figure 1.2. Cost impact decisions (Chang, 2013)

1.2. Problem definition

The first statement made in this introduction was that every construction project is unique and that there are several types of projects. The type of project subject to this research is reconstruction project in existing hospitals, necessary for the installation of large medical equipment. The type of equipment related to this research can be divided into 4 family types;

1) Magnetic Resonance Imaging (MRI): uses magnetic fields and radio fields to form images of the body (MRI Centrum, 2015). This type of equipment requires a movable table which makes it possible to move the patient into the hollow cylinder.

The machine produces heat, which asks for cylinders with liquid helium to cool the machine.

2) Computed Tomography (CT): measures the absorption of radiation of the body. The CT is a cylinder shaped machine which makes it possible to investigate the body part with radiation from different directions. The image that is created consists of thin slices, which are transformed into a 3D image of the body part (Gezondheidsnet, 2015).
3) X-Ray: uses electromagnetic radiation to investigate cardiovascular problems in a human body (Menselijk lichaam, 2015).
4) Digital Radiography is a form of X-ray, but instead of using a photographic film, the Digital Radiography uses a digital x-ray sensor. The advantage of this method is that less radiation can be used in order to get the same image results (Imaging Dynamics Company, 2006).

Before equipment can be installed in a hospital, the room needs to be modified. This is caused by the fact that the equipment for example generates heat and radiation. The process of making the room *installation ready* involves all the modifications to the room necessary for the equipment to be installed and can be defined as Building Works (BW). The costs related to these BW are site preparation costs. The construction processes are conducted in an already existing hospital which makes that it are re-construction projects. These four types of medical equipment families all require their own set of Building Works activities, which are summarized in Table 1.1. Explanations of the Building works can be found in Appendix 1. Next to the necessary building works, there are the building works which are requested by the hospital. This last set of building works make that this type of projects have a high level of customization, which makes every project unique.

The building works are currently not always included in the deal between the hospital and the medical equipment supplier, due to the negative impact on order intake and margin for the medical equipment supplier, caused by among others high site preparation costs. Nevertheless, in the future a turnkey deal is favorable, which means that the medical equipment supplier also takes care of the building works part with the help of a turnkey contractor.

Table 1.1. Building Works per Modality

Building Works	MR	CT	DXR	IXR
Demolition existing structure	O	O	O	O
Ceiling framing	O	O	R	R
Floor plates	R	R	R	R
Cable channel floor	R	R	R	R
- Flush mounted				
- Under floor				
- On floor				
Finishes (walls/floors/ceiling)	O	O	O	O
Lead protection		R	R	R
RG cage	R			
HVAC	R	R	O	O
Chiller	R	R		
Plumbing	O	O	O	O
- Medical gas	O	O	O	O
Electrical	R	R	R	R
- Generator	R	R	R	R
- Earthen	R	R	R	R
Lighting				
- Indication	R	R	R	R
- Warning	R	R	R	R
Communication				
- Internet	R	R	R	O
- Telephone	O	O	O	O
Protection				
- Fire	O	O	O	O
Facilities/furniture	O	O	O	O
- Curtain (leaded or not)				
- Cabinets				
- Desk				
- Chairs				

R = Required
O = Optional

1.2.1. Cause and effect analysis

To identify the causes for the negative impact of site preparation cost on order intake and margin for the medical equipment supplier, and with that indicates the relevance of this research, an Ishikawa analysis is conducted (Figure 1.3.). Ishikawa is a tool that is developed to map causes and problems within a process and identify the relations between different causes (Lean Six Sigma Tools, 2015). The categories selected for this Ishikawa analysis are 1) Policies & Strategies, 2) Environment, 3) People and 4) Process & Tools.

Policies & strategies

There are two main cause part of the chapter policies & strategies. First the lack of BW related policies, which means for example that there is no pricing strategy at the moment for BW. Second the standard 15% uplift on BW projects, which is necessary to compensate risks. The margin is high for this type of projects and is mainly caused by lack of knowledge of building works and the missing of reference price indexes.

Environment

When discussing environment, the contractor is the most challenging aspect, what is caused by the economic market conditions that needs to be considered when negotiating a bid of a contractor. For example, when the contractor has plenty of work that month, it would give a higher quotation than when the contractor hardly has any work for that month. Next to this there is bad transparency when it comes to the tenders. Most of the time this is just a total cost for the scope of work, no detailed cost breakdown structure is provided. Sometimes the project manager is forced to work with a one-time contractor, because this is the "house contractor" of the hospital. Negative causes from this could be that overpricing is done by the contractor, less quality of the delivered work, and less predictability of the work of the contractor. Contrary to this, project managers can always work with the same contractors, which makes that there is no challenging on price, due to the absence of reference price indexes. Another main cause when discussing environment is the large complexity due to the individual approach in every market. Sometimes one market consists of several countries, which all have their local approach. The is caused by the absence of a global vision on building works currently.

People

The different stakeholders in the process are not sufficient connected with each other, which is caused by the fact that there is no network defined, caused by the absence of a present global vision on building works. Also related to this is the time pressure the project manager and the entire project is under. Related to the time pressure is the fact that there is no time available to ask several quotations to set a basis for negotiation. The project manager is uncomfortable when BW is part of the deal, due to the fact that BW has its own language and the scarcity knowledge of BW by the project manager. The last difficulty in the project related to People is sharing. Currently, hardly any best practices are shared. Next to this there is no feedback from the suppliers on BW, which is caused by lack of knowledge of BW and the absence of a network and again the global vision on BW.

Process & Tools

Currently there is no central tool or archive which the project manager can use for feedback, which is related to the fact that no best practices are shared at the moment. Procurement is not able yet to facilitate volume and scale benefits when it comes to BW, because local suppliers are used in every market. Related to this is the preferred supplier base that every market should have, which involves supplier contracts for BW. Currently procurement in every market is using different models. In the entire process, BW is scattered centralized within the organization, which results in the fact that the organization cannot function as a one-stop-shop for their clients. Finally, every project manager has its own personal skills and way of working and therefore not every project manager is at the same level of knowledge when discussing BW.

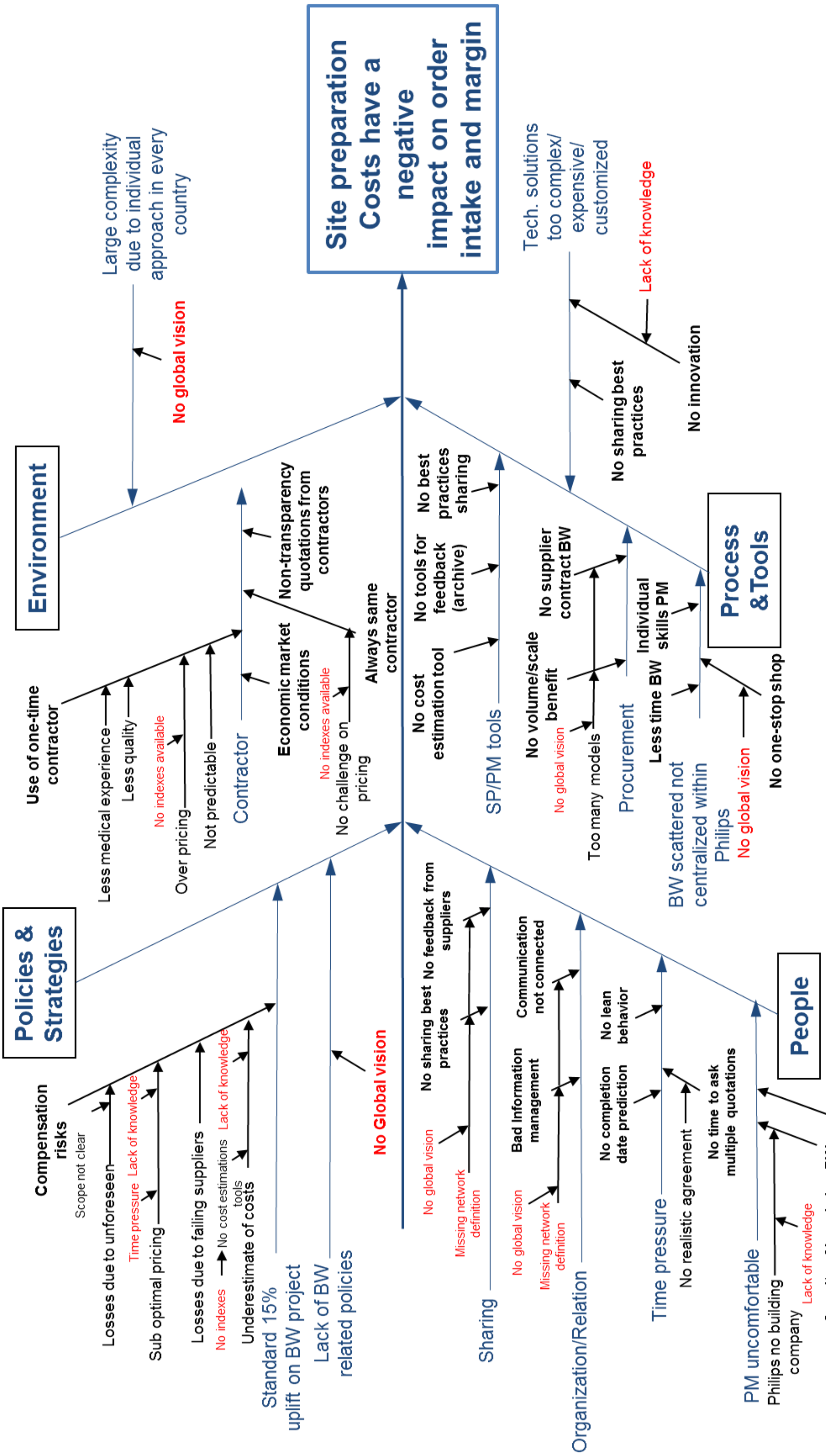

Figure 1.3. Ishikawa diagram

1.3. Research goal

The Ishikawa diagram showed four main reasons behind multiple causes in the diagram. First the lack of knowledge of BW, second the fact that there is no network defined currently for BW, which is related to the missing global vision on BW and finally, the absence of reference price indexes. Based on this the following research goal is formulated:

"Improvement of the insight and the creation of more knowledge of costs related to building works activities for the installation of medical equipment in existing hospital rooms"

This research goal could be translated into the following research question and sub-questions.

How can the insight in the cost influencing factors related to building works be improved when discussing the installation of large medical equipment in existing hospitals?

- What sub-processes are similar when analyzing historic data of different markets, which commonalities can be found?
- What are the cost drivers for the different activities within projects?
- What could be a format to facilitate future request for tenders, which is workable for all the stakeholders involved in the project?
- How can information management help in making the quotation process more transparent?

1.4. Research Design

The research design related to this research question is visualized in Figure 1.4.

The definition of the research scope is conducted based on interviews with stakeholders of the medical equipment supplier. After this, a research-related literature review is necessary in order to define what research has already been established in this field. The next step is data collection and analysis, which is two-sided, qualitative in the form of interviews and a questionnaire, and quantitative in the form of case studies. This together leads to the development of an Information Delivery Manual consisting of a process map, exchange requirements and functional parts.

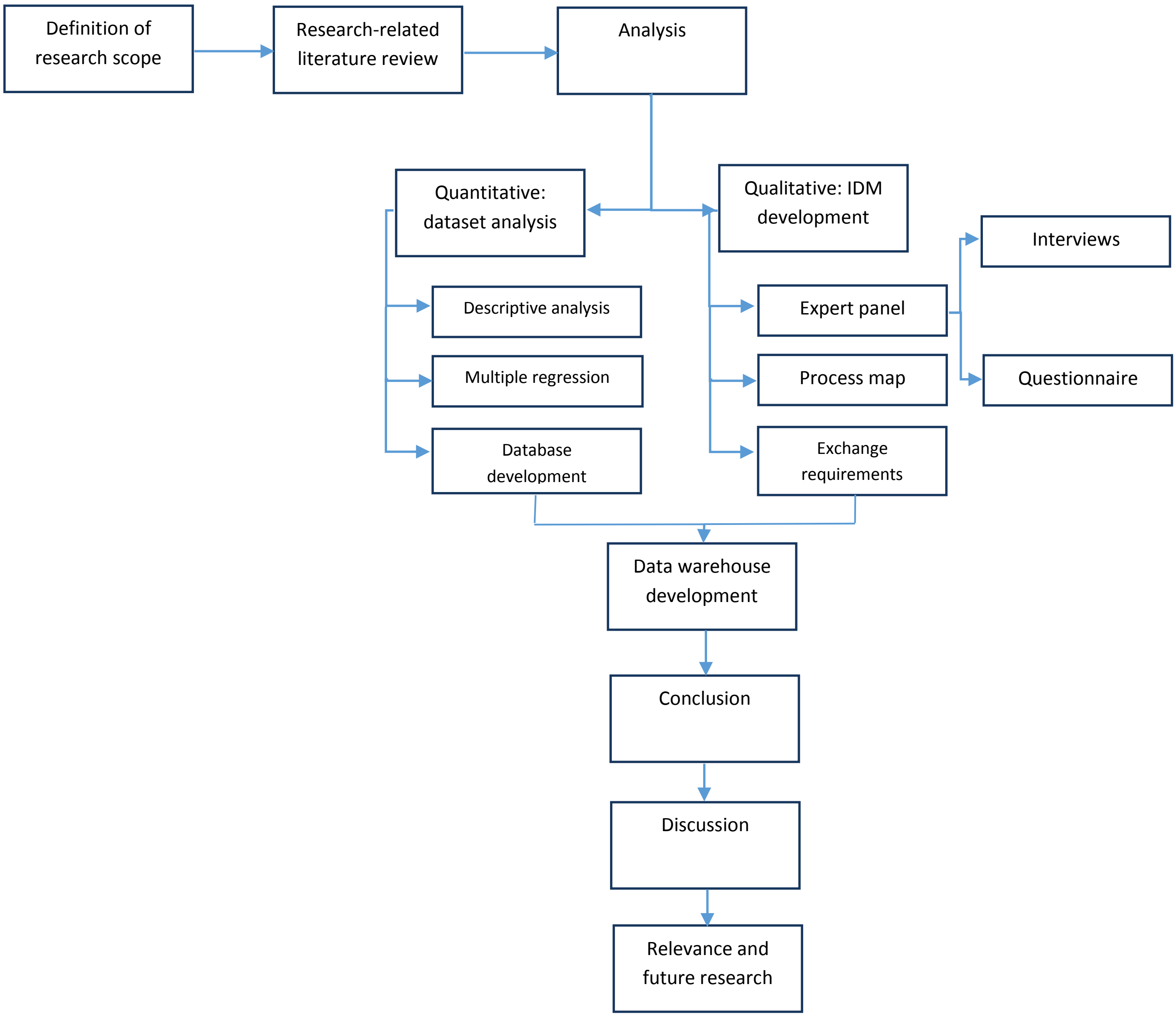

Figure 1.4. Methodology

1.5. Project boundaries

The BW activities concerning large medical equipment subject to this research are done differently all over the world. Because the time for this research only covers six month, the following project boundaries are set:

- The scope of this research is the low and medium complexity projects in existing hospitals, which means renovation, reconstruction and expansion BW activities.
- Focus on the Egyptian Market, because the most case studies were available
- Only projects related to the installation of a X-ray are considered

1.6. Expected results

The expectations of this research are that (sub) processes in the BW set of activities will occur that are repeatable for the type of medical equipment that is installed in existing hospitals. This means that the expectation is that the BW processes can (partially) be made repeatable. For example every X-ray produces radiation, which requires leaded protection.

Next to this the expectations are that the standardization of the whole process will improve project control and with that project cost control.

This research will only focus on the installation of an X-ray in existing hospital rooms, but the expectations are that the process and information management around the installation of the X-ray will be the same as for the installation of the other types of medical equipment.

Important for decision making in the quotation process is that this process should be supported by key parameters, which are based on different technical and economic aspects (Elgh, 2012). The expectations are that cost influencing factors for these type of projects will occur.

Chapter 2. Defining stakeholders, cost estimations and information management

2.1. Reconstruction projects in hospitals and its stakeholders

Building Works (BW) activities is the name for all the activities related to electrical and mechanical installation but also construction works, necessary to conduct in order to prepare the hospital room for the installation of large medical diagnostic equipment. For example, installation of HVAC or wall coverings.

There are different stakeholders involved in the entire process, to start with the client, is the hospital that wants to purchase medical equipment. The stakeholder within the hospital that is most of the time responsible for the contact with the medical equipment supplier, is the general manager of the hospital. The hospital contacts the Account Manager (AM) of the team of the medical equipment supplier. The AM negotiates about the type of equipment purchased by the client and when this is finished, the order is sent to the Project Manager (PM). This PM is responsible for the on time and within budget installation of the medical equipment in the existing hospital room and with that also responsible for the BW parts. The PM is responsible till the moment of order closing.

The PM cannot do this entire project including BW without the help of other stakeholders, to start with the Site Planning (SP) department of the medical equipment supplier. This department is responsible for the technical drawings of the medical equipment in the hospital room and with that, creating the right IFC model with all the information in it.

Later on in the process, procurement supports the PM during the negotiation process for finding the contractor with the best offer for the scope of work.

The BW is not conducted by the medical equipment supplier itself but with the help of Contractors, an external party. The contracting party agrees to perform the construction works within a specific budget and time, including material and labor.

The last step of the project is when the BW are finished and the room is so-called “installation ready”. The Installation team (IT) part of the medical equipment supplier than can start the installation of the equipment.

2.2. Cost estimation classification

Construction projects are part of the project category that is driven by cost indicators. That costs play an important role within a project is also shown by the definition of a project set by the BS 6079-2:200 project management vocabulary "*A unique process, consisting of a set of coordinated and controlled activities with start and finish date, undertaken to achieve and objectives conforming to specific requirements, including constraints of time, cost and resources*" (Lester, 2014).

According to this definition, a project has three parameters; time, cost and quality. It could be concluded that a proper project is completed on time, is accomplished within the budgeted cost and meets the quality requirements set at the beginning of the project (Lester, 2014). This can be related to the project or *iron triangle* as shown in Figure 2.1.

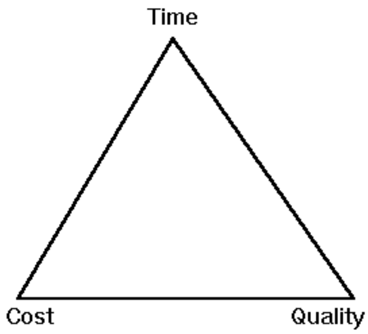

Figure 2.1. Iron Triangle

Currently, costs are still being seen as one of the main focus areas when discussing installation of medical equipment in existing hospitals. Hence, poor project performance has been a major concern for the stakeholders, client and contractor, for years now (Bari et al. 2012). By improving the cost estimation techniques, project managers are able to do more effective control on time and costs (Kim et al., 2004). This control can be improved when the cost-influencing factors are identified, which means that a clear understanding of the whole construction process is required (Bari et al., 2012).

Project cost management consists of a cycle of processes, to begin with planning, followed by estimating the budged, where after cost control is performed, all in such a way that the project can be completed within the agreed time and budget, in other words control of life-cycle costing of a project (Project Management Institute, 2004). Cost estimating is about setting up a cost estimation for the entire project. Important input is a work breakdown structure for the scope of work (Project Management Institute, 2004). Next, cost budgeting aggregates and estimates the costs for individual activities or for each individual work package, which results in a cost baseline (Project Management Institute, 2004). Last, cost control focusses on influencing the factors that create cost variances and controlling changes that are made to the project budget (Project Management Institute, 2004).

2.2.1. Types of cost estimation techniques

When taking a closer look at the actual cost estimation, research shows that this process mainly consists of three steps (Ma & Liu, 2014):

1. Classifying all the construction products required, into items.
2. Defining the quantities of each item
3. Calculate the price of each item and summarize to obtain the project cost

Cost calculations can typically be ordered in three types; pre-calculations, intermediate calculations and post-calculations. This is illustrated in Figure 2.2. by Phaobunjong (2002). Pre-calculations are done before the project has even started, these are generally rough or conceptual estimations to see if the project is feasible or not (Phaobunjong, 2002). Intermediate calculations are carried out during the project life cycle with the purpose to do cost control. Last, the post-calculations are done to get a grip on the actual cost of a project. These last calculations can be very important when it comes to cost engineering. The output of these calculations can serve as input for a cost engineering database (Ma & Liu, 2014).

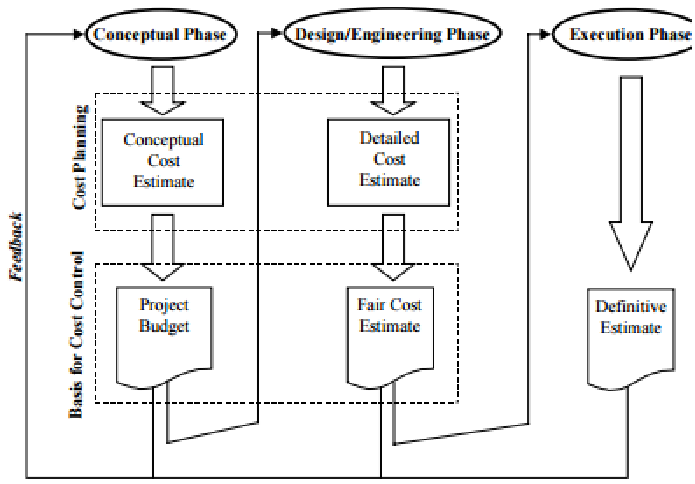

Figure 2.2. Cost estimating during the life cycle of a project (Phaobunjong, 2002)

Related to the three processes defined by the PMI (2004), it could be concluded that every process in the life cycle of the project has an own level of detail required for the cost estimations, which is also defined by the AACE classification. The first, process estimating, requires fewer details than the budgeting process. While on the other hand the cost control process requires a combination of the conceptual estimations made during the estimating process and the detailed estimation during budgeting, in order to reflect on the actual project cost. Concluding from this could be stated that there are three general types of cost calculations in the construction industry; rough estimations, detailed estimations, and a combination of both (Project Management Institute, 2004).

Related to the cost estimating during the life cycle of a project, the American Association of Cost Engineering (AACE) provides norms for cost estimations for all types of industries and with that also the construction industry (AACE, 2005).

AACE published a cost estimate classification system, which provides guidelines for applying the general principles of estimate classification to project cost estimates (AACE, 2005). Table 2.1. represent the classification provided by AACE and is only based on the level of project definition. Other characteristics in this matrix are secondary characteristics and tent to be correlated with the level of project definition. This matrix is for the process industry, which covers construction projects, therefore the secondary characteristics are not industry specific (AACE, 2005).

When taking a closer look at this classification format, it could be concluded that cost estimation is characterized by the level of project definition, the end usage, estimation methodology, expected accuracy range and the reparation effort. Nevertheless the primary characteristic is the level of project definition.

Table 2.1. AACE Classification (AACE, 2005)

	Primary Characteristic	*Secondary Characteristic*			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Conceptual estimations

Conceptual estimations are applied in the first phase of a project, the initiative phase and as a first draft in the definition/design phase. Conceptual cost estimations are necessary for almost all the stakeholders within the project; client, contractor and designer. The outcome of this estimation shows insight in the feasibility of the project and sometimes it can shows the best option out of some alternative designs (Kim et al., 2004).

During the initiative phase there is hardly any information available, on which the cost estimation can be based. The information available is most of the time high-level information, e.g. gross square footage area (Project Management Institute, 2004). The estimation is based on the conceptual design where no real specifications are available. This all leads to only a bid, existing of a final sum, which is not divided in sub processes and the cost of these processes.

The conceptual estimations are most of the time based on historic data, which is used as a reference projects, and therefore, searching for similarities between the projects is recommended. Next to this the estimation highly depends on the experience of the estimator and is thus a bit subjective (Rush & Roy, 2000).

Next to this there is a third input required for successful conceptual cost estimating, current data, which includes according to Phaobunjong (2002) data related to current cost and productivities but also data related to project conditions and future trends (Phaobunjong, 2002). The process of conceptual cost estimating is visualized in Figure 2.3.

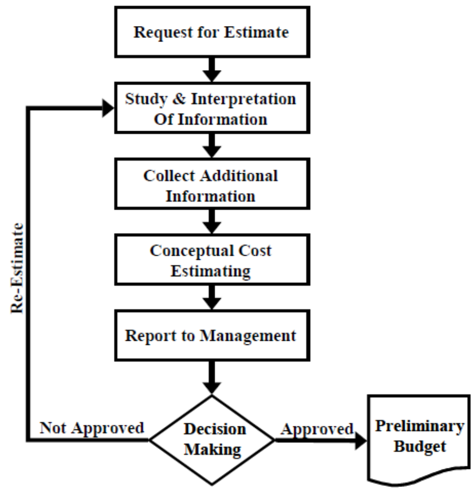

Figure 2.3.Process of conceptual cost estimating (Phaobunjong, 2002)

Referring back to the classification of cost estimating of AACE, conceptual estimating could be defined as class 5 (AACE, 2005). This class requires hardly any project definition, which is similar for conceptual cost estimating.

Detailed estimations

Detailed estimations are done in the next phase of the project life cycle, the definition/design phase. The estimation therefore relies on variables available about the entire design. Hence, this estimation contains details about labor, materials and equipment required to perform the different tasks. These three are important parameters for the detailed estimation and most of the time based on internal synthetics of an organization (Rush & Roy, 2000). Nevertheless a contractor, who provides this detailed estimation, often makes use of sub-contractors. This means that the contractor itself has no influence on the parameters of these tasks. In order to make these detailed estimations, good understanding of the project and the chapters of the project is required (Rush & Roy, 2000).

Dell 'Isola (2003) concluded that detailed cost estimation requires a structured process that involves three steps (Dell'Isola, 2003);

1) Establishing clear definitions of the scope and the physical nature of the project
2) Following an organized and consistent work plan, which is necessary for reviewing the estimate
3) presenting the estimate and compare it with estimates conducted by others

This estimation methodology requires very detailed information about the design and engineering of the construction project, which means that information about quantities and materials is necessary in order to define a unit price to build up the cost estimation. Related to this the detailed methodology could be defined as class 1 of the AACE classification system, where 50 - 100 percent of the project is defined (AACE, 2005).

2.2.2. Input: Types of data

Kim et al. (2012) discussed in their research that the estimation process requires four types of input variables (Figure 2.4.). First the Program of request, second some historic data, actual data and last some indexes. All these inputs need to be combined into a cost estimation by a cost expert, with expert knowledge (Kim et al., 2012)

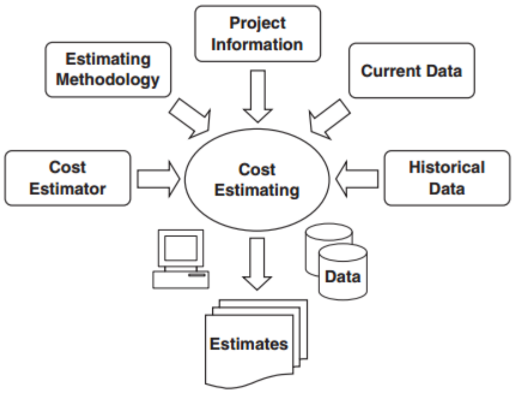

*Figure 2.4. Critical elements of cost estimating (*Kim et al., 2012)

Project information
This input provides all the information about the construction project that is available at the time of cost calculations, therefore this input depends on the life cycle phase of the project. The project information document should always include the scope and the major building characteristics of the project (Kim et al., 2012)

Historic data: direct cost
When using historic data is it necessary to search for similarities between the new project and the historic project. The more the projects are comparable, the more reliable the cost estimation will be. Next to this there is the level of detail in the cost estimation that is an important factor. When conducting detailed cost estimation, a breakdown structure of construction cost is necessary.
This breakdown includes labor cost, equipment and material cost, but also cost of overhead (Dell'Isola, 2003). A large part of this information is based on cost indicators, from which some can be achieved from historical data and some require some current information.

Ratios that can be achieved from historic data is information about labor hours necessary for one typical activity, but also information about materials that are needed for a certain type of construction activity. Materials and installations are part of the so called direct cost or hard cost, which represent the largest part of the entire cost of the project.

Another important indicator that can be based on historical data is contingency reserves, which are cost necessary to cover all the unknown cost, caused by all the information that is not available at the time the project costs are estimated. In other words, contingency represents the degree of risk in the estimation and is usually represented by a percentage of the estimated cost (Kubba, 2012). The degree of risk is something that could be learned from previous projects. When the project is accomplished and control cost calculations have been done, some relevant information about the contingency reserves could be said.

Current data: indirect cost

Next to hard cost, there are soft costs, also known as indirect cost, which are related to all the non-physical items within the construction project, e.g. fees involved within the project, overhead costs and permit costs (Kubba, 2012). These soft costs are defined as current data costs, because these costs differ per country and state. A good example of this are the land costs, related to the acquisition of the land.

Indexes

According to Dukers (2004), there are four types of cost indexes, related to the estimating method and the project phase (Figure 2.5.) (Dukers, 2004).

1. Functional cost indexes
   Used in the program phase, which consists of initiative feasibility studies and project definition. During this phase of the project there is hardly any information available and therefore a rough estimation is made. Information about the project that is available is in terms of *"the building of a hospital, suitable for 270 patient beds"*. Functional indexes therefore indicate the relation between quantities of a building and the function of the building. Hence, these indexes are expressed in m^2 or m^3 use of space per unit of the product or function (Dukers, 2004).

2. Design cost indexes
   Used when the design phase has been reached. During this phase of the project, the project program information will be draught. Hence, design indexes can be defined as the relationship indicator between the physical and recognizable parts of the building (Dukers, 2004). Examples of these indexes are form factor and the relationship between net- and gross floor area. Using cost indexes is also known as normalizing the cost data (Project Management Institute, 2004).

3. Technical cost indexes
   Used during the design phase and define the relation between quantity of an element cluster and the design cost index, which can be generated from previous detailed cost estimations (Dukers, 2004), e.g. *"the quantity m^3 concrete necessary for levelling the apparatus basis (floor) per m^2 gross floor area"*.

4. Cost indexes
   Related to the phase of the project and just like the technical indexes, can be generated from the recalculations of previous projects. When using cost indexes to make an element based cost estimation, these indexes are composed of four cost indicators; labor, material, equipment and sub-contractors (Dukers, 2004).

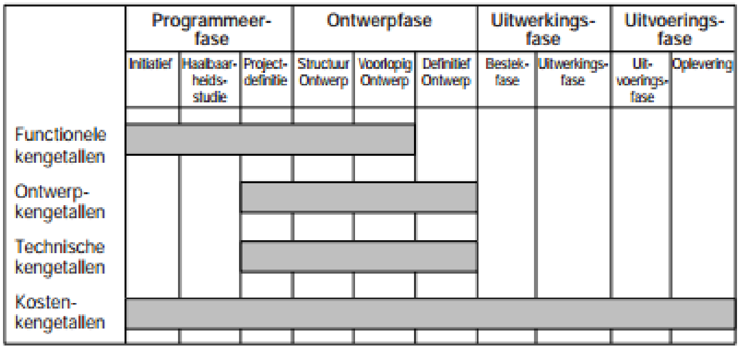

Figure 2.5. Estimating method related to project phase (Dukers, 2004)

Before generating cost indexes from previous projects, the PMI formulates the following considerations (Project Management Institute, 2004):

- Exclude special local conditions in historical data
- Adjust the cost for inflation index
- Adjust the cost for local index of construction cost
- Adjust for different regulatory constraints
- Adjust for local factors for the new facility

3.2.5. Translating: methods of measurement

After data collection, the next step in cost estimating is combining the input to an estimation, which requires a cost estimation technique. Ter Haar (2007) distinguishes three types of construction cost estimation methodologies (Haar, 2007);

1) Cost estimating per m^2/m^3: costs are calculated for a square cost of a building, this is a very rough estimation (Haar, 2007).
2) Element cost estimation: also known as the unit-cost method. The project is composed of different elements and knows a certain hierarchy in elements, e.g. single floor panel, heat exchanger, etc. (Project Management Institute, 2004).
3) Project parts estimation: divides the project into separate rooms that all have their own function (Haar, 2007).

2.3. State-of-the-art techniques

Next to the cost estimation techniques defined by ter Haar, implementation of state-of-the-art cost estimation techniques, currently used in the product development industry, is done more and more in the construction world. The main techniques further discussed in the literature review are shortly defined in this section.

Case-based reasoning (CBR) is a methodology that relays on a library of historic data and is able to retrieve situation similar to the problem at hand and generates a solution based on this historic data (Niazi et al., 2006).

Decision Support Systems (DSS) compare different design alternatives with the help of a decision framework. Due to the framework this method easily helps to find the required information in a fast way (Evans et al., 2006). According to Rujirayanyong and Shi (2006), DSS provides a platform, in the form of a data warehouse, for analyzing historical information that is important for making better business decisions. In the data warehouse is it possible to collect all the relevant data into one central system, which makes analysis of the data possible (Rujirayanyong & Shi, 2006). These research also state that a data warehouse holds all the business intelligence (BI) for the enterprise to enable strategic decision making (Rujirayanyong & Shi, 2006).

Multiple Regression Analysis (MRA) is a method that is based on a clear defined mathematical equation and can be used to detect cost influencing factors. This statistical method test one depending factor against several independent factors to find the cost influencing factors (Kim et al., 2004).

Neural Networks (NN) is a method that automatically analysis a set of historic data to learn more about the impact of the attributes on costs (Evans et al., 2006).

Feature based identifies product (or project) cost related features and the associate costs, to set up and estimation (Evans et al., 2006). Because this methodology works with feature comparison, this is highly suitable for the construction industry when working with CAD files and parameter cost engineering.

Activity Based Costing (ABC) is a technique that formulates costs of a project or product by decomposing the activities necessary to make the product or fulfil the project (Cooper & Kaplan, 1988).

2.4. Information management

Information management plays a very important role in the Architecture Engineering and Construction and Facilities Management (AEC/FM) industry, because several stakeholders are involved and information loss needs to be prevented. Therefore it is suggested to work with Building Information Model (BIM) when working with multidisciplinary projects. The definition of BIM according to the US National Institute of Building Services is *"a digital representation of physical and functional characteristics of a facility… and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition"* (NIBS, 2007). The BIM model is more than a 3D representation of the construction project.

When combining the 2D and 3D drawings with 4D (time), and 5D (cost), the model comes alive for all stakeholders involved (Smith, 2014).

According to Volk et al. (2014) BIM can be interpreted in a Little BIM way and a Big BIM way (Figure 2.6.). BIM in the narrow sense only considers the 3D model. On the other hand the broad definition of BIM considers the functional -, informational - and organizational and legal issues.

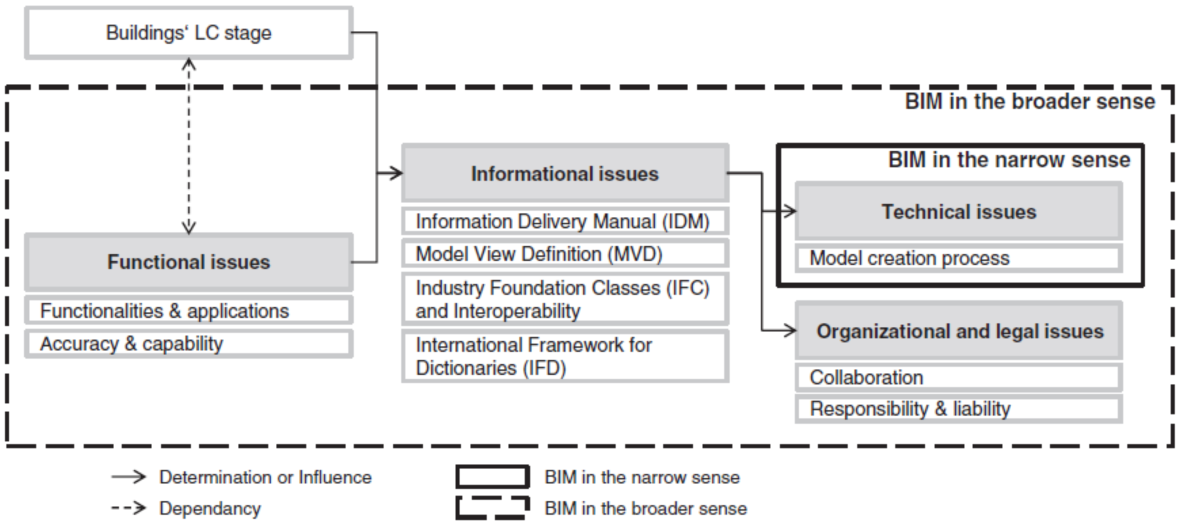

Figure 2.6. Definition BIM (Volk et al. 2014)

An Information Delivery Manual (IDM) is a way to control information expanse within the construction industry and it consist of four main things. First the Process Map (PM), which visualized all the processes and decision point within the process in a logical sequence. Next to this it identifies what information should be delivered by which stakeholder. The Process Map identifies so-called Exchange Requirements (ER), which provides a breakdown of technical information that is required by the exchange requirement. In order to make the BIM model accessible for all the stakeholders, buildingSMART international developed an open and neural standard, the Industry Foundation Classes (IFC) (buildingSMART, 2013). The ER part of the IDM describe the IFC entities related to the information exchange at that specific point in the process, which form the Functional Parts (FP) (Wix & Karlshøj, 2010).

When setting up an IDM it could be useful to use a Work Breakdown Structure (WBS) to get more grip on the processes related to the type of project the IDM is developed for. The WBS is a hierarchical tree structure, and enables the processes of a specific project to be broken down into smaller, more manageable sub-processes, which can be related to the different levels of detail of an industry standard for organizing processes.

The IDM developed for this project related to reconstruction works in existing hospitals, focusses mainly on the implementation of BIM within this project, and the possibilities of a BIM-based approach for the Tender of Building Project (TBP) process.

Chapter 3. Overview of Cost Estimation Techniques and Information Management within the construction industry

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Abstract

Cost control plays an increasing role in construction projects of these days. Cost estimation, influenced by several project cost indicators, is an important part of cost control and can be conducted with the help of different estimating techniques. Several researchers investigated the implementation of cost estimation techniques that are often used in the product development world, in the construction world. In order to conduct good cost control, good information management within the project is crucial. This could be standardized with the help of an Information Delivery Manual (IDM). Therefore this literature review present an overview of the cost influencing factors for construction projects, the implementation of state-of-the-art cost estimation techniques and information management related to cost control in the form of a building information modelling approach for cost calculations in the construction industry.

Keywords: Cost estimation, State-of-the-art cost estimation techniques, Cost influencing factors, IDM, BIM, Information Management.

3.1. Introduction

Today's world is a competitive world where profit margins and cost control play an important role and where the focus is more and more on decision making in an early stage of a project. Therefore, cost factors are in this process a major indicator (Günaydin & Dogan, 2004). This research focusses on the installation of large medical equipment in existing hospital buildings, which are re-construction projects, e.g. finishing inner walls, adjusting ceiling framing or finishing the floors. This type of construction project not only focusses on construction work activities but also require electrical- and mechanical installations. Nevertheless, just like every construction project, cost estimating is important to get a good grip on the total project, and form an important part of the cost control process during the total life cycle of a project. The currently available cost estimating techniques vary from extremely detailed cost breakdowns structures, most of the time base on bills of quantities (BoQ), to a rough overall cost analysis where only the total cost for the scope of work are indicated (Akintoye & Fitzgerald, 2000).

3.2. Cost influencing factors construction industry

Since several studies have stretched the importance of accurate cost estimation, it is important to define objective and consistent criteria for the selection of appropriate historical data regarding construction projects that can be used for cost estimating (Riquelme & Serpell, 2013). The research to cost influencing factors starts with analyzing the factors that cause cost overruns repeatedly. This is something that could be learned from historic projects and therefore it is necessary to store historic projects in a structured way, which makes analysis possible (Baloi & Price, 2003). However, every project is unique and therefore structured storage of historic projects becomes challenging when looking at the incredible degree of customization offered by the industry to the customer (Riquelme & Serpell, 2013).

Akintoye (2000) conducted a research to factors influencing project cost estimating practice. The outcome of the research was that the main cost influencing factors within the construction industry are: complexity of the project, scale and scope of construction, market condition, method of construction, site constraints, client's financial position, build ability and location of the project (Akintoye, 2000). The research showed that these factors have a direct effect on productivity levels on site and performance of the construction project. Another outcome of this research was that next to these factors project information is also a cost influencing factor (Akintoye, 2000). Therefore these factors always need to be considered by construction contractors in their cost estimating decisions.

The re-construction project in existing hospitals that are subject to this research have a high level of customization, this makes cost estimations based on historic projects challenging. There is a standard set of Building Works (BW) activities that are necessary to construct in order to make installation of the equipment in the room possible, but next to this the client could customize the room. Azman et al. (2013) highlight in their research factors which affect the accuracy of public project. Construction projects related to hospitals most of the time are public projects and therefore limited to a specific budget (Azman et al., 2013). Due to the fact that these projects are bound to a budget make that preliminary cost estimations are necessary. The problem with these projects is that only a few reference projects are available, what influences the accuracy of the cost estimations (Azman et al., 2013). These researchers found out that the type of project and contract form are cost influencing factor. Another finding was that the location is an important cost indicator for public project as well, because the funding could differ per region/state (Azman et al., 2013).

Riquelme & Seprell (2013) conducted a broad literature study regarding factors affecting the cost and productivity of construction projects. The output of this literature review is an Ishikawa diagram (Figure 3.1.) that shows the relation of the different factors. From this diagram can be concluded that cost are influenced by four main categories: project, environment, resource and stakeholders. Just like Akintoye, these researchers found that the project costs are affected by the project itself, project complexity, scale and scope. The researchers are also on the same page when it comes to environment, site conditions and climatic conditions (location of project), and information management between the different stakeholders.

Riquelme and Seprell also highlight the resources in terms of labor, materials, equipment and information. These factors are affected by quality and the availability of the resources (Riquelme & Serpell, 2013).

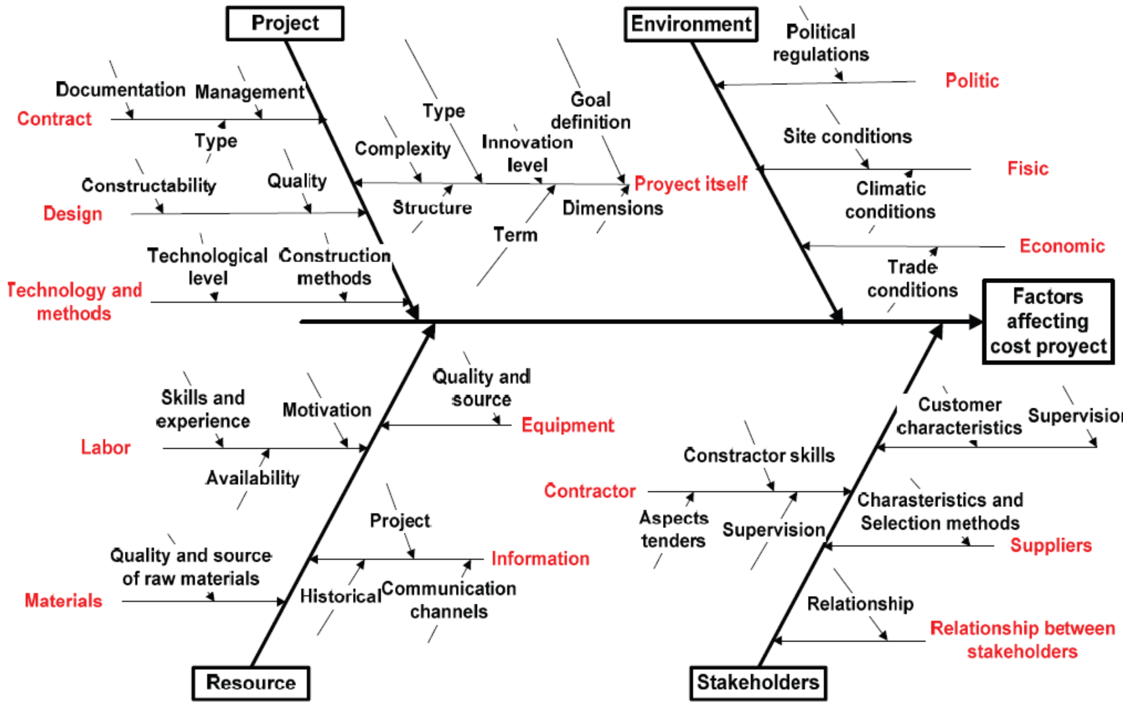

Figure 3.1. Ishikawa diagram cost influencing factors construction industry (Riquelme & Serpell, 2013)

Cheng (2014) conducted research to cost-influencing factors on construction projects with the help of Modified Delphi Method. This research mentions that contractors not only try to avoid cost overruns, but also try to increase the overall profits for the project (Cheng, 2014). The outcome of this research was that the factors with the strongest influence are as follow: clearly define the scope of project in the contract, cost control and contract dispute. This research is contract focused and highlights that clear communication between the different stakeholders is crucial, just like clear understanding of the client's needs in the initial stage of the project (Cheng, 2014).

Related to finding of Cheng (2014) that contractors try to avoid cost overruns and try to increase the overall profit of a project is the finding of Azman et al. (2013) that the number of bidders for a project is an influencing factor for construction costs. These researchers found that the bidders decrease their bid when many offers are expected (Azman et al., 2013). This means that the contractors are influenced by the competition and adjust their bid to this.

Sheth et al. (2010) conducted research to the refurbishment of hospitals and concluded that the building year of the hospital is important because of the level of complexity. The older the building, the more complex the refurbishment project will probably be (Sheth et al., 2010. Their research showed that refurbishing work is hospitals less than 20 years old is not difficult, whereas buildings of 20-40 years old can be complex in nature due to the need of infrastructure improvement, which involves internal and external layouts of the buildings plans.

3.3. Product cost estimation techniques

The main cost estimation classifications of the construction industry are conceptual and detailed cost estimating. Conceptual estimations are most of the time based on historic data, used as a reference projects and searching for similarities between the projects is therefore required. Next to this the estimation highly depends on the experience of the estimator and is therefore a bit subjective (Rush & Roy, 2000). On the other hand there is the detailed cost estimating process which is based on more detailed information and therefore can be conducted in a later phase of the project life cycle. Detailed information about the project is available when the project is defined and the design phase is finished. Hence, this estimation contains details about labor, materials and equipment required to perform the different tasks. These three are important parameters for the detailed estimation and most of the time based on internal synthetics of an organization (Rush & Roy, 2000).

Next to the general methods of measurement in the construction industry, there are several estimation techniques in the product development industry, which can be applied on construction projects. Nevertheless, these days more researchers develop cost estimating approaches in the construction industry, based on product cost estimation (PCE) techniques. These methodologies can be defined in different hierarchies, which is done by many researchers. Some different breakdown structures are shortly discussed in the next section.

3.3.1. Hierarchy PCE

The first classification is one that is used by many researchers and consists of 2 levels (figure 3.2.). The first level makes a deviation in qualitative and quantitative techniques. The second level divides qualitative techniques into intuitive and analogical techniques. On the other hand, quantitative techniques can further be categorized in parametric and analytical techniques (Datta & Roy, 2010).

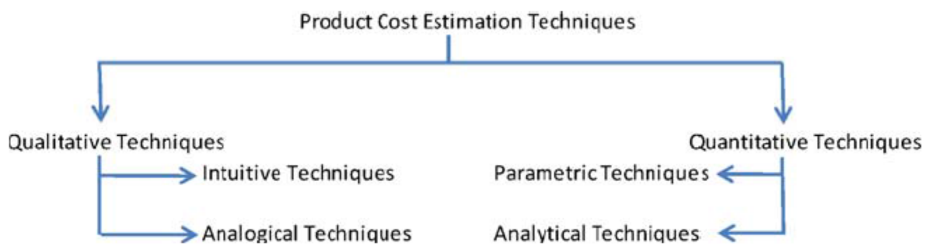

Figure 3.2. Classification of estimation techniques (Datta & Roy, 2010)

Another interesting classification is provided by Evans et al., (2006). These researchers start with a classification level transparent box and black box (Evans et al., 2006). Transparent box techniques describe estimation methods where the reasoning behind it is apparent. On the other hand black box techniques do not show the reasoning behind the solution (Evans et al. , 2006). Transparent box can further be classified in analogic and detailed techniques.

When a closer look at black box techniques is taken there is one more level to be discovered, consisting of expert judgment, neural networks and parametric techniques.

Caputo & Pelagagge (2008) developed their own breakdown of cost estimation methods, again separated in diverse levels (Caputo & Palagagge, 2008). The first level consists of qualitative and quantitative approaches. In their perspective, qualitative approaches rely on expert judgment and heuristic rules, which can be seen as the second level. On the other hand, quantitative estimation methods can be further classified in analogous models, statistical models and generative-analytical models. These three approaches form the second level of the quantitative estimation methods(Caputo & Palagagge, 2008). The last level in this classification is the third level, which only exists for the statistical approach. This techniques can further be divided into parametric and neural networks.

Niazi et al. (2006) provided a complete review of the different PCE techniques and thereby provided a classification (Niazi et al., 2006). This classification is more detailed than the classifications of the other researchers and therefore functions as a baseline for further research to these techniques. Nevertheless, the fourth level of detail is not considered in this research (Figure 3.3.).

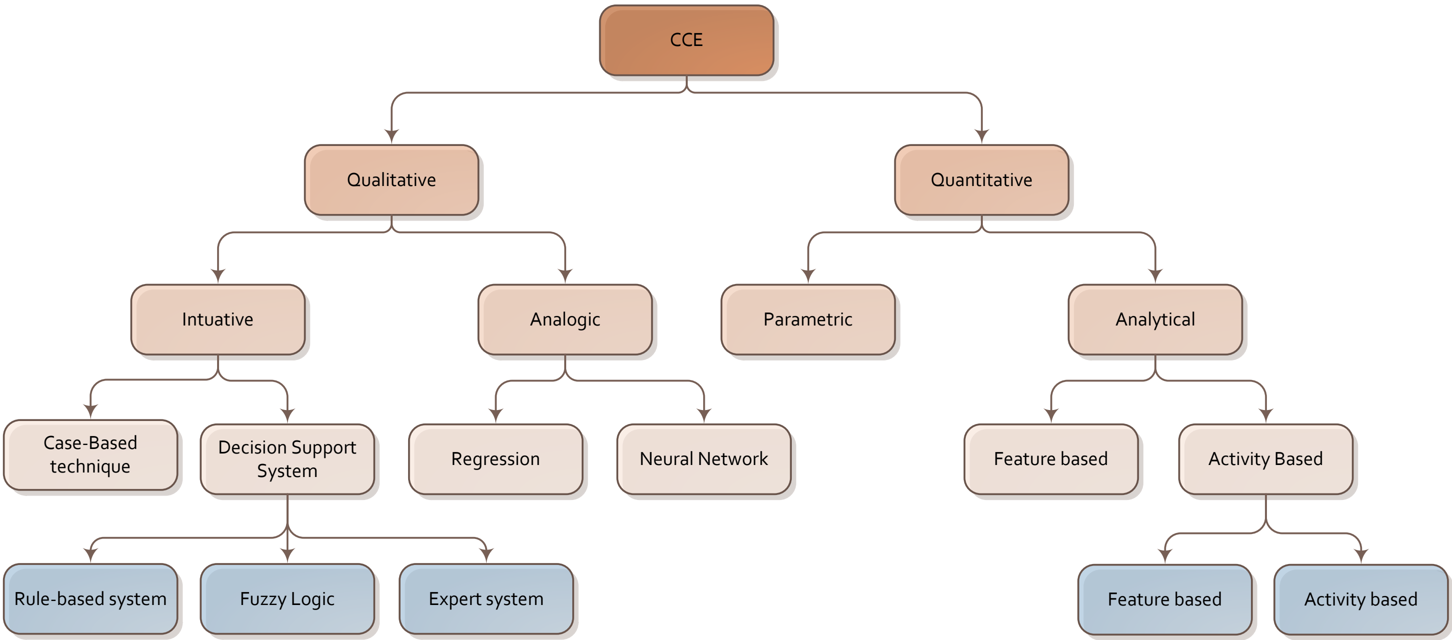

Figure 3.3. Construction Cost Estimation Classification, based on classification of Niazi et al. (2006)

3.3.2. Qualitative techniques

Qualitative techniques belong to the first level and are based on a comparative analysis, in which new projects are compared with projects that have already been established. The intention of this methodology is to search for similarities between the new and historic project. The cost of the historic project cannot be used before adequate adjustments has been made to these costs.

The project can be compared at different levels, nevertheless it is very important that sufficient historic data is available for the estimation to be reliable (Sheng, 2013). Next to historic projects data, this methodology also relies on the knowledge of experts. These experts are able to analyze the design of the project, the process and distinctive attributes (Chou, 2011).

3.3.2.1. Intuitive cost estimation techniques

The first second level technique of qualitative techniques is intuitive techniques. According to Datta & Roy (2010), intuitive estimations are based on the estimator's experience. Next to this another important input is past experiences in the form of historic projects (Niazi et al., 2006). This knowledge can be captured in the form of rules, decision trees and judgments, which again can be stored in a sort of database (Niazi et al., 2006). The two methodologies who are part of this technique are Case-based methodology and Decision Support Systems.

Case-Based methodology

Case-based reasoning (CBR) or methodology is an approach that uses historic data in the form of previous projects and represents the third level of intuitive techniques. This method searches for similarities between the previous projects and the new project (Evans et al., 2006). For a construction project, this would mean that a project is split down in several layers.

CBR has as an important feature that it cannot only store and organize historic data, but that it can also re-use and test the historic data available in the database (Marzouk & Ahmed, 2011). A CBR system chooses the situation that is most similar to the new project situation. The solution is based on the previous project data, adapted to the new project inputs (Rush & Roy, 2000). This so called cycle consisting of the following 4 steps; 1) retrieving the most similar case or cases, 2) reusing the information and knowledge in the new case to solve the problem, 3) revise the proposed solution, and 4) retaining the parts of this experience likely to be useful for future problem-solving (Figure 3.4.) (Marzouk & Ahmed, 2011).

CBR was used by Tah et al (1999) to develop and estimating model for construction planning of highway bridge projects. The basis for this research was a large number of conceptual object models, developed to identify the attributes and relationships between product and planning information (Tah et al., 1999). Other research was conducted by Graham & Smith (2004), who built a Case Based Estimator (CBE) to estimate the productivity of cyclic construction operations. The model was based on five input features, 2 outputs and a case base. This estimator was validated against performances from previous operations and a panel of professional construction planners. The model occurred to be more precise then the estimate planners (Graham & Smith, 2004). Next to these researcher, Marzouk and Ahmed (2011) developed a CBR model for estimating the cost of pump stations. First, fourteen cost influencing factors were identified, where after a CBR library was built based on 44 pump station projects. The outcome was that the accuracy of the results was improved considerably.

One disadvantage of CBR is that in order for the technique to be effective, the cost expert should have the access to many historic projects. When there is not sufficient data available this reduces the effectiveness of the CBR model (Rush & Roy, 2000).

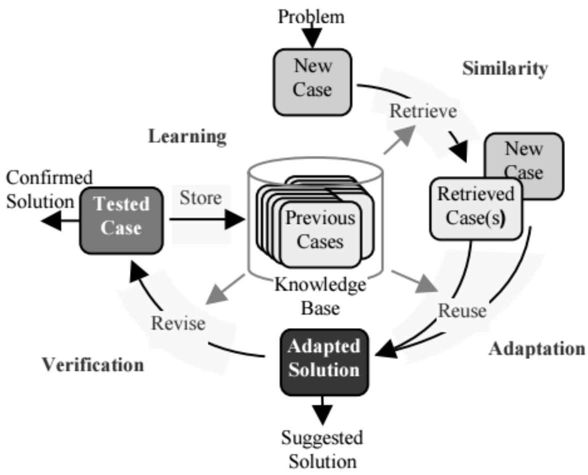

Figure 3.4. Case Based Reasoning-cycle (Rush & Roy, 2000)

Decision Support Systems

Next to CBR there is Decision Support Systems (DSS) as a third level techniques, which is useful when it comes to comparing design alternatives. DSS was first used as a framework for decision making in the 1970s. The then developed tool used a combination of artificial decision making and normal decision making (Lei & Moon, 2015).

A clear definition of DSS was provided by Power (2007) *"an interactive computer-based system or subsystem intended to help decision makers use communication technologies, data, documents, complete decision process tasks, and make decisions"* (Power, 2007). In the construction industry this approach could be used for comparing the different design alternatives. In such a way that cost estimators are better able to make a decision, based on judgment of different levels of the estimation process. Again this method used knowledge from experts that is stored in a database (Niazi et al., 2006). Since DSS is part of the intuitive cost estimation technique family, the expert knowledge within DSS is again stored as a set of rules.

Several researchers have tried to implement DSS in the construction industry, Bose and Sugumaran (1998) developed a data warehouse with the help of data mining, with the purpose to make the known facts and the related data better accessible for making better management decisions (Bose & Sugumaran, 1998). The main theory behind a data warehouse is that the data must be identified, catalogued and stored in a structure, to improve information management (Bose & Sugumaran, 1998). Chau et al. (2002), used DSS to develop a Construction Management Decision Support System together with a data warehouse, to support the daily work of the management process by making it able to track down and provide the required information in a direct, rapid and meaningful way. The potential of the application seemed to be considerable (Chau et al., 2002). Rujirayanyong and Shi (2006) developed a data warehouse for construction projects of large and medium contracting companies, which is project oriented (Rujirayanyong and Shi, 2006). The architecture of their data warehouse is shown in Figure 3.5. Other research has been conducted by Zhiliang et al. (2008), which used DSS to facilitate a standardized exchange document for construction projects.

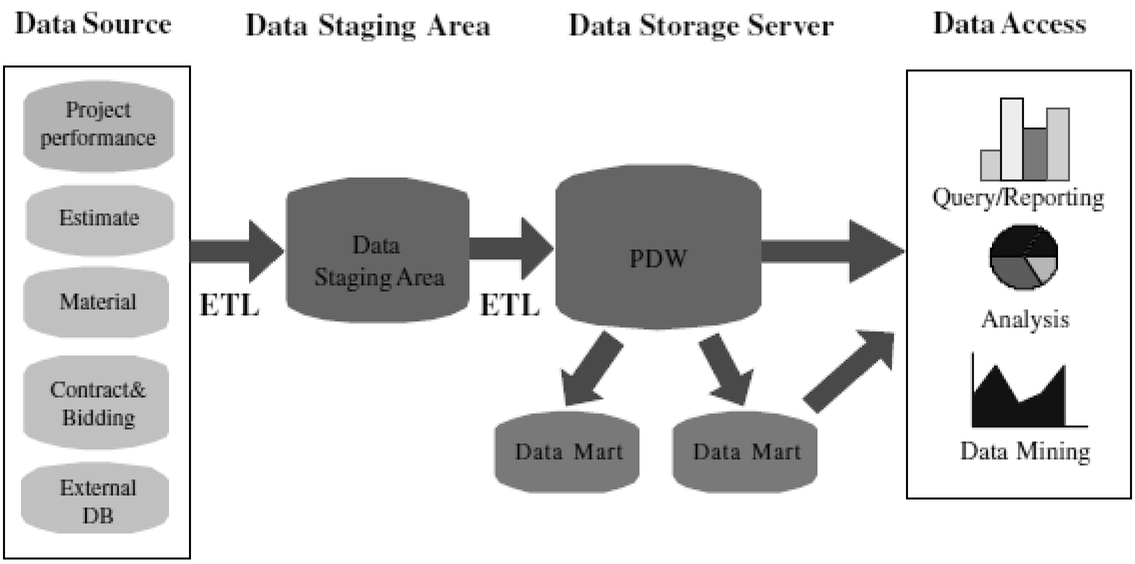

Figure 3.5. The project oriented data warehouse architecture (Rujirayanyong & Shi, 2006)

4.3.2.2. Analogical cost estimation techniques

This technique is based on the identification of similar projects, and therefore has the purpose to reuse the cost information of these similar projects, to estimate the future cost for a project. Adjustment of the cost is necessary because a project is never completely comparable with a historic project (Caputo & Palagagge, 2008). This technique can further be defined in regression analysis models and neural networks.

Regression analysis models

Since the 1970s, regression models have been used to perform cost estimation. This approach is based on clear defined mathematical equations. The general representation of a regression analysis is as follow (Kim et al., 2004):

$$Y = C + b_1X_1 + b_2X_2 + \dots + b_nX_n$$

In this equation, Y represents the total estimated cost, X_1, X_2, …, X_n represents the measures of distinguishable variables, these may help in estimating Y. C represent the estimated constant and all the b's represent coefficients that are estimated by a regression analysis. These coefficients depend on the availability of relevant data (Kim et al., 2004).

Predicting construction cost with the help of a regression analysis has been done by several researchers. Williams (2003) for example predicted the final cost for competitively bid construction projects based on regression models. These models were able to predict the project cost based on only the project low bid as input (Williams, 2003). Researchers not only focused on cost estimating within the construction industry, for example Guerrero et al. (2014) developed a regression model to predict construction time in the Spanish building industry. This model was based on some factors related to the project, project type, gross floor area (GFA), the cost/GFA relationship and many more. Next to the time, the regression model was also analyzed versus the variability of construction cost (Guerrero et al., 2014). Chou et al (2015) presented an optimization process for estimating project award prices.

Several techniques were used and Neural Network performed better than the regression model (Chou et al., 2015).

Neural Networks

Neural Networks (NN) represents the next generation when it comes to cost estimation techniques. This technique is related to the computerization of human thoughts (Rush & Roy, 2000). A NN not only computerizes the human thoughts but also captures the learning process of the human brain (Kim et al., 2004). This technique uses historic data and learns the impact of the attribute on cost by automatically analyzing this dataset (Evans et al., 2006). In other words it is all about learning a computer program the relation between attributes of the project and the cost. When providing the program with data of historic projects, the program can learn by what attribute the final project cost is the most influenced (Rush & Roy, 2000). One of the biggest advantages of using NN compared to using parametric costing, is that NN is able to detect hidden relationships among the data in the program (Rush & Roy, 2000). A typical representation of a NN is visualized in Figure 3.6.

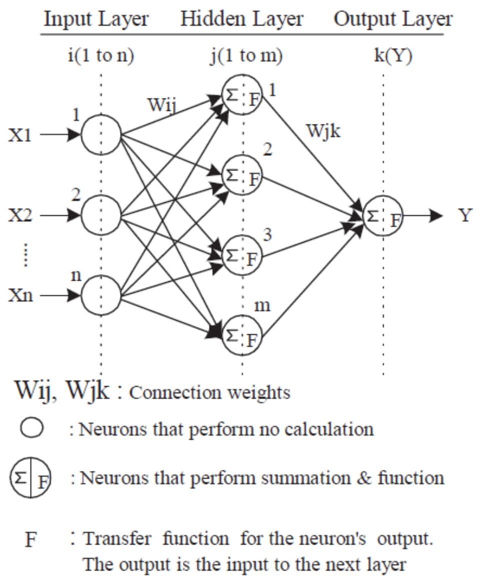

Figure 3.6. Neural Network representation (Kim et al., 2004)

3.3.3. Quantitative techniques

Contrary to the qualitative technique, quantitative techniques rely on detailed analysis of the project design. This methodology takes a closer look at the sub processes involved in the construction of the project. Hence, costs are estimated using an analytical function of variables which are representative for the project (Cheng, 2013). In order for these techniques to be successful, a detailed bill of materials and bill of quantities is required. The two quantitative techniques that are interesting for this research are parametric and analytic. Analytic technique can further be classified in feature based and activity based.

3.3.3.1. Parametric techniques

The first sort of methodology of the quantitative family is the parametric technique. This techniques uses, as the name already reflects, parameters to do estimations.

These estimations are based on an analytical function of a set of parameters that are characteristic for the product or in this research the project. Nevertheless the parameters do not describe the project completely (Datta & Roy, 2010). This technique is about discovering empirical relationships between the cost parameters. Next to this, parametric techniques focus on the selected physical or performance parameters, such as size of the product, quality and complexity of the project. These relationships are also known as Cost Estimating Relationships (CER) (Daschbach & Apgar, 1988). Furthermore, this method is suitable for cost estimation at an early project stage, but can also be used during later stages (Rush & Roy, 2000).

3.3.3.2. Analytical techniques

Next to the parametric technique there is the analytical approach, which is based on a detailed analysis of the work that is required, into the elementary tasks that are part of the manufacturing process (Datta &Roy, 2010). These techniques are used to explore the cost functions and the total cost of resources that are used for the several activities within the project (Evans et al., 2006). One of the difficulties with this technique is that it requires many project data, collecting this data is time consuming. Nevertheless, analytical techniques are able to closely estimate the actual cost of a project (Evans et al., 2006).

Feature based

The analytical technique can further be divided into two techniques relevant for cost estimation of construction projects. The first method is feature based costing, which identifies product (or project) cost related features and the associate costs, to set up and estimation. Because this methodology works with feature comparison, this is highly suitable for the construction industry when working with CAD files and parameter cost engineering. Cost information can be put into the CAD file as an extra dimension to do early in the project life cycle cost estimations (Evans et al., 2006). This method is highly suitable for construction projects because the construction industry already works with the CAD programs. In these programs the project is described as a number of features like walls, floors, etc. Each project feature is connected to manufacturing -, and planning requirements, therefore it already contains much information. By combining this with a 5^{th} dimension (cost), cost estimations can be done easily (Rush & Roy, 2000). When the same family of projects is discussed, cost information from the one project can be implemented in the other project and projects can be compared easily (Rush & Roy, 2000).

Activity based

Activity-Based costing (ABC) is a method that models the resources necessary to perform activities for various outputs and was developed by Cooper & Kaplan in 1988 (Cooper & Kaplan, 1992). According to Ben-Arieh & Qiam (2003), ABC makes it possible to evaluate the cost of a product, or in this context project, by decomposing the work required into elementary tasks or activities with known cost (Ben-Arieh & Qian, 2003). The process of ABC is visualized in Figure 3.7.

The graphical representation of ABC shows several steps to take, defined by Ben-Arieh &Qian, 2003). The first step is identifying cost centers, these cost centers are the resources directly used to produce the end product. Next it is necessary to analyze the indirect cost and calculate their cost-drivers.

Where after, it is time to assign resources to each cost center and determine cost center driver rates. In other words the total cost for each cost center is calculated. The fourth step is to identify the activities, where after analyzing each activity is necessary to find the total cost for each activity. When this is done, the activity drivers for each activity can be defined (Ben-Arieh & Qian, 2003).

According to Tsai et al. (2014), the main advantage of ABC is that it could improve the accuracy of cost-related data and with that have better control of project cost (Tsai et al., 2014) This researcher developed an ABC model for a life cycle assessment in green building projects, with the goal to control the life cycle costs of green building projects (Tsai et al., 2014).

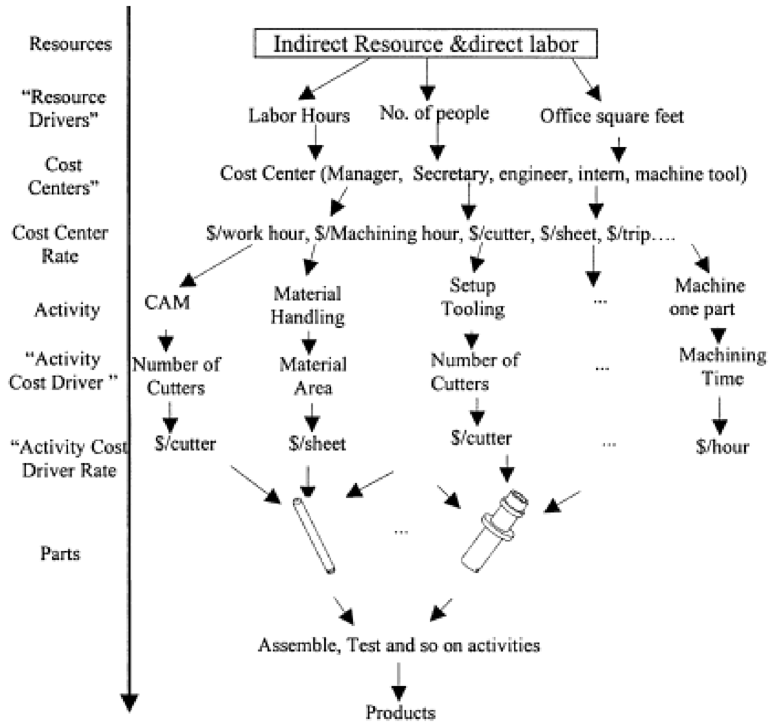

Figure 3.7. Activity-based costing implementation, example (Ben-Arieh & Qian, 2003)

Summary Cost Estimation Techniques

The purpose of this research is to gain more insight and create more knowledge of cost related to building works activities for the installation of large medical equipment in existing hospital rooms. Therefore a platform to facilitate information management is desirable. This is conducted in the form of a Decision Support System, which makes it possible to create a data warehouse and a standardized way to exchange documents. In order to define the cost influencing factors for this type of project, a Multiple Regression Analysis (MRA) is conducted. The outcome of the MRA is part of the data stored in the data warehouse.

3.4. Information Management

Information Management within construction projects is very important, nevertheless, streamlined information exchange remains a challenge (Eastman et al., 2010). Nowadays, the Architecture Engineering and Construction (AEC) industry heavily relies on computer software. In other words, the industry has become ‘information-centric’, where most of its tasks are involved with digitalized design and engineering information to create new tasks with added value (Kim, Kwon, You, & Lim, 2010).

The bill of quantity (BoQ), method has recently been accepted for tender of building projects (TBP) cost estimation in practice in many countries and regions of the world. This BoQ method involves breaking down the building into products, most of the times conducted by the tender, where after these products are classified into groups, called BoQ items. The last step in quantifying these BoQ items, where after the item cost for the bid can be calculated by multiplying the BoQ item with the quantity (Ma & Liu, 2014). It is necessary that the information of products, including their construction information, are available for the BoQ process. There are two kinds of specifications used to standardize the breakdown structure of buildings and the classification of BoQ items for different specialties in the architecture, engineering, construction, and facilities management (AEC/FM) industry. On the other hand the quote specifications are used to specify both the unit consumptions and the reference prices of the related quote items. This reference price can be adjusted to market prices (Ma & Liu, 2014).

3.4.1. Information Delivery Manual

Hjelseth (2011) discovered that the increasing integration of software tools and information systems within construction project accelerates the amount of information available in AEC/FM projects. Hence, to ensure optimum information quality, the amount of information in information systems should be kept to a minimum (Hjselseth, 2011). One way to control the information expanse is to develop an Information Delivery Manual (IDM), as a tool to conduct information management of construction projects. ISO 29481-1:2010 developed by buidlingSMART describes an approach to capture and specify processes and information flows for facilities of its entire life cycle (ISO, 2010).

According to the researchers Mondrup et al. (2014) the core of an IDM is standardizing a process, in order to do this, an IDM consists of 4 deliverables (Mondrup et al., 2014):

1. IDM use case: defines the activities, project participants, and information exchanges, as required for a specific AEC/FM process
2. IDM process Map (PM): displays the relationship between these activities, project participants and information exchange.
3. IDM exchange requirements (ER): define the information units, as required for each use-case-specific information exchange. These provide a breakdown of technical information that is required by the exchange requirement (Wix & Karlshøj, 2010).
4. IDM exchange requirement models (ERM): organize the ERs into Exchange Objects that is machine-interpretable data exchange packages.

When discussing an IDM the main roles of the process map are to set boundaries for the extent of the information contained within the process. Next to this it should establish activities within the process in a logical sequence and it identifies exchange requirements that support the activities in the process (Wix & Karlshøj, 2010). Next to standardizing a process, IDM is basically a documentation for serving software developers as well as expert AEC engineers at the same time. Hereby there is less focus on 'IT terms', which results in better readability for those not having background knowledge. The intention of IDM is not for direct translation into computer programs as IFC models. Concluding, IDM offers a structured approach for summarization of the required information and providing a good start point for concerting this summarization into a format that can be read by computers (Kim et al., 2010).

Related to developing an IDM, the United States Department of Defense introduced a so called Work Breakdown Structure (WBS), which is a project management methodology for defining and organizing the processes of a project (Mondrup et al., 2014). This can be useful for developing an IDM to get grip on the processes related to the project and the information required for those processes. When all the processes are mapped in a WBS, they can be translated into an IDM, which needs to be reusable across disciplines or organizations (Mondrup et al, 2014).

Bernard & Karlshoej (2012) stated that every construction project is unique and ever changing, therefore the processes within a construction project are unique and with that the information exchanges (Bernard & Karlshoej, 2012). This presents a considerable challenge to the concept of developing a standardized framework to define and organize information exchanges for which a WBS can form the first basis. For standardization Bernard & Karshoej (2012) used the OmniClass as industry standard, because of its deliverable-oriented hierarchical decomposition of the different AEC/FM disciplines, and the possibility to define an object in a high-level to more detailed way (Bernard & Karlshoej, 2012). Table 33 of the Omni Class structure allows for each discipline, or sub-discipline, mapping with a specific IDM package within the IDM framework. Nevertheless, Anumba et al. (2010) stated that when defining Exchange Requirements (ER), it is essential to focus as well on input (IRs) as output requirements (ORs) (Anumba, et al., 2010).

When an IDM is developed there is one last step necessary in order to make an IDM operable. This step is supporting the IDM by software, whit the idea that the software can interpret the relevant data and communicate it to the receiving side (buildingSMART, 2011).

Previous research to IDM related to the construction industry had been conducted. For example, Kim et al (2010) developed an IDM and used a Unified Modelling Language (UML) based conceptual model to create a database schema, because this is independent to any specific system type. For implementation of the defined IDM model these researchers used Microsoft SQL-Server for generating the database schema that corresponds to the IDM model (Kim et al., 2010). Next to this, this research team developed an application for browsing and editing the database.

In 2012 Obergiesser and Borrmann worked on the development of an IDM for the geotechnical infrastructural design and analysis process. With this suggested a BIM methodology within the infrastructural design, bedding and building industry.

However, an infrastructural BIM model does not exist yet and therefore requires development of a standard that is accepted by engineers. Future research of these developers will focus on defining exchange requirements for the infrastructural industry (Obergriesser & Borrmann, 2012). Instead of focusing on a complete process, the research team of Lui et al. (2013) worked on de development of an IDM for identifying the exchange requirements for the performance analysis of HVAC systems. The researchers developed an extended IDM approach, which means that they made four changes to the original IDM approach. By which a new step was added to directly identify the functional parts from exchange requirements. Which enables the identification of information that is not include in the IFC schema. This resulted in information items that were not covered by other data models (Liu et al., 2013).

3.4.2. Open standard

BuildingSMART developed a data model standard to describe, exchange and share information in an open and neutral format. This standard is called Industry Foundation Classes (IFC). The IFC definitions are able to contain semantic building data, which means that next to geometric information, also material properties and functional information can be saved in the IFC definition (buildingSMART, 2013). In order to represent a set of IFC entities that represent specific parts of a building, functional parts are described within the exchange requirement of the IDM. These functional parts from the key to finding the necessary IFC subset for exchanging information to the application. Functional parts therefore contain information such as IFC entities and property sets (Kim et al, (2010). In order to make the BIM model accessible for all the users, an open and neutral standard is favorable. Therefore the Industry Foundation Class was introduced as a commonly used data exchange standard for BIM (Gao et al., 2015). By using IFC it is possible to create a shared data model, workable for all the different stakeholders involved.

When taking a closer look at an IFC-model, this model consists of several layers described in the IFC4 Addendum by buildingSMART International Limited (2013) (Figure 3.8.):

1. *Resource layer*, which prescribes that the resource classes are used by classes in the higher levels. Resource classes may only reference or use other resources.
2. *Conceptual layer*, which provides a Core Project Model which contains the Kernel and several Core Extensions. Core classes within this layer may reference other core classes or reference classes within the Resource layer. Core classes are not allowed to reference or use classes within the interoperability or Domain/application layer.
3. *Interop layer*, which provides a set of modules defining concepts or objects common across multiple application types or AEC industry domains.
4. *Domain/Application Layer*: this layer provides set of modules tailored for specific AEC industry domain or application types. Next to this, the layer contains specialized model ‘adaptors’ to non-IFC domain application models.

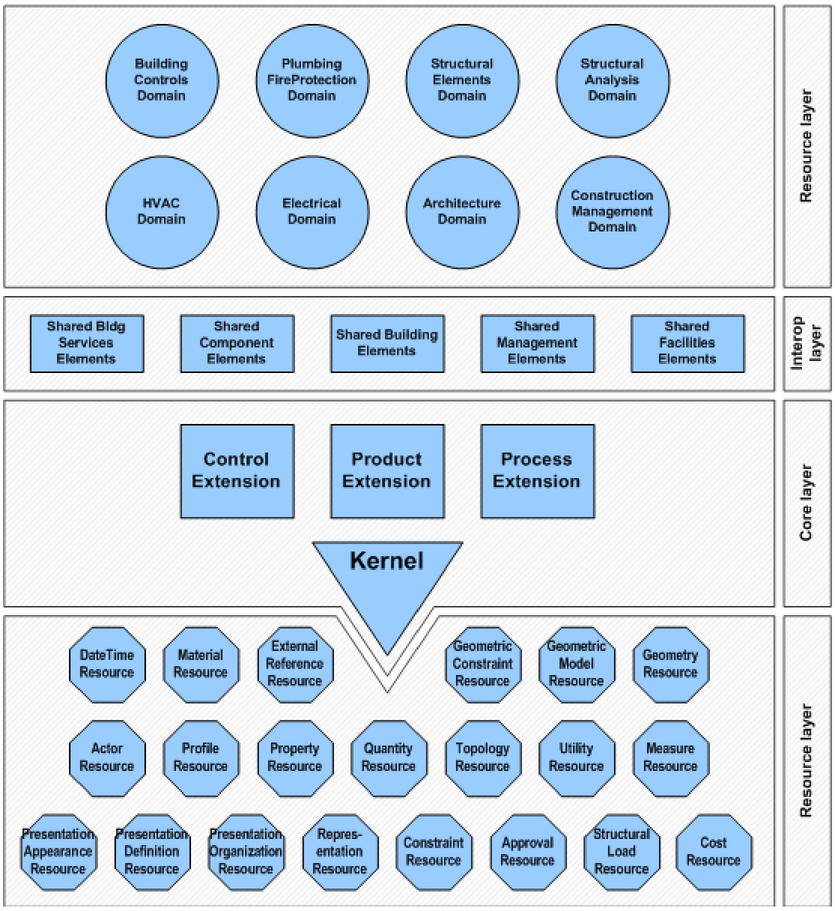

Figure 3.8. Data schema architecture with conceptual layers (buildingSMART, 2013)

All the resources in the resource layer in the IFC Model can be used or references by classes in the other layers. These resources all represent their individual business concepts. Which means that all information concerning the concept of cost is collected together within the cost schema *IfcCostResource*. Any classes within the core, interoperability or domain/application layers which uses cost information will reference this resource (buildingSMART, 2013).

An IFC model is built up out of *entities*, which are classes of information that are defined by common attributes and restrictions, which are defined by ISO 10303-11. The IFC model contains *attributes*, which is a unit of information within an entity and is defined by a particular type of reference to a particular entity (buildingSMART, 2013). Attributes can be divided in three types:

1. Direct attributes: scalar values or collections including set (unordered, unique), list (ordered), or array (ordered, sparse) as defined in ISO 10202-11
2. Inverse attributes: unit of information defining queries for obtaining related data and enforcing referential integrity
3. Derived attributes: unit of information computed from other attributes using an expression defined in the schema

The IFC model consists of *Objects*, which can be defined as anything perceivable or conceivable that has a distinct existence (buildingSMART, 2013). The objects in an IFC model are again defined by *Object Types*, which have common characteristics that are shared by multiple object occurrences. Attached to these object types are properties and quantity sets which define the object type (buildingSMART, 2013).

A *Property* in an IFC model can be describes as a unit of information that is dynamically defined as a particular entity instance. Object are described by *Property sets*, which is a concept template that describes how sets of properties are associated to objects or object types. These properties are usually defined by a name, value or unit triple (buildingSMART, 2013). The property sets for objects define how the occurrence of an object can be related to a single or multiple property set. There are also property sets for types, which are templates to describe how an object type can be related to a single or multiple property set, and these properties related to a specific object type are the same for all occurrences of this object type (buildingSMART, 2013). The relation between an IfcPropertySet and IfcObject is visualized in Figure 3.9.

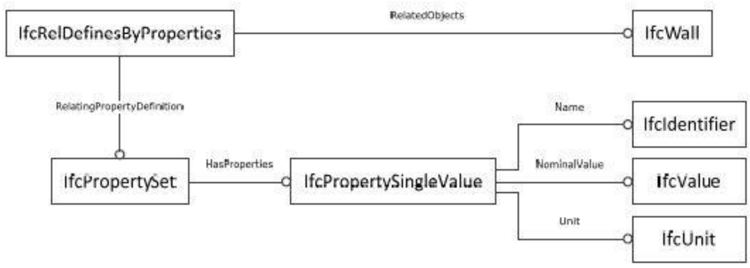

Figure 3.9. IFC property sets relation (Beetz, 2014)

Next to *Property sets,* object can also be defined by *Quantity sets*, which contain multiple quantity occurrences which makes that an object can be related to multiple quantity set occurrences. Quantities are defined by a name, value and when necessary a description and a formula. *MethodOfMeasurment* is a related attribute to *Quantity sets*, what specifies the method by which the quantities are calculated (buildingSMART, 2013). When the method of measurement is not a dependent factor for the definition of a quantity, it is called a *Base Quantity*. The fact that these quantities are not defined by a standard unit of measurement, makes that these quantities can be applied at an international level (buildingSMART, 2013).

The different objects in the IFC model are associated to one or more objects in the model. The so called *object association* indicated the means to associate sources of information to object definitions (buildingSMART, 2013). The different objects within an IFC-model can be related to each other. A very common example is the relation between the wall and a window. In IFC the relations is as visualized in the figure 3.10. Another important association in the IFC model is the *Classification associations*, which described how the object and object types can further be described by an associating references to external sources of information (buildingSMART, 2013). These information sources could be; a classification system, a dictionary server, any external catalogue that classifies the object further, or any service that combines the previous features (buildingSMART, 2013).

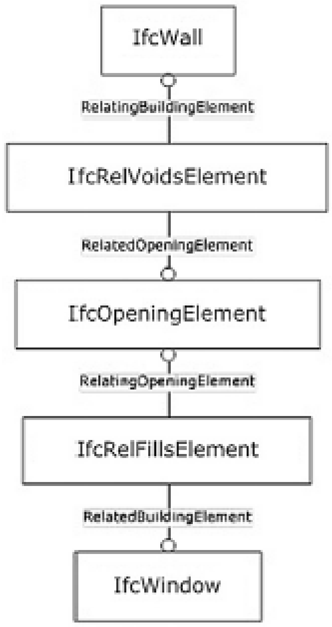

Figure 3.10. relationship between IfcWall and IfcWindow (Beetz, 2014)

The occurrence of a wall in the IFC model can be defined by two entities for wall. First the *IfcWallStandardCase*, which is used for all occurrences of walls, with a non-changing thickens along the wall path (buildingSMART, 2013). Next to this the thickness parameter can be fully described by a material layer set. The second occurrence of a wall within the IFC specification is *IfcWall*, which is used for all other occurrences of wall. For example walls with changing thickness along the wall path (buildingSMART, 2013).

3.4.3. BIM and cost calculations

IFC entities in an IDM are prescriptions for setting up an IFC model of a building. With this, BIM can provide a platform for all the stakeholder involved in the ACE projects, where information can be shared and a space where everybody can work. Therefore BIM could be seen as a primary tool for the whole project team (Smith, 2014). When adding the 4th (time) and 5th (cost) dimension in the BIM model, cost managers can explore various design and construction options and with that search for the most optimal scenario for the client.

Nevertheless, not every country is at the same level when it comes to the implementation of BIM within the construction industry. Countries that are ambitious and advanced in using BIM are the United Kingdom, where the government has introduced a BIM implementation strategy (Smith, 2014). Next to the UK there is Singapore, where the government has developed a strategy to implement BIM on public projects by 2015. Another strong supporter of the implementation of BIM for public projects is Norway. This government requires the use of BIM for all public projects. This also counts for the other Scandinavian countries such as Denmark and Finland (Smith, 2014). The Dutch Central Government Real Estate Agency introduced the RVB BIM-norm in 2011, which describes the specifications of the BIM information products that the contractor should deliver. This norm is developed for integrated contracts such ad Design Build Finance Maintain Operate (DBFMO) (Central Government Real Estate Agency, 2013).

When it comes to the 5th dimension (cost), the Royal Institute of Chartered Surveyors (RICS) has publishes the Black Book in 2012, which is a suit of documents that defines good technical standards for Quantity Surveying and Construction. Together with the New Rules of Measurements (NRM), which is a suite that provides a common measurement standard for cost comparison through the life cycle of cost management, they form the backbone of the fifth dimension within BIM. Because the NRM are integrally linked with BIM, a consistent approach for cost estimating and planning is accessible within the BIM model (Smith, 2014).

The implementation of BIM related to cost estimating has been the topic of research for several research teams. First Ma et al. (2011) proposed a BIM-based approach to classify construction products according to specifications. After this they developed a prototype system that was able to conduct semi-automatic and specification-compliant cost estimations of construction projects (Ma et al., 2011). Next to this, Lee et al. (2014) recommended an ontology-based process to infer unit item prices from BIM-based design results according to the predefined rules (Lee et al., 2014). The research of Lee et al. (2014) is related to quantity take-off (QTO) for cost estimation, which was originally preformed manually, not influenced by the use of 2D or 3D CAD tools. In other words, quantities were measured by the user and not the software. This was based on the fact that there are some disadvantages when it comes to the use of CAD-based design.

One way to fasten the process of QTO for cost estimating is by doing this with the help of a BIM-based model. According to Monteiro and Martins (2013), a BIM-based model is "*an assembly of objects defined by specific properties, some of which are the element's geometric attributes*" (Monteiro & Martins, 2013).In order to make a BIM-based approach for QTO successful, there is one big requirement: the use of a system that follows a desired structure in the organization of information. This system is most of the time referred to as a Work Breakdown Structure (WBS). A successful implementation requires that all the stakeholders involved in the process use the same WBS (Monteiro & Martins, 2013). Examples of these systems are Master Format, Omni Class, Uniformat, Uniclass, but also the Dutch NL/SfB classification. The implementation of this classification in BIM could be done by entering the codes of the elements in ID or Layer form.

According to the Industry Foundation Classes Release 4 (2013), the following domain with the related information is necessary in order to do better cost estimations based on the IFC model (buildingSMART, 2013).

Ifc and cost estimating: *IfcCostEstimatingDomain*
Cost estimating

- Identify objects
- Identify tasks needed to install objects
- Identify resources needed to perform tasks
- Quantity
- Costing and cost summarization

Quantities could be extracted from the IFC model, in order to set up a cost calculation. With the help of an IFC model, in which all the necessary elements are modelled, this could be an automated process based on quantity extraction from the IFC model.

Drogemuller & Tucker (2003) investigated the automation of quantity extraction from an IFC model and discuss two different extraction types (Drogemuller & Tucker, 2003):

1. Identification of components: such as walls, which have a certain length, area, volume or mass which describes this object.
2. Counting components: such as furniture and doors, this requires a simple query against the database.

In order to make to make the bill of quantity readable, classification of the objects in the IFC model is necessary and is assigned to *IfcClassification*, which identifies the classification system used as a notation source. The *IfcClassification* is part of the *IfcKernel* and identifies the classification system or source to which the classification system refers to (buildingSMART, 2013).

3.4.4. BIM for existing buildings

The implementation of BIM started not that long ago, which means that very old buildings most of the time do not have a BIM model. However, since BIM is a model that is useful during the entire life cycle of a building, it is worth exploring the possibilities for developing a BIM model for existing real estate. When discussing healthcare real estate such as hospitals, the maintenance phase is an interesting topic, due to the many mechanical and electrical installations in the building. Research conducted in the past related to the implementation of BIM in existing buildings focusses mainly on the life cycle of a building and its performances and maintenance (Volk et al., 2014). Nevertheless the implementation of BIM can have the advantage of risk mitigation or improvement of data management. These are two important factors related to the research scope of this report (Volk et al., 2014). Sheth et al. (2010) conducted a survey to discover the use of BIM for refurbishment projects in hospitals. The outcome was scattered and differed from "adapting slowly" to "no project is done without BIM" (Sheth et al., 2010). BIM was mostly implemented for large scale projects, which were more complex.

When implementing BIM after the completion of the building, it is important to define the information needs and the goal of the BIM model (Godager, 2011). BIM models are most of the time simpler and customized to the needs and therefore Godager calls it a slim BIM (Godager, 2011). This researcher studied a hospital project and the use of BIM during the management, operation and maintenance process, including rebuilding works (Godager, 2011). The main conclusion from this research was that to make the implementation of BIM for existing buildings a success the focus should be on the information available and necessary. For rebuilding work in hospitals a BIM model could be made partially (Godager, 2011).

3.5. Construction Classification

Classification or codification of the construction cost in such a way that different quotations can be compared with each other without the need to transform them into a standard format, is favorable. Another important reason for using a standard format is the fact that a construction project is mostly designed by a multidisciplinary team, clear communication is therefore very important. Hence, a standard format can be used to facilitate this communication (Humphreys & Wellman, 1996).

The Netherland developed a specific NEN norm in June 2002, NEN 2634, which is about terms, definitions and rules for translating information about cost and quality aspects of construction projects (Dukers, 2003). NEN 2634 describes the relationship between the project phase and the level of detail required for the cost estimation. Next to this, NEN 2634 defines the cost of the project into element clusters, elements and technical solutions (Figure 3.11.). Hence, an important conclusion could be that before a useful estimation could be conducted, these elements need to be precisely defined and captured towards each other (Dukers, 2003). According to NEN 2634, an *Element* can be defined as a building part or a collection of building parts, specified by acting according to the required functional accomplishment. The next level, *element cluster*, can be defined as a group of elements, with some specifications that are related to each other. The last level, *technical solutions* can be described as a part of an element that distinguishes itself in form, material or execution procedures (Dukers, 2003).

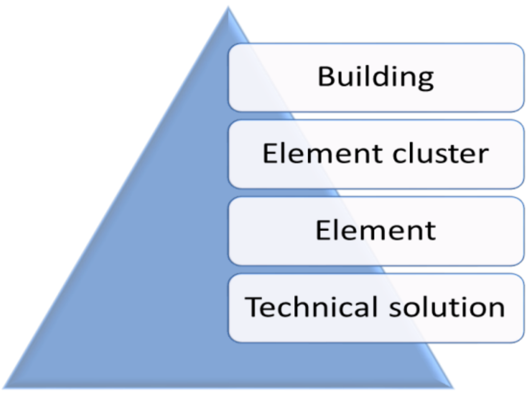

Figure 3.11. Classification NEN 2634

Dukers (2003) describes two types of classification systems, element based and execution based. The first, element based, is a classification system that classifies the cost of the project based on physical recognizable elements within the work (Dukers, Cost aded value, 2003), e.g. inner walls, outer walls, floors and more, in other words the function of the elements of the building (STABU, 2006). The second system, execution based, identifies the cost, based on the type of execution work, e.g. groundwork, masonry, concrete work and more (Dukers, 2003). Classification systems useful for construction works conducted with the use of BIM need to be able to classify buildings according to the following aspects; type of work, spaces, building systems & installation and contract forms (STABU, 2015).

ISO 12006-2:2015 was developed as a standard for organization of information about construction works. It serves a framework for classification and is not a classification system itself. The ISO consists of recommended classification table titles for both a form of function view on information object classes. The ISO 12006-2 also shows the relation between the different tables and with that serves a basis for BIM. The purpose of ISO 12006-2 is to serve organizations which develop and publish classification systems and with that makes it possible to create classification systems which can serve the local construction industry (ISO, 2015). According to Kang & Paulson (2000) a construction information classification system should consist of two parts, a Work Breakdown Structure (WBS) and an information management system (Kang & Paulson, 2000). In North America the Masterformat is used as a WBS and in Europe, the CI/SfB serves as a WBS.

Next to the ISO 12006-2, there is ISO 12006-3 which indicates a language independent information model which can be used to develop a dictionary than can be used to store or provide information about construction works. A general framework again forms the basis of this ISO to facilitate classification systems, information-, object- and process models (ISO, 2007). Based on this ISO standard, buildingSMART developed a Data Dictionary, bSDD, with the purpose to imporve the interoperability in the building and construction industry (buildingSMART, 2015).

Several organizations have developed a classification system that is aligned to the ISO 12006-2; BSAB 96 Sweden, BDK 2006 Denmark, NS3451:2009 Norway, Omniclass North America, Talo2000 Finland and CBI New Zealand. The alignment with the ISO standard assures practical use of information for these systems. And next to this, the developers of Omniclass believe that when following the framework provided by the ISO standards, that this will improve the ability to map between localized classification systems worldwide (OCCS, 2006).

This research focusses on construction works in existing hospitals and therefore a classification system that includes chapters related to reconstruction works in hospitals is required. An important indicator in these type of project is material definition, and therefore requires extra attention when searching for a classification system. Discussing a hospital case it is most common to first define the space, then the type of space and finally the type of activity conducted in this space together with the systems and products (BSRIA, 2014). In the case of a defect on for example an air treatment unit, it is easy to see what spaces are affected by the defect of the equipment.

Some different classification systems are compared for this research, after a short introduction of a couple of system, Table 3.1 provides an overview of the comparison for points interesting for this research.

CI/SfB stands for Construction Index/Samarbetskommitten for Byggnadsfragor and is being used as a representative WBS in Europe. This classification involves information about the unit of measurement for every classification part (Kang & Paulson, 2000).

Uniclass 1.4 was developed in the UK by the Construction Project Information Committee (CPIC) in 1997 as supersede for CI/SfB (Kang & Paulson, 2000). Currently Uniclass2 have been developed in 2013.

Different from Uniclass 1.4, Uniclass 2 is a unified system, which means that the tables correspond to one another, which makes the classification system more useable for BIM (Chapman, 2013). Uniclass 2 is alligned with NRM2 and therefore the unit of measurements are according this norm (Royal Institue of Chartered Surveyors, 2013). New Rules of Measurement (NRM) 2 – detailed measurements for building works, was publishes in April 2012 as a norm for standard method of measurement for the preparation of bills of quantities.

Omniclass is developed by North America by the OCCS and is the equivalent of the European Uniclass (OCCS, 2006).

CBI – Co-ordinated Building Information is developed by the construction industry of New Zealand and is based on the European Common Arrangement of Work Sections and ISO 12006-2. The size of this classification system is adjusted to better suit the construction industry of New Zealand.

Table 3.1. Comparison different classification systems

	CS/SfB	Uniclass2	Omniclass	CBI
Aligned to ISO standard (Kang & Paulson, 2000)	X	X	X	X
Element based	X	X	X	X
In English		X	X	X
Flexibility to identify different levels of detail (Cidik et al., 2014)		X	X	
Defines materials by substance with construction products (Kang & Paulson, 2000)		X	X	
Hospital classification of complex and spaces (BSRIA, 2014)		X	X	
Considers local construction industry (Kang & Paulson, 2000)	X			X
Unified system (Chapman, 2013)		X		
Up-to date system (Kang & Paulson, 2000)		X	X	X

Considering the fact that this research focuses on reconstruction projects in existing hospitals located in Europe, the choice for classification system is made for Uniclass 2. This format contains a decent level of detail when it comes to material definition and next to this is gives the possibility to define spaces for hospitals, something that is missing in the SfB systems. Uniclass2 can define systems in a building, for example a door set system. The table product can be used to define the material of the door set system. Finally the format is in English, which means that it should be understandable for different countries.

3.6. Conclusion

The literature review presented an overview of already established research to cost estimation and cost management in construction project. Several researched stretched out the relevance of cost control and insight in cost in order to strive project success. Therefore research has been conducted to state-of-the-art cost estimation techniques that have been the topic for many research. These techniques are highly related to cost influencing factors for construction industry projects, and therefore should be considered when discussing setting up a cost estimation model.

Next to cost influencing factors and techniques, information management plays an important role when it comes to project success. Projects are conducted by multidisciplinary project teams, all over the world. Therefore information loss is an increasing problem and the needs for standardization of processes increases. Hence, information flow management is necessary to ensure reliable exchange of BIM data between the different stakeholders op the project.

This literature review forms the basis for a larger research to gaining insight in the cost estimating process of projects involving the installation of large medical equipment in existing hospitals. The research focusses on information management and therefore the development of an Information Delivery Manual with a Decision Support System in the form of a data warehouse. Next to this cost influencing factors are determined by conducting a case study. These influencing factors are detected with the help of setting up a Multiple Regression Analysis (MRA) as discussed section 4.3.

Chapter 4. Insight in cost influencing factors and information management

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Abstract

Both qualitative and quantitative research is conducted in order to detect the cost influencing factors for construction costs related to the installation of large medical diagnostic equipment in existing hospital rooms. A literature review forms the basis for data collection. This data collection is followed by a case study on which statistical analysis are based in order to find cost influencing factors. One main statistical analysis in a Multiple Regression Analysis. The outcome of the quantitative research from the input for the qualitative research, together with the outcomes of interviews and a questionnaire. This information is translated into an Information Delivery Manual (IDM) with the purpose to facilitate future cost calculations for this type of projects and to improve transparency of the tender process.

Keywords: MRA, IDM, Process Map, Exchange Requirement, IFC

4.1. Introduction

Currently, costs estimating within construction projects are often conceptual estimations, which mean that they are based on scarce knowledge about the project specifications. To make this estimating process more accurate, it is necessary to look at new cost estimating techniques which are considering cost influencing factors of the typical project. The weight of cost influencing factors on the costs can be measured with the help of multiple regression analysis. When the cost influencing factors are clear, data related to cost calculations can be collected in a structured way. The final goal is setting up a data warehouse which makes cost analysis of historic project possible.

Related to this is the handling of information management within a complete project. The fact that information management can play an important role in striving to more accurate cost estimations and a better throughput time of the end to end project, could be supported by the implementation of a BIM-based approach. The development of an Information Delivery Manual (IDM) visualizes the complete process and the data object that needs to be shared by the different stakeholders in order to get the BIM model and what is possible to do with the BIM model when it is established.

4.2. Research design

The research model for this research consists of both quantitative and qualitative analysis. The qualitative part is based on a questionnaire regarding the process and the different stakeholders involved in the project. This information forms the basis for the development of a Process Map and the related exchange requirements.

On the other hand, quantitative research involves several case studies of historic projects from Egypt. These case studies are combined to a dataset which is the start for statistical analysis, in order to detect the cost influencing factors for this type of projects.

This chapter step by step explains what has been done. The several steps are visualized in the flowchart in Figure 4.1.

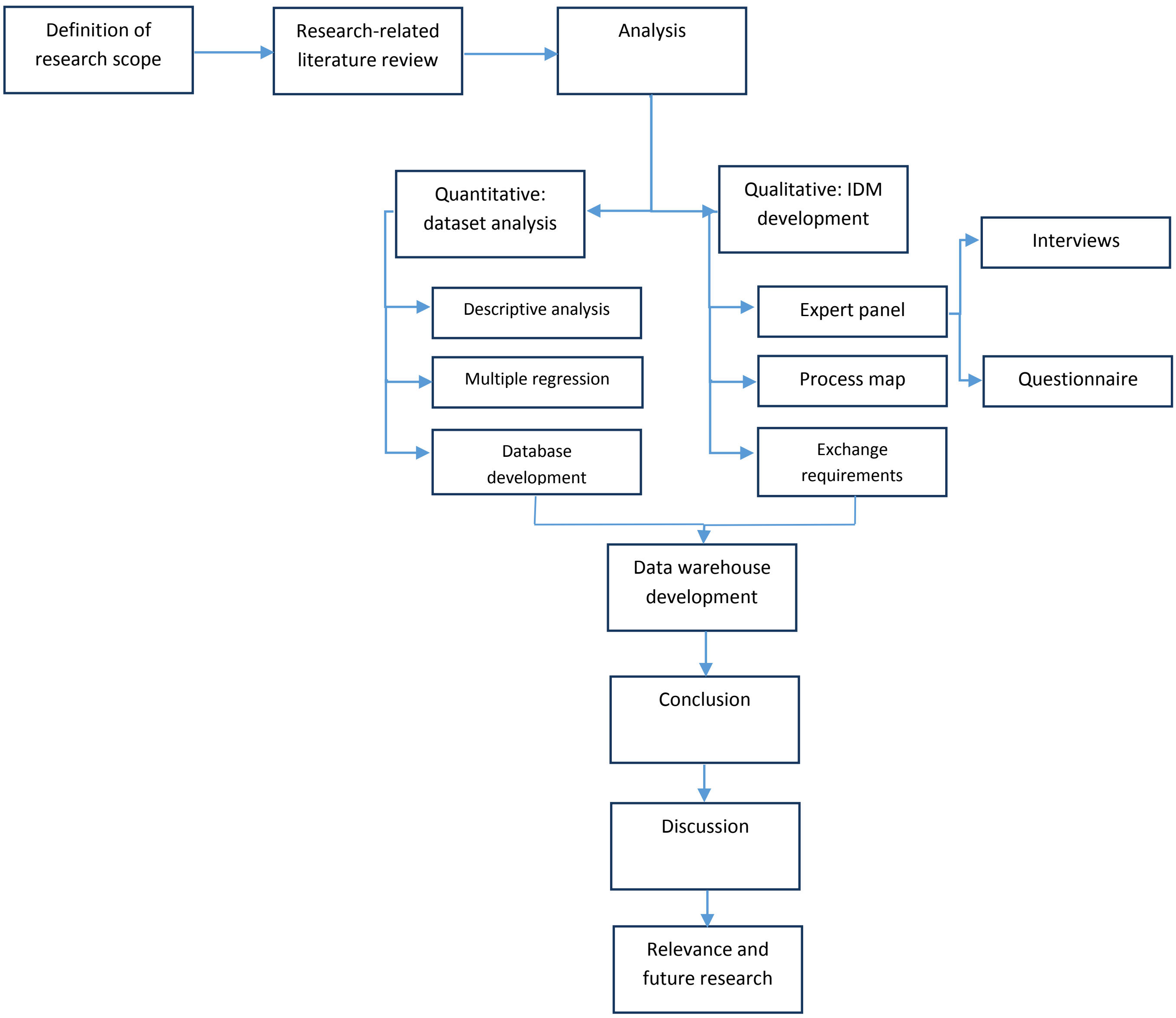


Figure 4.1. Research design

The first step in the complete research is defining the research and its scope, setting the boundaries. These steps are described in chapter 1, introduction to the research. The research definition phase is followed by a research-related literature review.
This review is conducted based on articles in scientific journals. Topics that were highlighted in this literature review are:

- Cost influencing factors in the construction industry; reconstruction projects in hospitals
- State-of-the-art cost estimation techniques in the construction industry
- Information management in the construction industry
- BIM-based quantity take off for cost estimation

The goal of the literature review was to get an overview of the already established research related to the mentioned topics, to form a basis for this research, and is therefore part of the qualitative analysis.

This chapter first discusses the quantitative analysis, which is followed by the qualitative research. Because different methods are used, especially in the dataset analysis part, the results for each analysis are being discussed directly after the description of the method.

4.3. Dataset Analysis

Data collection is needed for analysis project data (Rostami, et al., 2013), and should be stored in a flat database. Nevertheless, the data is derived from different sources, which one must be kept in mind. Rostami et al. (2013) selected some issues related to his research, from which some of them are related to this research as well, namely;

- Each project is unique and actual costs depend on many factors, which are not always consistently reported.
- The cost data represented in this study is total contract cost, it is not certain if the social cost were include
- Indirect cost should be added at the end of the cost estimations, together with the uncertainty.

Based on this knowledge there are some limitations related to this research, successively. Every project is unique, allowing only the general activities to be considered, and social costs are excluded from this research because no information about these aspects is available.

4.3.1. Variables: commonalities within markets

First, one must look for the commonalities in the collected data derived from different countries, to get a complete overview of the building works activities in the different markets. This commonality check forms the basis for setting up a standard quotation format, which can make the data comparable. The complete commonalities analysis can be found in Appendix 2. and is translated in a Work Breakdown Structure (WBS) (Figure 4.2.), As can be seen, the actual Building Works for the installation of large medical equipment in an existing hospital room consists of construction works and installations, and facilities, fixed as well as movable. With construction work, is meant all the building activities with a focus on the substructure of a building. Installations for this type of project are divided in mechanical and electrical installations. Due to the high level of customization of the different projects, the WBS structure is a generic model.

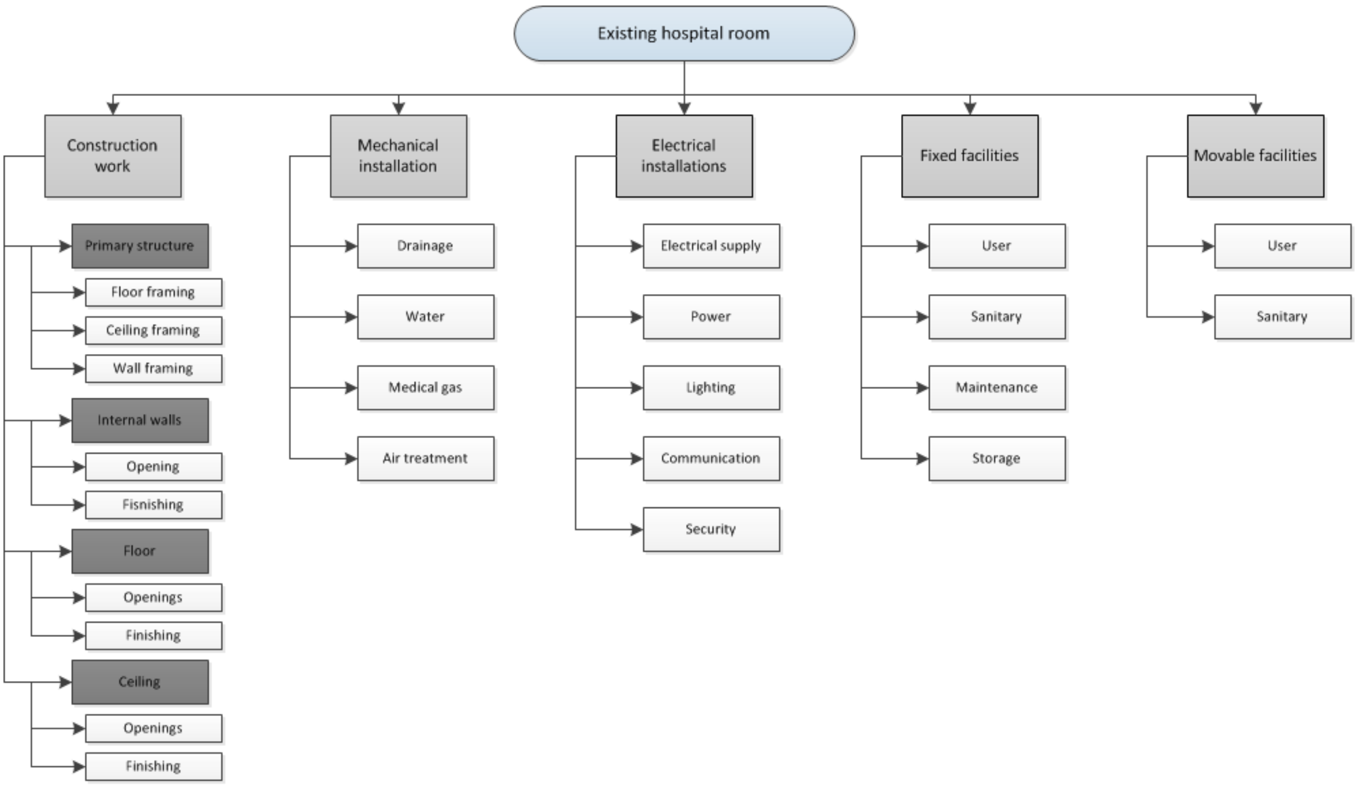


Figure 4.2. Work Breakdown Structure hospital projects

For the case study dataset analysis, several projects from Egypt were collected. These cost quotations were structured in a different way and therefore first needed to be translated to an industry standard classification system in order to make them comparable. Looking at the future, an element based format is preferred, because this could be used within a BIM-based approach (BNA, 2005). As mentioned in the literature study, the Uniclass2 is an element based system aligned with ISO 12006-2. Because building works projects focus on activities inside the building, not all the tables of the Uniclass2 need to be considered. The projects are in the detailed design phase, which results in the use of the *Systems* table and the *Product* table. On a higher level, the activities can be divided into construction works, electrical installations, mechanical installations, and Facilities. More about this classification format is discussed in section 4.4.2 Exchange Requirements.

4.3.2. Source of cost data

The cost data was obtained from a database of quotations from Egyptian project data. The quotations are competitive bids for re-constructing project of existing hospital rooms in the province Cairo or outside this province, in Egypt. All projects, except for 2 are located in the province Cairo and therefore the distinction "in Cairo" or "outside Cairo" is made. In total 56 quotations were used to set up a flat database as a start for statistical analysis. The data was obtained with the help of the large multinational in healthcare, all the data retrieved was coming from this one regional office and are all projects established in 2014, and the project cost are given in Egyptian Pound. The 56 quotations are related to 11 projects in total, from which every project consists of a minimum of 3 and a maximum of 6 quotations given by different contractors. These projects are collected because they are all defined by the same family of large medical equipment, X-ray, and therefore require the same type of building works activities.

A complete overview of the average costs in Egyptian pounds per project is given in Appendix 3. In order to prepare the dataset for statistical analysis for extraction of cost influencing factors with the help of a Multiple Regression Analysis (MRA), some first analyses could be conducted, in order to gain more insight in the available dataset.

4.3.3. Missing value analysis

Because the projects available for this research are all slightly different, due to the fact that every project is unique, there are many missing values to be found, especially in the fourth level, "Product level". Therefore a missing value analysis is conducted over the level "System level", which can be found in Appendix 4. These missing values make that the dataset is very limited and in order to do a regression analysis, the variables need to be combined to the level "System", because missing values cannot be used in a MRA analysis. This analysis shows that there is very limited information available for the variable "Fixed facilities" and "Movable Facilities". When combining the different element Types for these two variables, the standard deviation rises enormously. This is caused by the fact that the cost for facilities differ a lot for the different types of facilities. For example a *chair* is less expensive than the installation of *lockers for medical supply*. Therefore these variables are excluded from further research.

Another variable that has very limited input is Ss_55_70 "Mechanical Installations, Water". Only three projects have values for this variable, therefore this variable is excluded for further analysis. Next to this the variable Ss_55_20 "Mechanical Installations, Medical Gas", also shows limited values and is therefore excluded from the research as well.

The variables Ss_25_20 "Internal Wall, finishes" is for this analysis separated in Ss_25_20 "Internal Wall, finishes normal" and Ss_25_20_50 "Internal Wall, finishes security". The last variable shows wall finishing types that are necessary for safety reasons, caused by the fact that X-ray equipment involves radiation, which requires for example leaded protection.

4.3.4. Normalization of dataset

Data is presented in bill of quantity (BoQ) formats, which means that a description of an activity, defined by a quantity and a unit price is available. The total item price for the particular room can thus be calculated by multiplying the quantity by the unit price. In order to standardize the data, to make it comparable, it is necessary to divide the item price by the gross floor area of the complete room. This step is necessary because the variables of the case studies have a unit of measurement that could be “Length Meter”, “Square Meter”, or “Lump Sum”.

1. quantity * unit price = item price
2. item price / gross floor area = price/m² room (normalized price)

After this step every activity is described in cost per square meter room. Because the normalized costs of the different quotation per project sometimes differ a lot, the average of all the BoQ per project are calculated. This results in a histogram (Fig. 4.3) that shows the average total costs in EGP for the 11 projects summarized in Table 4.1.

Table 4.1. Total cost projects case studies

Project	Cost	Municipality	University
1	173755	Cairo	no
2	223658	Assuit	yes
3	176675	Cairo	no
4	252599	Cairo	yes
5	237760	Cairo	yes
6	196107	Cairo	no
7	244704	Cairo	yes
8	136968	Cairo	yes
9	254821	Mansoura	yes
10	290025	Cairo	yes
11	262246	Cairo	yes

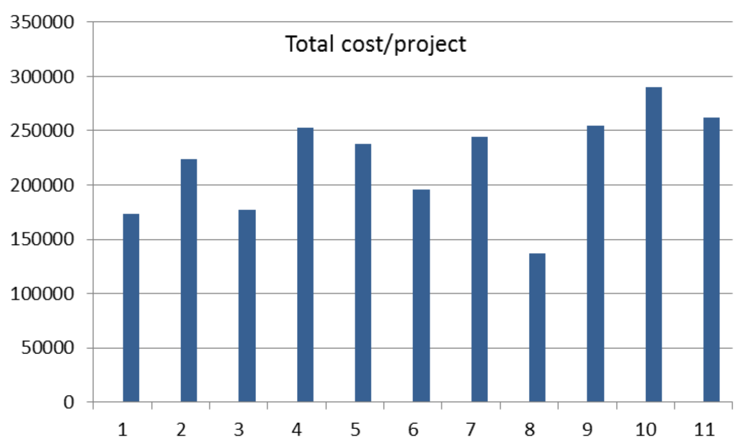


Figure 4.3. Histogram total normalized cost per project

This analysis shows higher costs per square meter room for the university hospitals, which makes it assumable that the construction costs for these type of project depend on the type of hospital. Remarkable is that hospital 8 is a university hospital but has the lowest costs/m² room. This could be caused by the fact that this hospital is part of the University of Cairo, maybe they got a special agreement. The university with the highest cost is a university which is mostly caused by the fixed and movable facilities. University hospitals have in most of the countries different funding and a different standard, which can be reflected in the finishing level of different building work activities.

4.3.5. Deviation of the mean in percentage

This analysis provides the first insight in defining the cost influencing parameters. The statistical analysis is conducted, based on normalized data as described in the previous section. The average unit costs per square meter room for each activity are calculated for the "System" level for all 11 projects. Next the difference related to the average in percentage is calculated for every average normalized unit price. This is done according the following formula as used by Botter (2013) in his research to cost estimation (Botter, 2013).

$$A_{k,j} = \frac{P_{k,j} - X_j}{X_j} \times 100\%$$

A_{kj} represent the difference in percentage for project k, element post j. P_{kj} represent the price per unit for the project k, element post j. The value X_j stands for the average unit price per square meter for all the projects, element post j. This analysis is useful when highlighting all the absolute deviations greater than 50 percent or greater than -50 percent in red (Table 4.2). The reason behind this analysis is that the projects where the costs differ significant are highlighted and cost influencing parameters can be searched for within the unit cost. A complete overview of the difference in percentage at detail level "Elements" is given in table 4.2. just as the results for a short descriptive statistics test, which involves calculation of the mean, standard deviation and the range. The outcomes of this analysis are shortly discussed in this section.

The first variable "Preparation systems, Ss_15_10" shows for 9 out of 56 quotations a score greater than -50% or 50%. This number can be caused by the fact that the unit of measurement for this variable is Lump Sum, which means that it is just a total price for the activity, not based on a real quantity.

The variable "Door and window systems, Ss_25_30" shows 7 quotations that are highlighted in red. 4 quotations are related to the same project and therefore it is likely that this project shows some error when it comes to this variable. Nevertheless, looking at the descriptive statistics, the mean is 209 and the standard deviation is 113. This is a particular high standard deviation, which means that the cost are scattered. This variable is the sum of the cost related to different doors present in the room. The cost between doors can differ a lot, because there are different types of doors, defined by height, width and other properties, e.g. leaded coating. Therefore it could be assumed that the door-type is an important cost influencing factor for this variable and is a big influencer for the total construction costs.

"Ss_70_80, Lighting systems" shows 11 quotations highlighted in red. This is unexpected, because all quotations have the same activities, installation of headlamp. It could be that the type of lamp differs, that different suppliers for the lamp are used in the different projects. This could be assumed from the descriptive statistics test, where the mean and standard deviation are calculated. The mean is *122* and the st. dev. is *49*.

The last variables that shows many highlighted quotations is "Communication systems, Ss_75_10". This variable is the variable with the lowest standard deviation of all (5,5), nevertheless, the reason that the percent deviation is high in this analysis is could be caused by the fact that the cost per variable are normalized and therefore the cost per square meter room are used. Hence, the gross floor area could be indicative for the cost of electric installations communications. Assumed by the fact that almost all projects require 2 telephone outputs and 2 internet outputs with constant unit cost.

Table 4.2. Difference of the mean in percentage

Case	Ss_15_10	Ss_20_10	Ss_25_30	Ss_25_20	Ss_25_20_10	Ss_30_42	Ss_30_36	Ss_65	Ss_70	Ss_70_80	Ss_75_10
1	-35%	21%	-16%	17%	37%	-6%	3%	6%	-22%	-23%	1%
2	-15%	26%	21%	24%	40%	6%	3%	26%	-30%	-28%	84%
3	2%	65%	-27%	42%	28%	-12%	3%	-13%	-44%	-28%	84%
4	-28%	-19%	-42%	98%		-29%	21%	4%	-42%	-18%	137%
5	88%	-1%	-18%	27%	30%	-19%	21%	25%	-32%	-22%	38%
6	6%	98%	-33%	10%	30%	1%	-15%	25%	-28%	-25%	177%
7	24%		40%	3%		3%	15%	37%	29%	-24%	43%
8	33%		18%	-8%		10%	9%	28%	-17%	4%	57%
9	-6%		-16%	34%		-18%	15%	33%	16%	-25%	84%
10	109%		60%	-9%		-27%	15%	36%	10%	-1%	43%
11	36%		-12%	-8%		1%	-19%	24%	4%	-18%	115%
12	-45%		66%	-26%	4%	3%	3%	8%	-38%	63%	-9%
13	-26%		95%	-23%	-6%	-13%	3%	3%	-48%	4%	-29%
14	23%		87%	-18%	-6%	-10%	9%		-39%	21%	-17%
15	-45%		62%	-34%	1%	-2%	-15%	7%	-38%	15%	24%
16	-22%	-14%	-16%	-15%	-24%	-13%	-3%	-27%	-16%	-36%	-53%
17	-61%	-6%	-32%	21%	-15%	-20%	21%	-2%	-23%	-23%	-29%
18	6%	-41%	-18%	-14%	-21%	-23%	21%	-23%	-10%	-26%	-59%
19	-67%	-21%	-25%	-31%	-14%	-4%	-15%	-23%	-7%	-30%	-17%
20	3%	24%	-13%	11%	8%	-3%	3%	16%	67%	-3%	-32%
21	-79%	48%	-2%	22%	10%	6%	3%	51%	77%	3%	-20%
22	-23%	5%	-13%	-5%	19%	17%	3%	35%	-7%	144%	-20%
23	-52%	-30%		67%	72%	-17%	21%	43%	72%	4%	3%
24	39%	-14%	-24%	11%	2%	-10%	3%	45%	45%	30%	-20%
25	-37%	-14%	-35%	-10%	14%	7%	-15%	30%	48%	8%	20%
26	6%	15%	53%	36%	-24%	-22%	-4%	-20%	-33%	-25%	-37%
27	8%	-16%	14%	24%	-30%	-19%	-4%	-9%	-51%	4%	-26%
28	54%	6%	-29%	13%	-20%	-9%	-16%	-13%	-40%	-19%	11%
29	16%	-3%	-8%	26%	-23%	13%	-21%	9%	-40%	-21%	-5%
30	-8%	24%	42%	-38%	7%	1%	3%	0%	37%	-37%	-41%
31	56%	-26%	7%	-32%	-9%	-9%	9%	11%	11%	-29%	-48%
32	-2%	15%	2%	-47%	31%	5%	-9%	0%	36%	-24%	-14%
33	-34%	-13%	62%	-50%	10%	21%	-9%	0%	-28%	-17%	-27%
34			26%	-10%	47%	50%	-23%	-36%	-28%	-35%	-12%
35	-23%		-35%	-16%	49%	73%	-36%	-17%	-16%	-30%	34%
36	-23%		7%	-24%	62%	-3%	-32%	-32%	-10%	-26%	30%
37	-16%	-1%	5%		-28%	1%	3%	-13%	30%	-53%	-56%
38	-20%	-32%	-25%		-27%	15%	-15%	0%	66%	-51%	-33%
39	1%	-44%	-34%		-40%	-12%	9%	-1%	0%	-47%	-55%
40	4%	-7%	-26%		-14%	4%	-9%	-12%	-5%	-41%	-22%
41	-33%	-35%	7%		-23%	21%	3%	-12%	-50%	-39%	-46%
46	-46%	-1%	-1%	15%	-10%	0%	3%	-11%	16%	50%	
47	37%	-32%	-17%	13%	-9%	21%	9%	-11%	-17%	61%	
48	-19%	20%	-27%	22%	9%	-8%	-3%	-26%	6%	66%	
49	-55%	-24%	-17%	11%	-12%	-2%	9%	-25%	-9%	55%	
50	-39%	27%	-3%	39%	2%	35%	9%	-11%	16%	50%	
51	-37%		-36%	-27%	-28%	0%	3%	-32%	34%	24%	-64%
52	-16%		-28%	-13%	-31%	-14%	-3%	-29%	26%	20%	-56%
53	32%			-46%	-28%	-1%	9%	-19%	17%	53%	-48%
54	-5%			-23%	-14%	4%	-9%	-32%	40%	48%	-22%
55	31%		-25%	-36%	-31%	-4%	9%	-34%	2%	40%	-48%
56	-6%		-23%	-26%	-23%	8%	-3%	-18%	66%	58%	-20%

4.3.6. Multi regression analysis

The second analysis conducted in order to find the cost influencing factors is a Regression Analysis, which tries to fit a linear model to the data and uses it to predict values of an outcome variable from one or more predictor variables. When several predictors are involved in the model, it's called a multiple regression and can be described by the following equation (Field, 2013).

$Y = C + b_1X_1 + b_2X_2 + \dots + b_nX_n$

In this equation, Y represents the total estimated cost, X_1, X_2, …, X_n represents the measures of distinguishable variables, these may help in estimating Y. C represent the estimated constant and all the b's represent coefficients that are estimated by a regression analysis. These coefficients depend on the availability of relevant data (Kim et al., 2004).

The MRA is selected because the standardized regression coefficient around the independent variable indicates the weight on the dependent variable (Field, 2013). In other words, the cost influencing factors can be discovered when setting up an MRA. Previous research showed that appropriate cases cost models based on regression analysis can provide a substantial improvement on existing methods of estimating, because several cases showed that cost predictions based on Regression Analysis were significantly more accurate than designers' early estimate (Mccaffer, 1999).

Therefore the aim of the Multiple Regression Analysis (MRA) is to determine the cost influencing factors for the set of construction activities, visualized in the WBS as discussed earlier. In order to do a MRA, the following data has been collected. The criteria for the data collection were based on the cost influencing factors found in the literature review.

- Gross floor area
- Number of tenders
- Month of the year 2014 the bid is established
- Breakdown of construction cost
- Type of hospital: university or not
- Municipality of hospital location (inside Cairo or outside Cairo)

In order to find a cost model that best describes the data collected requires the search for one variable or item of data that explains most of the variation in costs between the different schemas. It is likely that this variable has the highest correlation with costs. One important thing to keep in mind is that the greater the residual, the less accurate the model is (Mccaffer, 1999). Also, the model can contain any number of variables, until the best model possible is found. When this is the case, the residuals are made as small as possible. Nevertheless, the more variables included in the model, the more data is required to construct the model. The minimum number of data required is two or three times the number of variables included in the model according to Mccaffer (1999), nevertheless, Field (2013) suggest five times the number of variables.

In total four different MRA models are composed (Table 4.3.), all with a different dependent variable and the same independent variables. The independent variables are as follow: gross floor area, type of hospital, location, building month and number of tenders. The variables type of hospital and location are qualitative data and therefore require dummy variables (Table 4.4.)

Table 4.3. MRA models

MRA model	Dependent Variable
Total costs	Total costs related to the building works for the project (EGP)
CW	Total cost for all the construction works activities for the project (EGP)
MI	Total costs for all the mechanical installations activities for the project (EGP)
EI	Total costs for all the electrical installations activities for the project (EGP)

Table 4.4. Dummy variables

Variable	Description
Hospital Type	A dummy that equals 1 if the hospital type is university; o if otherwise
Location	A dummy that equals 1 if the hospital is located in Cairo; 0 if otherwise

Every model knows a total of 5 independent variables, in total there are 11 projects. The results of the regression could be used to test the following null hypotheses as shown in Table 4.5.

Table 4.5. Null Hypothesis

Ref.	Symbol	Hypothesis
1	Hospital Type	Type of hospital has no effect on construction cost
2	Location	Location of the hospital has no effect on construction cost
3	Building Month	Month of the year has no effect on construction cost
4	No. Tenders	Number of tenders has no effect on construction cost
5	GFA	Gross floor area has no effect on construction cost

There is one important note and that is that the formula, corresponding the different models, is only applicable for the same type of projects as used in the analysis. The outcomes of the regression analysis, the results, are discussed one by one. For this purpose, SPSS ANOVA is used to perform the MRA analysis. For each MRA model, the model significance is given as outcome of the ANOVA model and the parameter values of the independent variables are summarized.

MRA Total Costs

The ANOVA table (Table 4.6.1.) shows that the model with Total Cost as depend variable is significant. The F-statistic is 7,413 which mean that it is unlikely that all the variables have a zero coefficient. Next to this, the estimated values show only a significant *GFA* variable (Table 4.6.2.).

Table 4.6.1. ANOVA MRA total costs

ANOVA model	
F-	Sig.
7.413	.023*

*significant at 0.05 level

Table 4.6.2. Estimated values MRA total costs

Estimated values		
Variable	Beta	Sig.
Hospital type	.191	.345
Location	.209	.263
Building Month	.384	.076
No. Tenders	.365	.088
GFA	.628	.202*
Constant		.455

*significant at 0.05 level

MRA Construction Works (CW)

The ANOVA table shows that the model with Construction Works as dependent variable is significant (Table 4.7.1.). The F-statistics is 6.639, which means that it is unlikely that all the variables have a zero coefficient. Next to this, the estimated values show only a significant value for the variables *Building Month* and *GFA* (Table 4.7.2.).

Nevertheless the sig. level of the different variables shows the effect of each independent variable on the dependent variable. The outcome of this model a significant effect for the variable *GFA*. This means that the hypothesis 5 “Gross floor area has no effect on construction costs” can be rejected. It could be assumed that the *GFA* has a positive impact on the total costs. The higher the gross floor area, the higher the construction costs. Next to this the *Building Month* shows a significant value, which means that hypothesis 3 “Month of the year has no effect on construction cost” can be rejected. It could be assumed that the month of the year has an effect on the construction costs when discussing the costs for Construction Works.

Table 4.7.1. ANOVA MRA EW

ANOVA model	
F-	Sig.
6.639	.029*

*significant at 0.05 level

Table 4.7.2. Estimated values MRA EW

Estimated values		
Variable	Beta	Sig.
Hospital type	-.295	.186
Location	.388	.076
Building Month	.554	.028
No. Tenders	.299	.160
GFA	.740	.013*
Constant		.818

*significant at 0.05 level

MRA Mechanical installations

The ANOVA table shows that the model with Total Cost for Mechanical installations as depend variable is significant (Table 4.8.). The Sig. is 0.278 and larger than 0,05, what means that the model clarifies nothing. Next to this, the F-statistic is very low, 1.743, which means that it is very likely that all the variables have a zero coefficient. Therefore this model will not be discussed in more detail.

Table 4.8. ANOVA MRA Mechanical Installations

ANOVA model	
F-	Sig.
1.743	.278*

*significant at 0.05 level

MRA Electrical Installations

ANOVA table shows that the model with Electrical Installations as dependent variable is significant (Table 4.9.1.). The F-statistic is 29.513 which mean that it is unlikely that all the variables have a zero coefficient.

The outcome of this model shows a significant effect for the variables *Hospital Type, Location, No. of tenders and GFA* (Table 4.9.2.). This means that the hypotheses are assumed to be according the explanation in Table 4.10.

Table 4.9.1. ANOVA Electrical Installations

ANOVA model	
F-	Sig.
29.513	.001*

*significant at 0.05 level

Table 4.9.2. Estimated values Electrical Installations

Estimated values		
Variable	Beta	Sig.
Hospital type	.572	.002
Location	.292	.020
Building Month	.079	.422
No. Tenders	.202	.021
GFA	.521	.003*
Constant		.007

*significant at 0.05 level

Table 4.10. Results MRA Electrical Installations

Variable	Significant level	Sign	Hypothesis testing	Interpretation (other factors held constant)
Hospital Type	0.002	+	1, rejected	When the hospital type is a university hospital, the construction costs for electrical installations are higher.
Location	0.020	+	2, rejected	When the hospital is located inside Cairo, the costs for electrical installations are higher
Building Month	0.442	Irrelevant	3, not rejected	Month of the year has no effect on construction costs
No. Tenders	0.021	+	4, rejected	When the number of tenders is higher, the construction costs for electrical installations are higher
GFA	0.003	+	5, rejected	The higher the gross floor area, the higher the construction cost for electrical installations

In order to keep the regression model clear, the non-significant independent variables will be filtered from the model for the development of the software that will be discussed in section "4.2.2.3. Software Implementation".

With help of the MRA the cost influencing factors for a project can be identified, but next to this it can help in formulating ratios which can be used in a cost calculation tool. The MRA technique is used to calculate the attributes weight on the costs. The absolute value of the standard coefficient that is the output of the MRA model can be used as attribute weights for a cost calculation model that is project oriented (Jin et al., 2012). This could support future research into setting up a cost engineering structure for the Building Works processes for the medical equipment supplier. Before this step can be conducted, it is important to collect project data in a structured way, so that project comparison is possible. The process of structured data collection will be discussed in the next paragraph of this chapter, the development of an Information Delivery Manual.

4.4. Information Delivery Manual Development

In order to set up a good Information Delivery Manual, the several steps given by the buildingSMART Information Delivery Manual Guide to Components and Development Methods (2010) were followed (Figure 4.3.) The first step is process mapping, which resulted in a BPMN model of the relevant processes related to Building Works. The next step is formulating the exchange requirements, which can be found in the BPMN model. Next, functional parts are described, after which an exchange requirement model is prescribed with the help of setting business rules (Wix & Karlshøj, 2010).

The chosen development route for this research is "process discovery and data mining", because the Company Business case knows no initial presence of software or other exchange requirements. This approach is a linear sequence, with feedback between the different stages and is visualized in figure 4.4.

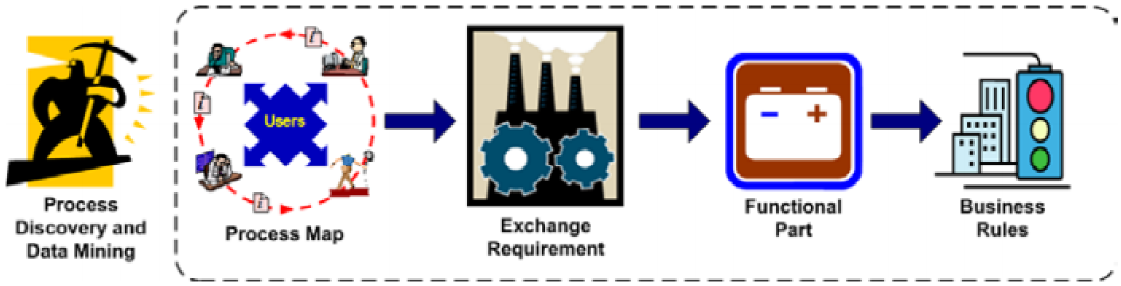


Figure 4.4. Process dicovery and data mining (Wix & Karlshøj, 2010)

The IDM approach is particular suitable for facilitating the identification of information items that are included in the IFC schema. The IDM consists of three parts; process maps (PM), exchange requirements (ER) and functional parts (FP) (Liu, et al., 2013).

4.4.1. Data mining process map

In order to get more understanding of the process related to the installation of large medical equipment in an existing hospital room, a questionnaire regarding the process was held among project managers from different countries. The questionnaire was conducted in order to gain insight in the process as it is right now. The IDM subject to this research is developed based on this qualitative data and will describe a BIM-based approach for this process.

The questionnaire was held on a global project manager workshop from the medical equipment supplier. Questions related to stakeholder involvement and templates regarding the cost calculation process were asked. In total 8 respondents were found to fill in the questionnaire, representing 6 different countries. The respondent consist of project managers and procurement specialist in the field and are considered as an expert panel. The outcome of the questionnaire is given in Appendix 5.

The first conclusion from this questionnaire is that all countries, expect for Italy, work with a pool of contractors, this pool is more or less the same for every project and contains 1-6 contractors that are asked to set up a quotation.

Next to this most countries, except for Swiss, ask one contractor for all three types of work, construction work, electrical installations and mechanical installations. The main focus of the project managers in these 6 countries lays on the equipment, the focus on BW only scores between 5-35%. When looking at the relationship between time, costs and quality, the answers variate between the different markets. Japan focuses to most on quality (70%), while Iberia only focuses for 20% on quality. Nevertheless, most markets focus more on time and costs than quality. This could be supported by the fact that negotiation about the offer always takes place expect when a detailed cost breakdown structure is provided.

When it comes to the involvement of the Project Manager in the process, the answers differ from “right from the first meeting with the client” till “after finishing the first draft for the equipment order”. Next to this, all the markets answered that the Project manager does the site visit, with or without the contractor.

The experts indicated that the process of request for quotation is transparent in their countries, except for France. This could be supported by the question what level of detail is used for the quotations, all experts indicated that the third level is used. This is the so-called Bill of Quantities, which separates the costs in quantities and unit prices. Nevertheless, the most experts have expressed that they would like to work with a more details level for setting up the quotations. A format that also includes labor hours, materials and equipment per activity.

4.4.2. Process Map

The first step in developing an IDM is setting up a process map, which is necessary to specify the processes in which the information requirements are involved. This process map provides a clear overview of the information that is necessary, as well as by what stakeholder the information should be deliverd and for what purpose the information should be used (Liu, et al., 2013). The Business Process Modeling Notation (BPMN), developed by the Object Management Group (OMG) is used for expressing the process map. The complete process is divided in two parts. Part I defines the processes from the “request of information” by the hospital, till the “order intake”, and discusses the complete contractor selection process for the building works related to the scope of work. Part II defines the process from “order intake” till “order closing”, and focusses on the processes occuring during the actual building works construction process.

The main stakeholder are visualized in the map and are as follows:

- Client: the hospital who wants to puchase medical equipment, contact with the client goes via the general manager of the hospital
- Account manager (AM): is responsible for the contact with the client and negotiation about the type of equipment.
- Project manager (PM): is responsible for the on time, within budget and according the expected quality installation of the medical equipment in th existing hospital room.

- Site planning (SP): the department of the medical equipment supplier that is responsible for the IFC model and the prefered room lay-out of the new situation in the existing hospital room.
- Procurement: this department is responsible for the selection of the contractor that gets the contract for the scope of work when it comes to building works. The main job of procurement is to support the propject manager in the selectionprocess for a contractor.
- Installation team (IT): take care of the installation of the medical equipment when the room is installation ready.
- Contractor: takes care of all the building works related activities that are necesarry befor the equipment can be installed.

The process will be discussed with the help of parts of the BPMN model, the entire model formulated in the IDM format as prescribed by buildingSMART can be found in Appendix 6.

Part I – Contractor selection installation medical equipment

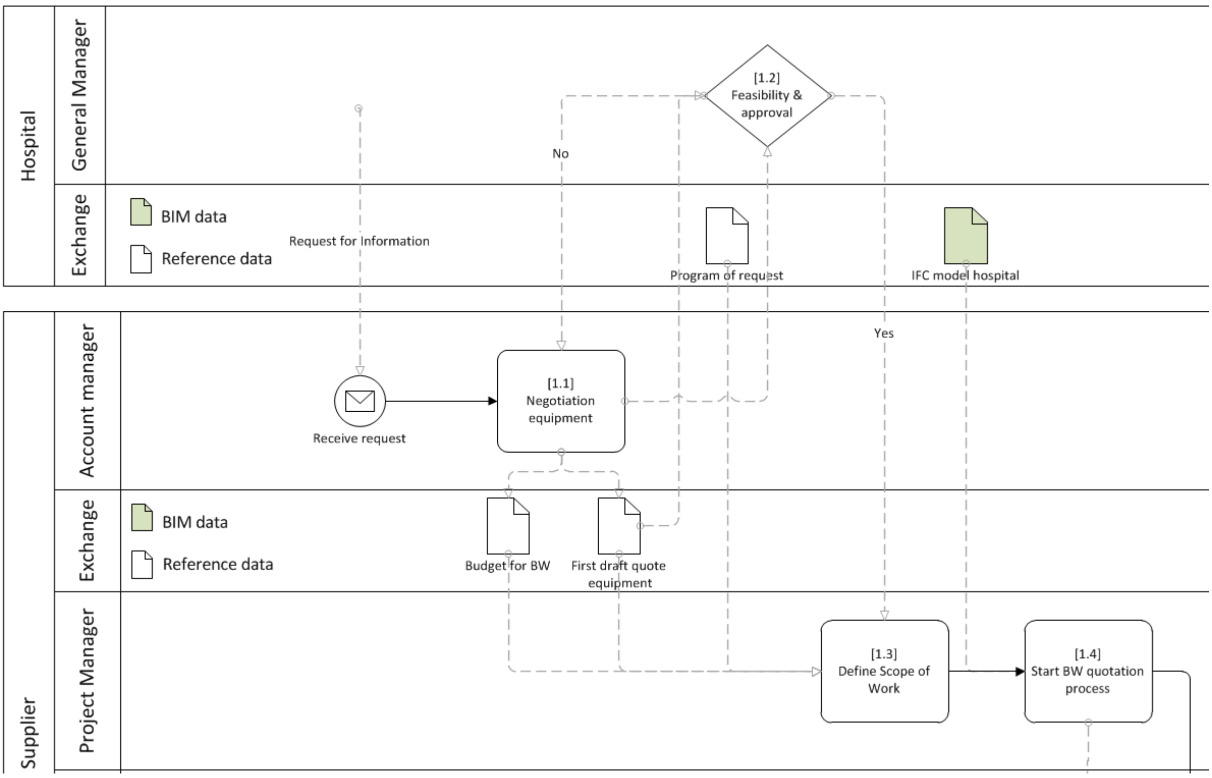


Figure 4.5. Part 1.1. BPMN model

The whole process of "The installation of an X-ray in an existing hospital room" starts with a request for information from the client sent to the account manager, to inform the medical equipment supplier that the hospital wants to purchase medical equipment. Documents related to this messages are *Program of request* and an *IFC model of the hospital*.

When the nogotiations about the medical equipment [1.2] is approved by the client [1.2], the task of the project manager is to define the scope of work [1.3], where after the quotation process for the selection of a contractor for the building works is startd [1.4].

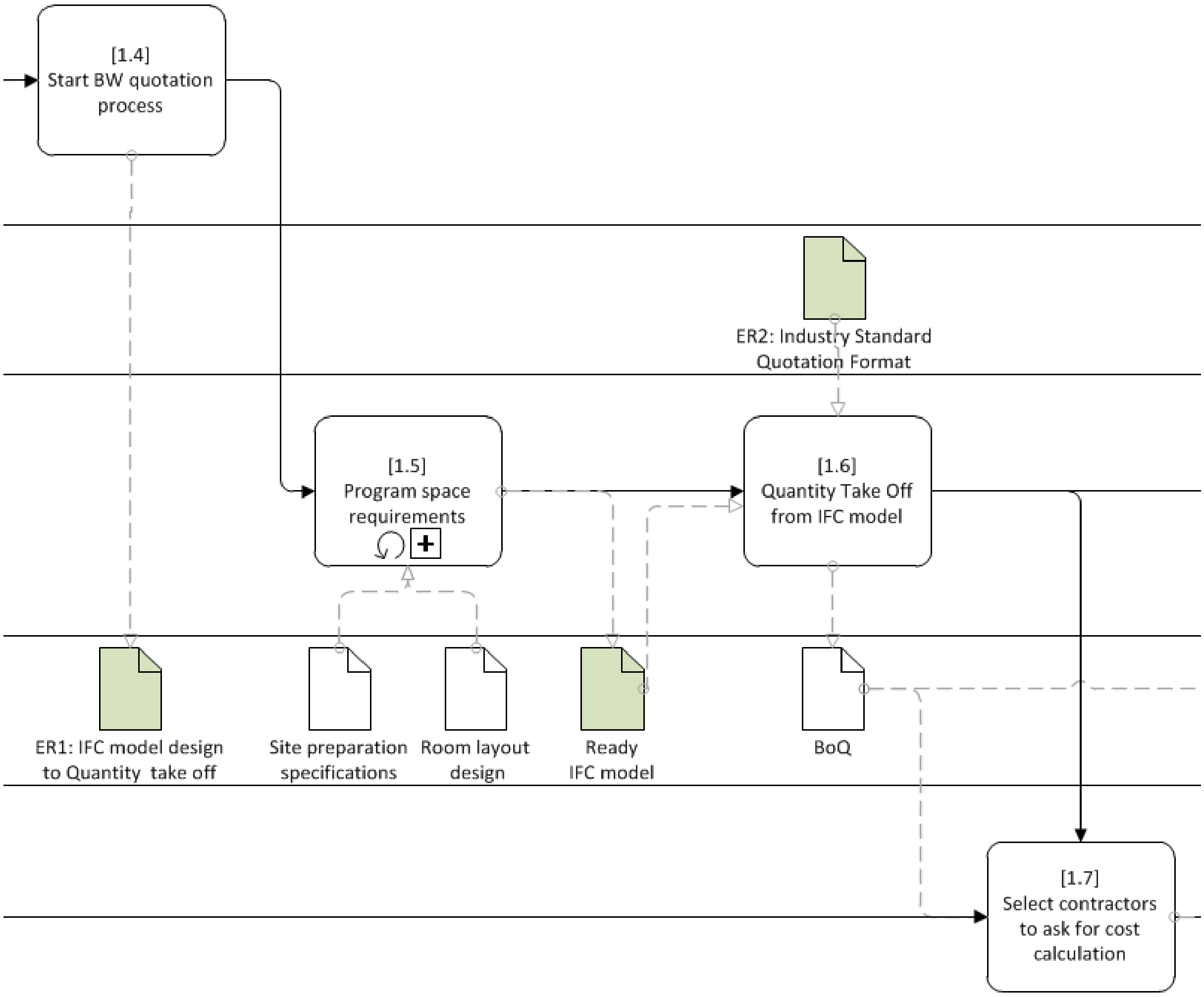


Figure 4.6. Part 1.2 BPMN model

The questionnaire showed that the project manager conducts a site visit befor involving contractors. Nevertheless, the new BIM-based approach make that this step can be exculded. The project manager informs site planning, who get started with adjusting the IFC-model, which is captured in the task *Program space requirements* [1.5] to the new situation [ER1]: the room including medical equipment. This is done with the help of the documents *site preparation specifications* and a *preferred room lay-out*. The output document of this process is an IFC model that is ready for quantity takeoff. Which forms the input for the task *quantity take off from IFC model* [1.6], which is conducted by site planning. The different tasks part of the BoQ are classified by a construction classification system [ER 2], which makes that the different projects can be compared with each other. The BoQ made with the help of the IFC-model is sent to the contractors, which are selected from the preferred supplier base by the department procurement [1.7].

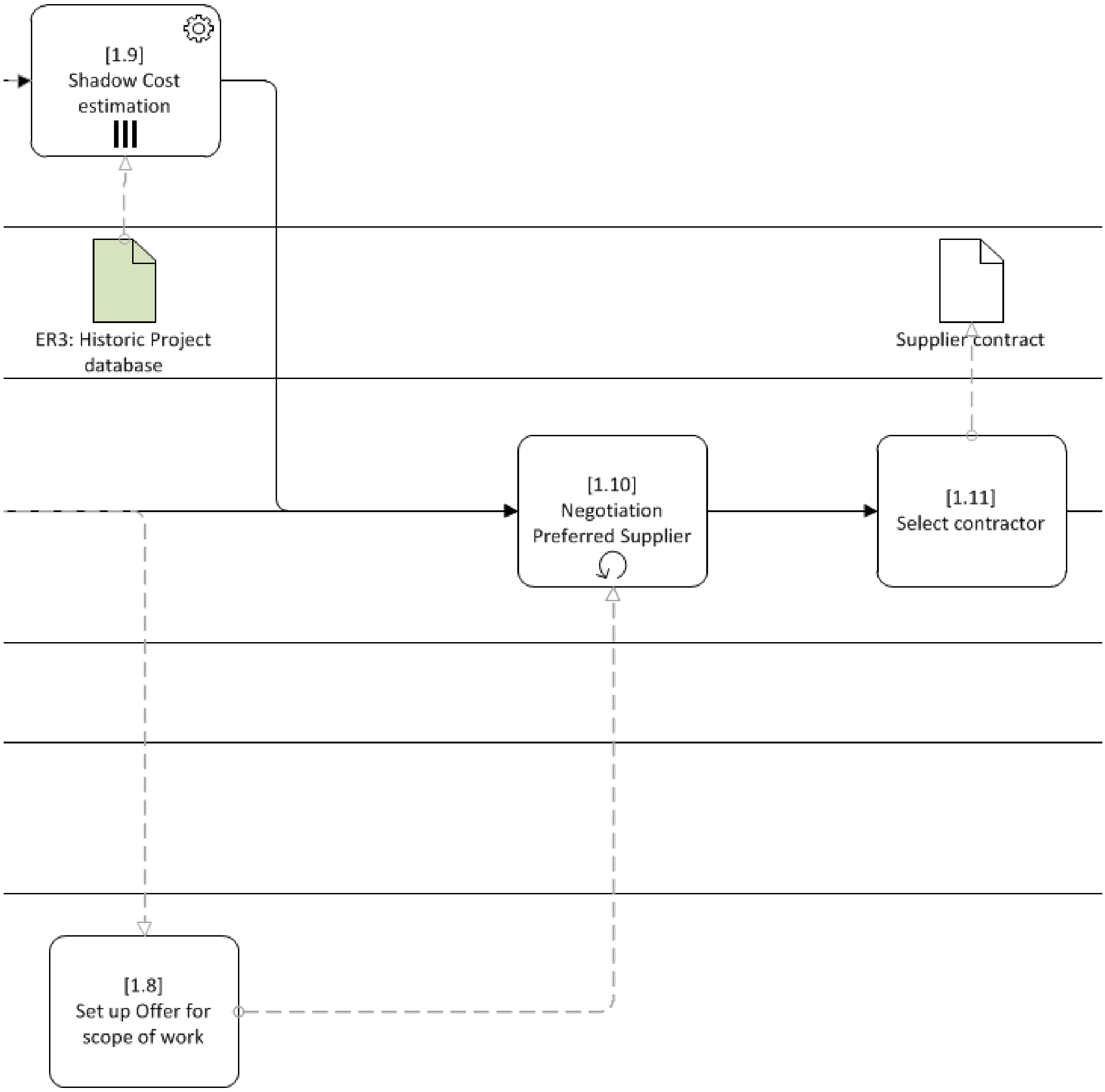
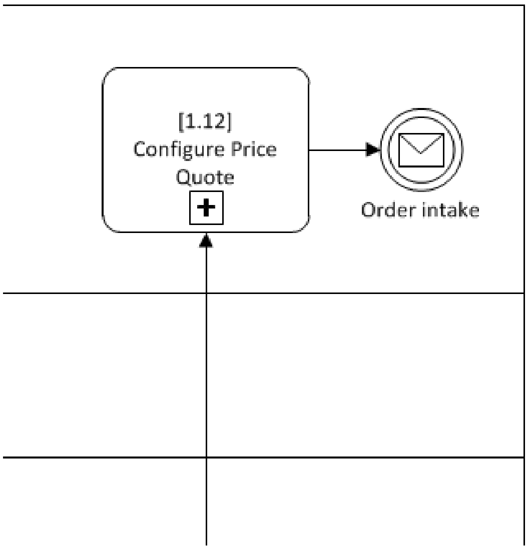


Figure 4.7. Part 1.3 BPMN model

The contractos set up their offer for the scope of work [1.8], while at the same time, the department site planning makes a shadow cost calculation for the scope of work [1.9]. This shadow cost calculation is set up with the help of historic projects which are stored in the project database [ER 3]. The offers from the different suppliers can be compared with the shadow cost calculation during the process of negotiation preffered supplier [1.10] which is done by procurement. When the negotiations are finished, a contractor is selected [1.11] which has a supplier contract as an ouput document.



When the contractor is selected, the process of configure price quote is conducted by the account manager. During this process the complete offer is checked by the acount manager together with the hospital. This process is part of the complete project managers blueprint and therefore not discussed in more detail in this report.

Figure 4.8. BPMN model part 1.4

Part II – Buidling works and installation of medical equipment

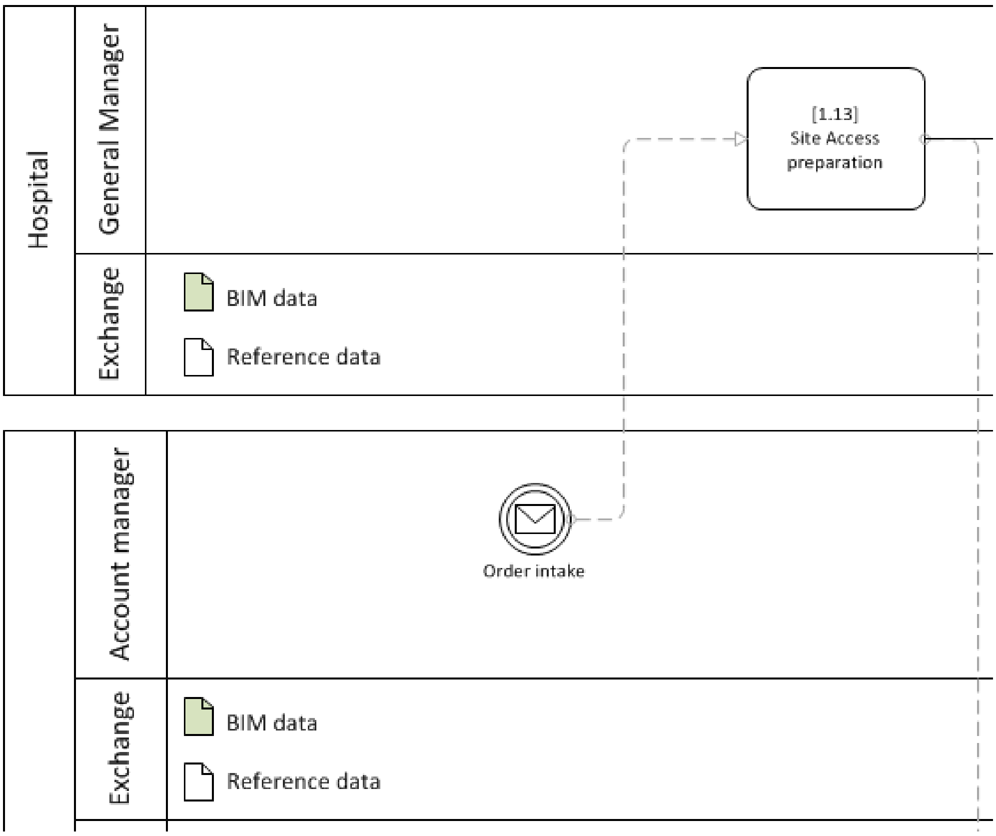


Figure 4.9. BPMN model part 2.1.

After order intake by the account manager, the hospital is responsible for making the site access ready for the contractor and the project manager [1.12].

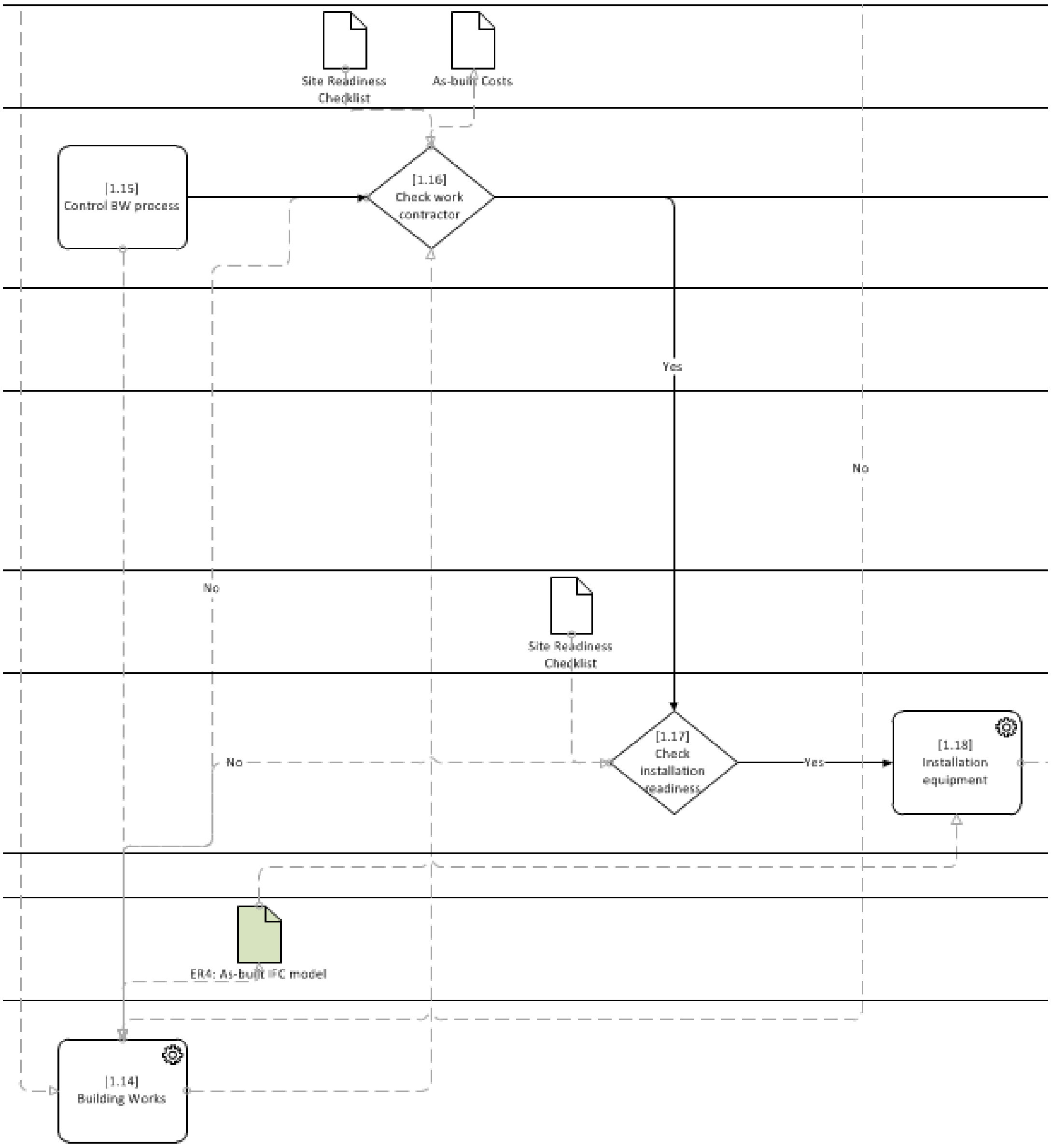


Figure 4.10. BPMN model part 2.2.

When the hospital made the site access ready, the contractor can enter the site and start the building works activities [1.13], which is a process that is constantly controlled by the project manager to check if the contractor in on time, within the budget and by the quality requirements of the client [1.14]. When the contractor has finished the building works, it should revise the IFC model to the As-built IFC model [ER 4], next to this, the project manager needs to do an installation readiness check [1.15], with the help of the documents *site readiness checklist* and defines the *as-built costs*. When the site is not installation ready, the contractor can get back to work. When the site is approved ready by the project manager the installation team can do an installation readiness check [1.16], with the same possibilities as the previous check. When the outcome of the check is yes, the installation team can start the installation of the equipment [1.17].

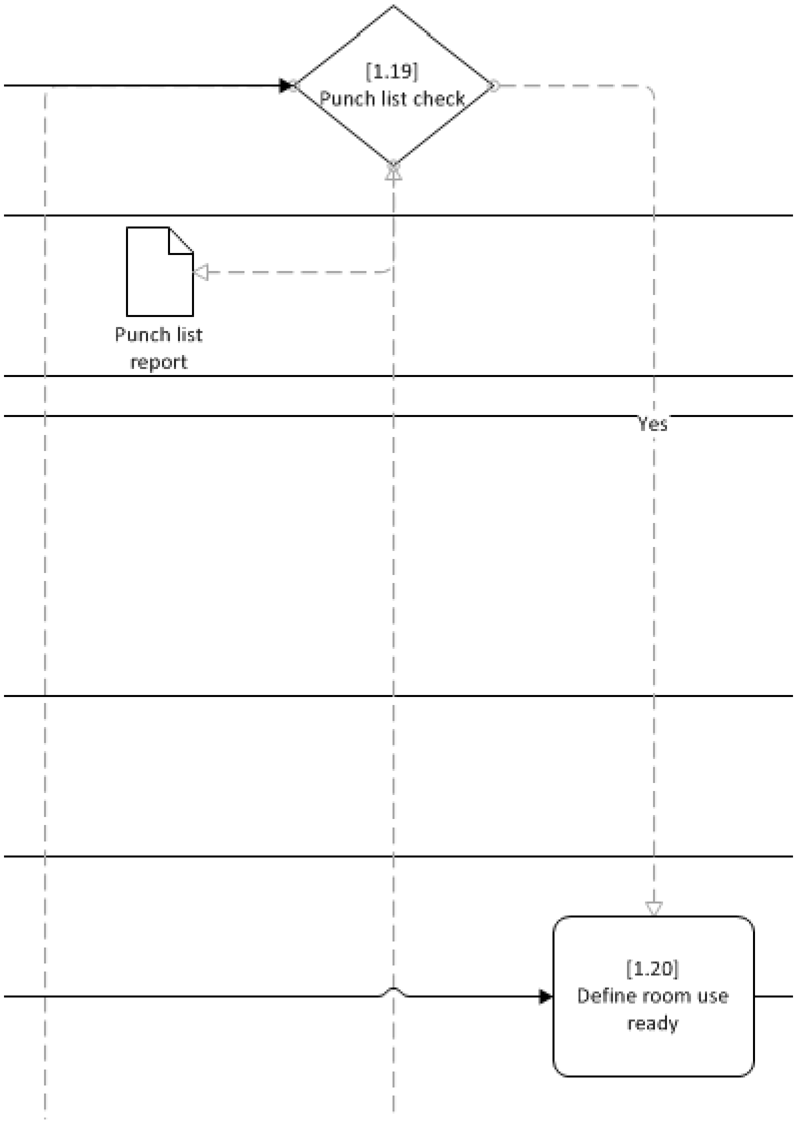


Figure 4.11. BPMN model part 2.3.

When the installation of the equipment is finishes, the hospital needs to conduct a punch list check [1.18], which is a check to find out what re-work by the contractor is necessary. During the installation of the equipment demage to the room could have been cause by the installation team. For example small holls in the walls or drillings in the floor that need to be fixed. The outcome of a *punch list report*, which stated what work needs to be done by the contractor. When this is complete, the project manager can define the room use ready [1.19].

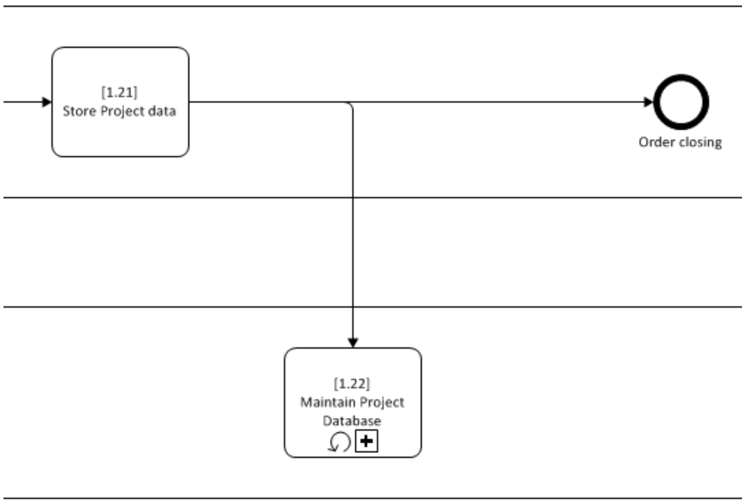


Figure 4.12. BPMN model part 2.4.

After the room is defined use ready, the project data needs to be stored in the project database [1.20], which needs to be maintained [1.21] by the department site planning. The final step is order closing.

4.4.2. Exchange Requirements

This section will describe the different Exchange Requirements (ER) related to the process, together with its functional parts (FP), according to the IDM Guide to components and Development Method developed by buildingSMART (2010) (Wix & Karlshøj, 2010). The FP for this IDM are based on the buidlingSMART standard, IFC4 (2013).

- ER 1: IFC model design to quantity take-off
- ER 2: Industry classification system: mapping table
- ER 3: Project cost database
- ER 4: Revised IFC model

ER 1: IFC model design to Quantity Take-off

Table 4.11. Project stage implementation exchange requirement

Project Stage	0	Portfolio requirements	
	1	Conception of need	
	2	Outline feasibility	
	3	Substantive feasibility	
	4	Outline conceptual design	✓
	5	Full conceptual design	✓
	6	Coordinated design and procurement	✓
	7	Production information	✓
	8	Construction	
	9	Operation and maintenance	
	10	Disposal	

Overview

The ER 1 “IFC model design to Quantity Take Off” is part of the process of cost calculations for Building Works (BW), which are all the construction works necessary in order to make a room installation ready when a hospital wants to install X-ray equipment. These Building Works activities can be divided into four types of works; construction works, mechanical installations, electrical installations, and facilities. BW are construction works and are therefore conducted by a contractor. Therefore this ER should function as a predefined way for modelling an IFC model for quantity take off to atomically generate bill of quantities (BoQ) with the help of CAD software. This BoQ can be sent to the contractors from the preferred supplier base to ask for their offer.

The principle of this exchange requirement is to facilitate developing an IFC model for the room including building works. The building works necessary for the equipment to function are prescribed in the document *Site Preparation Specifications*. The additional requests of the hospital are documented in the *Program of Request*. Because the additional requests differ per project, only the *Site Preparation Specifications* are considered in ER1.

Information Description

Information required concerning the external library reference includes:

- Name of the library
- Version number of reference
- Date
- Publisher or authority responsible for making it available

Information Requirements

Preconditions

Before this ER can be used by the involved stakeholders, some information needs to be collected and extracted from different documents and activities.

- Program of request provided by the hospital
- Existing IFC model provided by the hospital
- Negotiation about the type of equipment is done
- Budget for BW is set
- Site preparation specification document for the specific type of equipment

Information Units

The information requirements consists of several information units, which are shortly discussed in this section. The complete information requirements list including functional parts can be found in Appendix 7.

Project

✓	Project name *This is the project identifier*
✓	Client information of the hospital *This is the contact information of the client which is for this type of projects the hospital; hospital name, contact person.*
✓	IFC model author information *These are the contact details of the IFC modeler, which can be contacted for questions related to the IFC model*

Building

✓	Building identification *This is the building name, i.e. hospital name*
✓	Description *This is optional and a space for any descriptions related to the building*
✓	Building type *This is the classification of the building according to Uniclass2*
✓	Building storey *This indicates all information related to the location of the hospital room in the hospital.*

Space

✓	Space identification *This is the space name, i.e. hospital room number*
✓	Description *This is optional and a space for any descriptions related to the space*
✓	Space type *This is the classification of the space according to Uniclass2*
✓	Space measurements *This indicates all measurements related to the space; area, length, height*
✓	Covering *This indicates the covering of the floor and ceiling*
✓	Space ceiling framing *This defines the load the ceiling framing needs to be able to handle, and the static deflection*

Wall

✓	Wall identification *This is the wall identification*
✓	Wall type *This is the classification of the wall according to Uniclass2*
✓	Wall measurements *This indicates all measurements related to the wall; area, length, height*
✓	Internal wall identification *Industry classification, measurements and covering type*
✓	Wall openings *Industry classification, measurements and identification*
✓	Door *Industry classification, measurements and identification*
✓	Window *Industry classification, measurements and identification, including information related to the window frame*

Sanitary

✓	Sanitary identification *This is the sanitary name, i.e. toilet*
✓	Sanitary type *This is the classification of the sanitary according to Uniclass2*
✓	Sanitary measurements *This indicates all information related to the measurements of the sanitary*

HVAC system

✓	HVAC system identification *This is the HVAC system name*
✓	HVAC system type *This is the classification of the HVAC system according to Uniclass2*
✓	HVAC system definition *This indicates all information related to the casing, and space temperature requirements, space humidity and heat emission requirements.*

Electrical systems

✓	Electrical system identification *This provides information about power, circuit breaker and cable carrier*
✓	Electrical system type *This is the classification of the electrical system according to Uniclass2 of the different parts of the electrical systems.*
✓	Electrical system measurements *This provides all the requirements of the electrical systems when it comes to primary voltage of the systems, rated current, and the measurements and covering of the cable carriers.*

Lighting system

✓	Lighting system identification *This is the Lighting system name*
✓	Lighting system type *This is the classification of the lighting system according to Uniclass2*
✓	Lighting system measurements *This indicates all information related to the lighting system, i.e. contributed luminous*

Communication system

✓	Communication system identification *This is the communication system name, the outlet type*
✓	Communication system type *This is the classification of the communication system according to Uniclass2*
✓	Communication system measurements *This indicates all information related to number of pluggable outputs and the number of sockets*

Furniture

✓	Furniture identification *This is the furniture name, i.e. cabinet*
✓	Furniture type *This is the classification of the furniture according to Uniclass2*
✓	Description *This is optional and a space for any descriptions related to the furniture*
✓	Furniture type measurements *This indicates all information related to the measurements of the furniture; length, height, depth.*

ER 2: Industry Standard as quotation format

Table 4.12. Project stage implementation exchange requirement

Project Stage	0	Portfolio requirements	
	1	Conception of need	
	2	Outline feasibility	
	3	Substantive feasibility	
	4	Outline conceptual design	✓
	5	Full conceptual design	✓
	6	Coordinated design and procurement	✓
	7	Production information	✓
	8	Construction	✓
	9	Operation and maintenance	✓
	10	Disposal	

Overview

The ER 2 “Industry standard as quotation format” is part of the process of cost calculations for BW and forms the second ER for this IDM. An industry standard classification system is necessary to make comparisons between the different quotations given by different contractors possible. This ER should function as a predefined way of setting up BoQ to ask different contractors for their quotation and is therefore based on the WBS as defined in the dataset analysis section.

According to Zhiliang et al. (2011) generating automatic BoQ of the design is not that easy. In order to make the use of the IFC model for quantity take-off successful, there are some rules. One of these rules is that a proper industry standard classification system is required for defining the objects in the IFC model. In that case, the monitoring rules are able to recognise the objects in the model (Zhiliang et al., 2011). The literature review discussed several classification systems and concluded that Uniclass2 was the most suitable classification system to use for this type of re-construction projects. Based on the fact that this classification is alligned with ISO 12006-2 and that it is developed in the UK, and therefore written in English and is a unified system. Next to this it has a clear classification for hospital projects and a broad material defintion.

The hierarchy of Uniclass2 presented in table 4.13. shows that the building consisits of entities, which can be divided into activities, spaces and elements.

The spaces and elements can further be defined in systems. The systems can further be defined by products. The product level is the materialization level.

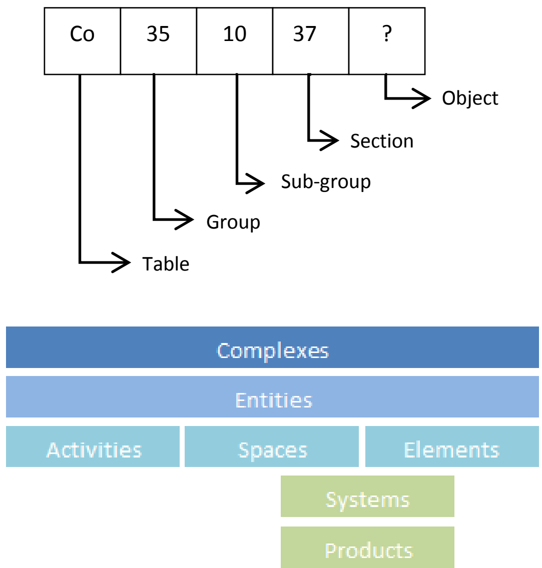
Table 4.13. Tables in Uniclass2

Table reference	Title
Co	Complexes
En	Entities
Ac	Activities
Sp	Spaces
EF	Entities by Form
Ee	Elements
Ss	Systems
Pr	Products
Zz	CAD
PP	Project Phases

Table 4.14. shows an example of the classification of the hospital room where the X-ray is going to be installed. The complete code for this classification is AC_35_10_37. The classification is unified from the complexes level till the product level. As can be seen by the classification code for the X-ray room, the code of Uniclass2 consists of 4 levels of detail; group, sub group, section and object.

Table 4.14. Unified classification of Hopsital room by Uniclass2

Co	Complexes
Co_35	Medical, health and welfare complexes
Co_35_10	Health complexes
Co_35_10_37	Large single Health Complexes
En	**Entities**
En_35	Medical, health, welfare and sanitary entities
En_35_10	Health entities
En_35_30_10	Large single health buildings
Ac	**Activities**
Ac_35	Medical, health, welfare and sanitary activities
Ac_35_10_18	Medical activities
Ac_35_10_18	CT and other scanning
Sp	**Spaces**
Sp_35	Medical, health, welfare and sanitary spaces
Sp_35_10	Medical spaces
Sp_35_10_51	CT and other scanning rooms
Ss	**Systems**
Ss_75	Signage, fittings, furnishings and equipment
Ss_75_50	Medical, health, welfare and sanitary systems
Ss_75_50_35	Healthcare imaging systems



Projects related to the installation of large medical equipment in existing hospitals are project in a detailed project phase, which means that all systems should be modelled. For this reason the classification of the table Ss-Systems can be used to classify the different building works activities.

The extraction of the right quantities is a combination of the Unit of Measurement, defined by Uniclass2 and the Quantity Sets and qualitative attribute entity definition of IFC4. The required quantities can be found in visualized in ER2 (Appendix 8).

Information Description

Information required concerning the external library reference includes:

- Name of the classification system library
- Version number of classification system library
- Release date of the classification system library
- Publisher or authority responsible for making it available

Information Requirements

Preconditions

Before this ER can be used by the involved stakeholders, some information needs to be collected and extracted from different documents and activities.

- Existing IFC model is adjusted to the to-built situation
- The classification system can be added to the IFC model for the different systems and building works activities.

Information units

The classification system is identifed by *IfcClassification* within the IFC model. The following attribute definition is required to structure this in a good way (Table 4.15), to make clear that everybody understands the classification system used. This format is defined for this ER and can be found in Appendix 8.

Table 4.15. attribute definition IfcClassification (buildingSMART, 2013)

Source	Source (or publisher) for this classification
Edition	The edition or version of the classification system from which the classification notation is derived
EditionDate	The date on which the edition of the classification used became valid. NOTE: the indication of edition may be sufficient to identify the classification source uniquely but the edition dat is provided as an optional attribute to enable more precise identification where required
Name	The name or label by which the classification used is normally known
Contains	Classification items that are classified by the classification

An example for the dataset of Egypt is given in Appendix 9. Here the Uniclass2 code is provided per activity. Most of the time this is a combination of a code for the system which is specified in terms of product classification, material use, with a code from the Uniclass2 table Products.

Next to this the Quantity definition of IFC release is provided and the corresponding attribute definition and quantity type. Finally this list provides information about the type of quantity, if it is and identification component or a counting component.

ER 3: Project database for cost comparison

Table 4.16. Project stage implementation exchange requirement

Project Stage	0	Portfolio requirements	✓
	1	Conception of need	✓
	2	Outline feasibility	
	3	Substantive feasibility	
	4	Outline conceptual design	✓
	5	Full conceptual design	✓
	6	Coordinated design and procurement	
	7	Production information	
	8	Construction	
	9	Operation and maintenance	
	10	Disposal	

Overview

The ER 3 “Project database for cost comparison” is part of the process of cost calculations for BW and forms the third ER for this IDM. This project cost database should function as a historic reference database and therefore some cost indicators should be considered in the database design. This ER defines the design of the database and information requirements.

For Building Works related projects it is necessary to create a data warehouse to make the collected IDM information exchanges, and business knowledge available. The first important step for the development of a data warehouse is identifying the data that will be uploaded to the warehouse (Rujirayanyong & Shi, 2006). This could be done according to two approaches, need-based or availability-based approach. This research uses the need-based approach because no cost-engineering database currently exists within the company for this type of project and the purpose is to indicate cost influencing factors. The findings from the literature review regarding “cost influencing factors in the construction industry” will provide the first input for the need-based data collection. The construction industry has a project-oriented nature, which results in the fact that the data warehouse developed in this research should be project-oriented (Rujirayanyong & Shi, 2006), and is functions as a decision support system.

Information requirements

The development of a database plays an important role in the whole information management process within a project, subject to this research. When the quantities are extracted from the BIM model codified according the Unicalss2 system, capturing this information in such a way that analysis can be done is necessary. Therefore the following database design is made (Figure 4.13). The main purpose of this database is gaining more insight in the costs related to the project and detecting cost influencing factors. Due to the high level of standardization of these type of projects, it is decided to classify the activities according to the *Systems* table of Uniclass2.

The literature review discussed the thoughts on cost estimation formulated by Kim et al. in their research conducted in 2012. These researchers formulated that project information is very important when it comes to cost estimation based on historic projects (Kim et al., 2012). This will therefore be the starting point for the database design. The literature review also discussed cost influencing factors in the construction industry, some of them were tested for this type of project. These factors all appeared to have some influence on construction costs and therefore should be considered in the database design.

Cost influencing factors:

- Gross floor area project
- Type of hospital
- Location of the hospital
- Number of tenders for this project
- Project date

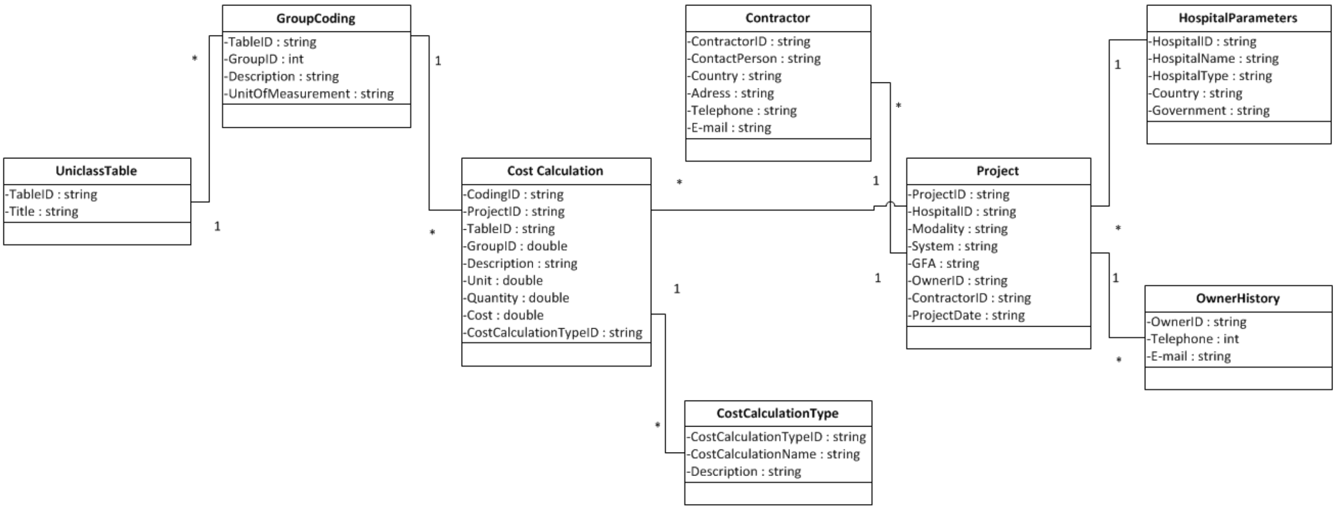


Figure 4.13. UML diagram project cost database

Nevertheless, the literature review showed that there are many more cost influencing factors, and therefore a more complex database design is favorable (Figure 4.14.). The impact on costs of these factors for this type of project is not proven yet, because no information about this was available. But when collecting information about these parameters, MRA can be used to indicate if the parameters are influencing the costs or not.

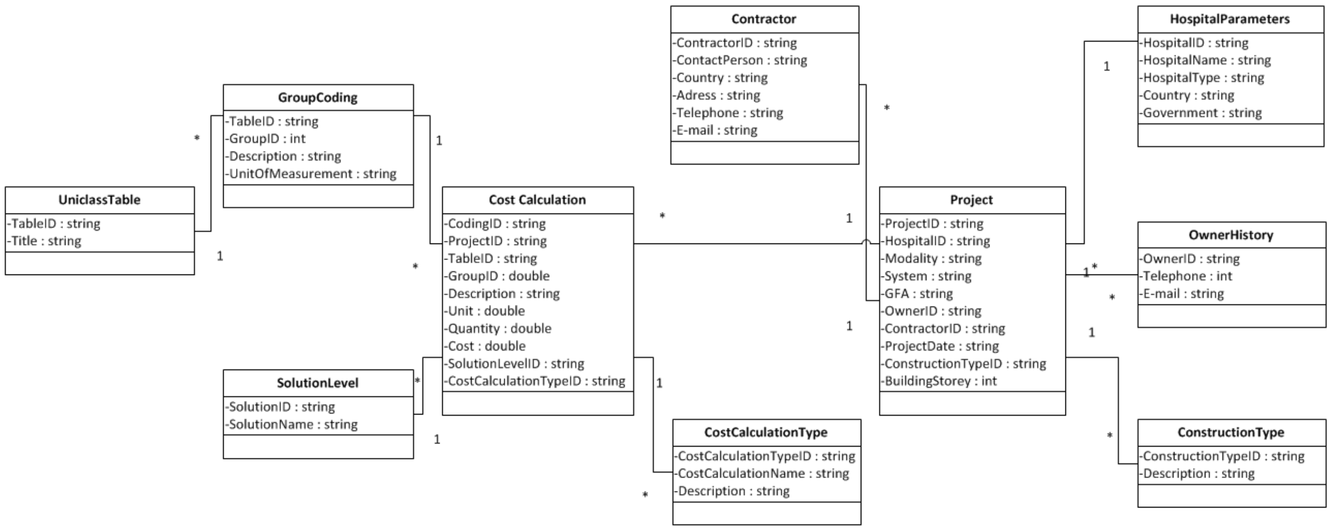


Figure 4.14. Favorable UML-diagram project cost database

Information Units

Hospital Parameters: there are several hospitals in one country, but it could be possible that one hospital is related to more projects, therefore a table with all hospital parameters is the first table in this database. This contains information about the hospital that is the same for every project within the hospital; name, type, country and government.

Project: contains information about every project, necessary to find reference projects in order to set up a cost estimation, to start with the modality type of the equipment that will be installed. Every type of modality requires their own set of building works, therefore this is an important indicator. Next the type of system, because there are some small variances within the building works requirements between the different system types. The gross floor area of the room, the construction type of the hospital, the OwnerID and the ContractorID. For one project, more tenders can be asked to set up a quotation.

Construction type: this table is an enumeration of the different construction types, and is linked to the project table, because a hospital can consist of several buildings, every building can have its own construction type.

Owner ID: includes all the information about the owner of the project, most of the time the project manager.

Contractor: for every project, between 3 and 6 contractors are asked for their tender. Within this table it is possible to select the type of quotation; tender quotation, shadow quotation, or as-built quotation. Information about the Quotation Types can be found in the Quotation Type table.

Uniclass Table: contains the different tables part of the Uniclass2 classification system and is the first level of detail for coding the different building works activities.

Group Coding: contains all the codes that could occur within one table of the Uniclass2 classification. This table functions as the mapping list from the IFC model to the database.

Solution Level: with solution level is meant the level of quality of the activity. There are three types, a high end solution, medium- or low end solution. The costs are depending on the solution level and are therefore interesting to collect.

Cost Calculation: this is the table where all the tables come together, and summarizes the cost per project number and tender. Next to this the quantity and a description of the work is provided in this table.

A prototype version of this database is built in Microsoft Access 2010 and filled with on example project from the set of case studies. Appendix 9 shows the translation of the Egyptian project to the Uniclass2 classification. The implementation requirements of the database are visualized in Table 4.17.

Table 4.17. Implementation database design

Type of information	Information Needed	Required	Optional	Data type	Units
Project					
	Identification	X		String	n/a
	Client information		X	String	n/a
	Model Author		X	String	n/a
	URL for Quantity report (BoQ)		X	URL	n/a
	URL for cost report		X	URL	n/a
	URL for cost comparison report		X	URL	n/a

ER 4: Revision model

Table 4.18. Project stage implementation exchange requirement

Project Stage	0	Portfolio requirements	
	1	Conception of need	
	2	Outline feasibility	
	3	Substantive feasibility	
	4	Outline conceptual design	
	5	Full conceptual design	
	6	Coordinated design and procurement	✓
	7	Production information	✓
	8	Construction	
	9	Operation and maintenance	✓
	10	Disposal	

Overview

The ER 4 "Revision IFC model" is part of the process of cost calculations for Building Works and forms the last ER for this IDM. The revision version of the IFC model should contain information about the as-built situation, to make the information in the project cos database complete.

The as-built conditions of a project are according to Akinci and Boukamp (2002) necessary for project control and for minimization of delays caused by late detected defects at the construction sites (Akinci & Boukamp, 2002). These researchers also discuss the fact that the storage of this as-built conditions can, just like the detailed design model, be stored in an IFC model. Nevertheless, to prevent information loss, it is necessary to save both models in different files, otherwise the information of the detailed design will be overwritten (Akinci & Boukamp, 2002).

Information requirements

The complete information requirements can be found in Appendix 10.

Preconditions

Before this ER can be used by the involved stakeholders, some information needs to be collected and extracted from different documents and activities.

- Existing IFC model is adjusted to the to-built situation
- Quotations of the contractor who was given the contract for the project is collected in the project cost database.
- The building works activities are finished

Information units

Material defintion can be done with the help of property sets or by IfcMaterial and are therefore defined in ER1 and ER4, collumn *IFC model Representation*. The material definition should be updated in the revised IFC model.

Next to material definition, it is necessary to gain insight in the labour hours related to specific activites. This type of information can be saved in the IFC-model, with the help of *IfcLaborResource*. The goal of this information object is to identify the skills that are required or used for a particular activity. The types of labor categories can be found under *IfcLaborResourceTypeEnum* and types relevant for this type of project can be found in Table 4.19. The intention of the enumeration is to identify the primary purpose of a labour resource, therefore only high-level categories are being considered (buildingSMART, 2013).

In order to make it possible to capture the schedules work and scheduled costs, together with the actual work and the actual cost, it is important to both specify them in the IFC-model. Therefore both Property sets can be found in Appendix 10. in collumn IFC cost and labour resources.

First the type of work is specified by one of the enumerations from *IfcResourceTypeEnum*, next the mapping path to the information required for cost and labour hour control is specified, together with the datatype as shown in Table 4.20.

Table 4.19. Enumeration IfcLabourResourceTypeEnum (buildingSMART, 2013)

Enumeration	Definition
Carpentry	rough carpentry including framing
Drywall	gypsum wallboard placement and taping
Electric	electrical fixtures, equipment, and cables
Finishing	finish carpentry including custom cabinetry
Flooring	carpet, tile, terrazzo, wood, or other flooring
HVAC	Heating and ventilation fixtures, equipment, and ducts
General	General labor not requiring specific skill
masonry	laying bricks or blocks with mortar
Painting	Applying decorative coatings or coverings
Paving	asphalt or concrete roads and walkways
Plumbing	plumbing fixtures, equipment, and pipes
Steelwork	erecting and attaching steel elements
Surveying	Determining positions, distances and angles
User defined	user-defined resource

Table 4.20. Property Set (buildingSMART, 2013)

Name	Property Type	Property Data	Property Data	Definition
ScheduleWork	P_referencevalue	IfcTimeSeries	IfcDuration	The scheduled work on behalf of the resource allocation
Actual Work	P_referencevalue	IfcTimeSeries	IfcDuration	The actual work on behal fof the resource allocation
ScheduleCost	P_referencevalue	IfcTimeSeries	IfcMonetaryMeasure	The budgeted cost on behalf fo the resource allocation
ActualCost	P_referencevalue	IfcTimeSeries	IfcMonetaryMeasure	The actual cost on bahalf of the resource allocation

Next to this, the quantities of the Labour recourses can be defined by *Qto_LaborResourceBaseQuantities* and are summarized in Table 4.21. (BuildingSMART, 2013).

Table 4.21. Qto_LaborResourceBaseQuantities (buildingSMART, 2013)

Quantity	Quantity Type	Defintion
StandardWork	Q_Time	Work that is performed at regular times, up to a particular limit after which overtime rates may apply
OvertimeWork	Q_Time	Work that is performed after exceeding a particular limit such as hours per day and/or hours per week, after which company or municipal policy requires a different rate to apply. Note: Policies for when overtime takes effect are the responsibility of the user or application; they are not modelled in IFC

4.4.3. Software implementation strategy IDM

In order to make the IDM operational, a software application is necessary, to facilitate a platform for the four different ERs in such a way that they are accasible for the different stakeholders. In other words the application should make it possible to exchange information according to the protocols established by the ERs and at the stage in the process that have been identified in the process map (Wix & Karlshøj, 2010). Therefore this section will first discuss the userinterface requirements for the database, where after the requirements related to the entire web application will be displayed.

User interface requirements database
The database is set-up in Microsoft Access 2010, which makes it possible to publish the database on the web, which requires a user interface. Before displaying this user interface, there are some activities that the user should be able to perform within the database.

- Enter new hospitals
- Enter new projects
- Enter the cost and quantities related to those projects
- Choose a cost estimating level
- Easily compare different quotations for 1 project
- Cross project comparison; related to project parameters

Select queries are implemented in the database to ask questions to the database. For example selecting only the cost calculations from one specific contractor. Or selecting only the costs for one typical activity. It is also possible to search for projects based on certain criteria with the help of queries. For example only selecting projects related to university hospitals or projects related to the installation of a specific type of system.

Requirements web-application

- The application will serve the PM, SP and contractors in the process
- The application should be able to serve the guidelines, regarding the rules for setting up de IFC-model (ER1), the rules for generating the BoQ from the IFC model (ER2), and the rules for setting up the Revised IFC-model (ER4).
- The application should facilitate the cost-database (ER3).
- The database contains all the information. In order to do cost-modelling analysis as performed in the section "quantitative analysis" of this report, a link to a Statistical Software Package is required. The pre-defined regression models, for all the different activities in the model, can be calculated within just one click.
- Weighing factors are the out-put of the regression analysis, these factors can be used to do future shadow cost-estimations.

The web-interface in figure 4.15. shows an example of how the software should look like.

The Process map is located on the first page of the web-interface. When clicking on the ER in the process map, the user gets directly linked with the ER menu, where all the ERs are located in the form of different tabs. When clicking the tab of ER3, the user is directly transferred to the cost database.

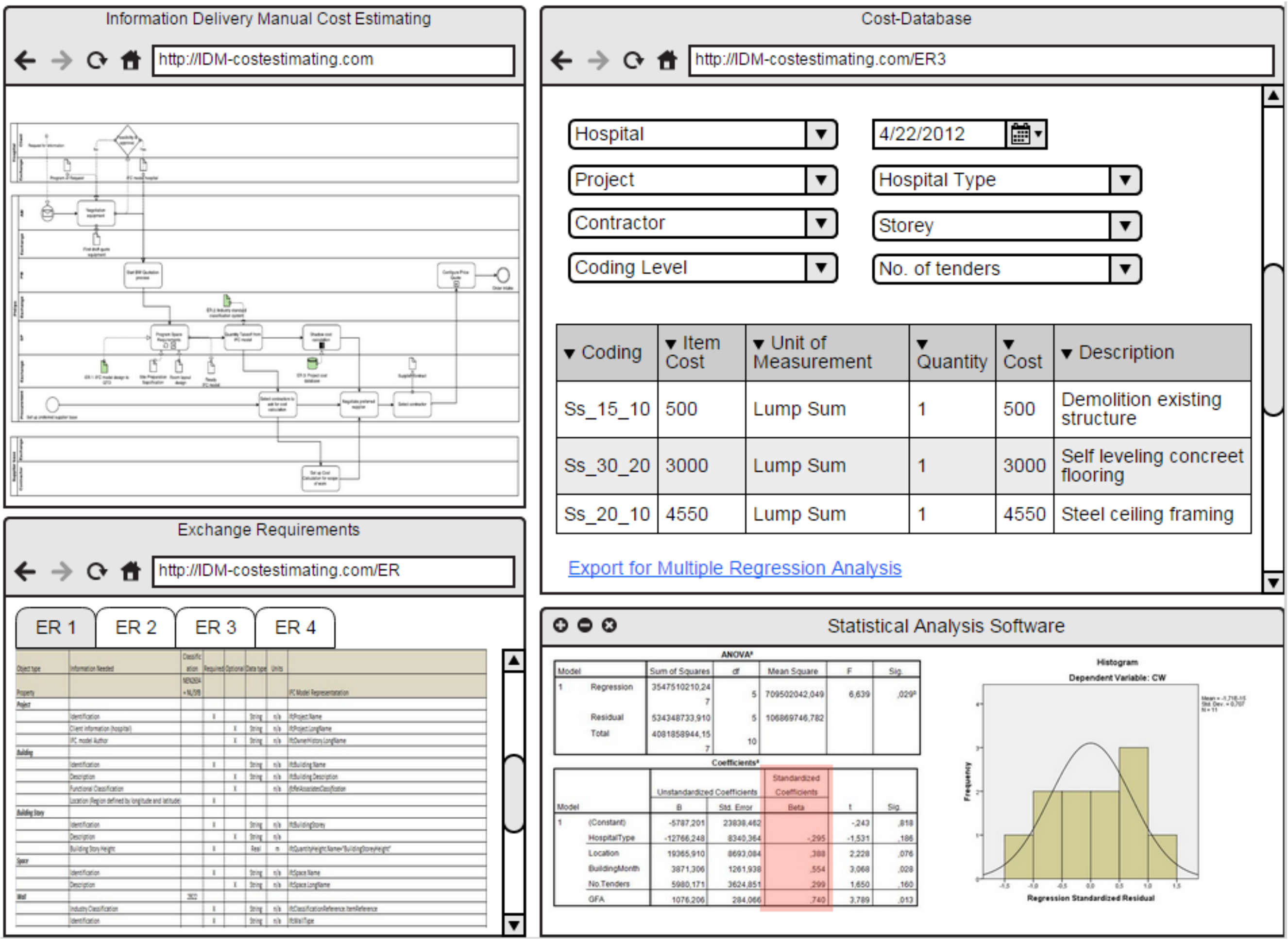


Figure 4.15. Mock-up web-interface IDM

4.5. Discussion

This chapter started with the statement that every project is unique but that searching for commonalities should be possible. Next to this implementing a certain level of standardization in the processes part of the project. Several analysis were conducted together with the development of an IDM. However, some point of discussion are necessary for interpreting the results of this research.

4.5.1. Dataset analysis

The commonalities check revealed that there these types of projects can be defined by a generic WBS. Next to this there were different ways of documentation quotations. Therefore the suggestion of a standard approach could be supported by this fact, to make the projects comparable to each other.

The results of the MRA conducted for this research are not very reliable, due to the small sample size. Field (2013) suggest a minimum sample size of five times the number of independent variables (Field, 2013). Which means that for this MRA model, 5*5 = 25 projects are necessary minimal. Nevertheless this MRA shows how analysis could be conducted in the future, in order to calculate ratios for cost estimation.

Next to this, there are more independent variables that could influence the building costs, for example the storey of the hospital the room subject of the project is located on, or the construction type of the building. Hence, a large dataset and detailed project information is required in order to test cost influencing factors for this type of construction projects.

Another thing that should be considered is that building costs are in most of the countries still largely based on guess work, what means that they are affected by the economic work conditions of a contracting company. When a contractor has much work at the moment of request for quotation, it would add some costs to the bid, because the contractor does not really needs the project. On the other hand, when the contractor does not have much work, it is more likely that the costs of its bid will be lower, because the contractor needs the job. A cost estimation that is close to reality could be difficult to achieve for this reason. Nevertheless, this knowledge could be kept in mind when negotiating with a contractor. Therefore the *Month* in the year was set as an independent variable, to test if this could influence the costs. When enough projects are collected, a more reliable statement about this independent variable could be formulated.

The difference in costs could also be caused by the level of detail when it comes to finishing the room. Some hospitals require a high standard, because they are for example a private hospital. Other state funded hospitals maybe do not have the same budget as a university hospital. Nevertheless, the rules regarding funding are different for every country, which makes it hard to capture on an European or global level.

Last the regression models modelled for this research are very generic, due to the limited data available. When more data is available more detailed regression models could be made. For example models with the costs for a HVAC installation as independent variable, or wall coverings as independent variable. This could provide a better insight in the costs on a more detailed level.

4.5.2. Information Delivery Manual

The development of the IDM for this research is trying to formulate a standard way of working. Nevertheless, the IDM should function for different countries. Not all the markets are as far developed when it comes to working with BIM. Next to this, the fact that this type of projects is conducted in existing hospitals, means that it is expected that every hospital has an existing BIM model. This is not the case, especially for very old hospital building. When the BIM-based approach is not used for the development of the hospital, it could be suggested to model the hospital partially. Only the room subject to the project and the direct surrounding rooms could be modelled. However, problems could occur when the mechanical and electrical installations should be modelled in the IFC model. Therefore this path of standardization will take some year before it will function optimal. Nevertheless, when the IDM is implemented and the process of an "installation medical equipment" is conducted according to this IDM for several years, a proper dataset will be collected in the project database. This database can be used to do analysis as conducted in the section of quantitative analysis. Based on this historic project database, future shadow cost estimations could be conducted by the producer of medical equipment.

The research started with the statement that every construction project is unique. This IDM is a standardized way to communicate processes in this type of construction projects. Next to this it should minimize information loss, and when well implemented it should even fasten the lead time of a complete end to end project. However this type of projects know, beside de necessary building works for the equipment to function well, a high level of customization. The customization part makes that standardization is challenging. The IDM developed in this research focusses on the necessary building works as prescribed in the document Site Preparation Specifications. Next to this is gives the entities necessary for furniture. Modelling the customized set of building works requires skills from the modeler to translate the program of request into a BIM model.

Another questionable process is the site visit, which is in most markets conducted by the Project Manager and sometimes also the contractor. The implementation of a BIM-based approach should make a site visit superfluous. Although, experience learns that a project manager will most of the time conduct a site visit to define the scope of work, before informing Site Planning about the project.

The last questionable part of the IDM development is ER4 revision model. Experience of the medical equipment supplier learns that it is hard to get a grip on the as-built information related to labor hours, materials and costs. Therefore it is the question if this information will be collected after implementation of the IDM. Even so, it is highly recommended to collect as-built information, because this could provide insight in the risks and the cost post unforeseen. Risk mitigation could be done with the help of as-built information.

4.5.3. Future research

This research is the start of a larger research with the purpose of developing a cost engineering infrastructure for building works projects on an European level. This research showed that first collection of historic project data in a structured way is necessary in order to conduct analysis. When sufficient data is collected, the search for cost ratios based on historic data collection could start and with that the development of a shadow cost calculator for building works project based on historic projects.

Next to this more research is needed to see if implementation of a BIM-based approach for quantity take-off is reachable for the medical equipment supplier. Investigation focusing on the question if BIM is possible to be performed in-house or that the help of a turnkey-contractor is required for setting up the to-built BIM model.

Chapter 5. Conclusion and Relevance of the research

The goal of this research was to provide more insight in the costs related to building works activities and therefore create knowledge and capture this knowledge. This chapter will first provide an answer to the research questions as formulated in chapter 1. Where after the relevance of this research in terms of societal- scientific- and beneficiary relevance is discussed.

5.1. Conclusion

The intention of the methodology section of this graduation research was to find an answer to the research goal and its related sub-questions. This conclusion tries to formulate an answer to the sub-questions based on the outcomes of the different analysis conducted in the methodology part and the conducted literature review.

"Gain more insight and create more knowledge around costs related to building works activities for the installation of medical equipment in existing hospitals".

What sub-processes/factors are similar looking at the historic data of the different markets, which commonalities can be found?
The cross-market analysis was part of the quantitative research and the outcome of this was a WBS, as visualized in section 4.3.1. The main conclusion from this is that BW consists of construction works, mechanical- and electrical Installations and fixed- and movable facilities. Within these chapters there are some variances possible, which makes that every project is unique. Therefore the WBS provided in section 4.3.1. is a generic model. Another finding from this commonalities check was that every market structures the costs related to the activities in a different way. The most frequently used format is a bill of quantity, which separates the costs into quantities, unit cost and item costs. An important thing to consider when defining a quotation format is the information the project manager wants to get when doing a request for tender.

What are the cost drivers for the different activities within the project?
The outcomes of the different dataset analysis are discussed on by one to answer this sub-question.

Normalized total costs
The total project costs for all 11 projects were calculated based on the normalized values for the different activities. The results were presented in a histogram and showed that the total costs of the project was higher for university hospital then non-university hospitals. This could be caused by the fact that university hospitals in most countries have a different type of funding and therefore more money for the BW available.

Deviation of the mean in percentage
The second analysis was based on the difference related to the mean in percentage. The basis for this analysis was the normalized costs (cost/m² room) for all the different activities. The conclusion from this analysis was that activity "Preparation systems, Ss_15_10", has many projects with a deviation greater than -50% or 50%.

This activity has Lump Slum as unit of measurement and therefore it could be assumed that the great deviation in costs is caused by this unit of measurement. Next, "Door and window systems, Ss_25_30", also scores many projects with a deviation greater than -50% or 50%. Because this are the normalized costs, it could be assumed that GFA is a depending factor for door costs. The last outcome of this analysis was that the activities "Ss_70_80, Lighting systems" and "Communication systems, Ss_75_10", both part of electrical installations shows many projects with a great deviation from the average costs. Therefore is could be assumed that the GFA of the room is an important indicator for the electrical installations activities.

Multiple Regression Analysis
In order to identifying the cost influencing factors with the help of a Multiple Regression Model, a literature study to already established research in this area was conducted. Based on this literature study, some dependent variables were selected to set up a Multiple Regression Model; *GFA, No. of tenders, Building Month, Location and Hospital type*. All the MRA models appeared to be significant except for the model with Mechanical Installations costs as independent variable.

For the MRA model total costs, *GFA* appeared to be significant, therefore it could be assumed that when the *GFA* of a project increases, the total costs increase as well. MRA Construction Works showed a significant outcome for *Location*, *Building Month* and *GFA*. *Location* could be clarified by the fact that the contractor is maybe further located from the hospital, when the hospital is outside of the municipality Cairo. The costs could be higher due to transportation of material and equipment. The fact that *Building Month* shows a significant relationship with construction works costs could be caused by the season. For example in summer less work is available then in winter and therefore the contractor will offer a lower price in summer than in winter. The last MRA model that was significant and therefore clarifies something was the model with Electrical Installations as independent variable. The dependent variables that were significant were *Location*, *No. of tenders*, *Hospital Type* and *GFA*. For *Location* the same clarification could be assumed as given for the MRA Construction works*. No. of tenders* here is significant, which could mean that when more tenders are involved in the tender phase, the higher the costs for electrical installations are. The fact that the *Hospital Type* is significant for this MRA model is supported by the findings of the deviation of the average costs in percentage analysis and therefore the same clarification could be assumed.

Remarkable is that the dependent variable *Hospital Type* only shows a significant outcome in the MRA model for Electrical Installations, while the total normalized cost histogram showed that the total costs for BW appeared to be depending on the *Hospital Type*. However, all the assumptions made in this research are assumptions and no hard facts, because the analysis are only based on 11 projects.

What could be a format to facilitate future requests for tender, which is workable for all the stakeholders involved in the project?
With the eye on the future, an element based classification is favorable, because this supports a BIM-based approach. The analysis part of this research made use of the Uniclass2, which is aligned with ISO 12006-2. This research asks for a classification system that is workable in different countries, because the final goal is to create an European cost engineering structure for building works project within different markets.

To design the format in such a way that it is able to facilitate cost estimation, a layered structure is required. The cost estimator should be able to structure the costs in different levels of detail, e.g. group, sub-groups, sections and objects. The format should facilitate the possibility to calculate the costs related to for example wall finishing type painting, but also for example the total costs for electrical installations work.

How can information management help in making the quotation process more transparent?
In order to gain insight in the answer to this question, qualitative research formed the main input. The questionnaire with Project Managers from different markets as respondent, together with interviews with different stakeholders in the process formed the basis for developing a Process Map, together with the related ERs and their related functional parts. The intention of an IDM development it to standardize the processes related to a project. This standardization causes that the processes will be conducted in a structured and matching way. Therefore it will be easier to gain insight in the status of the project. Next to this the IDM clearly stated what information in necessary for what process, and which stakeholder is responsible for the information. The IDM has the purpose to collect project data regarding project costs in a structured way. For Building Works related projects it is necessary to create a data warehouse to make the collected IDM information exchanges, and business knowledge available. Therefore, in a few years a database with complete historic project information will be established, which could be used as a reference database to do cost calculations. Hence, information management can play an important role in the cost estimation process.

The different techniques discovered the same outcomes and the same influencing factors, therefore it could be concluded that the analysis show some consistency in the data.

5.2. Relevance

5.2.1. Societal relevance

The main societal issue related to this research is creating more transparency in the quotation process related to the building works activities necessary for the installation on medical equipment in existing hospital rooms. Tenders are mostly not very transparent and therefore no opening for negotiation is given by the contractor. This together with the fact that the medical equipment supplier is not a building company and therefore has no or limited knowledge about building costs, causes that he quotation process is not fair.

Not only transparency in costs is necessary but also transparency in information management between the different stakeholders. Therefore the development of the IDM should prevent information loss or problems related to the stakeholders that are responsible for providing the information. Good information management goes together with creating more transparency in the quotation process. When improving the lead time of a project, less extra costs are involved.

Funding of the hospitals is different within every country and therefore different stakeholders are involved. In order to get better funding, to make the installation of new equipment possible, better insight in the cost calculation process could be favorable.

5.2.2. Scientific relevance

Much research has been conducted regarding cost estimation techniques based on historic data. Though, this project starts even before the cost estimation process and focusses more on structuring the processes necessary in order to collect historic data in such a way that accurate cos estimations can be conducted based on this data. The main difficulty when facing cost estimation in the construction industry is the fact that every project is unique and therefore accurate cost estimations are difficult. Nevertheless, with the help of software and for example a BIM-based approach, more detailed information about cost calculations could be collected. Therefore it is very useful to conduct research regarding optimizing the information collection process.

Regarding the scientific relevance, this research shows an overview of already established research and tried several methods in order to get more grip on the cost calculations process related to the project subject of this research. Therefore this research shows an approach to start research in this field but is not ground breaking, this is also caused by the fact that this research is the start of a larger research into cost calculations related to the installation of large medical equipment in existing hospitals.

5.2.3. Beneficiary relevance

The beneficiary relevance of this research is expressed in terms of usefulness for the company. The research is based on a company question, capturing information and knowledge of costs related to building works activities in existing hospitals. Therefore an IDM is developed in order to structure processes related to cost calculations for this type of projects. The IDM prescribes a structured way of data collection, which will make cost comparisons in the future possible. Nevertheless very accurate cost calculations will never be achieved when basing the cost calculations only on collected costs of historic projects. Construction costs always have a subjective character. With this is meant the fact that it is depending on the economic market conditions at the moment of cost calculations.

Another thing that should be considered is that the costs related to construction projects differ per country and sometimes even per district within a country. Therefore when making shadow cost calculations based on these historic projects, a large database is necessary, sorted per country and per municipality.

Next to this, there are companies that are specialized in cost management and with that in cost estimations. Considering the fact that it will cost several years to collect the data in the structured way, prescribed by the IDM, it could be more efficient to outsource this cost calculation activities. However, the BIM-based quantity take-off approach could lead to more accurate cost estimations and a more transparent estimation process, because the data is collected in a more detailed way as it is done currently. In order to make this whole approach beneficiary, software implementation is crucial.

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Appendixes

Appendix 1. Defining Building Works Activities

Demolition of existing structure
The building works take place in an already existing hospital room and therefore almost every time demolition of the existing structure is necessary, which includes demolition of existing flooring or ceiling.

Ceiling framing
This is a frame of steel which supports the attachment of the equipment to the existing ceiling structure.

Floor plates
Necessary to support the heavy weight of the equipment or operating table part of the equipment.

Cable channel floor
This is the way the cables of the equipment are finished. This can be done in three different ways.

1. Flush mounted: the cables are mounted directly under the floor (figure 1.1.)

Figure 1.1. Flush mounted floor cabeling

2. Under floor: core drilling is necessary to drill through the floor and cables are stored underneath
3. On floor: the cables are stored in a box mounted on the floor

Finishes
This subject covers all the finishes of floors, walls and ceiling and is optional for the customer and knows many types of finishes. For example painting the walls, or wall cladding, but also resilient floor covering.

Lead protection
These are leaded shields to protect from radiation produced by the equipment. The lead could also be in the form of leaded tiles or in doors and windows.

Rf cage
This is a cage that covers the complete procedure room from the magnetic field created by the MRI. The control room by this type of equipment is located outside of the procedure room due to the magnetic field in the procedure room (Figure 1.2.).

Figure 1.2. RG cage (IMEDCO AG, 2015)

HVAC
Heating, ventilation and air conditioning, required for MR and CT and optional for DXR and IXR.

Chiller
Transfers heat to water via heat exchanged in the liquid cooling cabinet. This is a closed loop but has a permanent connection to the main water supply. The chillers needs to be places outside of the building where good air flow is available (Philips Healthcare, 2011) (Figure 1.3.)

Figure 1.3. Chiller (General Air Products, 2015)

Plumbing
This is optional and depends on the program of request from the hospital. Part of plumbing is Medical Gases, for example helium necessary for cooling of the coils in the MRI. Next to this also the general plumbing work for the installation of a sink or a toilet could be included in the work.

Electrical
All the types of equipment require power, facilitated by a generator and the equipment needs to be earthen. Furthermore the electrical installations are depending on the request of the client.

Lighting
The installation of safety light and the normal indication lights, and more. Next to this, the installation of lights are according to the wishes of the client.

Communication
In the form of internet outputs and telephone outputs.

Protection
In the form of fire protection, which is not prescribed by the medical equipment supplier and is therefore depending on the wishes of the client.

Facilities/furniture
The installation of curtains (for changing space client) or cabinets to store smaller medical equipment, but also a desk and chair for the control room, and more.

Appendix 2. Commonalities BW activities different markets

NAM	Egypt	Australia	China	Belgium	Japan	UK	RH-DHV	Arcadis	Nordics	Middle east	Spain
Execution based	**Execution based**			**Element based**	**Execution based**	**Element based**	**Element based**	**Element based**	**Element based**	**Execution based**	**Element based**
General Conditions			Overhead				Preliminaries	Preliminaries		Detailed drawings and shop drownings	
							management (preliminaries)				
Architectural & Engineering Fees			Supervising Fee		Supervising fee		Design and project team fees, project funding			Certificates	
Bonds											Structure
Existing Conditions/Site work	Civil and Finishing works		Building	Demolition	Building		Site preparation	Facilitating works	Demolition	System dismantling	Previous jobs
									core drilling		
Concrete							Substructure	Substructure	New structures (walls)		
Masonry							External superstructure	Superstructure			
Metals											
Carpentry/millwork											
Thermal & moisture protection											
Openings									Working in floor	Door and Windows	
Finishes				Wall covering/finishing		Finishes	Internal finishing	Internal finishes	Ceiling, floors, interiors	Ceiling, flooring, walls	Vinyl flooring/division interior
									Male work (internal finishing)		
Specialties		Quench pipe	Shielding	MR/ RF cage	Shielding				Radiation protection	Chiller, piping and quench piping	
Equipment			Other Equipment	Divers (equipment)	Other equipment						
Furnishings	Furnishing work	Cabinetry, wall construction, lighting		Windows and doors, including furniture			Furniture and fittings	Fittings, furnishing, equipment		Furnishing/ accessories and third party items	
Special Construction							Special equipment and installation				
Conveying systems				Controls							
Fire Suppression		Fire protection				Fire protection and detection				Fire fittings & alarm systems	Protection and safety
Plumbing	Furnishing work	Water	Chiller Pipes	Sanitary	Quench	Sanitary ware	Services installations	Services			Plumbing
			Quench Pipes		Chiller pipes						
HVAC	Air conditioning and Electricity works	HVAC	A/C	Air treatment	A/C	HVAC			HVAC / sprinkle/ ventilation	HVAC	Air conditioning/ ventilation
Electrical		Electronics	Electrical	Electricity work	Electrical	Electrical				Lighting	Electrical installation Lighting
Communications											Signaling and communication
Electronic Safety & Security		Emergency Venting System		Protections		Security and access control					
Exterior Improvements				Walls			Site and external works	External works			
Utilities				Ceilings							
Others											
		Medical gas	Misc.	Normal installation costs	Misc.	Medical gasses	Prefabricated buildings/units	Sector specifics	Washing and cleaning	Medical gas	Medical gas
		Ambient experience			Overhead	Noise criteria	Taxes		Disposal handling	Health, safety and cleaning	SEG Application Security Plan works
		Hospital delivery ready					Incidentals			System transportation and installation support	
							Site acquisition				

Appendix 3. Overview projects Dataset

Description	Unit of measurement	1	2	3	4	5	6	7	8	9	10	11
Cracking and destruction works, removal and closing existing door openings in the walls, as described in the drawing, transferring wastes promptly to public landfills and regular cleaning works.	LS	5083	5980	6250	5625	5980	7125	4125	4000	5500	5500	5350
By Square Meters, building works with 12 cm bricks. The price includes transporting, supplying and storing	m2	98	110		110	115	98	99		98	89	96
Base of ordinary concrete dimensions specified graphics work taking into account the weight of the equipment that will be installed	LS										1080	
Supply and installation of steel beams to the ceiling unnecessary comments catheter device sectors and lengths according to the executive for graphics and paint sectors textured weatherproof steel	LS	11975			12075	10808	11375	12125		12300	13890	
Supplying and installing Leaded door, 120 cm with affixed by rigid vinyl and installing stainless steel strips from bottom and the middle of the door	No.	4758		5125				4763			3660	
Supplying and installing 120 cm door affixed by rigid vinyl and installing Stainless steel strips from at the bottom at 90 cm height	No.			3550		5350				4500		
By No. Supplying and installation 140 cm Leaded sliding door with a thickness of 2 mm, price includes installation	No.				5330		28750					
Supplying and installing 90 cm door affixed by rigid vinyl and installing Stainless steel strips from at the bottom at 90 cm height	No.		2950			3225	2513	3550				2967
Supplying and installing 90 cm door affixed by rigid vinyl and installing Stainless steel strips from at the bottom at 90 cm height	No.						3638			3420	3720	3917
Supplying and installing a 80 cm door affixed by rigid vinyl and installing Stainless steel strips from at the bottom at 90 cm height	No.	3092										
Supplying and installing 100 cm door affixed by rigid vinyl and installing Stainless steel strips from at the bottom at 90 cm height	No.				3825							
Supplying and installing security glass door 120 cm wide and 220 cm high and the price includes the supply, installation, isolation spacers and accessories	No.			4863								
Supplying and installing a 60 cm door affixed by rigid vinyl and installing Stainless steel strips from at the bottom at 90 cm height							3200					
By No., Supplying and installing two shutters door with 1.5 m width covered with Ilmenite sheets on both sides. The item includes accessories and gateposts including painting	No.			5588					5533			
By No., Supplying and installing two shutters door with 1.2 m wide covered with Ilmenite sheets on both sides. The item includes accessories and gateposts including painting	No.				3340				3033			
By No., Supplying and installing 0.7 m wide door covered with Ilmenite sheets on both sides. The item includes accessories and gateposts including painting	No.											
Supplying and installing leaded door with 150 cm, height 90 cm.	No.										5790	
By Square Meters, supplying and conducting plastering works for walls.	m2						54				63	
By Square Meters, Supplying and executing washable plastic paint from "JOTUN" or equivalent brand, with three putty knife of paint.	m2	53		54	45		45		50			
By Square Meters, Supplying and installing wall Vinyl in accordance with the approved sample by Hospital's management.	m2						200					
By Square Meters, Supplying and installing Italian white marble walls inlaid with Indian green marble.	m2											
By Square Meters, radiation insulation works with 1.5 mm thickness and 2.5 mm height with installation of not less than 10 cm and fixing for preventing leak of radiation	m^2				426	458	415	420		429	446	432

Description	Unit of measurement	1	2	3	4	5	6	7	8	9	10	11
Supplying and installing of shaved Leaded dimensions of 122 * 82 cm of wood	LS				883	942	888				910	
Arranging the walls using tiles lead 1.5 mm	m²	472		424					432			
Supplying and installing wooden Leaded Frame, including all required for well-done works	LS			913					967			
By Square Meters, Supplying and installing wall claddings of Ilmenite after the sample being approved by site engineer. The price includes installation tools and wall tiles from the same sample	m²		227		229	219		198		203	222	282
By Square Meters, Supplying and installing wall Vinyl in accordance with the approved sample by Hospital's management.	m2	213		203					192			
Flat supply Surface paints and work according to the color and sample approved and according the industry standards	m2		77								61	50
By Lump sum, casting a concrete base for the apparatus table with self-levelling.	LS		108					1400		1380		873
Fixing the apparatus bases by using Hilti nails and casting grout to achieve the finishing level of the room with dimensions and sizes of the table base and the Poly G	LS			2550	775	1050	725	1275	1533	1120		723
Supplying and executing vinyl antistatic flooring for the apparatus room, control room and cabinets room with 60*60 cm including supplying, installing and self-levelling as well as transferring wastes to public landfills	m²	316	289	310				303	222	315	304	298
Supplying and executing vinyl antistatic flooring with 60*60 cm and an electrical resistance of 105 ohm, resistance to friction, heat and chemicals. Including supplying, installing and self-levelling as well as transferring wastes to public landfills	m²				283	264						
Supply and install FLOOR DUCT from the galvanized iron 20 cm width – 10 cm depth with a stainless cover 3 mm	LM	260		294	233	230	325	293	317	304		358
Supplying and installing porcelain flooring in size 60 * 60 cm color samples and approved by the site engineer and the price includes installation and transfer of waste to landfills	m²			198					207			
By square meter, supplying and installing mosaic floors (25 cm * 25 cm) including all required for well-done work.	m²					92						
By Square Meters, supplying and installing plopped ceiling with 60*60 of plaster slabs with not less than 9 mm thickness. The price includes accessories	m²	88	93	83	88	85	79	81	77	81	87	83
Supplying and installing 1.5" polypropylene pipes required for water cooling unit of the apparatus from the place of installation above the building to cabinets room. The item includes supplying and installing 3 1.5" valves	LS		4060									
Supply and install "by LS Lump Sum" 4 French gas outputs (Oxygen output – Nitrous output – Suction output – compressed air output).	LS		2596			2245	2450	2675		2184	1750	
A meter of external copper pipes.	LM		153		151	148	153	139		155	145	159
Supply and install a concealed split air conditioner "Carrier 3hp Air Conditioner", the item includes supply and install sheet, thermal insulation, air outlets, wire, 32 ampere key and the drain works	No.		9060					8775			10340	8292
Supply and install a concealed split air conditioner "Carrier 3hp Air Conditioner", the item includes supply and install sheet, thermal insulation, air outlets, wire, 32 ampere key and the drain works	No.		8240		6663	7825	8075	7725		7900	8180	
Supply and install a concealed split air conditioner "Carrier 4hp Air Conditioner", the item includes supply and install sheet, thermal insulation, air outlets, wire, 32 ampere key and the drain works	No.					8758				9100		
By Number, supply and installation of air-conditioning system with capacity of 3 hp, technical requirements with D-conditioning drainage of PVC pipes of all vehicle adaptations and even appropriate exchange director	No.	7387		7888					8400			
Fan installation and expel 1000C.F.M item includes work sheet	No.		1390									
Make an electric plug includes cut off, covers after the approval of the site engineer and the item includes drilling	No.	172	184	179	165	170	149	168	153	162	179	168

Description	Unit of measurement	1	2	3	4	5	6	7	8	9	10	11
Number of electric panel as a master key 200 ampere, a contactor 200 ampere, phase sequence and it has 3 signal lamps, earth bar, ground bar, as well as 3 keys "63 ampere" and earth leakage key "30 mm ampere".	LS		7700	8100	8375	10333	10500	10350		10740	8920	9883
Number of electric panel as a master key 200 ampere and it has 3 signal lamps, earth bar, and neutral bar as a requirement for the uninterruptible power supply "UPS".	LS		3960			4183					2880	2942
Number of electric panel as a master key 200 ampere and it has 3 signal lamps	LS							3550		4580		
Number of electrical panel as a master key 150 AMP, a contractor 150 ampere, phase sequence and it has 3 signal lamps, earth bar, and neutral bar, as well as earth leakage key "30 mm ampere"	LS	8883							8667			
Supply and installation of electric cable 3 won 3 * 70 mm +1 * 35 mm Ground + 1 * 35 mm legacy of copper hair	LM		302		309	302		231		259	352	294
Supply and install electric cable 3 phase 4*25 mm from hair copper.	LM					133		123		142	182	153
Supply and install Italian duct cable size 8*10 cm.	LM		98			92	160	108		121	90	79
50 mm cable 5 party (the price of one meter longitudinal only)	LM	289		269					257			
Supply and install cable tray, aluminum cable holder 40 cm width, including duct and the final installation	LM		301	293	280	287	289	281	293	275		300
Supply and install cable tray, aluminum cable holder 30 cm width, including duct and the final installation	LM	274										
Supply and install lighting headlamp size 60x60 "approved brand" with all its accessories and the price includes supply, hang, drilling and the key by using appropriate installation methods	No.	316	350	339	314	343	304	313	300	308	364	312
Supply and install of lighting panel and air conditioners.	LS		1640			2650	1875	1925		1880	1540	2058
Installation of LED lighting	No.										226	
Number 1 plate Electricity unnecessary lighting and comprehensive adaptations and pieces of certified brand	LS				1600							
Make an internet output includes cut off, covers after the approval of the site engineer and the item includes drilling	No.	208	242	223	228	227	240	195	237	234	212	224
Make a telephone output includes cut off, covers after the approval of the site engineer and the item includes drilling	No.	198	229	223	211	216	224	195	215	211	212	215
Supply basin sterilization 2 Eye pump item bearing upon the work of exchange and nutrition	Ls				13200	14283		11575		11390	17500	11167
Supplying a locker for keeping medical instruments and catheters, made of Aluminum with dimensions of 1.6 m width * 2m height * 0.4 m depth.	No.		3780		3863	4033	2748	13988		3390	4250	4718
By No., swivel chair with approved brand and a desk.	No.		900	750	856	842	825	725	883	800	630	767
By No. three-seater of certified brand	No.			1388								
Supply and install curtain with dimensions 1,5 * 2	No.										730	
Supplying and installing Counter with 3 m* 55 cm dimensions and a height of 90 cm height installed on stainless steel pillars	LS		6800	7850	5215	6750	4875	6850	6500	6220	8990	5662
Office supply 4 chairs and a wooden counter, 2.40 m * 0,50 m * 0,90 m	LS	9120										

* Costs are in Egyptian pounds

Appendix 4. Missing values analysis

Project	Ss_15_10	Ss_20_10	Ss_25_30	Ss_25_20	Ss_25_20_50	Ss_30_42	Ss_30_36	Ss_55_70	Ss_55	Ss_65	Ss_70	Ss_70_80	Ss_75_10	Ss_40	Ss_40
1	106	244	182	553	700	364	85			927	435	100	10		
2	139	256	260	585	716	411	85			1107	392	93	18		
3	167	333	158	672	653	342	85			767	316	93	18		
4	117	163	124	932		275	100			916	326	106	23		
5	306	200	178	600	661	316	100			1100	380	101	13		
6	172	400	144	519	661	393	70			1093	405	96	27		
7	202		302	488		399	95	86	34	1205	723	98	14	224	197
8	216		254	434		424	90	83	17	1125	464	134	15	110	178
9	153		181	634		319	95		52	1164	650	98	18	103	128
10	341		345	431		284	95	52	69	1194	615	128	14	86	150
11	221		190	432		390	66		52	1088	581	106	21	128	90
12	90		357	348	531	399	85			948	347	211	9		268
13	120		420	365	480	338	85			900	289	134	7		366
14	200		404	386	479	349	90				341	156	8		386
15	90		349	311	515	380	70			936	349	149	12		343
16	127	173	181	401	389	339	80			642	472	82	5	507	126
17	64	191	146	573	432	311	100			856	433	100	7	124	103
18	173	120	177	408	402	299	100			679	507	95	4	293	114
19	53	160	161	325	437	371	70			674	522	91	8	192	72
20	167	250	188	525	549	376	85		35	1017	937	126	7	231	169
21	35	298	212	575	564	410	85		38	1322	993	133	8	250	219
22	125	212	188	450	607	452	85		17	1180	519	316	8	283	187
23	78	141		788	879	323	100		58	1250	964	135	10	115	142
24	227	173	163	525	520	349	85		58	1270	813	168	8	346	163
25	102	173	139	425	581	415	70		54	1139	833	140	12	306	92
26	173	232	330	640	387	302	79		32	700	375	97	6	161	143
27	175	170	246	586	357	314	79		54	795	273	135	7	71	138
28	250	214	154	533	406	353	70		36	761	336	104	11	132	89
29	189	196	198	596	396	437	65		54	955	336	102	9	28	96
30	150	250	307	294	547	392	85		25	875	766	81	6	383	170
31	253	150	232	322	467	353	90		67	969	624	92	5	217	125
32	160	233	220	252	667	408	75		33	877	764	98	8	273	93
33	107	175	350	238	560	469	75		53	880	406	107	7	263	165
34			271	423	751	580	64			563	407	84	9		213
35	125		141	395	763	670	53			728	474	90	13		88
36	125		230	357	825	378	56			600	505	96	13		188
37	138	200	228		368	390	85		19	759	728	61	4	284	128
38	130	138	162		372	444	70		40	879	929	64	6	44	68
39	165	113	142		306	340	90		50	868	562	69	4	338	96
40	170	188	160		438	404	75		24	768	533	76	8	218	74
41	109	131	231		394	468	85		40	774	281	79	5	196	124
46	88	200	214	544	459	386	85		17	776	649	194		514	133

Project	**Ss_15_10**	**Ss_20_10**	**Ss_25_30**	**Ss_25_20**	**Ss_25_20_50**	**Ss_30_42**	**Ss_30_36**	**Ss_55_70**	**Ss_55**	**Ss_65**	**Ss_70**	**Ss_70_80**	**Ss_75_10**	**Ss_40**	**Ss_40**
47	224	138	180	535	464	470	90		11	782	464	209		350	277
48	131	243	156	574	557	357	80		31	649	592	215		254	139
49	73	154	180	521	451	379	90		49	659	509	200		224	155
50	100	257	210	654	523	523	90		17	776	649	194		514	133
51	103		138	346	368	389	85			598	750	160	4	120	91
52	138		155	412	350	334	80			624	704	156	4	138	137
53	215			256	368	384	90			706	658	198	5	100	153
54	155			362	438	403	75			598	784	191	8	100	94
55	214		163	301	350	371	90			581	571	181	5	75	109
56	153		166	351	394	417	80			719	929	204	8	175	128
Average	163	202	216	472	510	387	82	74	39	877	561	129	10	217	153
St. Dev.	82	61	74	143	138	70	11	16	16	206	197	51	5	124	73
Min	46	113	124	238	306	275	53	52	11	563	273	61	4	28	68
Max	390	400	420	932	879	670	100	86	69	1322	993	316	27	514	386

* Costs are in Egyptian pounds

Appendix 5. Outcome PM Questionnaire

	Question	France	Swiss	Swiss	India	Iberia	Iberia	Italy	Japan
1	Average number of contractors asked for a bid	1-2	3		5-6	2-3	2-3		
2	Work with a set of preferred suppliers	yes, same pool	yes, same pool	yes, only one contractor		yes, same pool	yes, same pool	yes, one contractor	yes, same pool
3	Contact three different suppliers for Civil works, Electrical installations Mechanical installations	yes and no	yes	yes, different for 3 types	no	no	no	no, supplier for all three types	no, supplier for VW and for EI and MI
4	Stakeholder that does the site visit	PM	PM	AM, PM, contractor	PM and construction expert Philips	AM, PM, contractor	AM, PM, contractor	PM, contractor	AM, PM, Contractor, SP
5	Relation between equipment and building works	90-95% - 5-10%	70% - 30%	90%-10%	80-90% - 20-10%	Depends on modality to be sold and scope	it depends	depends on the type of project, public or private	65%-35%
6	Relationship between time, costs and quality	40% - 20% - 40%	50% - 25% - 25%	high-med-med		20%-70%-30% (120% because this is what the client thinks is important)	10%-70%-20%	Defined by the scope of work, provided by the client (33%-33%-33%)	20%-10%-70%
7	Do you negotiate about the offer	yes always	yes always	yes, always	no, not when a detailed cost structure is given in the offer	yes always	yes, always	no, discount in some cases	no, when a detailed cost structure is given
8	When gets the Pm involved in the process	Try at the first meeting, but most of the time when the first draft of the order is done	right from the start	when the first draft of the order is done	right from the start	before the quotation to customer	before quotation to the customer	between first meeting with customer and the order	little bit early of the O/T
9	How is the risk calculated/defined	fixed percentage	based on risk assessment by contractor	based on risk assessment by contractor	Turnkey Pm of Philips	based on experience of customer and AM	based on the experience	no contingency, everything is pre-calculated once scope of work is agreed on	share risk between Pm and contractor
10	Are all important stakeholders visualized in the process map	yes	yes	yes	yes	yes	yes	yes, one contractor	yes
11	Are all the milestones visualized in the process map	yes	yes	yes	yes	yes	yes	no, in public tender: s.o.w., start of BW, end of BW, change request	yes
12	Are all the documents gathered in the process map	no; no fixed format used	yes	yes	yes	yes	yes		yes
13	Is the process of Request for Quotation transparent in your market	disagree	neutral		strongly agree	strongly agree	strongly agree	strongly agree	neutral; it is impossible to have consolidate one it should be controlled by Km
14	Which stakeholder in your markets sets up the bill of quantity		expert within Philips: pm	contractor	expert within Philips: turnkey manager	contractor	contractor	contractor	contractor
15	What industry classification system is used in your market		no	SIA	CPWD format	no	no	Prezziario Regionale	no
16	Delete 3 element clusters that are not relevant for your market								
17	Add 3 element clusters that are relevant for your market								shielding, support structure
18	What is the level of detail of the quotations made by the contractors	level 3	level 3		level 3	level 3 (but 4 if requested)	level 3 (but 4 if required)	level 3	level 3
19	What is the level of detail that you would prefer to work with	level 4	level 2	level 4	level 4	level 3	level 3	level 3	level 4

Appendix 6. Process Map

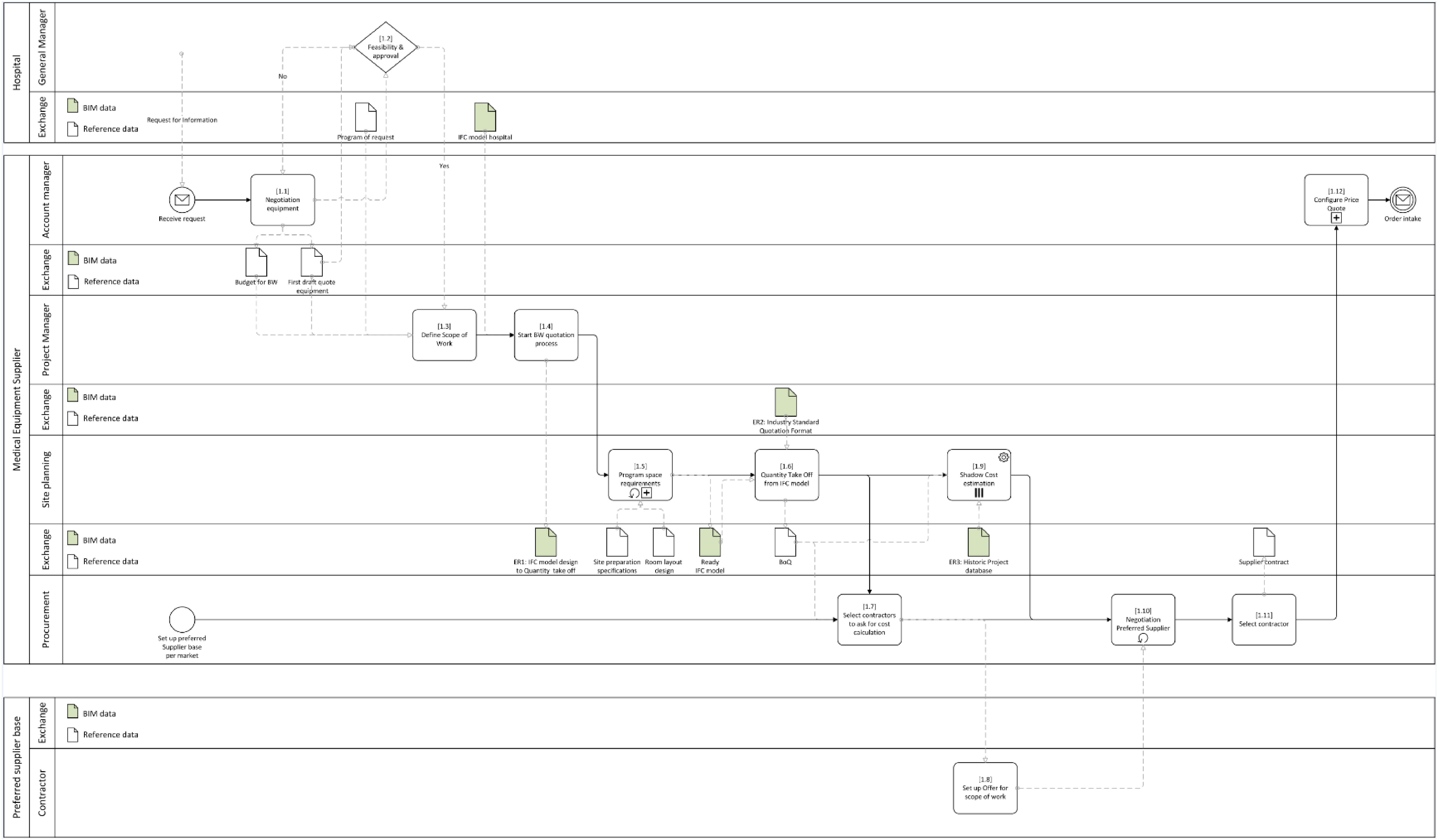
Name: Process Map Cost Estimating Building Works

Identifier BP-1

Change Log		
2015-05-18	Created	Nicole van Riel n.s.m.v.riel@student.tue.nl
2015-05-19	Changes; numbering processes and data objects	Nicole van Riel n.s.m.v.riel@student.tue.nl
2015-05-20	Changes; ER1 and ER2	Nicole van Riel n.s.m.v.riel@student.tue.nl
2015-07-07	Change PM	Nicole van Riel n.s.m.v.riel@student.tue.nl
2015-07-28	Added the lane procurement to the process	Nicole van Riel n.s.m.v.riel@student.tue.nl
2015-07-29	Re-number processes	Nicole van Riel n.s.m.v.riel@student.tue.nl
2015-08-03	Split process map in 2 parts	Nicole van Riel n.s.m.v.riel@student.tue.nl
2015-08-03	Final version	Nicole van Riel n.s.m.v.riel@student.tue.nl

Exchange Requirements	IFC model design to quantity take off
	Industry standard quotation format
	Historic project cost database
	As-built IFC model

Part I – Contractor selection installation medical equipment



Receive request for information

Type	Message event	
Name	Receive request for information of the hospital	
Documentation	The account manager receives the Request for Information (RfI) from the client. The account manager is responsible for responding to this RfI by informing the client about the possibilities.	

Negotiation Equipment [ID: 1.1]

Type	Task	
Name	Negotiation equipment	
Documentation	The account manager of Philips negotiates about the offer of the equipment offered by Philips, with the general manager of the hospital who is interested in purchasing new medical equipment of Philips. Input document is the “program of request” provided by the hospital. Output document is he “first draft quote equipment” made by the AM and the budget left for the building works part of the deal.	

Feasibility and approval [ID: 1.2]

Type	Gateway
Name	Feasibility & approval
Documentation	After the account manager and the client together defined the equipment that will be purchased by the client, the client needs to do a feasibility and approval check. When the check is positive, the project manager can start with the building works process. When the check is negative, negotiation about the equipment can start again.

Define scope of work [ID: 1.3]

Type	Task	
Name	Define scope of work	
Documentation	When the account manager and the hospital has decided what type of equipment will be installed in the room, it is the job of the project manager to define the scope of work, which includes the building works and the additional requirements by the hospital. Important input documents are: Budget for BW First draft quote equipment Program of request	

Start BW quotation process [ID: 1.4]

Type	Task	
Name	Start BW quotation process	
Documentation	After the scope of work is defined by the Project Manager, the next step is starting the building works quotation process. For this, the existing IFC model of the hospital is required.	

Program space requirement [ID: 1.5]

Type	Standard Loop Collapsed Sub-Process	
Name	Program space requirements	
Documentation	The department Site Planning is responsible for implementing the new situation in the existing IFC model. This is based on the documents “Site preparation specification” and the “room lay-out design”. All the required building works are drawn into the 3D model. When it is a turnkey deal, also the additional requirements from the client (building works that are not necessary for the equipment to function) are drawn into the 3D model.	

Quantity take off from IFC model [ID: 1.6]

Type	Task	
Name	Quantity take off from IFC model	
Documentation	When site planning has drawn all the BW items in the IFC model, quantity take off can be conducted with the help of software. Input document for this task is “Industry standard quotation format (ER 2)” and the output is “Bill of Quantity”	

Set up preferred supplier base per market

Type	Start event	
Name	Set up preferred supplier base per market	
Documentation	The department procurement is responsible for setting up a preferred supplier base for every country. This base contains the contractors that are asks for their offer, every time the medical equipment supplier needs to install medical equipment in a hospital.	

Select contractors to ask for quotation [ID: 1.7]

Type	Task	
Name	Select contractors to ask for quotation	
Documentation	The procurement specialist asks the contractors from the preferred supplier base to set up a quotation. This quotation is based on the “BoQ” generated from the IFC model by the department site planning.	

Set up offer for scope of work [ID: 1.8]

Type	Task	
Name	Set up offer for scope of work	
Documentation	All contractors from the preferred supplier base give their cost calculations in the format of the BoQ generated by Site Planning.	

Shadow cost estimation [ID: 1.9]

Type	Task, ongoing process	
Name	Shadow cost estimation	
Documentation	While the contractors are setting up their cost calculations for the scope of work, the department Site planning generates a shadow cost calculation for the project which can serve as a basis for negotiation with the contractors. The shadow cost estimation is based on historic project data that is collected in a project database.	

Negotiation Preferred Supplier [ID: 1.10]

Type	Standard Loop Collapsed Sub-Process	
Name	Negotiation preferred supplier	
Documentation	The market procurement specialist negotiates with the contractors form the preferred supplier base about their offers which they have submitted. This negotiation is based on the feedback provided by the shadow cost estimation done by Site Planning.	

Select contractor [ID: 1.11]

Type	Task	
Name	Select contractor	
Documentation	When negotiation is finished, the market procurement specialist selects a contractor that will be involved in the project for the building works activities. The output document is a supplier contract.	

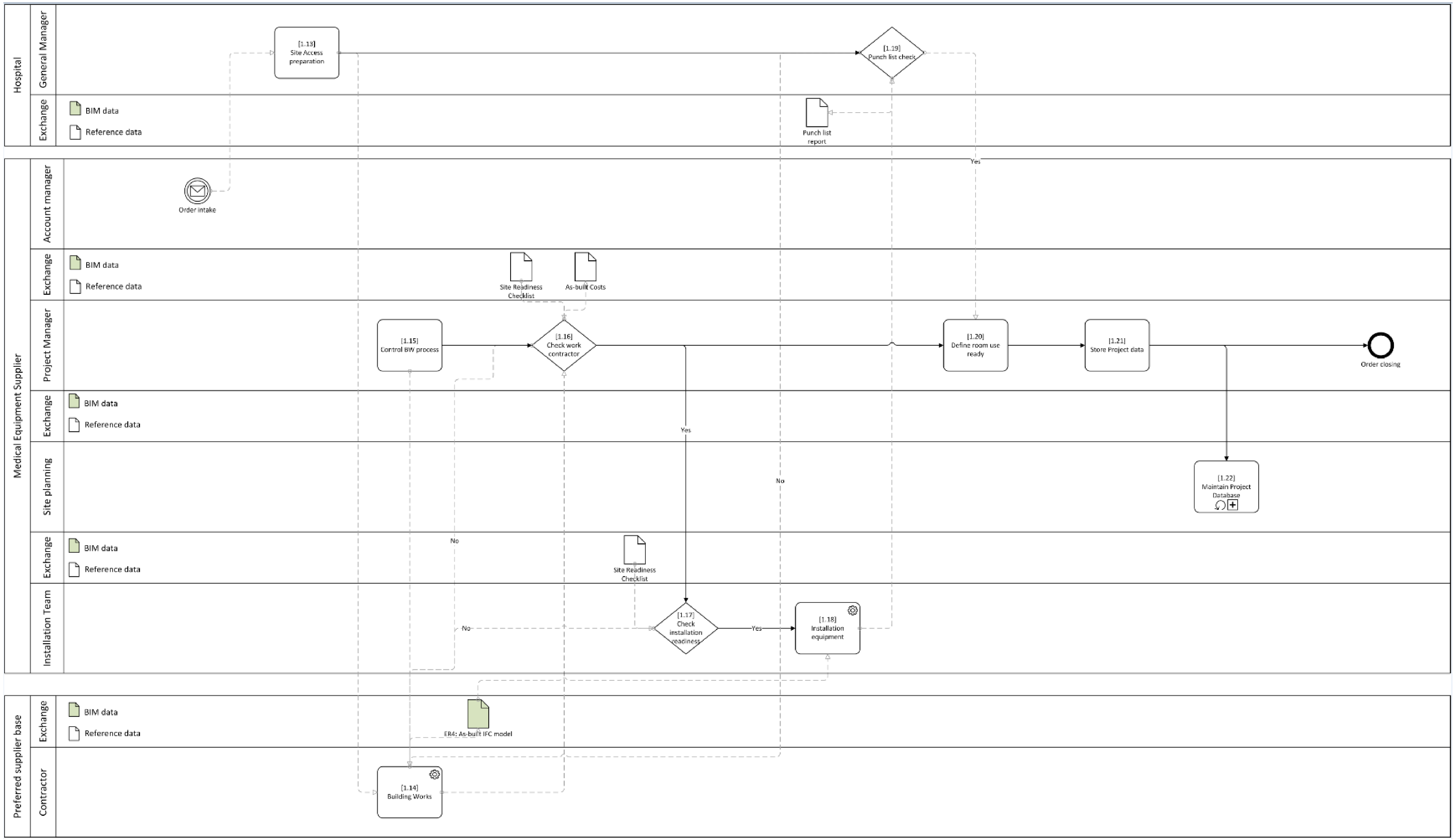
Configure Price Quote [ID: 1.12]

Type	Service task	
Name	Configure Price Quote	
Documentation	Before the order intake takes place, the process configure price quote is conducted, this is a process that is part of the entire *end to end* project and therefore not displayed in further detail in this process map.	

Order intake

Type	Message intermediate event	
Name	Order intake	
Documentation	After the Configure Price Quote process the order intake takes place. The account manager is responsible for this process.	

Part II – Building works and installation of medical equipment



Site Access Preparation [ID: 1.13]

Type	Task	
Name	Site Access preparation	
Documentation	After the order intake an before the contractor can start with the Building Works activities, the hospital needs to make sure that the room subject to the project is made accessible.	

Building Works [ID: 1.14]

Type	Task	
Name	Building Works	
Documentation	The contractor can start with the Building Works activities necessary to make the hospital room installation ready. Input document is “IFC model for quantity take off” and output document is “As-built IFC model”. The contractor needs to make a new version of the IFC model for the as-built situation.	

Control Building Works Process [ID: 1.15]

Type	Task	
Name	Control BW process	
Documentation	While the contractor is working on making the room installation ready, by conducting the building works activities, it is the job of the project manager, to control the process. The project manager should check during the construction works, if the contractor is on time, within budget and according the quality standard required by the hospital.	

Check work contractor [ID: 1.16]

Type	Gateway
Name	Check work contractor
Documentation	When the contractor is done with the building works activities, the project manager has to check the work regarding the scope of work, before letting in the installation team. When everything is okay the installation team can take over the process, if not, the contractor needs to make changes to the building works.

Check installation readiness [ID: 1.17]

Type	Gateway
Name	Check installation readiness
Documentation	After the project manager has checked the work of the contractor regarding the scope of work, the installation team needs to check if the room is ready for installation. When this is not the case, the contractor can get back to work. When the room is installation ready, the installation team can start the installation of the equipment.

Installation Equipment [ID: 1.18]

Type	Service task	
Name	Installation Equipment	
Documentation	This is a service activity provided by the installation team from the medical equipment supplier.	

Punch list check [ID 2.4]

Type	Gateway
Name	Punch list check
Documentation	When the installation of the equipment is done, the hospital does a punch list check, to check if the room is in the conditions according to its wishes. During the installation the room can be damages by accident, for example holes. The client can make a punch list to define what work needs to be fixed by the contractor after the installation of the equipment is done.

Define room use ready [ID: 1.20]

Type	Task	
Name	Define room use ready	
Documentation	After the installation of the equipment and the Punch list check of the client, the project manager should define the room use ready.	

Store Project Data [ID: 1.21]

Type	Task	
Name	Store Project Data	
Documentation	When the equipment is installed and the as-built drawings are established, the project data needs to be stored in the project database, including the final bill of quantity. This is done by the project manager.	

Maintain project database [ID: 1.22]

Type	Standard Loop Collapsed Sub-Process	
Name	Maintain Project Database	
Documentation	When the project is stored, the project database needs to be maintained by the department Site Planning. This database can function as a reference for future projects.	

Order closing

Type	End event
Name	Order closing
Documentation	The Project manager can close the order when the room is use ready and the project information is stored.

Specification of Data Objects

Library Data Objects

Program of Request

Type	Library objects providing information
Name	Program of Request
Documentation	The Program of request is provided by the hospital and contains all the information about the room where the equipment will be installed. Next to this is contains all the requirements from the hospital, related to the project.

IFC model hospital

Type	Library objects providing information
Name	IFC model hospital
Documentation	The existing IFC model of the hospital provided by the hospital.

First draft quote equipment

Type	Library objects providing information
Name	First draft quote equipment
Documentation	This is de document about the offer done by Philips to the Hospital. It contains information about the type of equipment and the system name. Next to this is shows how much the equipment will cost. When the hospital has a maximum budget for both the equipment and the building works, the Project Manager needs to take this into account.

Budget building works

Type	Library objects providing information
Name	First draft quote equipment
Documentation	This is de document about the offer done by Philips to the Hospital. It contains information about the type of equipment and the system name. Next to this is shows how much the equipment will cost. When the hospital has a maximum budget for both the equipment and the building works, the Project Manager needs to take this into account.

Site preparation specification

Type	Library objects providing information
Name	Site preparation specifications
Documentation	This document is made by the department site planning and contains all the information related to mechanical and electrical installations required for the installations of a specific type of equipment. Installations that are indicated in this document are: • Power supply • Lighting requirements • Air treatment requirements • Safety requirements • Communication requirements • Plumbing requirements • Requirements regarding ceiling/floor support structure equipment

Room lay-out design

Type	Library objects providing information
Name	Room lay-out design
Documentation	This document is the proposed room lay-out by the medical equipment supplier, taking into account the minimal distances necessary to work in an optimal way with the equipment.

Ready IFC model

Type	Library objects providing information
Name	Ready IFC model
Documentation	The output for the process *Program space requirements*, is the document Ready IFC model, which is an BIM exchange data file, and forms the input for the process *Quantity take off from IFC model*.

Bill of quantity

Type	Library objects providing information
Name	Bill of quantity
Documentation	The bill of quantity is a list of activities which are defined by a quantity and a unit, extracted from the IFC model. The contractors can fill this BoQ with their unit prices and item prices (quantity * unit price).

Supplier contract

Type	Library objects providing information
Name	Contractor contract
Documentation	This is the contractor that includes the costs given by the contractor for the set of building works activities.

Site Readiness Checklist

Type	Library objects providing information
Name	Site readiness checklist
Documentation	This is a checklist, provided by site planning, to help the project manager on deciding whether the room is ready for the installation of the equipment or not.

As-built costs

Type	Library objects providing information
Name	As-built costs
Documentation	This document includes all the information related to the as-built costs of the project. This can be made when the room is installation ready.

Punch list report

Type	Library objects providing information
Name	Punch list report
Documentation	This report is the output of the punch list check conducted by the hospital and is a list of the work that is necessary to be performed by the contractor after the installation of the equipment is done.

Specifications of Exchange Requirement Data Objects

ER1: IFC model for quantity take off

Type	Exchange requirement data object
Name	Quantity Take-off for Cost Estimating
Documentation	The existing IFC model of the hospital is used to adjust the room subject to the project. All building works activities can be drawn into the model, together with the equipment. This model can be used for a BIM-based approach for quantity take off. This process can replace the time consuming site visit.

ER2: Industry standard classification format

Type	Exchange requirement data object
Name	Industry standard quotation format
Documentation	This exchange requirement contains all the information related to the classification system of the objects in the IFC model that is used in this process, to make sure that all stakeholders work with the same classification. This exchange requirement forms a sort of mapping table for the next exchange requirement.

ER3: Historic project database

Type	Exchange requirement data object
Name	Historic project database
Documentation	The historic project database, is a data warehouse that contains all the cost information of historic projects. Cost influencing factors are taken into account and therefore shadow cost estimations could be conducted with the help of this database.

ER4: As-built IFC model

Type	Exchange requirement data object
Name	As-built IFC model
Documentation	This exchange requirement contains all the information related to the classification system of the objects in the IFC model that is used in this process, to make sure that all stakeholders work with the same classification. This exchange requirement forms a sort of mapping table for the next exchange requirement.

Appendix 7. Exchange Requirement 1

Object type	Information Needed	Required/ Optional	Data type	Units					
Property					**IFC Model Representation**	**Range**	**Property Type**	**Data Type**	**Description**
Project									
	Identification	R	String	n/a	IfcProject.Name				
	Client information (hospital)	O	String	n/a	IfcProject.LongName				
	IFC. model Author	O	String	n/a	IfcOwnerHistory.LongName				
Building									
	Identification	R	String	n/a	IfcBuilding.Name				
	Description	O	String	n/a	IfcBuilding.Description				
	Functional Classification	O	String	n/a	*IfcRelAssociatesClassification*				
	Address	R	String	n/a	IfcPostalAddress				
Building Story									
	Identification	R	String	n/a	IfcBuildingStorey				
	Description	O	String	n/a	IfcBuildingStorey.Description				
	Building Story Height	R	Real	m	IfcQuantityHeight.Name="BuildingStoreyHeight"				
Space									
	Identification	R	String	n/a	IfcSpace.Name				
	Description	O	String	n/a	IfcSpace.LongName				
	Functional Classification	O	String	n/a	*IfcRelAssociatesClassification*				
	Space Height	R	Real	mm	IfcQuantityLeHeight.Name="SpaceHeight"	2900 mm (+10/-0mm)			
	Gross Area	R	Real	m²	IfcQuantityArea.Name="GrossSpaceArea"				
	Net Area	R	Real	m²	IfcQuantityArea.Name="NetSpaceArea"				
	Space Floor Finishing	R	String	n/a	IfcSpace -> IfcCovering -> IfcCoveringType				
	Has non-skid surface	R	Boolean	n/a	IfcSpace -> Property.Name = "CoveringFlooring"		IfcPropertySingleValue	IfcBoolean	
	Has anti-static surface	R	Boolean	n/a	IfcSpace -> Property.Name = "CoveringFlooring"		IfcPropertySingleValue	IfcBoolean	
	Space Ceiling Finishing	R	String	n/a	IfcSpace -> IfcCovering -> IfcCoveringType				
	Permeability	R	Real	ratio	IfcSpace -> Property.Name = "CoveringCeiling"		IfcPropertySingleValue	IfcNormalisedRatioMeasure	
	Tile Length	R	Real	mm	IfcSpace -> Property.Name = "CoveringCeiling"		IfcPropertySingleValue	IfcPositiveLengthMeasure	
	Tile Width	R	Real	mm	IfcSpace -> Property.Name = "CoveringCeiling"		IfcPropertySingleValue	IfcPositiveLengthMeasure	
	Ceiling Load	R	Real	kg/m³	IfcSpace	2320 kg/m³			
	Beam Length	R	Real	m	IfcQuantityLength.Name="BeamLength"				
	Beam Height	R	Real	m	IfcQuantityHeight.Name="BeamHeight"				
	Beam Width	R	Real	m	IfcQuantityThickness.Name="BeamThickness"				
	Static Deflection	R	Real	mm		1,7 mm (with 1000 kg stand)			

Object type	Information Needed	Required/ Optional	Data type	Units					
Property					IFC Model Representation	Range	Property Type	Data Type	Description
Sanitary									
	Identification	O	String	n/a	IfcSanitaryTerminalType				
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference				
	Nominal Length	R	Double	mm	IfcSanitaryTerminalType -> IfcQuantityLength.Name = "NominalLength"		IfcPropertySingleValue	IfcPositiveLengthMeasure	Nominal or quoted length of the object
	Nominal With	R	Double	mm	IfcSanitaryTerminalType -> IfcQuantityWith.Name = "NominalWith"		IfcPropertySingleValue	IfcPositiveLengthMeasure	Nominal or quoted width of the object
	Nominal Depth	R	Double	mm	IfcSanitaryTerminalType -> IfcQuantityDepth.Name = "NominalDepth"		IfcPropertySingleValue	IfcPositiveLengthMeasure	Nominal or quoted depth of the object.
HVAC system									
	Identification	O	String	n/a	IfcAirToAirHeatRecoveryType				
	Industry Classification	O	String	n/a	IfcClassificationReference.ItemReference				
	Casing material	R	String	n/a	IfcAirToAirHeatRecoveryType IsDefinedBy IfcMaterialConsituentSet		IfcShapeAspect		Material from which the casing is constructed
	Media material	R	String	n/a	IfcAirToAirHeatRecoveryType IsDefinedBy IfcMaterialConsituentSet		IfcShapeAspect		Primary media material used for heat transfer
	Space Temperature Max	R	Real	°C	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"	10 °C	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure/THERMODYNAMICTEMPERATUREUNIT	Temperature of the space, that is required from designer view point.
	Space Temperature Min	R	Real	°C	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"	30 °C	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure/THERMODYNAMICTEMPERATUREUNIT	Minimal temperature of the spare that is required from the designer view point
	Space Humidity	R	Real	%	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"	20-80%	IfcPropertySingleValue	IfcRatioMeasure	Humidity of the space or zone that is required from the designer view point
	Air Conditioning	R	String	n/a	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"		IfcPropertySingleValue	IfcBoolean	When applicable indicated with TRUE, otherwise with FALSE
	Heat Emission	R	Real	W	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"	1900W	IfcPropertySingleValue	IfcString	Heat Emission in the examination room, given in Watt
	Heat Emission	R	Real	W	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"	500W	IfcPropertySingleValue	IfcString	Heat emission in control room, given in Watt
	Heat Emission	R	Real	W	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"	2400W	IfcPropertySingleValue	IfcString	Heat emission in technical room, given in Watt
Electrical System									
Power	Identification	O	String	n/a	IfcTranformerType				
	Industry Classification	O	String	n/a	IfcClassificationReference.ItemReference				
	Primary Voltage	R	Real	V	IfcTranfrmerType -> Property.Name = "TransformerTypeCommon"	3*400 - 480 V ±10%	IfcPropertySingleValue	IfcElectricVoltageMeasure	The voltage that is going to be transformed and that runs into the transformer on the primary side
	Primary Frequency	R	Real	Hz	IfcTranfrmerType -> Property.Name = "TransformerTypeCommon"	50-60 Hz	IfcPropertySingleValue	IfcFrequencyMeasure	The frequency that is going to be transformed and that runs into the transformer on the primary side

Object type	Information Needed	Required/ Optional	Data type	Units					
Property					IFC Model Representation	Range	Property Type	Data Type	Description
Circuit Breaker (earthen)	Identification	O	String	n/a	IfcProtectiveDevice				
	Industry Classification	R	String	n/a	IfcClassificationReference.ItemReference				
	Rated current	R	Real	V	IfcProtectiveDevice -> Property.Name = "ProtectiveDeviceType"	63-125 A	IfcPropertySingleValue	IfcReal	The value for the movement of electrically charged particles
Cable carrier									
	Identification	O	String	n/a	IfcCableCarrierFitting				
	Industry Classification	R	String	n/a	IfcClassificationReference.ItemReference				
	Width cable carrier	R	Real	mm	IfcCableCarrierFitting -> Property.Name = "CableCarrierSegmentTypeCableTraySegment"		IfcPropertySingleValue	IfcPostiveLeangtMeasure	The nominal width of the segment.
	Height cable carrier	R	Real	mm	IfcCableCarrierFitting -> Property.Name = "CableCarrierSegmentTypeCableTraySegment"		IfcPropertySingleValue	IfcPostiveLeangtMeasure	The nominal height of the segment.
	Cover cable carrier	R	String	n/a	IfcCableCarrierFitting -> Property.Name = "CableCarrierSegmentTypeCableTraySegment"		IfcPropertySingleValue	IfcBoolean	Indication of whether the cable tray has a cover (=TRUE) or not (= FALSE). By default, this value should be set to FALSE.
Lighting System									
	Identification	O	String	n/a	IfcLightFixture				
	Industry Classification	R	String	n/a	IfcClassificationReference.ItemReference				
	Contributed Luminous	R	Real	lux	IfcLightFixture -> Property.Name = "LampTypeCommon"	50-100 Lux	IfcPropertySingleValue	IfcLuminousFluxMeasure	
Communication System									
	Identification	O	String	n/a	IfcOutletType				
	Industry Classification	O	String	n/a	IfcClassificationReference.ItemReference				
	Is Pluggable Outlet	R	String	n/a	IfcOutletType -> Property.Name = "OutletTypeCommon"				
	Number Of Sockets	R	Real	no.	IfcOutletType -> Property.Name = "OutletTypeCommon"				
Furniture									
	Identification	O	String	n/a	IfcFurniture				
	Industry Classification	O	String	n/a	IfcClassificationReference.ItemReference				
	Description	O	String	n/a	IfcFurnitureTypeEnum = ENUMERATION OF (CHAIR, TABLE, DESK, BED, FILECABINET, SHELF, SOFA, USERDEFINED, NOTDEFINED); END_TYPE				
	Nominal Height	O	Real	mm	IfcFurniture -> Property.Name = "FurnitureTypeCommon"		IfcPropertySingleValue	IfcPositiveLengthMeasure	The nominal height of the furniture of this type. The size information is provided in addition to the shape representation and the geometric parameters used within.
	Nominal Length	O	Real	mm	IfcFurniture -> Property.Name = "FurnitureTypeCommon"		IfcPropertySingleValue	IfcPositiveLengthMeasure	The nominal length of the furniture of this type. The size information is provided in addition to the shape representation and the geometric parameters used within
	Nominal Depth	O	Real	mm	IfcFurniture -> Property.Name = "FurnitureTypeCommon"		IfcPropertySingleValue	IfcPositiveLengthMeasure	The nominal depth of the furniture of this type. The size information is provided in addition to the shape representation and the geometric parameters used within.
	Main Color	O	String	n/a	IfcFurniture -> Property.Name = "FurnitureTypeCommon"		IfcPropertySingleValue	IfcLabel	The main color of the furniture of this type

Appendix 8. Exchange Requirements 2

Attribute definition	
Source	NEN 2634:2002
Edition	2002
Edition Date	June 2002
Name	NEN2634
Contains	See classification below
Attribute definition	
Source	Functionele gebouwelementen/Elementenmethode 2005
Edition	2005
Edition Date	-
Name	NL/SfB
Contains	See classification below
Attribute definition	
Source	STABU
Edition	2012
Edition Date	-
Name	STABU
Contains	See classification below

Uniclass2	IFC model representation	Description Uniclass2	Description	Unit of Measurement	Qto	Attribute Definition	Quantity type	Qto Type
Ee_25_25_10	IfcWallType	Internal wall, structure	Construction works , Primary structure, internal walls, constructive, building works	m^2	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Ee_25_25_45 -> Pr_20_85_32_36	IfcWall -> IfcWallType -> IfcMaterialLayerSet	Internal walls face A finishes, Hardwood Frames	Construction works, internal walls, finishing, Wood (width mm, height mm, depth mm)	m^2	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Ee_25_25_45 -> Pr_35_31_22_64	IfcWall -> IfcWallType -> IfcMaterialLayerSet	Internal walls face A finishes, Plastic texture paints	Construction works, internal walls, finishing, paint	m^2	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Ee_25_25_45 -> Pr_35_31_64	IfcWall -> IfcWallType -> IfcMaterialLayerSet	Internal walls face A finishes, Plasters and Renders	Construction works, internal walls, finishing, plaster	m^2	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Ee_25_25_45 -> Pr_35_57_71_20	IfcWall -> IfcWallType -> IfcMaterialLayerSet	Internal walls face A finishes, PVC tiles	Construction works, internal walls, finishing, vinyl	m^2	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Ee_25_25_45 -> Pr_35_93_96_19	IfcWall -> IfcWallType -> IfcMaterialLayerSet	Internal walls face A finishes, Ceramic Tiles	Construction works, internal walls, finishing, ceramic	m^2	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Ee_25_25_45 -> Ss_25_60_50_45	IfcWall -> IfcWallType -> IfcMaterialLayerSet	Internal walls face A finishes, Lead Cladding Flashing Systems	Construction works, internal walls, finishing, radiation insulation (lead) (width mm, height mm,	m^2	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components

Uniclass2	IFC model representation	Description Uniclass2	Description	Unit of Measurement	Qto	Attribute Definition	Quantity type	Qto Type
			depth mm)					
Ee_30_10_42 -> Ee_30_10_47	IfcSpace -> Property.Name = "CoveringCeiling"	Roofs ceiling or soffit coverings/ roof ceiling or soffit finishes	Construction works , Primary Structure, ceiling, steal ceiling framing (constructive framing)	m²	Qto_WallBaseQuantities	IfcPositiveLengthMeasure	Q_Length	Identification components
Ee_30_40_40 -> Ss_30_42_72_75	IfcSpace -> IfcCovering -> IfcCoveringType	Upper Floors Floor Coverings, Resilient Tile Floor Covering Systems	Construction works, floor, finishing, vinyl flooring (60*60 cm tiles)	m²	Qto_SpaceBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Ee_30_40_42 -> Pr_25_71_52_37	IfcSpace -> IfcCovering -> IfcCoveringType	Upper Floors Ceiling Or Soffit Coverings/ Gypsum Plasterboards	Construction works, ceiling, finishing, ceiling tiles	m²	Qto_SpaceBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Ee_65_50_80	IfcAirToAirHeatRecoveryTyp e	Building Air Conditioning	Mechanical installations, air treatment, ventilation (hp; ampere key)	No. of units		PredefinedType (identifies the predefined types of transformer from which the type required may be set)	Q_Weight	Counting components
En_70_10_10	IfcTranformerType	Electrical Power Generation Buildings	Electrical installations, general electrical work (ampere master key)	no. of points of connection or installed power		PredefinedType (Defines the type of air to air heat recovery device)		Identification components
PP_90_20_60	IfcWallType	Project Phase, Demolition	Construction works, Primary structure, internal walls, Cracking and destruction works, removal and closing existing door openings in the walls.	m²	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Pr_15_57_33_68	IfcSanitaryTerminalType	Polypropylene (PP) Water Retention Geotextiles	Mechanical installations, Water, general, water cooling, polypropylene	m piping or mo. Of points of connection	Qto_SanitaryTerminalBaseQu antities	IfcQuantityLength.Name = "NominalLength"	Q_Length	Identification components
Pr_30_59_23	IfcWall	Stainless steel door frames	Construction works , Internal walls, opening filled with door. (Width mm; Height mm, Material)	No.	Qto_OpeningElementBaseQu antities	ifcQuantityArea.Name="WallOpeningGrossArea"	Q_Area	Identification components
Pr_35_31_06_29	IfcSpace -> IfcCovering -> IfcCoveringType	Fine Concrete Levelling Screed Mixes	Construction works, floor, finishing, self-levelling floor	m²	Qto_SpaceBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Pr_35_93_96_19	IfcSpace -> IfcCovering -> IfcCoveringType	Ceramic Tiles	Construction works, floor, finishing, ceramic flooring	m²	Qto_SpaceBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Pr_35_93_96_53	IfcSpace -> IfcCovering -> IfcCoveringType	Mosaic Tiles	Construction works, floor, finishing, mosaic flooring	m²	Qto_SpaceBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Pr_40_30_66_18	IfcFurniture	Curtains	Movable facilities, curtains	No.	Qto with the help of counting query			Counting components
Pr_40_30_78_48	IfcFurniture	Lockers	Fixed facilities, storage, lockers (mm width, mm height, mm depth)	No.	Qto with the help of counting query			Counting components

Uniclass2	IFC model representation	Description Uniclass2	Description	Unit of Measurement	Qto	Attribute Definition	Quantity type	Qto Type
Pr_40_30_79_37	IfcSanitaryTerminalType	Health Care General Wash Basins	Fixed facilities, sanitary, hand washbasin	no.	Qto_SanitaryTerminalBaseQuantities	IfcQuantityLength.Name = "NominalLength"	Q_Length	
Pr_40_50_12_57	IfcFurniture	Office Chairs	Movable facilities, furniture	No.	Qto with the help of counting query			Counting components
Pr_40_50_21	IfcFurniture	Desks, Tables And Worktops	Movable facilities, desk	No.	Qto with the help of counting query			Counting components
Pr_65_70_11_84	IfcSpace -> IfcCovering -> IfcCoveringType	Stainless Steel Floor Cable Ducting	Supply and install FLOOR DUCT from the galvanized iron 20 cm width – 10 cm depth with a stainless cover 3 mm, as well as finalizing the works according to the industry standards.	m/m²	Qto_SpaceBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Identification components
Pr_80_77_12_17	IfcCableCarrierFitting	Cable Trays	Electrical installations, central energy, canalization (width cm cable tray; material)	no. or m	Qto_CableCarrierFittingBaseQuantities	IfcQuantityLength.Name = "NominalLength"	Q_Lenght	Identification components
Ss_25_30_20	IfcWallType	Sliding door set system	Construction works , Internal walls, opening filled with sliding door. (Width mm; Height mm, Material)	No.	Qto_WallBaseQuantities	IfcQuantityArea.Name="GrossArea"	Q_Area	Counting components
Ss_70_30_25_25	IfcProtectiveDevice	Earthen And Bonding Systems	Electrical installations, earthen, general	no. of points of connection or installed power	Qto_ProtectiveDeviceBaseQuantities			Counting components
Ss_70_80_33	IfcLightFixture	General Space Lighting Systems	Electrical installations, light, general inside, 220 V	Lumen per Watt or no. of points of connection	Qto_LightFixtureBaseQuantities	Qto with the help of counting query		Counting components
Ss_75_10_21	IfcOutletType	Data Distribution And Telecommunications Systems	Electrical installation, communication, internet output	no. of points of connection	Qto_OutletBaseQuantities	Qto with the help of counting query		Counting components
Ss_75_10_21	IfcOutletType	Data Distribution And Telecommunications Systems	Electrical installation, communication, telephone output	no. of points of connection	Qto_OutletBaseQuantities	Qto with the help of counting query		Counting components

Appendix 9. Example Case Study

Hospital case 1
Cairo – Egypt
University Hospital

February 2014

Cardio Vascular

Works	Uniclass2	Uniclass description	Items	Unit	Qty.	BioMed	EG	HT	Limits	UC	Unicon
Civil & finishing works	Ss_15_10_20	deconstruction and demolition system	Cracking and destruction works, removal and closing existing door openings in the walls, as described in the drawing, transferring wastes promptly to public landfills and regular cleaning works.	LS	1	3000	4500	5000	3000	10000	5000
	Ss_20_05 Pr_20_93_52_15	internal wall substructure, clay bricks	By Square Meters, building works with 12 cm bricks. The price includes transporting, supplying and storing	m2	25	70	70	100	90	150	110
	Ss_25_20 -> Pr_25_71_52_37	Wall cladding system, gypsum plasterboards	By square meters, supplying and installing gypsum boards with thickness of at least 12 mm.	m²	25	175	230	175	210	125	165
	Ss_25_20 -> Pr_35_31_22_64	Wall cladding system, plastic texture paints	By Square Meters, Supplying and executing washable plastic paint from "JOTUN" or equivalent brand, with three putty knife of paint.	m2	25	60	65	65	40	40	50
	Ss_30_47 -> Pr_25_71_52_37	Ceiling and soffit covering and finishing system, gypsum plasterboards	By square meters, supplying and installing gypsum ceiling tiles according to industry standards and approved by site engineer.	m²	45	85	85	85	100	100	70
	Ss_30_40_40 -> Pr_35_57_71_20	Resilient tile floor covering system, PVC tiles	Supplying and executing vinyl antistatic flooring for the apparatus room, control room and cabinets room with 60*60 cm including supplying, installing and self-levelling as well as transferring wastes to public landfills	m²	40	320	390	310	285	250	340
	Ss_25_20 -> Pr_35_57_71_20	Wall cladding system, PVC tiles	By Square Meters, Supplying and installing wall Vinyl in accordance with the approved sample by Hospital's management.	m2	130	180	190	220	315	200	170
	Ss_25_30_20_37	high security door set system	Supplying and installing leaded door with 120 cm.	No.	1	5100	7800	4100	3050	4500	4000
	Ss_25_30_20_25 -> Pr_30_59_23	door set system, stainless steel door frames	Supplying and installing a 80 cm door affixed by rigid vinyl and installing Stainless steel strips from at the bottom at 90 cm height		1	3100	3900	3000	2550	3500	2500
	Ss_20_10_75_45	light steel framing system	Supply and installation of steel beams to the ceiling unnecessary comments catheter device sectors and lengths according to the executive for graphics and paint sectors textured weatherproof steel	LS	1	11000	11500	15000	7350	9000	18000
	Ss_25_45_88_40	Internal wall tiling system	Supplying and installing leaded tiles, 1,5 mm, walls	m²	70	450	460	420	650	425	425
Air-conditioning	Ss_65_80_05	Central air conditioning system	Supplying and Installing Air-conditioning system with 3HP capacity, D-conditioning drainage of PVC pipes.	No.	6	6950	8300	5750	6870	8250	829000
Electrical	Ss_70_80_33	General space lighting system	Supply and install lighting headlamp size 60x60 "approved brand" with all its accessories and the price includes supply, hang, drilling and the key by using appropriate installation methods	No.	14	320	300	300	340	325	310
	Ss_75_10_21	Data distribution and internet communications systems	Make an internet output includes cut-off, covers after the approval of the site engineer and the item includes drilling, installing as well as the necessary accessories for finalizing the works	No.	2	110	200	200	290	150	300
	Ss_75_10_21	Data distribution and telecommunications systems	Make a telephone output includes cut-off, covers after the approval of the site engineer and the item includes drilling, installing as well as the necessary accessories for finalizing the works	No.	2	110	200	200	225	150	300
	Pr_80_77_12_17	Cable trays	Supply and install cable tray, aluminum cable holder 30 cm width, including duct and the final installation	LM	18	310	260	250	245	300	280
	Pr_65_70_11_84	Stainless steel floor cable ducting	Supply and install FLOOR DUCT from the galvanized iron 20 cm width – 10 cm depth with a stainless cover 3 mm, as well as finalizing the works	LM	12	300	240	250	80	350	340
Furnishes	Pr_40_50_12_57	Office chairs	Office supply 4 chairs	LS	1	7600	11000	11500	9100	5000	9000
	Pr_40_50_21	Desk, tables and worktops	wooden counter 2,40 * 0,50 * 0,90 m								

* Costs are in Egyptian pounds

Appendix 10. Exchange Requirement 4

Object type	Information Needed	Required/ Optional	Data type	Units				
Property					IFC Model Representation	IfcLaborResourceTypeEnum	IFC cost and labor resources	Data Type
Project								
	Identification	R	String	n/a	IfcProject.Name			
	Client information (hospital)	O	String	n/a	IfcProject.LongName			
	IFC. model Author	O	String	n/a	IfcOwnerHistory.LongName			
Building								
	Identification	R	String	n/a	IfcBuilding.Name			
	Description	O	String	n/a	IfcBuilding.Description			
	Functional Classification	O	String	n/a	*IfcRelAssociatesClassification*			
	Address	R			IfcPostalAddress			
Building Story								
	Identification	R	String	n/a	IfcBuildingStorey			
	Description	O	String	n/a	IfcBuildingStorey.Description			
	Building Story Height	R	Real	m	IfcQuantityHeight.Name="BuildingStoreyHeight"			
Space								
	Identification	R	String	n/a	IfcSpace.Name			
	Description	O	String	n/a	IfcSpace.LongName			
	Space Height	R	Real	mm	IfcQuantityLeHeight.Name="SpaceHeight"			
	Gross Area	R	Real	m^2	IfcQuantityArea.Name="GrossSpaceArea"			
	Net Area	R	Real	m^2	IfcQuantityArea.Name="NetSpaceArea"			
	Space Floor Finishing	R	String	n/a	IfcSpace -> IfcCovering -> IfcCoveringType	Finishing/Painting	IfcSpace -> IfcMaterial -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Has non-skid surface	R	Boolean	n/a	IfcSpace -> Property.Name = "CoveringFlooring"			
	Has anti-static surface	R	Boolean	n/a	IfcSpace -> Property.Name = "CoveringFlooring"			
	Space Ceiling Finishing	R	String	n/a	IfcSpace -> IfcCovering -> IfcCoveringType			
	Permeability	R	Real	ratio	IfcSpace -> Property.Name = "CoveringCeiling"			
	Tile Length	R	Real	mm	IfcSpace -> Property.Name = "CoveringCeiling"			
	Tile Width	R	Real	mm	IfcSpace -> Property.Name = "CoveringCeiling"			
	Ceiling Load	R	Real	kg/m^3	IfcSpace	Steelwork	IfcCeilingl -> IfcCeilingType -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Beam Length	R	Real	m	IfcQuantityLength.Name="BeamLength"			
	Beam Height	R	Real	m	IfcQuantityHeight.Name="BeamHeight"			
	Beam Width	R	Real	m	IfcQuantityThickness.Name="BeamThickness"			
	Static Deflection	R	Real	mm				

Object type	Information Needed	Required/ Optional	Data type	Units				
Property					IFC Model Representation	IfcLaborResourceTypeEnum	IFC cost and labor resources	Data Type
Wall								
	Identification	R	String	n/a	IfcWallType	Drywall	IfcSpace -> IfcWallType -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Industry Classification	R	String	n/a	ifcClassificationReference.ItemReference			
	Wall length	R	Real	m	ifcQuantityLength.Name="WallLength"			
	Wall Height	R	Real	m	ifcQuantityHeight.Name="WallHeight"			
	Wall Thickness	R	Real	m	ifcQuantityThickness.Name="WallThickness"			
	Floor Finishing type (classification)	R	String	n/a	IfcFloor -> IfcFloorType -> IfcMaterialLayerSet	Flooring	IfcSpace -> IfcMaterial -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
Internal Walls								
	Identification	R	String	n/a	IfcWallType			
	Industry Classification	R	Boolean	n/a	ifcClassificationReference.ItemReference			
	Wall length	R	Real	m	ifcQuantityLength.Name="WallLength"			
	Wall Height	R	Real	m	ifcQuantityHeight.Name="WallHeight"			
	Wall Finishing type (Classification)	R	String	n/a	IfcWall -> IfcWallType -> IfcMaterialLayerSet	Painting/general/ finishing	IfcSpace -> IfcMaterial -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
Wall Openings								
	Identification	R	String	n/a	IfcOpening			
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Opening Width	R	Real	m	ifcQuantityLength.Name="WallOpeningLength"	Carpentry	IfcSpace -> IfcMaterial -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Opening Height	R	Real	m	ifcQuantityHeight.Name="WallOpeningHeight"			
	Opening Depth	R	Real	m	ifcQuantityDepth.Name="WallOpeningDepth"			
	Opening Gross Area	R	Real	m^2	ifcQuantityArea.Name="WallOpeningGrossArea"			
	Opening Net Area	R	Real	m^2	ifcQuantityArea.Name="WallOpeningNetArea"			
Door								
	Identification	R	String	n/a	ifcDoor IfcRelDefinedBy IfcOpening	Carpentry/ Steelwork/General	IfcDoor -> IfcDoorStyle -> IfcMaterial -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Door type	R	String	n/a	ifcDoorStyle			
	Door With	R	Real	m	ifcQuantityLength.Name="DoorLength"			
	Door Height	R	Real	m	ifcQuantityHeight.Name="DoorHeight"			
	Door Material	R	String	n/a	IfcDoor -> IfcDoorStyle -> IfcDoorStyleConstruction			

Object type	Information Needed	Required/ Optional	Data type	Units				
Property					IFC Model Representation	IfcLaborResourceTypeEnum	IFC cost and labor resources	Data Type
Window						Carpentry/ Steelwork/General	IfcWindow -> IfcWindowType -> IfcMaterialConsituentSet -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Identification	R	String	n/a	ifcWindow			
	Industry Classification	R	String	n/a	ifcClassificationReference.ItemReference			
	Window type	R	Real	n/a	ifcWindowStyle			
	Window With	R	Real	m	ifcQuantityLength.Name="WindowLength"			
	Window Height	R	Real	m	ifcQuantityHeight.Name="WindowHeight"			
	Exterior or Interior Element	R	Boolean	n/a	*ifcRelAssociatesClassification*			
	Window Frame Depth	R	Real	m	ifcQuantityDepth.Name="WindowFrameDepth"			
	Window Frame Thickness	R	Real	m	ifcQuantityThickness.Name="WindowFrameThickness"			
	Window Leaf Thickness	R	Real	m	ifcQuantityThickness.Name="WindowLeafThickness"			
	Window Gross Area	R	Real	m^2	ifcQuantityArea.Name="WindowGrossArea"			
	Window Frame Material	R	String	n/a	IsDefinedBy IfcMaterialConstituentSet			
Sanitary						Plumbing	IfcSpace -> IfcSanitaryTerminalType -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Identification	O	String	n/a	IfcSanitaryTerminalType			
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Nominal Length	R	Double	mm	IfcSanitaryTerminalType -> IfcQuantityLength.Name = "NominalLength"			
	Nominal With	R	Double	mm	IfcSanitaryTerminalType -> IfcQuantityWith.Name = "NominalWith"			
	Nominal Depth	R	Double	mm	IfcSanitaryTerminalType -> IfcQuantityDepth.Name = "NominalDepth"			
HVAC system						HVAC	IfcSpace -> IfcAirToAirRecoveryType -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Identification	O	String	n/a	ifcAirToAirHeatRecoveryType			
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Casing material	R	String	n/a	IfcAirToAirHeatRecoveryType IsDefinedBy IfcMaterialConsituentSet			
	Media material	R	String	n/a	IfcAirToAirHeatRecoveryType IsDefinedBy IfcMaterialConsituentSet			
	Space Temperature Max	R	Real	°C	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"			
	Space Temperature Min	R	Real	°C	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"			
	Space Humidity	R	Real	%	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"			
	Air Conditioning	R	String	n/a	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"			

	Heat Emission	R	Real	W	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"			
	Heat Emission	R	Real	W	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"			
	Heat Emission	R	Real	W	IfcAirToAirHeatRecoveryType -> Property.Name = "SpaceTermalRequirements"			
Object type	**Information Needed**	**Required/ Optional**	**Data type**	**Units**				
Property					**IFC Model Representation**	**IfcLaborResourceTypeEnum**	**IFC cost and labor resources**	**Data Type**
Electrical System								
Power	Identification	O	String	n/a	IfcTranformerType	Electric	IfcSpace -> IfcTransformerType -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Primary Voltage	R	Real	V	IfcTranfrmerType -> Property.Name = "TransformerTypeCommon"			
	Primary Frequency	R	Real	Hz	IfcTranfrmerType -> Property.Name = "TransformerTypeCommon"			
Circuit Breaker *(earthen)*	Identification	O	String	n/a	IfcProtectiveDevice	Electric	IfcSpace -> IfcProtectiveDevice -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Rated current	R	Real	V	IfcProtectiveDevice -> Property.Name = "ProtectiveDeviceType"			
Cable carrier								
	Identification	O	String	n/a	IfcCableCarrierFitting	Electric	IfcSpace -> IfcCableCarrierFitting -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Industry Classification	R	String	n/a	ifcClassificationReference.ItemReference			
	Width cable carrier	R	Real	mm	IfcCableCarrierFitting -> Property.Name = "CableCarrierSegmentTypeCableTraySegment"			
	Height cable carrier	R	Real	mm	IfcCableCarrierFitting -> Property.Name = "CableCarrierSegmentTypeCableTraySegment"			
	Cover cable carrier	R	String	n/a	IfcCableCarrierFitting -> Property.Name = "CableCarrierSegmentTypeCableTraySegment"			
Lighting System								
	Identification	O	String	n/a	ifcLightFixture	Electric	IfcSpace -> IfcLightFixture -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Contributed Luminous	R	Real	lux	IfcLightFixture -> Property.Name = "LampTypeCommon"			

Object type	Information Needed	Required/ Optional	Data type	Units				
Property					**IFC Model Representation**	**IfcLaborResourceTypeEnum**	**IFC cost and labor resources**	**Data Type**
Communication System								
	Identification	O	String	n/a	ifcOutletType	Electric	IfcSpace -> IfcOutletType -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Is Pluggable Outlet	R	String	n/a	IfcOutletType -> Property.Name = "OutletTypeCommon"			
	Number Of Sockets	R	Real	no.	IfcOutletType -> Property.Name = "OutletTypeCommon"			
Furniture								
	Identification	O	String	n/a	IfcFurniture *(IfcPropertySet,,Pset_FurnitureTypeCommon")*	General	IfcSpace -> IfcFurniture -> IfcConstructionResource -> Property.Name="ConstructionResources"	IfcTimeSeries / IfcMonetaryMeasure
	Industry Classification	O	String	n/a	ifcClassificationReference.ItemReference			
	Description	O	String	n/a	IfcFurnitureTypeEnum = ENUMERATION OF (CHAIR, TABLE, DESK, BED, FILECABINET, SHELF, SOFA, USERDEFINED, NOTDEFINED); END_TYPE			
	Nominal Height	O	Real	mm	IfcFurniture -> Property.Name = "FurnitureTypeCommon"			
	Nominal Length	O	Real	mm	IfcFurniture -> Property.Name = "FurnitureTypeCommon"			
	Nominal Depth	O	Real	mm	IfcFurniture -> Property.Name = "FurnitureTypeCommon"			
	Main Color	O	String	n/a	IfcFurniture -> Property.Name = "FurnitureTypeCommon"			