Master Thesis

BIM Quantity Takeoff:

Assessment of the quantity takeoff accuracy as an automatic process. The special case of Revit and Vico office.

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Abstract

Date:	**Abstract:**
August, 29th 2014 **Key words**: BIM, BIM quantity takeoff, BIM 4D, BIM 5D.	This report starts with the analysis of theoretical aspects of BIM as a new trend to manage building projects: general advantages, the concept of interoperability, the automatic process of quantity takeoff and finally the use of BIM for planning and estimating construction activities. Then, based on this theoretical part both quantitative and qualitative researches are developed in order to show: the real influence that the method of designing has on the accuracy of quantities whereas, the qualitative research is focused on explaining that BIM is not equal adopted by all companies that work around the same project. Architectural firms represent the institutions that more use BIM for designing followed by engineering consultancies and construction companies.

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Abbreviations

CAD	Computer Aided Design
BIM	Building Information Modelling
IPD	Integrated Project Delivery
AEC	Architectural Engineering Construction
ICT	Information and Communication Technology
PM	Project Manager
FM	Facility Manager
LOD	Level of Development
IFC	Industrial Foundation Classes
BIMXPs	Building Information Modelling Execution Plans
RFID	Radio Frequency Identification
LBMS	Location Based Management System
LBS	Location Breakdown Structure
LOB	Line of Balance
LBM	Location Based Management
LPS	Last Planner System
CPM	Critical Path Method
PERT	Program Evaluation and Review Technique
BQ	Bill of Quantity
COBie	Construction Operations Building Information Exchange
RICS	Royal Institution of Chartered Surveyors
NRM	New Rules of Measurement
ADP	Abstract Data Type
ROI	Return on Investment
RFIs	Request for Information
SD	Schematic Design
DD	Detailed Design
CD	Construction Detailing
VDC	Virtual Design Construction
MEAs	Model Element Authors
UNICLASS	Unified Classification for the Construction Industry
CIS/2	CIMSteel Integration Standards
BLIS	Building Lifecycle Interoperability Software
GSA	General Services Administration
NBIMS	National BIM Standard
XML	Extensible Mark-up Language
IDM	Information Delivery Manuals
MVD	Model View Definition
AEX	Automating Equipment Information Exchange
AGCxml	Association of General Contractors
GBxml	Green Building
OSCRE	Open Software Consortium for Real State
OGC	Open Geospatial Consortium
WBS	Work Breakdown Structure
STF	Structural Floor
STW	Structural Wall

Introduction

1. Background

Nowadays, construction industry experiences many changes concerning how to increase the efficiency on its processes having always, as a reference of management, the procedures that make more profitable the manufacturing industry. Building Information Modelling (BIM) promotes a modern collaborative method of working in the Architectural, Engineering and Construction (AEC) areas where, each participant that have assigned an individual task, should adopt a new behaviour based on the interchange of knowledge and information, with the aim of overcoming new challenges and increment the common benefits of the group.

This new trend is partially motivated by the necessity of being successful on the development of complex projects, which create the necessity of collaboration between designers, owners, stakeholders, financial firms, administrations, contractors and subcontractors. As a result, information and communication technology (ICT) has grown up really in the last years trying to offer precise tools to satisfy these new requirements (Bryde et al. 2013) (Bryde et al. 2013).

Governments are encouraging BIM, countries in the North of Europe (Norway, Finland and Denmark), America, UK and Australia are clear examples of this movement. These countries are eager to show decisive results that could establish BIM as competitive method for getting more efficient and transparent the construction industry (Smith 2014a). United Kingdome, Singapore and Australia have developed strategies to leverage BIM and become the leaders on this sector (Smith 2014a). As a consequence, in a short period of time many different disciplines want to be enclosed within this method of management and also, a large number of new software are under development to cover the necessities. A clear example is the feature of BIM as an n-D tool: 3D for designing models, 4D to schedule plans, 5D to manage costs, 6D regarding maintenance, 7D is about sustainability and 8D linking model with health and safety.

At this time, there is an important necessity of demonstrating that BIM can improve the way of managing AEC process. As a recent technology as it is, uncertainty and reticence are the common reactions between professionals. The initial investment is higher in comparison with other tools, new and different skills are required, old mind – set that promote fragmented methods of management need to be replaced by modern behaviours, which are based on the collaboration of all members, the necessity of giving more importance to the success of the group instead of looking for individual goals, (..) can be the most important barriers that need to be overcome and see BIM as a positive and innovative technology and way of management.

This master thesis will be focused on the analysis of how data is transferred between BIM platforms, the exchange of information is an important necessity on the way of enclosing the whole group of workers inside the same model, information needs to be added and extracted from the model to develop tasks that starts in the first idea until the demolition of the real construction. In this report, Revit and Vico will be the BIM tools that cover the 3D, 4D and 5D dimensions and allow professionals to: design the model, extract quantities from it and manage this data to plan the schedule, on the execution process and budget on the estimation phase.

By the fact of offering these tools a new method of developing what is done by other more well-known software, a further analysis is required to show how data is managed and also give an idea concerning the benefits that could offer on the AEC field.

2. Problem statement

Some of the problems in the AEC sector is there are so many different professionals working on different parts of the project (structure, services, design, distribution…) following a fragmented method of management. Each of this parts must be based on a common “idea” and follow the same criteria of others, they are key parts of information that, all together, allow the possibility to create the project. If information is not accurate and exact enough next stages will be affected by it.

BIM could make more efficient these stages in order to avoid many of the most typical mistakes when they work separately. At this point, cost estimation and schedule plans are key aspects and steps on this process. They base their accuracy on the precision of other previous stages. The process of transferring information and the capacity of software to manage inputs which are outputs from other programs has relevant importance. More different steps in the middle of the process could create mistakes and losses of information during the data conversion. In addition, the use of many different programs can make this process more difficult in terms of compatibility and process automation

It is essential to know if Vico office, as a BIM tool which encloses cost and planning dimensions and is fuelled by the outputs extracted from a 3D BIM tool, can offer advantages in terms of efficiency and accuracy to manage this information. Whether it can avoid manual measures motivated by losses of information and also if the method followed on the designing process can produce that outputs and inputs between the 3D BIM tool and Vico are different, creating lack of reliability on these technology.

3. Aims & Objectives

The principal objective of this report is to show the advantages of using BIM tools, combining Revit and Vico Office 4.7 as a multidimensional tool against traditional methods of extracting quantities. The main points will be taken into account are: the accuracy to manage information between different software tools and the enhancement provided by a multidimensional tool as Vico office is.

Research questions:

- Does the method of designing the 3D model has influence on the accuracy of quantities transferred from Revit into Vico?
- Can Vico office offer more accurate cost estimations and schedule plans that are based on quantities extracted from Revit?
- What is level of implementation of BIM, as a multidimensional tool, between companies that have adopted this technology to manage projects?

4. Research methodology

The research methodology will base its development on the next items:

- **State of the art**. It will be focused on the theoretical analysis of scientific literature. It will start from the general concept of BIM as a new collaborative process, then will continue with its analysis as an “n-D” tool.
  This chapter will enclose the next general areas:

- General concept of Building Information Modelling as a tool and process to manage information in different phases of the project.

- Theoretical study of specific challenges in BIM: automatic quantity takeoff processes and the concept of interoperability. Besides, it is analysed the multidimensional characteristic of BIM, with specific interest in the 4^{th} and 5^{th} dimensions to manage construction schedules and budgets.

- **Experimental analysis**.

  - Analysis of QTO. It will be based on the analysis of the problem statement, following the theoretical study developed in the state of the art. This quantitative research follows the study developed by some authors, based on the automatic process of extracting quantities from BIM models.

  - Survey. To obtain real data from the construction sector about how far BIM 4D / 5D is implemented. In addition, to know what advantages or disadvantages this technology offer to the company.

- **Conclusions and further researches**.

  - Final results will be compared to obtain conclusions and promote new future researches.

5. Limitations and scope

The limitations follow the next structure:

- Academic limitations:
  - Linguistic problems when some literature concerning BIM 5D was found in Norwegian.
  - Four months to develop a project that enclose BIM as a general concept and 4D and 5D has been a shorter period of time to investigate deeper the topic.
  - The author is not an expert in BIM. The previous experience he has in relation with this topic is a basic level of Revit.

- Technical limitations:
  - Several problems related with the licence of Vivo reduce the availability of the program during the summer (part of July and August)
  - The author developed the project with no BIM experts supervision.

- Professional limitations:
  - The quantitative research is based on hypothetical models that simulate technical solutions can appear on the project, they do not cover all range of technical details therefore, this affects to the accuracy of the data. On real projects, technical details should be extracted and compared with the total dimension of the project to provide precise deviations.
  - The lack of time motivates the possibility of checking these hypothetical models into a real project.

Regarding the scope of this report, the state of the art gives a general understanding about many concepts related with BIM. It tries to start from the main ideas of what BIM promotes, explaining important barriers and positive aspects, giving details after that about interoperability, quantity takeoff processes, BIM 4D and BIM 5D.

The experimental part shows a method to demonstrate the accuracy of the takeoff process between BIM tools. Topic that could be helpful for Quantity Surveyors or any other users related with this field.

In general the report would be suitable to introduce basic users in the world of BIM, its philosophy and as a tool to manage costs and project schedules from a theoretical point of view.

State of the Art

1. BIM. Introduction and definition

1.1. From CAD towards BIM

Computer Aided Design (CAD) has meant leaving pencils and papers to develop projects. The incorporation of computers and software was the principal change within CAD but, unexpected, the way of working still continue being the same (Real 2014), lines and drawings organized in different layers was the important improvement but, the lack of information in the model has been the drawback since CAD appeared.

Building Information Modelling (BIM), as it will be explained deeper in next chapters, has offered the chance to implement information inside this lines and complex drawings, transforming then in intelligent models. As Lucrecia Real (2014) mentions, this advance was more significant than the previous advance from handmade designs towards CAD design.

BIM is focused on object – models with parametric features. This combination has supposed the start of the transition from CAD into BIM technology and process (Lee & Wu 2005). The start of a new way of working encouraged by the complexity of projects, the necessity of being more efficient managing resources, the demand of more sustainable solutions and, as a general reason the obligation of giving more reliability to the construction industry following some of the rules of the manufacturing industry, are the main motivations for companies acquire this technology of management.

1.2. BIM. Definition

A sort of definitions of BIM can be found along the extensive literature concerning BIM. Lee & Wu (2005) define it as a multidimensional process and tool enable to change the Architectural, Construction and Engineering (AEC) fields. As n-D tool different dimensions, from the early design to the demolition phase, can be manage within BIM in order to enclose the whole life cycle of the project. Thus BIM promotes the exchange of information across all integrates of the project and encourages a collaborative method of working, which is also an important new concept that tries to change the common fragmented behaviour of construction projects. Sharing information includes the exchange of structured data, semi-structured and unstructured information (Matipa et al. 2013).

BIM is the development of a model to simulate the different stages on the project and it is based on a computer and software technology. This model is an information storage from which, any user is allowed to extract and incorporate information increasing the reach of the model in terms of information (Azhar et al. 2012).

Besides, Shim et al. (2012) introduces the concept of parametric representation within the definition of BIM as an important concept. It mentions that this advance is the most important difference against the traditional methods. In addition, interoperability becomes an indispensable concept within the process of sharing information (Lucas et al. 2008). BIM pushes the use of electronic documentation as a principal change instead of paper and printed data, this fact facilitates the flow of information and accelerates processes (Bryde et al. 2013)

Summarizing some of the concepts concerning the definition of BIM from distinct authors, it can be say that it is a process based on the computer technology which principal objective is introduce a collaborative behaviour between all parts involved in the life cycle of the project. To allow this, BIM is presented as a multidimensional tool which encloses all phases, from the early idea on the design (energy and light simulations, cost estimations, planning, sustainability, maintenance, health and safety…), through the construction and maintenance of the building until its final demolition. As a consequence of introducing a collaborative concept, interoperability between all members has more importance as a clue to share information. This requirement is pushed by the necessity of providing the same information attached in the model to all the team. This 3D model is not only a draw composed by lines and colours, it is a rich combination of drawings and information in the same network, defined with parametric elements, changeable in information, dimensions and other parameters.

Explaining the concept of BIM means talking also about terms like Integrated Project Delivery (IPD) and Lean Construction (Azhar et al. 2012). Philosophies which are closed related with terms like efficient use of the resources, the promotion of collaborative behaviours and the reduction of waste.

IPD is a philosophy based on that all members should work together (owner and contractors). It means a process based on a method and supported by technology (CHOLAKIS 2011). The concept of Lean refers to a philosophy as well but, on the contrary of IPD, it is focused on the construction profitability and on the customer demands. Its main idea is develop things only once and right (Seed 2010)

Azhar et al. (2012) and Lee & Wu (2005) explain BIM as the most important step to push the construction sector towards the manufacturing industry. BIM process reduces costs, increases profitability, allows a better time management and also encourages a more efficient relation between memberships. There are several challenges to overcome such as: the evolution on the on the Information and Communication Technology (ICT), personal skills and the use of general standards to ensure an efficient performance and data transference between software platforms.

1.3. Why BIM is necessary

Bryde et al. (2013) bases the necessity of implementing BIM on the increasing complexity of the projects and the demand of information between the different members and their dependence between each other (public institutions, financial entities, lawyers, stakeholders, engineers, architects, contractors, trades, suppliers and owners). Besides, Project Managers (PM) trust the benefits of BIM and IPD through the use of more collaborative and communication tools to manage construction projects.

The principal aim of BIM is achieve some goals such as: eliminate the waste, increment the feedback, encourage the decision making based on more reliable data, deliver information faster, reinforce the team, work as a team and remove fragmented processes (Bryde et al. 2013).

Real (2014) affirms that BIM is such a recommendable technology to develop projects where challenging goals need to be overcome, such as: different geographical locations, demand of high quality, more efficiency, fast reactions against changes and finally to the communication inside the group members. BIM is a tool which offers mechanisms which allow project managers to provide all their client´s requirements.

1.4. Difference between BIM and 3D CAD

BIM has been conceived to manage intelligent models where all 3D elements are parametric objects, which are categorized in Families, Categories and Types (Family: Windows; Category: Wooden windows; Type: Wooden window with two layers for example). On the other hand, 2D/3D CAD means a graphical representation of geometrical elements which do not follow any construction specification or standard these designs do not have attached information and, the only way to understand the design is through the support of extra external data (Azhar 2008).

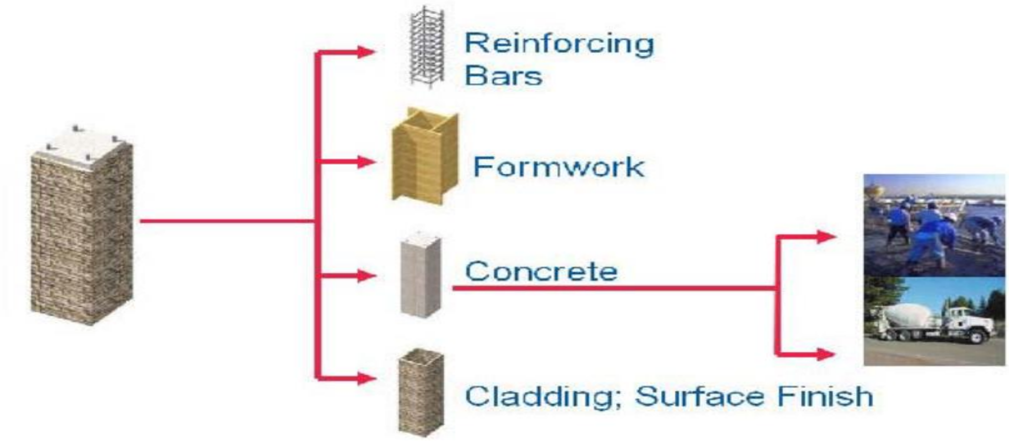


Figure 1: Sample of information attached in a 3D BIM element (Issa et al. 2009)

Azhar et al. (2012) enumerate a general list where the typical features of no BIM models are collected: (1) 3D models within no information (Building Models), (2) Model with no support of simulation in early stages of the design, (3) Multiple 2D elements which must be gathered to define the model, (4) Models which do not offer automatic changes in multiple views simultaneously when one view is modified.

1.5. Concept of BIM as a Technology

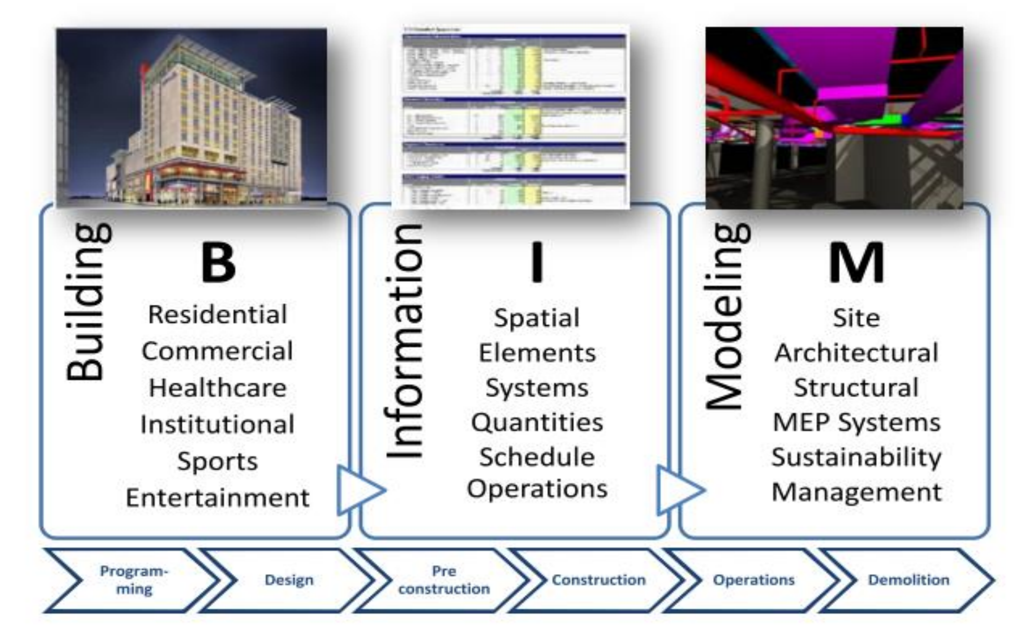


Figure 2: Meaning of Building Information Modelling. (Azhar et al. 2012)

Issa et al. (2009) presents BIM as a tool that make possible the simulation of models before its executions, providing the chance to collect information from the model in early stages, that can contribute to decrease uncertainty and risk.

1.6. Concept of BIM as a process

(Azhar et al. 2012) bases the definition of BIM as a process on the possibility to enclose all memberships enrolled in the project in a collaborative environment. Owners, architects, engineers, contractors, subcontractors, suppliers, public administration (…) are collaborative member, working on different parts, of the goal.

(Azhar et al. 2012) defines the two fundamental pillars of BIM such as: collaboration and communication.

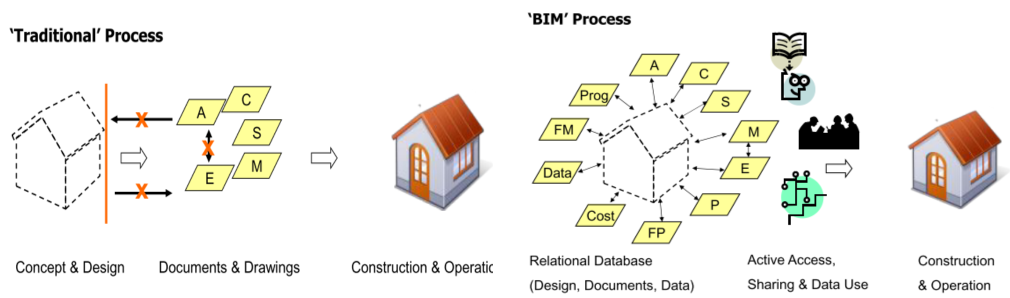


Figure 3: Differences between how information is managed using traditional methods in comparison with it processed with BIM (Azhar et al. 2012)

1.7. BIM to manage the life cycle of the project

The life cycle of the project is defined as the process which encloses all stages from the first idea until the demolition of the real construction. On this process large amount of information is produced in a fragmented way. This data provided by different sources, at any stage of the process, must be gathered and well managed in order to enable its use on next stages. BIM aims to ensure that all this process is carried out following a collaborative strategy where work-sharing means success (Lucas et al. 2008).

To achieve this goal two main points should have taken into account:

- Standards are required to categorize and codify the information in order to follow same rules managing information. At this time standards are not established on the AEC sector.
- The model should evolve depending on the level of detail is has. This level increases by adding more information inside the model and becoming it richer concerning the quantity and quality of data it has.

BIM can help in different stages in the life cycle of the project at different levels (Azhar et al. 2012):

- Programming: analysis of spaces and regulations regarding the locations´ requirements.
- Design: this phase can be split in three main phases: (1) Schematic Design (SD): Simulations and 3D models in order to obtain more efficient, sustainable and a range of different possible solutions of the same product, (2) Detailed Design (DD): Building and structural analysis, (3) Construction Detailing (CD): Schedule planning and shop drawings, detection of

interferences across different disciplines (e.g. structural and architectural design with the installations´ disposition).

- Pre-construction phase: BIM allows construction managers to achieve more reliable data concerning cost estimations. Secondly, the use of Virtual Design Construction (VDC) offers the possibility of analysing coordination activities on the jobsite. Further analysis regarding constructability are possible in order to find an efficient construction plan.
- Construction Stage: at this phase BIM can facilitate the coordination of meetings, show the progress of the construction, integrate and accelerate the requests for information (RFIs) enclosing information in the model. It is crucial at this stage that any new data should be updated in the BIM model in order to provide the last version of information and also, when this step on the process finishes, provide it to the facility managers (FM)
- Maintenance: information from previous stages will be used by FM during the entire life of the building. Lucas et al. (2008) confirms that most of the lifecycle cost occurs during maintenance stages, around the 85% of the total project´s cost during its life cycle occurs after the process of construction is finished, therefore the fact of providing accurate information to FM has a relevant impact over the efficiency of this process. At this point the most relevant data is that concerning any technical detail of the building, services and spaces. This information is useful for any required maintenance work, managing emergency situations, developing tasks regarding the organization of spaces and keeping under control the building´s value on the market.

Eadie et al. (2013) mentions that BIM is more used at early stages than in advanced phases. The common trend is that BIM is less demanded at the same time the project becomes more difficult to be managed and also requires the interaction of more members. It mentions also that the collaborative aspects encouraged by BIM have more positive impacts than the software technology itself.

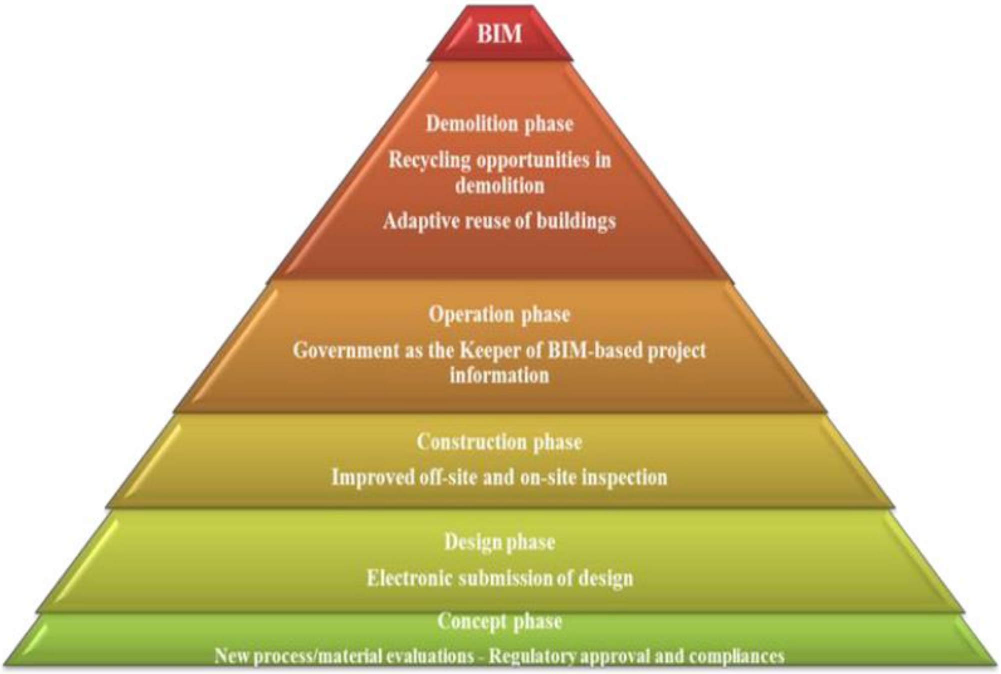


Figure 4: Steps to implement BIM. (Alrashed et al. 2014)

Particular characteristics of the construction site make difficult the implementation of BIM at the same level in all stages (Alrashed et al. 2014) as a consequence of some aspects like: technological factors, all construction projects are different, workers´ skills are not the same in all places and cultures, the lack of standards and interoperability issues which make difficult the exchange of information using the codification.

1.8. Examples of BIM implementation. The Panama Chanel

1.8.1. Introduction

This project has offered the possibility of testing the real advantages of BIM to manage the design process, the interference between disciplines and to overcome the threat of working in different geographical places.

The use of BIM is required by the necessity of reducing risks on such a huge investment, offering more reliable data concerning planning and finally to be more efficient. These reasons encourage project managers to leave CAD as an essential designing tool and implement BIM as a revolutionary management process.

1.8.2. About the project

The necessity of developing this project is to allow bigger ships to cross from the Pacific Ocean to Atlantic Ocean and vice versa. The main challenge of the project is to overcome the different level between the two oceans (26 meters) through three chambers. To success on this goals the whole project is divided in two sectors, Atlantic and Pacific sectors, which are developed in two different offices located in Chicago en Argentina.

Figure 5: (Real 2014)

The reasons to implement BIM are that should be helpful to deal with next obstacles:

- Communication between members (with different languages and geographical location).
- Interoperability between different complex software on the design process.
- Fast reaction against multiple changes which could make spend much more time than it is required using BIM.

1.8.3. BIM. The key of the success.

Implementation of BIM in this project has modified information flow, it has been required training and time to implement the system. In this case the software which was used was Autodesk Revit Structure from the 2008 version.

All the model has been based on parametric families, fact that offers such a huge advantage of saving time when modification are required on the design. To store and share information between the different offices one common database was provided all members were enable to have access to it.

The fact that demonstrates how far BIM has been useful in this project was that one when one element of the Chamber had to be modified. Only one modification on one parametric family was reflected in all project. Only one day was required to update the model.

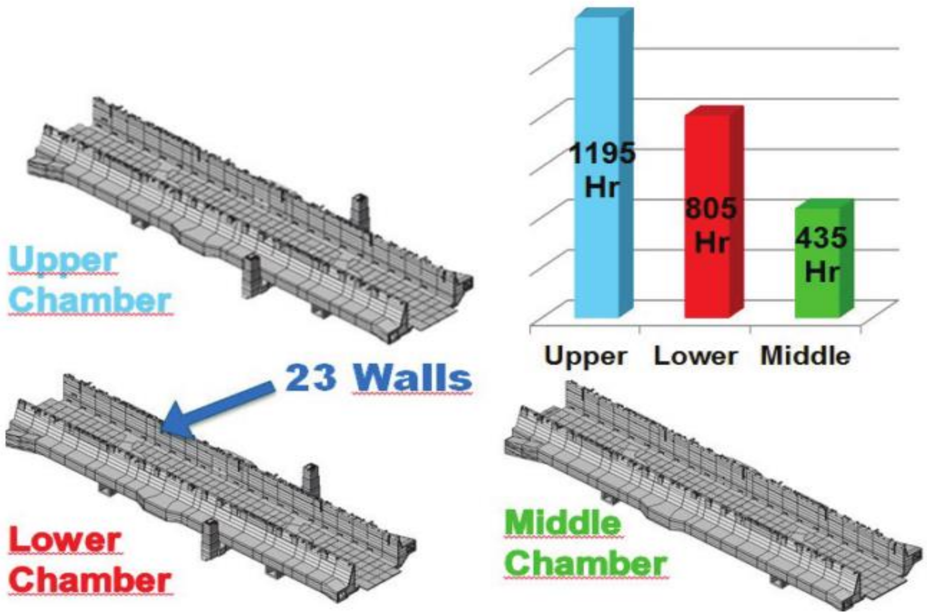


Figure 6: Time required to design the three chambers. Advantages of using parametric elements.(Real 2014)

The chart above shows the difference of time which was required to design the first chamber in comparison with the third one, the saving time was around the 60%.

The use of BIM allow users to solve problems between different departments in charge of various parts of the project.

1.8.4. Standards and protocols

The BIM execution plan defined in this project offered to possibility of guiding the whole team making them follow the same standards. Within this plan two aspects have had relevant importance:

- The Level of Development (LOD): It must be indispensable establish a common level of detail that the project must achieve at any milestone. This provides the possibility of having under control the evolution of the project and also the quality of information is exchanged.
- Designate Model Element Authors (MEAs): They are responsible that the model has the correct LOD which is specified at the model element table (Van 2008)

1.8.5. Conclusions

Real (2014) makes reference to a huge value of BIM in the lifecycle of the project. In this project BIM has been link between the project creation and its management, encouraging efficiency on the use of resources and the participation of all member as a whole. It has offered the possibility of having better coordination and communication, reducing risks using simulation on the pre-construction stage, making members have access to the same level of updated information and finally, increasing productivity in terms of time and cost.

The transition from CAD into BIM is a corporative and managerial decision and it implicates a process of changing (Real 2014).

1.9. General advantages and drawbacks of BIM

Many different authors have collected a sort of advantages and disadvantages of BIM. Bryde et al. (2013) enumerates BIM´s positive aspects ordering them from the most relevant to the least significant: the reduction in terms of cost and time, better communication and coordination in the group and finally, the increase of quality in the final product.

BIM contributes to overcome the independent behaviour between members of the team promoting a collaborative environment (Bryde et al. 2013). Migilinskas et al.(2013) includes in this list the advantage of BIM tools to reduce the amount of mistakes and lack of information inside projects. In addition, better geometrical and more visual models can be managed and simulated in order to detect conflicts or collisions across different disciplines (architecture, structure, MEP) in the project (Azhar 2008).

Quickly and more accurate processes, the chance to enclose all phases which integrate the whole life cycle of the project, the option to simulate the 3D model before its physical development to offer better solutions and higher customer´s satisfaction are the most exceptional aspects of BIM according to Eadie et al. (2013)

Azhar et al. (2012) elaborates a classification of advantages regarding the different stakeholders take part on the project. From the point of view of the owners, they will be provided by more reliable financial information, a better project marketing and finally, they will have access to the total project´s information easily. Designers based their benefits on having a more accurate visual analysis of the model, the chance to incorporate virtual simulations to check some features, sustainable options are allowed to be enclosed in this phase and the possibility of producing documents much faster. Construction managers see its high level of information in early stages, better cost estimation, planning and profitability as the best advantages of BIM. Finally, FM will be provided with an accurate amount of reliable information which will facilitate and increase the efficiency of their obligations.

Some authors like Russell et al. (2014) look ahead and see the option of interconnecting additional tool with BIM and automatize, in a chain of production, some processes as it has been developed on the manufacturing industry.

According to Isikdag & Underwood (2010) BIM would help to automate processes on pre- construction´s stages within lifecycle of the project. They mention also that some requirements would be indispensable to achieve the full potential of BIM such as: have a more efficient information management, a more collaborative aptitude and finally, automate processes providing more accurate information.

On the other hand, BIM is not a well experimented method to manage construction projects, it is quite recent and depending on the complexity and size of the project, team´s attitudes which can favour its adoption, the level of collaboration and communication that members are available to offer can give a vision of BIM as an expensive and bad tool to manage construction projects (Barlish & Sullivan 2012).

Russell et al. (2014) makes reference to similar drawbacks as the lack of experience and conservative behaviour that hinder the implementation of BIM. The huge initial investment and several software problems to manage the model are more negative aspects to take into account. Looking at the educational system, most students base their practical knowledge on no BIM models. Therefore, this fact could be transferred to the real life where only a short number of potential employees are experts on this field.

There are some important disadvantages according to Azhar et al. (2012) and based on the definition of BIM as a process and technology.

Regarding BIM as a technology, some of the most repeated negative aspects are: the low development of standards to work in a cooperative groups, interoperability issues between distinct BIM platforms which, causing losses and distortions of information (Lee & Wu 2005), do not permit reliable transferences of information and finally, the lack of compatibility that forces to re-input the data and spend time reworking (Migilinskas et al. 2013). The use of inadequate hardware forces the fragmentation of projects in order to be managed, fact that can be another important technical issue when projects are extremely complex (Bryde et al. 2013).

In addition, several handicaps should be enumerated when BIM is treated as a process tool. Here it would be included contractual and legal issues. There is so much confusion around the legal proprietor of the information. As a consequence, the flow of data is restricted (Bryde et al. 2013) and member are reluctant to exchange their own databases. In addition, appears the necessity to name who is responsible of entering information and checking its accuracy. Therefore, a new cost must be taken into account on the whole process, which had never been necessary. The concept of collaboration blurs the level of responsibility between the members so some contractual agreements must be signed to clarify this situation.

2. BIM as tool in progress development

2.1. Introduction

BIM bases its success on the promotion of a revolutionary collaborative method of managing project´s information. This procedure would not be possible if the manner to share information are not well defined and are considered accurate methods of information exchanging. To achieve this goal has been defined different levels which define the degree of BIM implementation should be acquired and, concurrently, several standards are being developed to allow an exchange of data between software platforms avoiding loss of information.

2.2. Maturity of BIM

The aim of the 4 maturity levels in BIM is to specify what technical features and collaborative approaches are required on this process of evolution. In addition, it shows also transparency concerning which is exactly offered to clients. The situation of the construction sector and organizations are at different level of evolution so through this scheme can be provided the line should be follow to evolve (Government Construction Client Group 2011). Then are explained the 0 – 3 levels:

Level 0: All communication is basically based on paper or electronic paper exchange.

Level 1: CAD 2D and 3D working on collaborative environments under the directive of the BS1192:2007. Data concerning cost estimations is processed by no integrated tool at this stage.

Level 2: Different BIM´s disciplines must be adopted at this level to manage 3D intelligent models using ERP. The 4D and 5D disciplines should be incorporated to manage time and cost. This is the level required by the Government of UK to be adopted before 2016 (BIM Task Group 2014).

Level 3: A collaborative network should be fully implemented and BIM must have a multidisciplinary level, information across the members involved in each project should be interoperable using IFC and IFD open standards using a “virtual service” and, in addition, the whole lifecycle of the project will have to be carried out using BIM technology.

Different levels have different requirements regarding standards and technical approaches on deliveries. This draft exposes what is explained at the standard B/555 regarding design, modelling and information sharing in UK (BSI Standards Development n.d.), with the main goal of decreasing risks, pollution and delays on projects. On the other hand, it looks for improving the cost management process reducing extra charges (Government Construction Client Group 2011).

UK is focused on leading the BIM process in the next years. Therefore, there a special rush to ascend on the maturity´s levels therefore, the level 2 should be fully adopted by 2016. Zeiss (2014) explains that the improvements offered by this level 2 are:

- Better digital visualization: the 3D model can be visualized and checked by stakeholders before starting construction activities, fact that allows participant to suggest improvements a more efficient possible solutions.
- Detection of interferences: clash detection between disciplines can solve many mistakes in early stages when its solution is much cheaper than on the construction field.

- Constructability: this allows to define the specific technical requirements to build what it has been designed.
- Scanning: the use of laser to scan existing building will provide accurate information.
- Information attached in the model will enhance operations of maintenance.

In this level there will a large amount of data to be managed. COBie standard should be implemented at that time to manage non-graphical data (Building SMART alliance n.d.).

On the contrary, there are some aspects that should be improved until 2016. The handicap of designing existing buildings needs to be overcome by specialising software to develop these tasks and then, the LOD standard is not well defined yet. Finally, the Unified Classification for the Construction Industry (Uniclass 2) is under evolution and also, there is a serious reluctance to adopt BIM on the maintenance of buildings due to interoperability issues (Zeiss 2014).

At this time, the Government of UK, before solving the main problems to adopt the level 2 in 2016, is focused on implanting the level 3 on 2018. However, it is not defined at all.

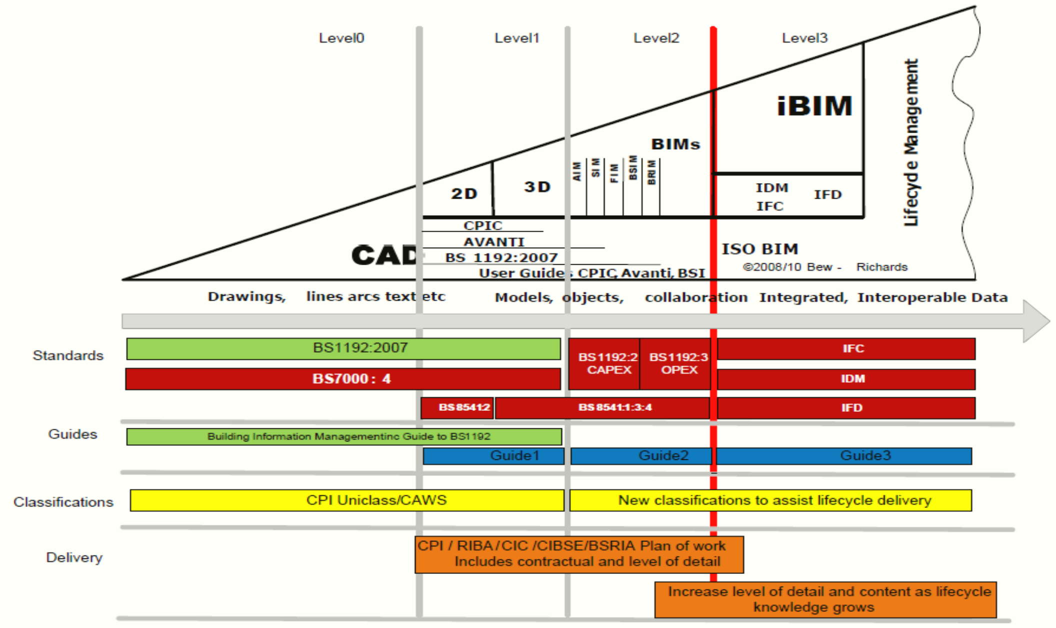


Figure 7: Scheme of levels of maturity on BIM (Government Construction Client Group 2011)

2.3. Level of Development and Building Execution Plans.

Forum, (2013), has defined Level of Development (LOD) as the manner to standardize the content of details, taking into account different levels, which define intelligent BIM models. LOD has been developed to regulate deliveries in a collaborative BIM framework specifying: the quantity and quality of information attached in the delivery milestones which help BIM managers to define execution plans presenting which objective should be achieve in each deadline (Bedrick 2008).

It should be explained the difference between level of development and level of detail as well. The first one makes reference to the level of reliability of the model and, on the other hand, the second one specifies how much the model is detailed.

The use of LODs standards tries to avoid common mistakes very typical in traditional methods:

- Define the evolution of the project in terms of information´s richness. At any level it is known how the project evolves.
- Explain how accurate models are independently of their appearance or how they look like in the model.
- To schedule the work and prepare teams to deliver or receive information.

In fact, it is established a minimum required detail in order to consider a model reliable enough to be interoperable, this level is the LOD 350 (Bedrick 2008).

The LOD levels are: conceptual (LOD 100), close geometry (LOD 200), exact geometry (LOD 300-350), construction (LOD 400) and as-built (LOD 500). Move forward from one to the immediately after means an exponential rise on time and effort on the modelling process. In addition to this, the more detailed is the model the more positive influence can have over the management process (Leite et al. 2011). On the list below are better defined the stages compose this framework (Forum 2013):

LOD 100: The model is a generic representation. Information related to the model can extracted through the areas in order to obtain estimations. Taking a wall as an example, at this LOD it would be modelled as a mass.

LOD 200: The model has attached general information regarding the shape, orientation, quantities and location. Continuing with the same previous example, here the wall would have information concerning thickness, location, quantities and almost exact measures.

LOD 300: Information attached in the model is more exact and extensive. More accurate data from the previous level is provides and also information regarding material´s properties and features.

LOD 350: The only difference against the last level is that here is reported information about constructability.

LOD 400: Specific information is provided in the model about all parts and elements and it is considered the most accurate information to be used before the construction process. It would be at the level of shop drawings on the field.

LOD 500: It is an identical representation of the real building. At this level any information regarding the previous stages has to be enclosed and it will be used by Facility Managers (FM) in next stages.

The definition of these steps creates the necessity of naming a LOD coordinator who is in charge of fixing deliveries and sharing responsibilities between the members of the team. This project manager receives the name of Model Element Author (MEA)

There is a close relation between the LOD and BIM Execution Plan (BIMEP), which would be focused on specific details, deadlines and singular deliverable specifications. BIMEP will ensure that the flow of information follows an standard rule and also defines the correct use of BIM (Building SMART alliance 2014) in each project. It is developed for each project and, in addition, is focused on defining the goals of the team following some rules:

- Be aware that the whole group understand the aim of creating a strategic as BIMEP is.
- Responsibilities and duties need to be clear and defined.
- The execution plan must be viable within the capabilities of the group
- Within the plan should be explained the manner to give training to new members.

- A formal contract should be signed to be aware that the different teams achieve their goals
- This plan gives the chance to measure the progress on the project.

For different phases must be overcome in order to establish a BIMEP, they are: the real objectives and uses of BIM, definition of which activities are going to be developed in BIM, how information is exchange and finally, specify the technical requirements needed to complete the whole process (Baker et al. 2012)

2.4. Interoperability

2.4.1. The concept

The exchange of information can have an important positive impact over the productivity and the quality of the final product. However, sharing information within BIM environment is real obstacle that need to be overcome to be totally successful on the BIM implementation (Fallon & Palmer 2007) and (Steel et al. 2010).

The concept of interoperability refers to the exchange of structured information attached in intelligent parametric models along the members involved in the same project (Grilo & Jardim-Goncalves 2010). This data transference needs to be subjected to agreements in order to specify which type of information is required to be sent or received. The success of this movement of data depend on the software´s tools capability to extract this data to be used for example in cost estimations, energy and structural analysis, fabrication, maintenance, etc. (Fallon & Palmer 2007).

The collaborative approach proposed by BIM forces the necessity of sharing many different types of electronic documents. This information must be structured in a specific manner to give the capacity of making it understandable to any software and user. Concerning the type of information two different types are distinguished: structured and unstructured data.

Unstructured data

Under this category are enclosed documents which do not follow a formal structure such as correspondence, drawings and projects´ reports. Reading them is the only manner to interpret the meaning they want to transfer. This type of information is not interoperable even though it is compatible with software. The clear example is the CAD drawings, the only way to codify the information is in layers with no inherent structure. This is why quantity takeoff from CAD can result in many mistakes.

Structured data

The clearest example of structured data are BIM models. They support intelligent data interpretable and interoperable by BIM tools. This optimizes processes by the fact of not having the necessity to re-interpret the information. In addition, it automatizes some tasks as it is the quantity takeoff.

2.4.2. Register of data

Most of the software´s vendors define a specific format of data which not ease the interoperability with others, this can become problematic the exchange of information between different platforms. The ideal situation would that one where data is sent and received maintaining the same data codification. It would decrease the time needed to manage the information, increase the quality and reduce the working time.

Based on the proprietary of the data can be distinguished two types of standards: “De facto” and “De jure” standards.

“De facto standards”, an example of this type of standard is the DXF format. These types are usually programed by one software seller and after that adopted by more. On the other hand “De jure standards” are developed by organizations as it is the International Alliance for Interoperability (AIA), the International Organization for Standardization (ISO) and also the Open Geospatial Consortium (OGC). Many organizations take part on a common agreement to develop them making them more flexible than the other type. Industrial Foundation Classes (IFC) is a clear example of “open” standard no developed by any software (Building SMART 2014).

2.4.3. Structured standard formats

CIS/2: CIMSteel Integration Standards is focused on the structural steel design and developed by ISO STEP. It encloses the whole life cycle of structural project (design, analysis, details, and construction) (National Institute of Standards and Technology n.d.)

The **AIA´s IFCs**: developed as a consequence of a broader alliance within the AEC industry with the main goal of providing worldwide standards. They are focused on the interoperability of intelligent building models enclosing the life cycle of the project. It has been promoted by the ISO like a Publicly Available Specification (PAS): ISO/PAS 1639 (Building SMART 2014). It is very possible that two software platforms offer the chance to import – export IFC files but, depending on how the information is mapped this exchange can be not as success as it had been expected.

This problem demonstrates the necessity of mixing knowledge regarding construction and also concerning standards´ language. As a result, the first solution has been define specific standards related to the type of data they have to codify. These are:

BLIS: Building Lifecycle Interoperability Software. It allows the exchange of specific views such as: geometrical perspectives, architectural spaces, Heating – Ventilating – Air Conditioning (HVAC) schemes, HVAC quantities takeoff, planning and calculation of loads (Building Lifecycle Interoperable Software n.d.).

GSA: General Services Administration. This standard is focused on codifying information regarding conceptual design.

NBIMS: National BIM Standard. It allows the flow of graphical and non-graphical data concerning services (National BIM Standard-United States n.d.).

COBIE: Construction Operations Building Information Exchange. As a part of the NBIMS and supported by the U.S. National Aeronautics and Space Administration (NASA), it is focused on interoperating data concerning systems and equipment´s specifications to FM (Building SMART alliance n.d.).

IDM: Information Delivery Manuals. This standards allows the update of data concerning the performance of equipment or systems that, because they had not been fully defined on early stages, had to be specified during the construction (Information Delivery Manual n.d.).

IFC – MVD: IFC Model View Definition. The aim is to join different disciplines in the same IFC view as it could be the architectural and structural design. It decreases the total number of views that must be supported by software (Building SMART alliance n.d.).

AEX: Automating Equipment Information Exchange. It allows the exchange of data about equipment and installations (Automating Equipment Information Exchange n.d.).

AGCxml: It is focused this standard on the flow of information between contractor and owner based on RFIs, contracts, orders, changes and economical accountability (The Associated General Contractors of America n.d.).

gbXML: Green Building XML has been develop to allow the interoperability between BIM models and software´s energy analysis (The Green Building n.d.).

OSCRE: Open Software Consortium for Real State. It is based on the interoperability between owners, real state managers and services´ suppliers (Open Standards Consortium for Real Estate n.d.).

OGC: Open Geospatial Consortium. It targets on location and geospatial systems. Buildings are in a physical space and this information should be transferred as well. City GML is an example of this type standard developed in Germany which allows the transference of cities´ 3D models (Open Geospatial Consortium n.d.).

Before concluding, Lanka & Modelling, (2013), exposes a sort of problems which AEC needs to overcome to solve some issues that appear in collaborative situations when interoperability features are required: (1) lack of coordination, (2) Information losses during conversions and transferences of data, (3) Issues regarding data interpretation from other members, (4) Lack of data updates as a consequence of changes, (5) No well-detailed models, (6) Lack of reliability on the transferred data.

3. BIM as a multidimensional tool to manage construction projects.

3.1. BIM and Quantity takeoff management

3.1.1. Introduction

Many authors have achieved at the same conclusion, concerning the automatic QTO offered by BIM, saying that it is the most important improvement offered by this technology of management (Monteiro & Martins 2012), (Monteiro & Martins 2013), (Wijayakumar & Jayasena 2013) and (Stenstrand et al. 2010).

Automate quantity extraction from a 3D BIM model means a relevant advance since this data will be the principal input to manage next construction processes such as: cost estimation on the phase of tendering, planning of activities. At early stages it will provide useful data to forecast costs and, once the project is under construction, this data can be used for obtaining rates regarding the economic evolution of the construction. As a consequence, the fact of obtaining reliable data from 3D BIM models is a decisive task in order to provide more accurate outputs in following stages (Monteiro & Martins 2013).

Automatic QTO can enhance the performance of construction managers and QSs whether data is accurate enough. Wijayakumar & Jayasena (2013) enumerates four main steps on the QTO process that should be accomplish: takeoff the data, squaring, abstracting and billing. The reliability of the three last stages depends on the accuracy of the first one. Construction managers state that the possibility of automating the quantity takeoff can improve schedules, estimations, control of production and tendering. However, as it will explain on next chapters, the quality of the design has influence on the success of these tasks (Monteiro & Martins 2012).

Most BIM tools offer QTO´s options but they are not capable to manage this data at all. This information must be transferred to other specific software in order to be reorganized and used to obtain new outputs. This exchange can be done directly, when both software tool use the same proprietary format or indirectly converting the data in a common language understandable by both tools, this third part is very often the IFC format (Monteiro & Martins 2013).

3.1.2. The influence of the 3D model´s design over the QTO

The method for designing a BIM model has been demonstrated that has relevant influence over the accuracy of the quantity takeoff. There are two methods for creating a 3D BIM model: geometrical and analytical designs. The first one is focused on the shape of element and spatial configurations whereas the second type concerns about how to exchange the data and also to determine the settings. This implicates an important challenge on the takeoff process since any element composed by different layers and materials will be detected as a single component, allocating the same thickness and measurements in all its extension. The total surface of the whole object will be the same area of each layer but, it can happen that material can change in the same layer or some other elements (structural columns) pierce some of these layers, therefore not all compositions will have the same area (Monteiro & Martins 2012).

Monteiro & Martins (2012) analyse these interferences between design and quantity takeoff defining four different procedures on the design process and studying the accuracy of the data extracted from each one. Archicad and Vico were the BIM tools used for designing and calculating quantities and data is translated into IFC and then it is opened by Vico to check if the data has been affected by this process. The four procedures that they define are:

- Design of each element of the model independently.
- The structure is completely separated from other parts of the model.
- Define new families when the composition of layer.
- Define one family that will be used for the whole model.

The results of this analysis gives important details to understand whether the method of creating the model influences over the accuracy of quantities.

Method 1: Design of each element of the model independently**.**

This procedure consists in each layer has to be modelled separately. The positive aspects are that they can be isolated when it is required and the model is more flexible and detailed than the other methods. However, it consumes more time on the design process, joining layers and finally the model is heavier because it has to support a lot of data. Besides, geometrical settings can be required on the connection of elements, fact which increases the time on the design. The definition of openings could be a serious drawback since they have to be modelled in each layer which composes the element, for example the layers of the façade. If this is not configure using this procedure the opening´s area will be only subtracted from the layer where the opening is located.

Method 2: The structure is completely separated from other parts of the model**.**

Using this procedure structure and architecture must be design separately. In this case whether one structural element is embedded in one wall or floor, it must be left isolated from the other element. As a result, if the wall has two different materials, at least it will be composed by three.

In the case of multilayer walls they can be modelled with the same composition from the bottom until the top level assuming that there is a small deviation on quantities. The time saved on the design process can compensate the deviation in quantities.

Method 3: Define new families when the composition of layer.

This method consists in defining the number of families (for example walls) depending on the total types are required. This is a more accurate procedure than the previous one but many mistakes can be produce defining levels (taking the example of the wall) and, in addition to this, when openings are modelled it is very important be cautious concerning where this opening is modelled. Another important disadvantage can be related with the complexity of the model. Whether many types of families has to be assembled in the same constructive element the required time for designing will be higher. As a result, this combination can decrease the quality of the outputs.

Method 4: Define one family that will be used for the whole model**.**

Following the procedure of this method the model is designed from scratch, this is similar to the method 3 but more simplified. Elements in the model have both architectural and structural features. This procedure offers some advantages such as: geometrical connections are better defined and the model is not as heavy as it is using other methods.

Problems using this method can appear since elements are more compacted, therefore isolate parts of the building can be harder and, in addition, the transference of data using IFC can be affected negatively by this type of design.

The current tools and project´s requirements transform this method in the least feasible in terms of quantity takeoff. The lack of research on this specific fields do not allow to gi ve a final and definitive conclusion concerning the most efficient method of designing however, early research proposes that methods one and two could be the most efficient (Monteiro & Martins 2012).

As Monteiro & Martins (2012) have analysed and, also based on what (Kiviniemi et al. (2007) mentioned on their article, quantity takeoff is very related with the manner of designing the model, input´s quality and also how information is extracted. As an example, Wijayakumar & Jayasena (2013) explains how quantities can be affected by this fact. Using Revit, openings can be defined following four different methods: opening tool, edit profile tool, opening family tool and void extrusion but only the two first options deduct the opening´s area from the wall´s surface.

If the main objective of the 3D BIM model is that it is going to be used in the whole life cycle of the project, therefore, it has to be modelled in the way that allows to achieve this goal (Kiviniemi et al. 2007).

3.1.3. Manual QTO vs. Automatic QTO

Traditionally, QTO was developed manually measuring directly from physical papers, with the chance of using 2D or 3D CAD tools appeared the possibility of extracting quantities from the screen, besides the first option, and type this data in an Excel spreadsheet. BIM has revolutionized these tasks providing automatic procedures to extract the data.

Kim et al. (2012) say that this new automatic method is a highly advance in comparison with manual procedures. According to Monteiro & Poças (2013), the most important disadvantages of this manual process are: interferences between disciplines are not easily detectable, many mistakes can be performed, complicated representations can have different interpretations and cascading problems can caused lack of reliability. To sum up:

- Manual measurements can offer low level of accuracy because, on this type of tasks, human mistakes can be produced on the process and they are difficulty detectable.
- Personal interpretations can have high influence on the measurement´s specifications, causing low level of details.
- Depending on the stage of the project, quantity surveyors can have different interests and also give more importance to different parts of the data, fact that can make them to achieve to different quantities.

An automatic quantity takeoff process should follow some directives and organize the data concerning different requirements: counts, lengths, areas, volumes and weights. In addition, there are three types of information concerning quantities: information attached in the model clearly, data which are not fully represented but it can be deduced and finally, quantities that are not clearly defined in the model and also cannot be deduced (Wijayakumar & Jayasena 2013). The first type can be managed in two different ways: just counting it or, on the contrary, it must be identified in order to extract areas, volumes and lengths and then prepare these settings as an outputs.

Stenstrand et al. (2010) specify that if accurate data is required the 3D model must be define following rules regarding how to name items, always according to QSs´ requirements, clashes should have been solved before extracting the data, then there should have an agreement for stating exactly which tools are used on the design and finally, the model which is used for this tasks must be the last updated.

On the one hand, manual processes are error prone but, on the other hand, automatic quantity takeoff is not in absolutely the solution to overcome traditional mistakes. Rules of measurement need to be followed to avoid re-works, the method of designing have direct influence on the accuracy of quantities and finally, different BIM software tools provide quantities in not alike ways (Wijayakumar & Jayasena 2013)

3.1.4. Advantages and disadvantages

Monteiro & Poças (2013) summarize a sort of advantages offered by the automatic process of extracting data from the BIM model: (1) A general rise of accuracy on the measurements, (2) The possibility of linking the measures to a BIM tool to plan activities, (3) BIM QTO allows the chance of comparing measures during different stages of the project, (4) Capability to extract partial data from some elements or spatial areas, (5) Automatic QTO reduces the error in terms of accuracy until less than 1% whether it is compared with traditional manual methods, (6) Option to extract quantities of non-typical elements. BIM QTO gives the chance to obtain data concerning number of openings, its total area, classify and count elements depending on the type of materials, etc.

Monteiro & Martins (2012) advertise that the automatic option of extracting quantities in BIM is its most relevant feature. The negative aspect is that some requirement are indispensable to make this process reliable. One of them is that the minimum level of detail in the model is something crucial to manage accurate data, Monteiro & Poças (2013) explain that this LOD should be 300 at minimum in the case of Archicad, whether this is achieved accurate data can be provided.

In addition to the LOD, the method of creating the model must be well-defined but, serious lack of information is detected concerning this problem. As far as it is studied, it should be analysed the relation between the time required to define the model and the accuracy that could be achieved investing this time in order to define the design´s procedure (Monteiro & Martins 2012).

Stenstrand et al. (2010) present as principal issues that the model should be detailed enough, quantities must be checked, however BIM can provide automatic quantities and some rules about how to calculate measures should have been defined before the start. The main drawbacks which impedes the suitable adoption of this advance are also the reticence to adopt this approach, problems to achieve the same LOD in all disciplines of the project before starting the QTO process and finally, problems concerning the exchange of data between BIM tools and QTO programs. The most negative aspect is how to control the design process to make the model totally adaptable to this task.

3.1.5. Challenges to overcome

Monteiro & Poças (2013) enumerates important challenges that should be overcome or are under development to make useful BIM quantities. QTO do not provide the whole data required to produce Bill of Quantities and also, the more evolved is the BIM model the more difficult is to manage data and create BOQs.

The first requirement to automatize this process is have a system to organize the information. This is called Work Breakdown Structure (WBS) and it should be adopted by all participants on the project to stay away from mistakes and omissions.

Most of the BIM software are not enable to manage outputs and create cost estimations therefore, information needs to be transferred into another tool to process it. At this point IFC plays an important role enabling this movement of data. However, some data losses are detected when this open BIM standard is required. Furthermore, there are no well-defined frameworks which specify the rules concerning information exchange between designers and main contractors. As a consequence, most times the BIM model created by the design team is not enough and a new one must be modelled. To conclude, Monteiro & Poças (2013) confirm that QTO is the least standardised process on the AEC field.

3.2. 4D Planning

3.2.1. Introduction

The 4th dimension of BIM links the 3D model with the option of scheduling activities. This option allows to create virtual simulations based on plannings which can provide a better understanding of the construction sequence. These simulations can be helpful to enhance the clash detection across disciplines at early stages, to manage the jobsite, to communicate how some processes should be done, to estimate costs and to manage resources close related with the procedure of construction (Chau et al. 2004), (Mahalingam et al. 2010) and(Jiang 2011b).

Seppänen (2014) goes further on this definition adding more details within this dimension based on scheduling, saying that it does not help users to obtain more accurate planning or to manage the project more efficiently. On the contrary, the optimization of the schedule is the most important approach of this improvement of BIM, without this, this dimension would be only a visual simulation which cannot provide more details than a video. The link between the CPM and the option to visualize this schedule is the key point for starting this phase. This simulation should take into account the quantities based on locations, resources, rates of productivity and costs. Durations must be demonstrated and justified through this sort of information, which makes reference to the “I” of BIM.

There is a clear difference between 4D simulation and 4D schedules. The first one is the result of defining the planning and the sequence of any process. Nevertheless, the 4D schedule is the result of extracting the whole information mentioned in the previous paragraph. The process starts extracting quantities from the model, then allocating these quantities to the pre-defined locations, applying a logical sequence and optimizing the process removing stops and starts within the same task with the consequently risk reduction.

4D is seeing like the next step to process all extracted quantities from the 3D model which are addressed to schedule the construction process.

3.2.2. Line-Base Management System (LBMS)

Kenley & Seppänen (2009) has collected many different names which can define the same method for planning activities. Some of them are: Harmonograms, Line of Balance, Flowline or Flow Line, Repetitive scheduling method (…), finally, Line of Balance is the most common name used by them.

Going deeper in the distinct methods of planning projects two main ways within two subgroups are well-defined and are also studied in this chapter:

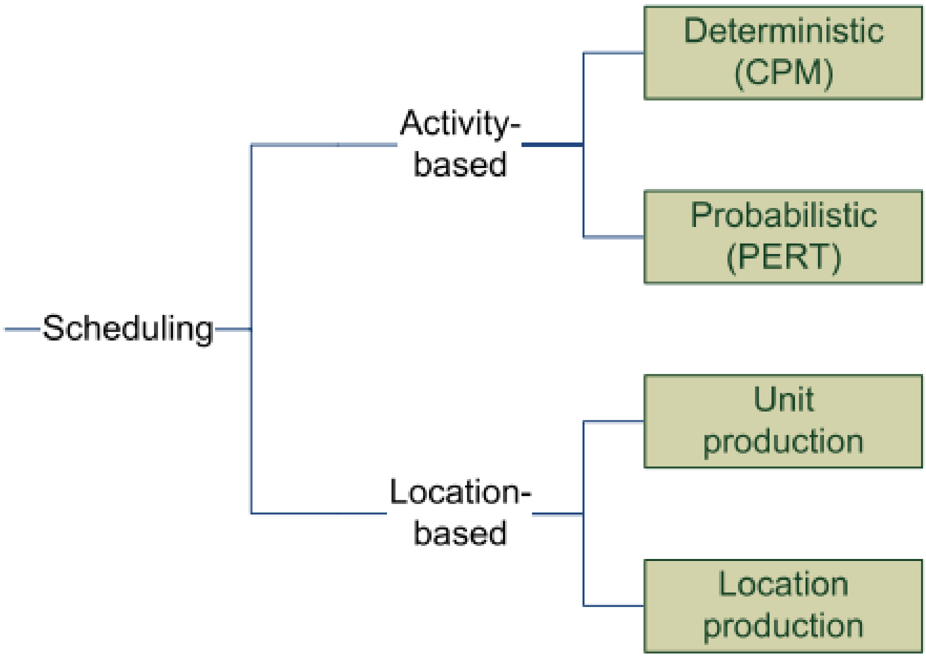


Figure 8: Methods of scheduling. (Kenley & Seppänen 2009)

Activity based methodology.

This type of schedule management centres its performance on the activities and their relationship. It can be based on a deterministic (CPM) or probabilistic (PERT) procedure.

Critical Path Method (CPM) is one of them most common manner of scheduling processes. It consists in a list of linked activities that follow a logical order. Each activity has a specific duration. On this network the longest path is defined as the critical path, its activities do not have floats and, unless any deviation affect to this chain it will define the total length of the project (Hergunsel 2011a).

CPM presents weaknesses on construction projects. Resources are not well-represented on this method as a consequence of treating activities as independent items and not as an integrated system.

On the one hand, on the CPM network the length of each activity is obtained in a deterministic way, it means that is not possible to manage uncertainty in each activity. On the other hand, if the length is calculated under a probabilistic approach the method is called Program Evaluation and Review Technique (PERT) (Martinez 2013).

Location based system

This method integrates activities as a continuous process being focused on the resources that are based on locations and tasks. These two concepts are the relevant keys on this chapter for planning construction projects. Within the concept of task defined before there are two types of subcategories which are: unit production and location production.

On the one side, unit production measures the units of outputs per time, it is represented by a line of balance and this chart shows information concerning the rate of production depending on quantities. On the contrary, location production is focused on work locations. This production is typified by a flow line which starts at the bottom of the building and finishes on the top.

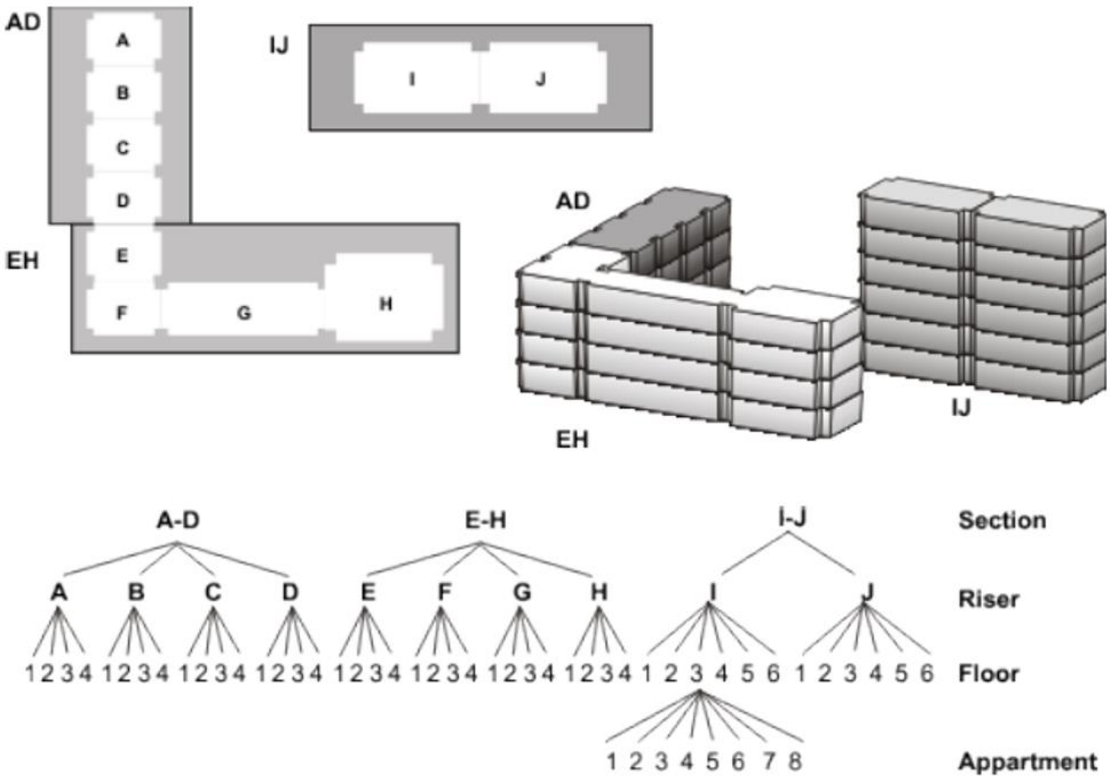


Figure 9: Hierarchical distribution of activities. (Kenley & Seppänen 2009)

On this method based on locations it should be defined a hierarchical Location Breakdown of the Structure (LBS), concept that will be explained in next sub-chapters. To sum up, production based on location is focused on the different performances depending on distinct locations (Kenley & Seppänen 2009).

Location based management offers more advantages than unit production methods because it integrates all activities in groups (tasks) and, in addition, manages the schedule depending on the different locations as groups integrated by tasks where, as a key part of the process, the movement of resources will enable to optimize projects.

Seppänen (2009) enumerates the next list of elements as part of the location base: (1) Location Breakdown Structure (LBS), (2) Location Base Quantities, (3) Location Base Tasks, (4) Duration based on quantities, productivity and resources, (5) A CPM network. Buffers and lags.

(1) Location Breakdown Structure (LBS)

Locations need to be divided in a hierarchical substructure to allow the information to be managed. In this scheme higher locations include lower ones. The aim of the highest location is to optimize the sequence of the construction. The intermediate levels are used for planning structure´s flows and finally, the lowest level allows to plan details (Seppänen 2009).

The LBS is typified by a vertical axis where it is shown the hierarchical organization of the project as it is shown on the figure below.

Quadrant:	Floor
Center	Roof
	3
	2
	1
Northwest	Roof
	3
	2
	1
Northeast	Roof
	3
	2
	1

Figure 10: Example of Location Breakdown Structure. (Seppänen 2009)

Locations must include the following information:

- 3D building components or objects.
- Quantities. These quantities should be extracted from the 3D model through the quantity takeoff management (automatic process in Vico office). Any change of measures should be typed manually.
- Representation of building systems (i.e. scaffoldings and cranes should be measured as well).
- Information concerning price of material should be included. This link between cost and planning gives details regarding the cash flow.

(2) And (3) Location Based Quantities and Tasks.

Quantities are a fundamental element in the construction management process. These quantities will be calculated based on their locations. Therefore, the quantity takeoff cannot be done until locations had not been defined.

Quantities based on locations are important because the same activity can take longer or shorter time according to it. This fact should be planned in order to not be out of the schedule.

The flow line which is shown below illustrates the location (on the vertical axis) and the time per location depending on quantities (on the horizontal axis), that represents the same task distributed along the different locations defined in the project.

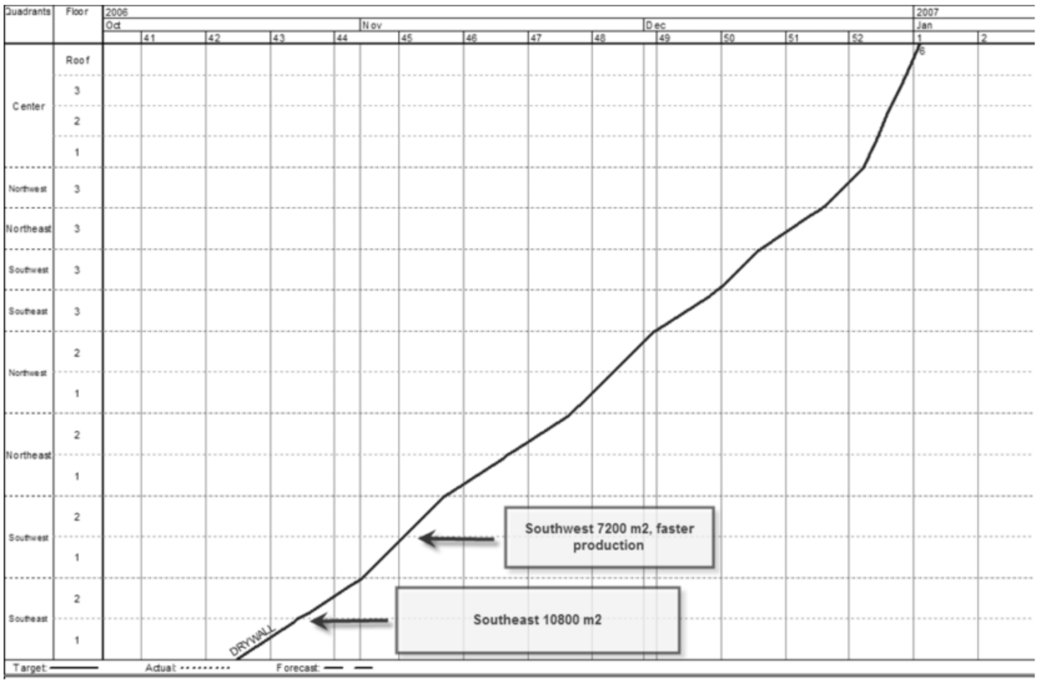


Figure 11: Example of Flow Line Chart. (Seppänen 2009)

Tasks contain data and also enclose the same type of activities repeated in distinct locations and relate time, costs and resources. The same task will have the same resources in all locations and the quantities, productivity and crews are the variables along the project (Kenley & Seppänen 2009).

Each task contains the next information (Kenley & Seppänen 2009): (1) data of production, (2) demand and consumption of resources, (3) crews, (4) constraints (logical relationship between tasks), (5) any detail concerning the task or the method of control and (6) information regarding previous projects which allow the forecast of future plans.

(4) Duration based on quantities, productivity and resources

Durations within the LOB method are calculated using quantities, resources and consumption rates. Consumption is defined as the total time which is required to produce one unit of each item. Duration will be the total amount of hours to finish one task in one location (Kenley & Seppänen 2009).

In order to calculate the duration is required being focused on the optimal crew size, having this concept as the starting point. Total performance can be increased of decreased changing the size of the crew.

(5) A CPM network. Buffers and lags

LBS generates a CPM plan which links all tasks (Kenley & Seppänen 2009) and relates them with their locations. The main difference with the traditional CPM plan is that the work can be scheduled continuous or discontinuous. This continuous option is the key to achieve more optimized processes (Seppänen 2009).

Kenley & Seppänen (2009) define five different levels of activities on the CPM procedure: (1) Relationship between tasks, (2) Relationship between activities, (3) Logical relation between activities enclosed in tasks, (4) Location lags relating tasks and locations, (5) CPM network linking tasks.

At this point should be define new concepts of lags and buffers, which can create confusion, however they are different. Lags are added to the CPM to protect the schedule from future deviations and decrease the risk. LBM adds the concept of buffer which, on the contrary, are additional time between tasks and they are represented through empty space between geometrical representations of tasks. The aim of buffers is to protect the schedule from possible deviations of time in flow line charts (Seppänen 2009) (Kenley & Seppänen 2009).

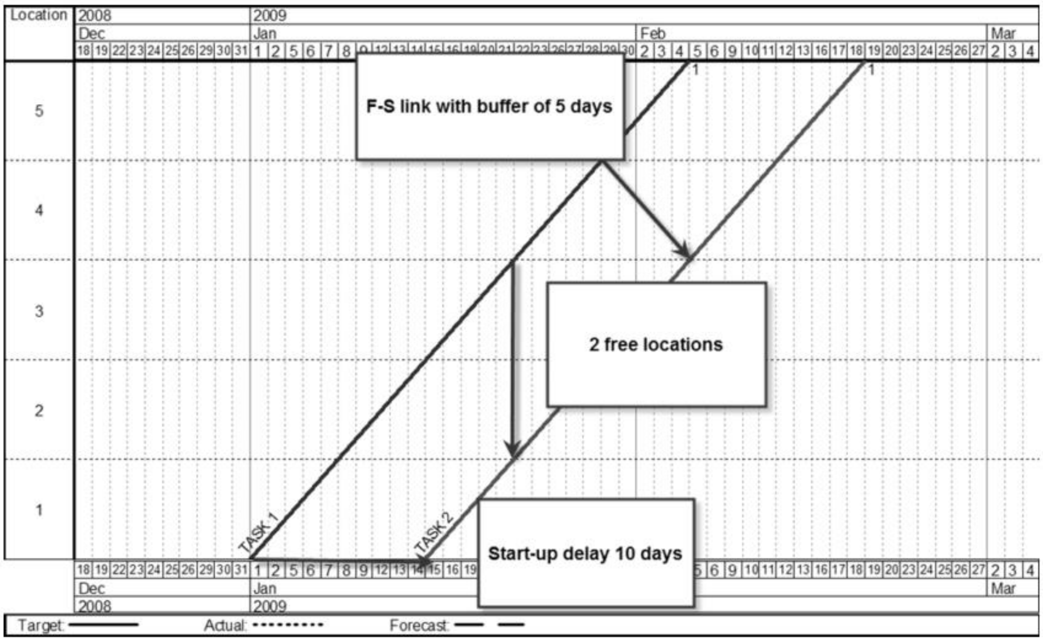


Figure 12: Flow line chart. Buffers between tasks(Seppänen 2009)

On the one side, buffers are not part of the task. On the other side, lags are incorporated inside activities in CPM networks.

3.2.3. Location Based Management and Last Planner System

Seppänen et al. (2010) explain that LBM and Last Planner System (LPS) can complement themselves. Both methods follow the same goals: decrease the waste and risks and promote the increase the productivity. On the one hand, LPS promotes a social and collaborative behaviour to improve the reliability inside the group of work (Lean Construction Institute n.d.). On the other hand, LBM is a more technical process focused on achieving more accurate construction schedules and reducing deviations (Seppänen et al. 2010) .

Figure 13: Meeting for organizing schedules (Lean Construction Institute n.d.)

They can be combined through their different roles, LPS is focused on weekly planning tasks and LBM provides more accurate forecasts and, parallel, prevent from future issues decreasing the probability of future deviations.

Seppänen et al. (2010) conclude confirming that there are real advantages on this combination: reduction of the schedule length, productivity would be increased whereas delays may be reduced.

3.2.4. Optimization of LBMS

The aim of optimizing a flowline is to reduce the risk of deviation in project schedules as a consequence of collisions between tasks and, in addition to this, to assign tasks to locations where no work is taking place (Seppänen 2014). A flowline network offers a more visual and more intuitive manner for optimizing schedules taking into account the next items:

- Buffers. Free locations between tasks where any activity can be performed.
- The increse or decrease of rates of production (modifying the slope of the line).
- The update of resources in order to increase the performance.
- Keep tasks as a continuous process or splitting them as a non continuous system.

Figure 14: Example of flow line charts. (Jongeling & Olofsson 2007)

In the Figure above it can be seen an example of flow line optimization. Firstly, all the interferences must be detected and analysed and secondly, a strategy has to be proposed to remove this issues on the schedule before starting the tasks.

Interpretation of the issues: (1) The same task is taking place in different locations at the same time, (2) Collision between two tasks, (3) No enough time between tasks (buffer), (4) Many tasks starting at the same time, (5) Loss of time between tasks.

After optimizing the flowline, it should look like the figure on the right. When tasks do not show conflicts it can be said that the schedule is optimized. The chance for enhancing the schedule using a geometrical network is more intuitive than the options offered by Gantt charts (Jongeling & Olofsson 2007).

3.2.5. Gantt vs. Line of Balance. Advantages and disadvantages

Nageeb & Johnson (2007) elaborated a list of advantages and drawbacks based on the comparison between Gantt charts and LOB to plan construction projects. Afterwards, Kala et al. (2012), Martinez (2013) and (Seppänen 2014) have focused their reports on studying the positive and negative aspects of LOB against the traditional methods of scheduling as well.

Gantt charts have been a popular procedure for scheduling activities as a consequence of a large number of software that support these processes against the lack of tool to manage flow lines. Nevertheless, LOB is easier to understand than Gantts, this system facilitates any update along the construction process, offers better features to optimize performances and is more visual and suitable to manage repetitive activities. Besides, LOB would be more favourable if it would be used linked with 3D BIM models (Nageeb & Johnson 2007). It offers more accurate schedules and shows the development of tasks within the specific time and location.

LOB reduces the time required to plan processes but, above all, the lack of education on this field, the conservative behaviour on the construction industry and finally, the reduced number of software tools which ease the development of these tasks retrain its implementation. Other negative aspects mentioned by Nageeb & Johnson (2007) are that activities are only allowed to be divided by locations instead of other criteria and also, these charts do not show a clear critical path, fact that can mean an important disadvantage for anyone who has been working with Gantts for such a long time (Nageeb & Johnson 2007).

Kala et al. (2012) specify that LOB is more precise than Gantts because schedules consider quantities extracted from 3D BIM models, rates of productivity and the location breakdown. Information and data about production can be collected from the field on real time.

CPM uses durations and resources based on the experience to forecast schedules, whereas LOB demands more variables to predict the planning such as: (1) Start and finish date of the task, (2) Update the progress of completing tasks, (3) Resources and locations attached to each task, (4) Days when work is stopped per task and location.

Martinez (2013) reports a sort of advantages and disadvantages between Gantt charts and LOB. Flow lines drafts offer better optimizing features than CPM to its geometrical network. LOB is focused on the continuity of the task along different locations in the project, reducing risks of overlapping and collision of resources. In addition, this method bases its planning on the CPM and PERT procedures, following their principles of relation between activities. LOB can be benefitted by its relation with Lean´s philosophy. The Flowline shows the progress of each task in a 2 axis chart where, the vertical one defines the location and the horizontal specifies the duration. The slope indicates the rate of progression. This representation is the fact that make it more visual and understandable than Gantts charts. LBS is an important aspect which allows the project to be organized in a hierarchical system, this option cannot be developed through other methods of scheduling (Martinez 2013).

Finally, Seppänen (2014) point out that CPM is almost a perfect method to plan but the most relevant inconvenient would be that is not focused on the management of resources, more people in the same location with the purpose of increasing the performance would be a wrong solution and the only thing could happen would be the disturbance between workers therefore, the level of performance would decrease. He adds that CPM is not as good as the LBMS managing new updates and showing early warnings before starting activities.

3.3. 5D. Cost estimation

3.3.1. Introduction.

Bryde et al. (2013) and Mitchell (2012) define the aim of BIM 5D: the cost estimation within BIM. This dimension allows to link cost data to the 3D model and it includes also the dimension of planning (4D). Smith, (2014), goes a bit further on this definition including that 5D in BIM should include quantities, prices and schedules on the estimation process.

Mouflard (2013) explains that not all dimensions of BIM cannot be managed together due to interoperability issues. Therefore, 4D and 5D are BIM´s dimensions that should be connected to the 2D and 3D models separately. The process that should be followed is: quantities should be extracted from the 2D and the 3D and this data must be linked with the next two dimensions for obtaining schedules and costs. He makes reference also for the possibility of integrating cost management and LBM. 5D defines costs and provides the option to calculate the cash flow and the rates of productivity based on locations. Integration of 4D / 5D shows how much influence has the planning over the cost and its direct relation. It would facilitate the decisions making and the growth of profitability at early stages (McCuen 2008).

Even though the process of estimating is a crucial stages on the construction management´s field and BIM allows the chance to automate this task, its adoption is widely questioned (Sattineni & Bradford 2011)

Requirements of 5D BIM dimension

The data required for estimating prices is: quantities of the project and information concerning prices.

Quantity takeoff in 2D requires such a long time measuring from the screen, fact that involves many mistakes, low level of accuracy and long time on the process. This task requires precision and also should be developed at early stages during the pre-construction process for optimizing prices. Therefore, BIM would be a suitable tool to enhance this process (Jiang 2011c) giving the chance for automating the takeoff process.

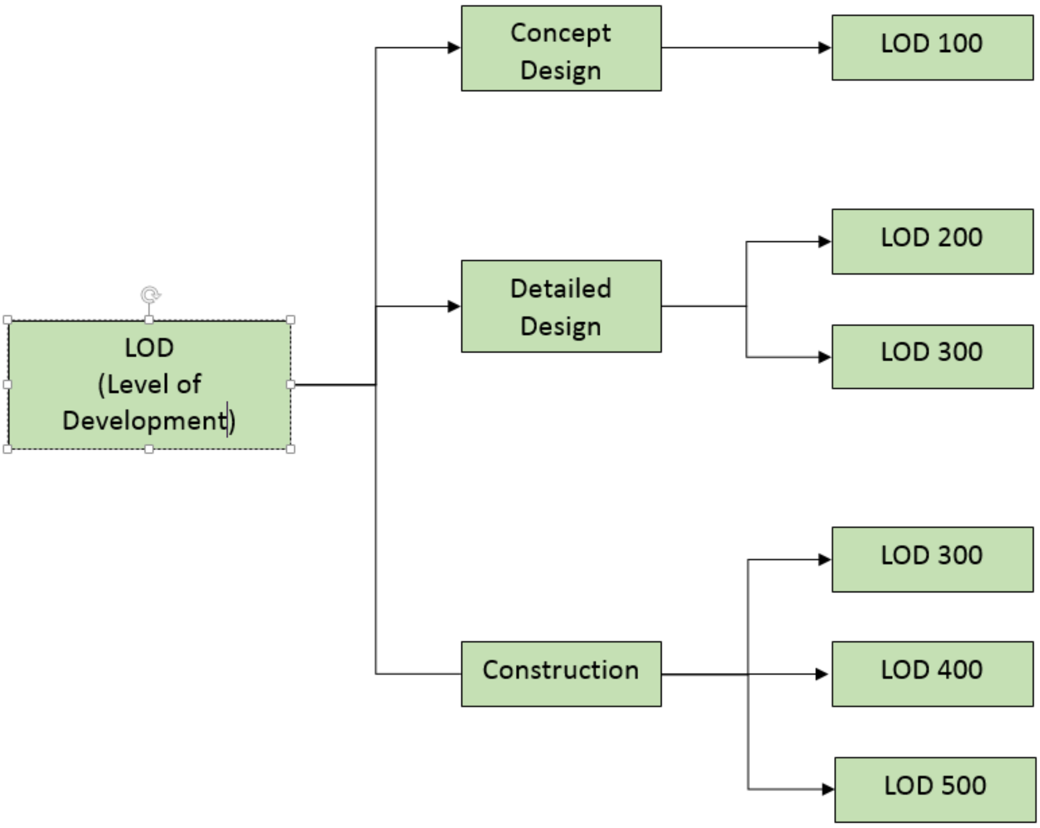


Figure 15: Stages on the growth of the project. (Mitchell 2012)

Cost estimation, due to its level of repercussion, needs to be carried out by expert cost estimators who should analyse elements such as materials and their assembly. In this point, the level of development of the model has relevant importance as it will explain in next chapters. This information is essential to achieve important levels of accuracy on the estimation process defining the unit material, labour cost and profits. The unitary labour cost is obtained defining how much time is needed to complete one unit of measurement, whereas the material cost is the total required money that has to be spent on each material for completing one unit of measurement. When this total is fixed the total price is the result of multiplying it per quantities (Hergunsel 2011b)

3.3.2. Influence of the LOD over the cost process

As it has been introduced on the chapter 3 (3.3), there are different levels of development. Mitchell ,(2012), explains the process that should be followed in any estimation depending on the LOD of the model.

CONCEPT DESIGN

At this level, the only general aspects that can be managed are: first ideas regarding the design, location features, considerations of the project and client´s requirements.

LOD 100

The model is not defined and 5D Quantity Surveyors (QS) base their estimations on their own experience to enclose all aspects of the project. To complete the estimation information is extracted from the 2D design. This phase allows to try different designs as simulations for analysing their repercussion over the estimation.

Benchmarking takes place at an elemental level but nevertheless, it can provide useful results. The experience from other projects is the support to work on new estimations at this level and also to compare different costs. Structural elements, different types of walls, windows, etc. are estimated per unit of measurement (i.e. 300 $ per sqm for structural columns). At this moment a general idea of the price is achieved, therefore some efficient measures can be taken on this early stage. The improvement of inefficiencies can be translated into a 20% of savings within the estimation, in addition to this, this fact does not have any extra negative effect on the development of the project.

DETAILED DESIGN

At this level of development the model must be a schematic design and the estimation is linked to the model in order to create a living cost plan. This is the key step to update endless estimations at any time the model is modified. As a consequence, this can be used for forecasting final budgets, changes, investments or any contractor´s requirement. It encloses:

On the Schematic Design (LOD 200) the model is defined using generic materials and details regarding finishes and services. Once the project has achieved this level a specific codification into the cost estimation must be incorporated. The estimation links both architectural and structural model at this stage nonetheless, not all elements are fully detailed. 5D QSs has to turn to the 2D design to extract measures for deeper details on the procedure.

The Developed Design LOD 300 implicates that the model must be presented with information regarding sub-categories of units and quantities. An extra category of costing is provided to the model and also dynamic links are kept to enable endless updates when the model change. Here should be included the architectural, structural, MEP and civil models if they are required in the project. Measures from the 2D could be essential as well as in the LOD 200.

The living cost plan is still offering, at this point, the possibility of checking further alternatives and options against the initial cost proposal, which enable the analysis of more efficient solutions in terms of materials, systems and technical approaches.

As it has been mentioned before, a new subcategory is added in order to define much better the items on the estimation. Hence, it must be followed a standard or code in order to enhance the communication between members. This codification would facilitate benchmarking, however there is no an international standard regarding this topic. As a consequence, each 5D QS usually uses their own codification to name the categories. However, some of the most required and useful standards are: (1) MasterFormat (North America), (2) Construction Operations Building Information Exchange (COBie), UniFormat II (US), (3) ACMM (Australia), BCIS and UniClass (UK).

When bids are replied the bill of quantity (BoQ) allows the 5D QS to carry out comparisons between offers, in addition, it is available to be used during the lifecycle of the project in order to evaluate the progression of payments, budgets´ variations and possible depreciations.

CONSTRUCTION

At the LOD 300, prices offered by each contractor must include enough information in order to be compared rated and evaluated. On the construction process dynamic links offers the chance of updating changes an endless number of times, obtaining reliable and information quickly. As the project increases the level of information from the LOD 300 to the LOD 400 any change has to be incorporated to the model and also 5D QS should coordinate BoQ and update any variation in terms of costs. In addition, any fluctuation needs to be reported in terms of prices, payments or any other change regarding cost information at the LOD 400 and costs are integrated in the model.

At the LOD 500, the final information regarding costs collected on the construction process must be update in the model in order to be used on the next stage by facility managers during the lifecycle of the project. This data should mirror the reality. This stage encloses distinct types of information such as: cost information, suppliers, estimated costs on operations of maintenance and depreciation.

3.3.3. Standardization of the estimating process

As it has been explained in the chapter 3 (3.4), the lack of standards is a relevant drawback. The 5D of BIM needs to be based on international common rules as well as the other dimensions in order to improve the collaboration of members. The aim of this standard is to establish minimum requirements in terms of data and nomenclatures. The Royal Institution of Chartered Surveyors (RICS) is working on the New Rules of Measurement (NRM) to standardize the process of costing and estimating in construction projects (Smith 2014b). This fact would provide worldwide rules applicable to any element of the project RICS (n.d.).

It includes three parts:

- NRM 1: rules focused on estimating and planning costs. It is a guide which explains how no measurable information can be managed: profits and overheads, fees, inflation, preliminary costs, risk margins, etc. The client is provided with more reliable information in terms of costs.
- NRM 2: focused on giving details concerning building works´ measures and descriptions for tendering processes. It makes reference to details of BOQ such as production, displaying of the required information to prepare BOQ, organization of no measurable building items, risks and works.
- NRM 3: it is a guideline focused on the non-measurable works concerning maintenance and also jobs that are not reflected in any item.

The link between BIM and the NRM is that the process of estimating takes the information from the model through the use of a third part and change it into different domains (i.e. IFC Quantity Resource) for sharing it. On the one hand, NRM is a virtual codification which can be used for estimating prices, fact that could improve the 5D QS´s tasks, who could be involved on this management process at early stages. On the other hand, the barrier that the NRM need to overcome is that one concerning Abstract Data Type (ADP). Any domain should recognize this data to obtain successful results. In addition, IFC plays an important role as a process which transforms outputs into inputs which will be used in other software (Matipa et al. 2013) but losses of information can happen on the process.

3.3.4. Linking the 3D model to 5D

Jiang (2011) has defined three types of linking the model in order to transfer the information into the cost estimation´s tool.

- Transferring the data from the model into estimation tools.

This process encloses the tasks of extracting the data from the 3D model and exporting it to any spreadsheet like Microsoft Excel is. In this case, the disadvantage is that at any time the model changes information needs to be exported and structured again. This fact limits the number of cost simulations.

- Linking the 3D BIM model with 5D BIM tools.

The BIM model is connected directly with the tool for estimating costs through a plug-in. In this case all the features attached in the model are reflected on the 5D and also, if some information is required to complete the estimation it can be generated on the 3D model.

- Using a specific quantity takeoff tool.

The third case is the use of specific tool to takeoff the quantities from the model. It reduces the possibility of missing information and also offers special features to modify the data. After extracting all data from the model it is exported as an output into an Excel spreadsheet where is managed and linked with any cost database.

3.3.5. Estimating costs in BIM

Mitchell (2012) affirms that accuracy on the cost estimation decreases the project´s risks and also increases the profitability. Collaboration from early stages is desirable if reliable and useful data is demanded. However, most times when this is not possible many important aspects are not taking into account and the 5th dimension of BIM is simply reduced to a quantity takeoff. Collaboration from the very beginning would make disappear some of the next common drawbacks:

- An exact estimation is not achieved until the model has a LOD 300 or better.
- The design cannot be benchmarked and more efficient solutions cannot be provided.
- There is no live feedback between QS during the process of designing.
- The lack of transparency is typical and the cost estimation process seems to be an isolated task.

It is known that early changes are not as influential as any modification while the construction is taken place. Rework means delay projects, fact which is translated in lower benefits. The process to avoid this negative aspect should follow the next steps: the first estimation is developed, the price and design is compared against other projects, at that time QS should report feedback to the design team for suggesting improvements and finally, the process is repeated again until finding the most efficient solution. The advantage here is that 5D QS can repeat procedure and endless number of times offering different combinations and more economical solutions.

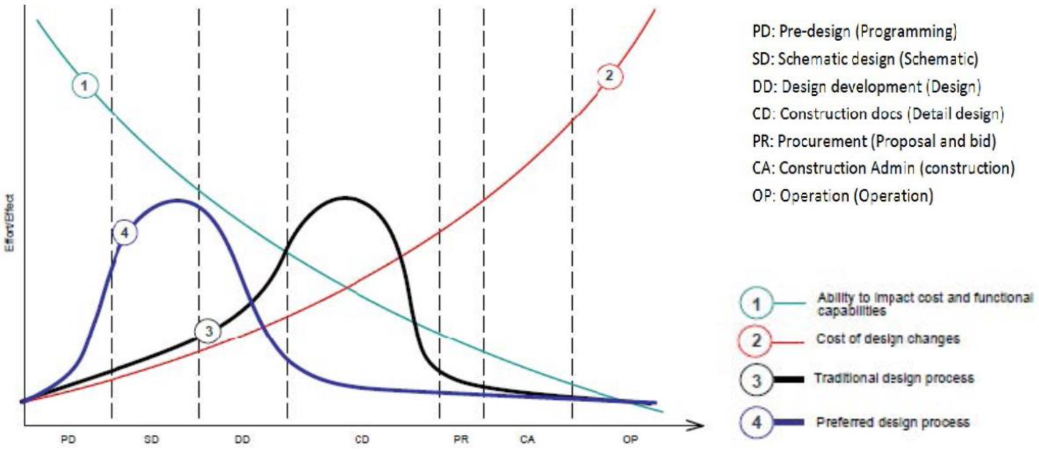


Figure 16: Distribution of activities on the life cycle of the project. (Yu et al. 2011)

When the phase of designing finishes and estimations are fit, the cost plan is developed and this will be the baseline for monitoring any variation during the construction phase. QS are enabled to carry out more estimations concerning any change could happen for providing feedback and suggesting any correction.

Software technology is essential and helpful on this approach but, Mitchell adds that in addition to this, there are relevant aspects which do not have direct relation with technology but have relevant influence:

- Experience: acquired from previous projects which allows QS to solve rapidly the most important problems and suggest advice as well.
- Intelligence: a cost database is essential for having a general idea concerning labour and prices, trends on bench marketing and relation between quality and price.
- Technological aspects: the use of dynamic links established between the model and tools for pricing can provide a better performance in the live cost planning.

3.3.6. Advantages and disadvantages

Lanka & Modelling (2013) define that the most important advantages offered by BIM on 5D are the automatic extraction of data from the model, which increases the productivity and eliminates a large number of mistakes. The better visualization of the model, the 3D view optimizes its understanding and provides more accurate details and finally, the possibility for linking the 3D model with specific tools offers the chance of making an endless number of estimations when the model suffers modifications.

In addition to the previous paragraph, the option offered by BIM to interconnect design, cost estimation and planning allow managers to evaluate the project as a whole from the beginning (Popov et al. 2010).

The scarcity of standards is the key to leverage this dimension of BIM. At this moment this is an important issue translated in the loss of information when it is exchanged. Standards should be more developed and not only at software level, also in terms of practical rules and guidelines (Lanka & Modelling 2013)(Smith 2014a). Uniformat (US) is a clear example of a guideline where construction works have an attached codification (Aibinu & Venkatesh 2013).

Smith (2014) also includes that there is a refusal when QS are asked for sharing cost databases between all fellows involved in the same project. This fact is seen as an aspect that can have a negative influence on their business.

On the one hand, 5D offers the possibility to extract information much faster than using 2D designs, enabling QS to save around 90 per cent of the time that they have to spend on the quantity takeoff using CAD tools. This offer the chance for spending more time looking for the most efficient solution. On the other hand, 5D is not only an automatic procedure, it requires knowledge, provided by other previous projects along years of experience, market´s information concerning labour and material prices. In addition to this, QS need technology to deal with the actual requirements on the market they need to manage accurate information provided from other member therefore, they must use suitable tools for developing their tasks (Mitchell 2012). Mitchell (n.d.) adds in another report that early collaboration with designers in order to analyse the project and give suggestions that would eliminate the typical lack of lack of transparency on isolated cost processes.

Some drawbacks on the implementation of BIM 5D are the low level of experience using BIM, worker´s skills are not enough to achieve the required performance and also, to know how this technology must be introduced in the system. Cultural aspects can have several relevance against the adoption of new technologies. In addition, data extracted from the model is very questioned concerning its accuracy. Depending on how the model has been designed quantities can vary, this fact creates doubts regarding how far this automatic process reliable enough. Quality of quantities of the attached information, is most of the times not enough to provide accurate estimations. The efficiency of this process is highly dependent on the design phase, it is here when a collaborative work is required and indispensable between them (Aibinu & Venkatesh 2013).

Many authors have mentioned that the reduction of time on the quantity takeoff is such a relevant of BIM. Nonetheless, Aibinu & Venkatesh (2013) states the opposite point of view explaining that, whether quantities and data are not well defined on the design process, information is not useful for estimating costs. As a consequence, the time is saved extracting data is consumed checking it and understanding in detail how it is organized. Sattineni & Bradford (2011) affirms that BIM does not make reduce time on estimations and also it does not raise the quality of the estimation unless, designers and engineers provide a rich and well-defined BIM model suitable for being used by QS Another negative aspect on the cost estimation field is the lack of recognition of changes on the project. This means that BIM 5D will be not a helpful dimension except there is a collaborative environment from early stages.

Aibinu & Venkatesh (2013) makes reference also to the way in which project changes are re-updated after the quantities had been input by QS, that means rework to refresh the new data. Not all the 5D software tools offer a bidirectional behaviour to reflect the new data. Besides, QS explain that only quantities are transferred but description are not attached into the model. Descriptions are an important part of the BOQs and they provide more information to subcontractors concerning scope, technical solutions and processes. BIM tools cannot provide descriptions of items and this information is not able to be computed in the way that QS require it.

Stanley & Thurnell (2014) complete the previous disadvantage supporting that 5D would be outside of the BIM target if the link to the model is not a live link which allows endless number of quantities´ updates when the model changes. They affirm that one of the most important problems concerning 5D are about quantification, how data is extracted from the model and how modifications can be managed.

Experimental study

1. Analysis of QTO

1.1. Introduction

The analysis of QTO will consist in studying the accuracy of the QTO extracted from several types of geometric models defined combining different variables that are defined in the next chapter. This practical approach would show how much influence has the method of designing over the accuracy of quantities extracted from 3D models. This assessment is based on the research developed by Monteiro & Martins (2012) and Monteiro & Martins (2013), where they analyse the accuracy of the QTO tool in Archicad and investigate four procedures for creating a 3D BIM project for comparing after the reliability of outputs.

Quantities will be extracted as outputs from Autodesk Revit 2014 and export as inputs into Vico Office 4.7, which are the BIM tools provided for this analysis, and both of them are going to be compared, in terms of accuracy, with manual measurements to check their reliability. In this case, Vico is linked with Revit as a plug-in. In spite of modelling a project, some specific models are created simulating geometrical connections such as: wall + wall, wall + structural elements, openings in walls and structural elements + structural elements.

The aim to develop this analysis to give a general perspective concerning how precision is managed when different BIM tools are linked and also information is transferred between software platforms. Many authors mention than the automatic QTO offered by BIM is a great advantage however, the time saved on this process is needed to check and understand how the 3D model is designed and the accuracy of this data.

1.2. Research Methodology

On this quantitative research different 3D models, designed in different ways to create different constructive solutions, are going to be combined. Concerning the models six types are defined: (1) Wall: outer wall which consists of five layers that receive the next nomenclature starting on the exterior side till the interior part: M1-M2-M3-M4-M5. (2) Wall + STW: this BIM model shows what can be a real situation of a structural wall (STW) introduced in wall. (3) Wall + Slab: it is shown the encounter between one horizontal slab and wall. (4) Structural Wall + Beam: in this model is simulate the real situation where the structural wall is embedded in the wall. (5) Structural Wall + Slab: this 3D model represents the case where and horizontal slab is supported by a vertical structural wall. (6) Beam + Slab: this model simulates a beam embedded in the slab.

This five types of model are modelled, in this specific case, following nine different methods which are: (1) Multilayer design or Method 1: this method is used for designing walls where each layer is modelled separately. (2) Single element or Method 2: method applied on walls also but they are modelled as a compacted element composed of various layers. (3)(4) Join/unjoin: feature for defining the geometry of embedded element inside horizontal or vertical components. This method is used for the models number 2 and 4. (5)(6) Attach/detach: it is a method of modelling in Revit 2014 for defining the technical connections between horizontal and vertical 3D elements that is used for designing the model number 3. (7)(8) Opening tool and edit profile tool: both types are applied on the model number 1, the first one is the option for creating openings in walls meanwhile the second one is the tool to shape the wall.

Finally, six different constructive solutions are reproduced in order to create with distinct ways of designing the same 3D visual solution. These technical solutions are: (1) Geometric Connections: it consists in connections in corners, this technical approach is used for the models number 1, 4, 5 and 6. (2) Geometric Intersection: on the model number 1 to represent the interconnection between two crossed walls. (3) Structural Wall partially embedded: it represents the real situation when one structural element is introduced in one wall and interrupt the continuity of some layers, as it is shown on the model number 2 (i.e. outer walls). (4) Slab partially embedded: this technical model shows the connection between one slab and the outer wall where, the first one can interrupt the vertical continuity of interior wall´s layers, shown on the model number 3. (5) Opening: it is the representation of openings in walls. This technical solution is applied on the model number 1. (6) Structural element: this technical solution is used for designing the stair as an example of conflictive element when it is measured due to its geometrical definition, as it is represented on the model number 7.

Concerning the codification of models the table 1 summarizes the different variables and each individual code. Three groups of parameters which are combined depending on the required technical solution.

Model (X)	Method of designing the model (Y)	Constructive solution (Z)
1. Wall	1. Multilayer design or Method 1	1. Geometric Connections
2. Wall + STW	2. Single element or Method 2	2. Geometric Intersection
3. Wall + Slab	3. Unjoin	3. Structural Wall partially embedded
4. STW + Beam	4. Join	4. Slab partially embedded
5. STW + Slab	5. Detach	5. Opening
6. Beam + Slab	6. Attach	
	7. Opening tool	
	8. Edit profile tool	

Table 1: Variables for creating models

According to the table above, each model is codified based on the variables X, Y, Z. As an example, the model called “Wall + STW” would be (X2), designed using the “Method 1” and the “Unjoin” Revit feature would be (Y1 + Y3) and the option defined by “STW partially embedded” would be (Z3). This specific example would be defined through the code: (X2, Y1 + Y3, Z3).

With regarding the measures that are extracted from each model, as a consequence of the large number of possible dimensional parameters that can be used for different items, only some specific values are compared on this analysis. Concerning the units of measure utilise in this process, they are: (1) Meters -m-: for measuring horizontal and vertical dimensions such as lengths, widths and heights; (2) Square meters –m^2-: for quantifying the amount of material in layers that compose walls and also for surface areas; (3) Cube meters –m3-: for calculating the amount of concrete in structural elements.

For analysing the accuracy of quantities models are measured manually following hypothetical requirements explained in the table 2, as it could be, as an example, the surface area in walls (i.e. for painting), in structural elements (i.e. for measuring and estimating the formwork), volume of concrete (i.e. for measuring and pricing concrete), etc. This manual measure is considered the most precise and accurate dimension that, during the research is compared with the data extracted from Revit (3D BIM) and Vico office 4.7 (4D / 5D BIM). Therefore, the procedure encloses the following steps: (1) 2D – Revit: it compares the accuracy of Revit quantities against manual measures; (2) 2D – Vico: it analysis different values between the manual data and the outputs that are extracted from Vico; Finally, (3) Revit – Vico: this comparison shows the difference behaviour of these two BIM tools extracting outputs.

For calculating the average deviation measuring each model, it is obtained the average length, surface area, and volume of the dimensional parameters offered by the BIM tools. This results are obtained always in absolute value. In addition. All models classified within the same "type of model" (Table 1) are measured following the same rule and extracting the same information to allow the analysis.

Further, as it can be seen on the plans placed on the appendix section, in order to have a clear idea concerning the behaviour of the model when various elements are joined or attached, within the same Revit file two models, which have the same features, are created (i.e. for analysing the connection between wall + structural wall is duplicated and the structural wall is imbedded in one of the multilayer walls) in order to allow the analysis of the algorithm that is used for taking off the quantities. This method of modelling is applied on the models that simulate intersection between walls, openings in walls, walls + structural walls and walls + slab.

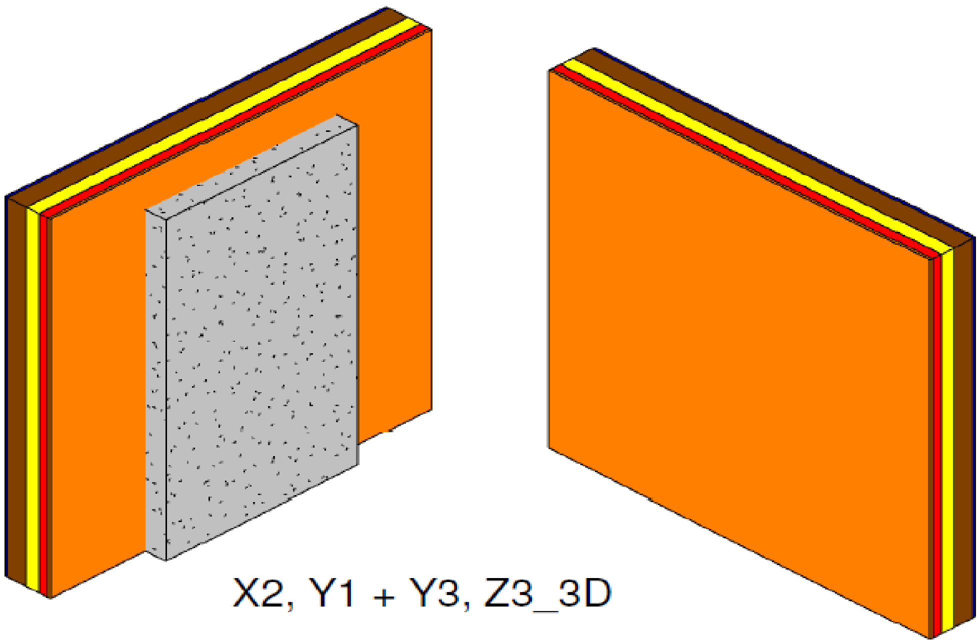
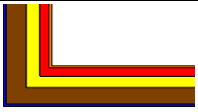
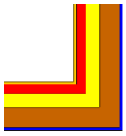
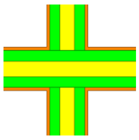
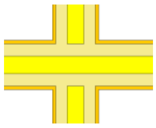
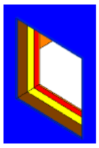
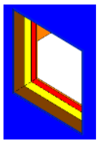
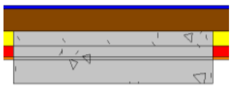
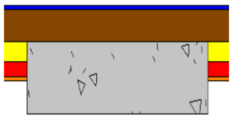
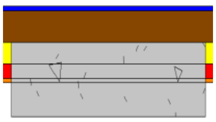


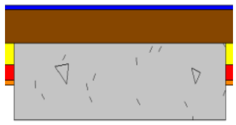
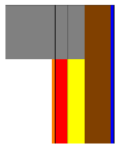
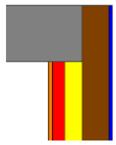
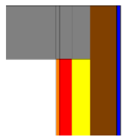
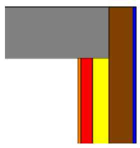
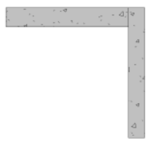
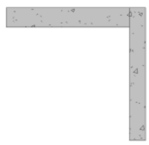
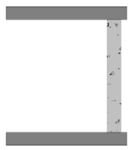
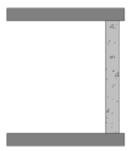
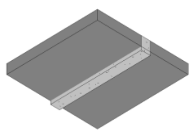
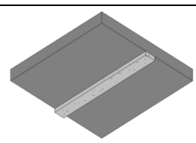
Figure 17: Duplication of models for QTO

Finally, when some quantity is not provided by the BIM tool and it is required for calculating the average deviation, it is established as a general method the option of typing an "X" instead of keeping empty the cell or typing a "0".

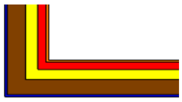
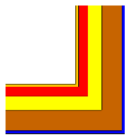
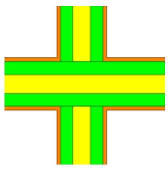
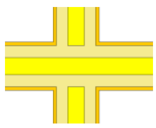
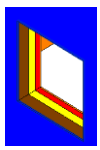
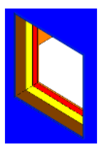
The following two chapters show the models that are analysed on this quantitative research, the variables that are combined for creating them as well as the codification that is used for naming each 3D design, nomenclature that will be used on the analysis of results.

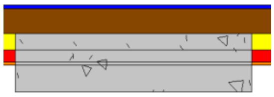
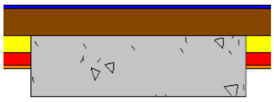
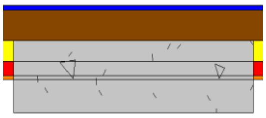
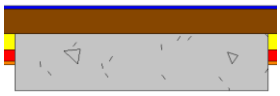
Combination of variables

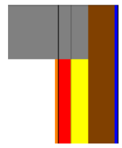
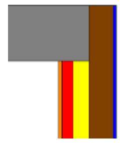
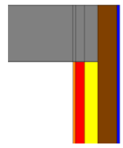
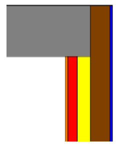
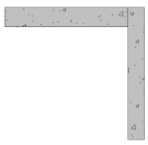
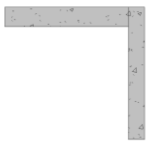
Model	Method of designing the model	Constructive solution	Image	Code
1.Wall	1. Method 1	1. Geometric Connection		(X1, Y1, Z1)
	2. Method 2	1. Geometric Connection		(X1, Y2, Z1)
	1. Method 1	2. Geometric Intersection		(X1, Y1, Z2)
	2. Method 2	2. Geometric Intersection		(X1, Y2, Z2)
	1. Method 1 + 7. Opening tool	5. Opening.		(X1, Y1 + Y7, Z5)
	1. Method 1 + 8. Edit profile tool	5. Opening		(X1, Y1 + Y8, Z5)
	2. Method 2 + 7. Opening tool	5. Opening.		(X1, Y2 + Y7, Z5)
	2. Method 2 + 8. Edit profile tool	5. Opening.		(X1, Y2 + Y8, Z5)
2. Wall + STW	1. Method 1 + 3. Unjoin	3. STW partially embedded		(X2, Y1 + Y3, Z3)
	1. Method 1 + 4. Join	3. STW partially embedded		(X2, Y1 + Y4, Z3)
	2. Method 2 + 3. Unjoin	3. STW partially embedded		(X2, Y2 + Y3, Z3)

Model	Method of designing the model	Constructive solution	Image	Code
	2. Method 2 + 4. Join	3. STW partially embedded		(X2, Y2 + Y4, Z3)
3. Wall + Slab	1. Method 1 + 3. Unjoin	4. Slab partially embedded		(X3, Y1 + Y5, Z4)
	1. Method 1 + 4. Join	4. Slab partially embedded		(X3, Y1 + Y6, Z4)
	2. Method 2 + 3. Unjoin	4. Slab partially embedded		(X3, Y2 + Y5, Z4)
	2. Method 2 + 4. Join	4. Slab partially embedded		(X3, Y2 + Y6, Z4)
4. STW + Beam	3. Unjoin	1. Geometric connection		(X4, Y3, Z1)
	4. Join	1. Geometric connection		(X4, Y4, Z1)
5. STW + Slab	3. Unjoin	1. Geometric connection		(X5, Y3, Z1)
	4. Join	1. Geometric connection		(X5, Y4, Z1)
6. Beam + Slab	3. Unjoin	1. Geometric connection		(X6, Y3, Z1)
	4. Join	1. Geometric connection		(X6, Y4, Z1)

1.3. BIM models

Nº	Code	Image	Research
1	(X1, Y1, Z1)		These two models compare two different ways for designing the same multilayer wall. In this case both walls are connected on the corner to simulate what could be a real situation on any building´s facade. These models allow the analysis of the influence that two modelling methods called "method 1 and method 2" have upon the next dimensional parameters: lengths in meters, inner and outer surface areas (m2) and quantity of material that composes the wall (m2). These measures could be used for estimating wall´s materials, baseboard and wall´s cladding.
2	(X1, Y2, Z1)		
3	(X1, Y1, Z2)		These models simulate an example of intersection between inner walls. In this case only three layers are used for designing them (M3, M4, M5) and two different methods of designing are used for defining them as it happens on the previous models, called "method 1 and method 2" (Y1 and Y2), that are the variables in these models. The measurements that are studied in this case are: m^2 of each layer in order to know the quantities of material, the surface area (m2) and the length (m) that could be used for estimating the baseboard and cladding.
4	(X1, Y2, Z2)		
5	(X1, Y1 + Y7, Z5)		These models analyse if the way for defining openings (Y7 and Y8) has influence on the accuracy of quantities in Revit and Vico. In this case the method of designing the wall is not a variable, only using the "method 1" (Y1) in both models. With regarding the measurements, the next dimensional parameters are analysed: lengths (m), m2 of each layer and inner and outer surface areas. These values can be used for estimating materials such as: baseboard, cladding and materials for building the wall.
6	(X1, Y1 + Y8, Z5)		

Nº	Code	Image	Research
7	(X1, Y2 + Y7, Z5)		These models follow the same rule that the previous one with the difference of using a wall designed using the "method 2" (Y2). The same methods of creating openings are compared (Y7 and Y8) and the measurements compared are: meters in lengths and square meters for quantifying material in layers and inner and outer surface areas.
8	(X1, Y2 + Y8, Z5)		
9	(X2, Y1 + Y3, Z3)		These two model simulate a real situation when two different elements are embedded, in this case a structural wall is partially introduced in the wall, this fact allows the analysis of how programs subtract the volume of the structural wall from the multilayer wall. This could be a real case when one pillar and wall are connected in a facade. Models compare the influence that the Revit options called "unjoin and join" have over the accuracy of measures and are also the variables. In this case the method for designing the wall is not a variable, this model uses the "method 1" (Y1). Concerning the dimensional parameters analysed they are: horizontal lengths (m) for estimating the baseboard and quantity of materials that compose the wall (m2).
10	(X2, Y1 + Y4, Z3)		
11	(X2, Y2 + Y3, Z3)		These models simulate the same situation exposed on the previous example. In this case the wall is created using the "method 2" for the design process, that is not a variable in this case, using as variable the Revit option called "join and unjoin" (Y3 and Y4). Regarding the dimensional parameters compared between these two 3D models, they are: lengths (m) and, for quantifying inner and outer surfaces and layer´s materials, square meters (m2).
12	(X2, Y2 + Y4, Z3)		

Nº	Code	Image	Research
13	(X3, Y1 + Y5, Z4)		These models compare the influence of the Revit option called "detach and attach" (Y5 and Y6) on the accuracy of quantities and, in this case this is the variable, combined with the "method 1" on the design of the wall, which is not the variable in this example. Here is simulated the connection between slab and wall that could be a real example in any building facade. Concerning the parameters analysed, they are: inner and outer surface areas (m2), quantity of materials that composed the wall (m2) and the volume (m3) of concrete in the slab.
14	(X3, Y1 + Y6, Z4)		
15	(X3, Y2 + Y5, Z4)		In this case it is simulated the same previous example with the difference of using the "method 2" (Y2) as a non variable. The Revit options called "detach and attach" (Y5 and Y6) are the variables in this case as well. Finally, the analysis of dimensional parameters is focused on: lengths (m), square meters (m2) for quantifying materials on the wall and volume (m3) for calculating the concrete in the slab.
16	(X3, Y2 + Y6, Z4)		
17	(X4, Y3, Z1)		It is simulated in these models the connection between the same structural wall used for the rest of the models with an horizontal concrete beam. In this case the variables are the Revit options called "join and unjoin" (Y3 and Y4) in order to define the connection between both structural elements. Concerning the dimensional parameters, that are object of analysis here, they are: the height (m) and the volume (m3) in the case of the structural wall, regarding the beam they are the length (m), surface areas (m2) and concrete volume (m3).
18	(X4, Y4, Z1)		

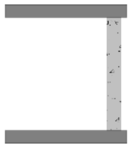
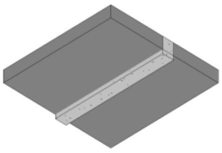
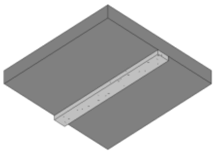
<table>
<tr><th>Nº</th><th>Code</th><th>Image</th><th>Research</th></tr>
<tr><td>19</td><td>(X5, Y3, Z1)</td><td></td><td rowspan="2">These models represent the technical connection between structural wall and slabs, both designed with concrete as a principal material. In this case two Revit options called "join and unjoin" (Y3 and Y4), which are the variables as well. Concerning the parameters, object of study in this example, they are: height (m), surface area (m2) and concrete volume (m3) on the structural wall and, in the case of the slab the surface area (m2) and the concrete volume (m3) are the parameters that are compared. Furthermore, the total concrete volume is studied closely to verify possible variations in this structural element as a whole.</td></tr>
<tr><td>20</td><td>(X5, Y4, Z1)</td><td></td></tr>
<tr><td>21</td><td>(X6, Y3, Z1)</td><td></td><td rowspan="2">These models simulate a structural element that consist of one horizontal structural floor supported by a horizontal beam that, in this case, is partially embedded in the other element. In this case the variable is the Revit option called "join and unjoin" in order to analyse in detail how these BIM tools measure lengths (m), surface areas (m2) and concrete volumes (m3) in both structural elements.</td></tr>
<tr><td>22</td><td>(X6, Y4, Z1)</td><td></td></tr>
</table>

Table 2: Definition of models

1.4. Research findings

Different models are gathered in three main groups with the aim of interrelating the results, designing methods and the type of software used for taking off quantities. Following this methodology for analysing the data, the four are created depending on the type of elements that integrate the BIM model, these are: (1) Multilayer walls, (2) Multilayer walls + vertical structural elements, (3) Multilayer walls + horizontal structural elements and (4) Structural elements.

1.4.1. Multilayer walls

Within this group are analysed the models that are designed with the next codification: (X1, Y1, Z1), (X1, Y2, Z1), (X1, Y1, Z2), (X1, Y2, Z2), (X1, Y1 + Y7, Z5), (X1, Y1 + Y8, Z5), (X1, Y2 + Y7, Z5), (X1, Y2 + Y8, Z5). This assessment shows clearly which designing method offers more reliability on the QTO process. Graphics below compare the different ways of modelling and the average deviation according to the tool that is used for the task.

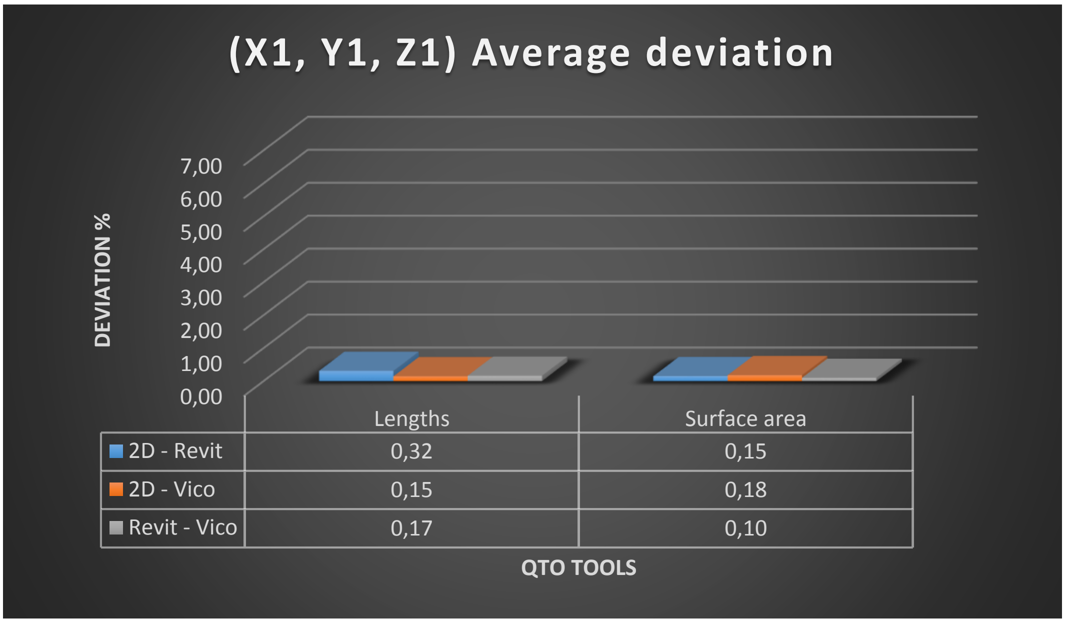


Figure 19: (X1, Y1, Z1) Average deviation

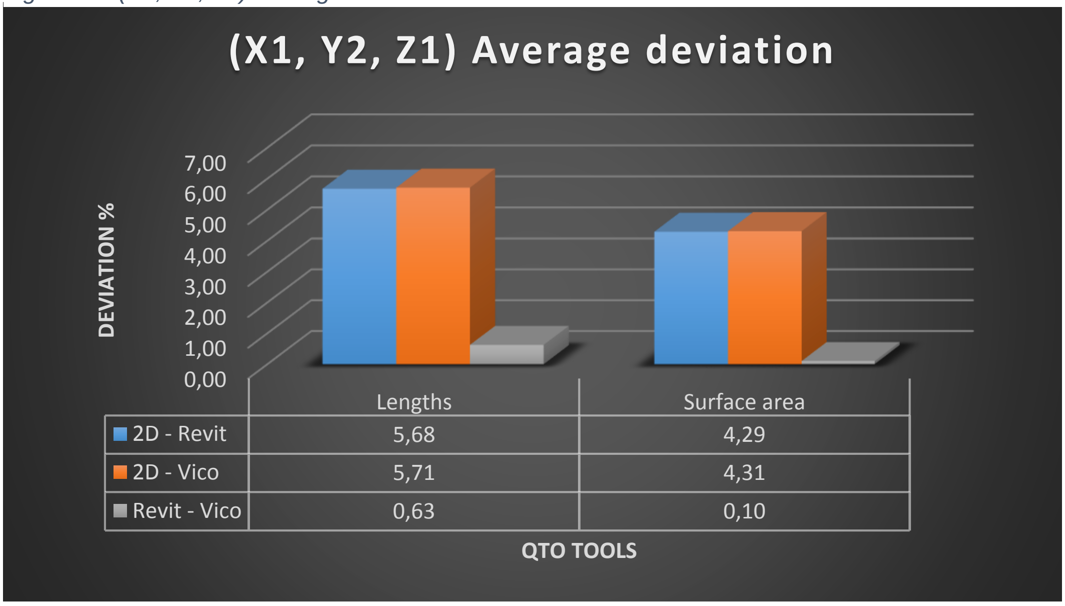


Figure 18: (X1, Y2, Z1) Average deviation

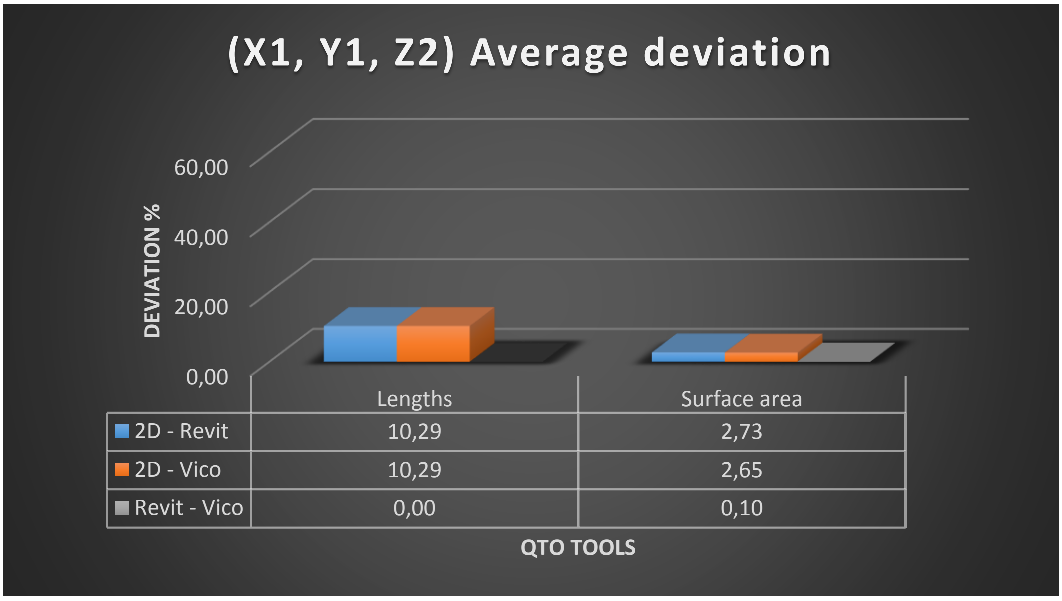


Figure 21: (X1, Y1, Z2) Average deviation

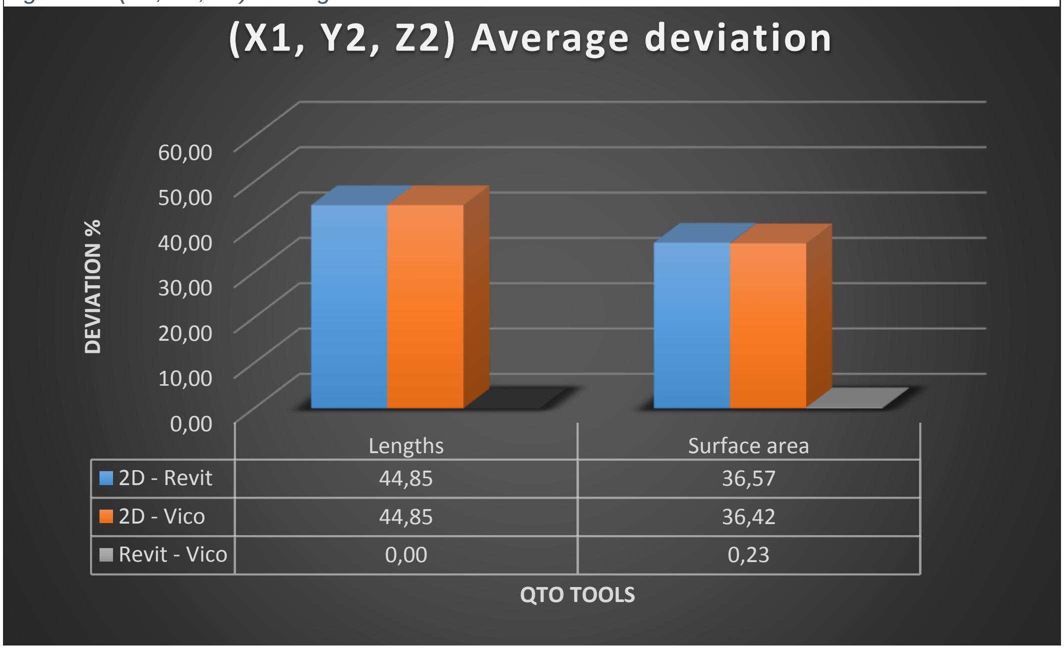


Figure 20: (X1, Y2, Z2) Average deviation

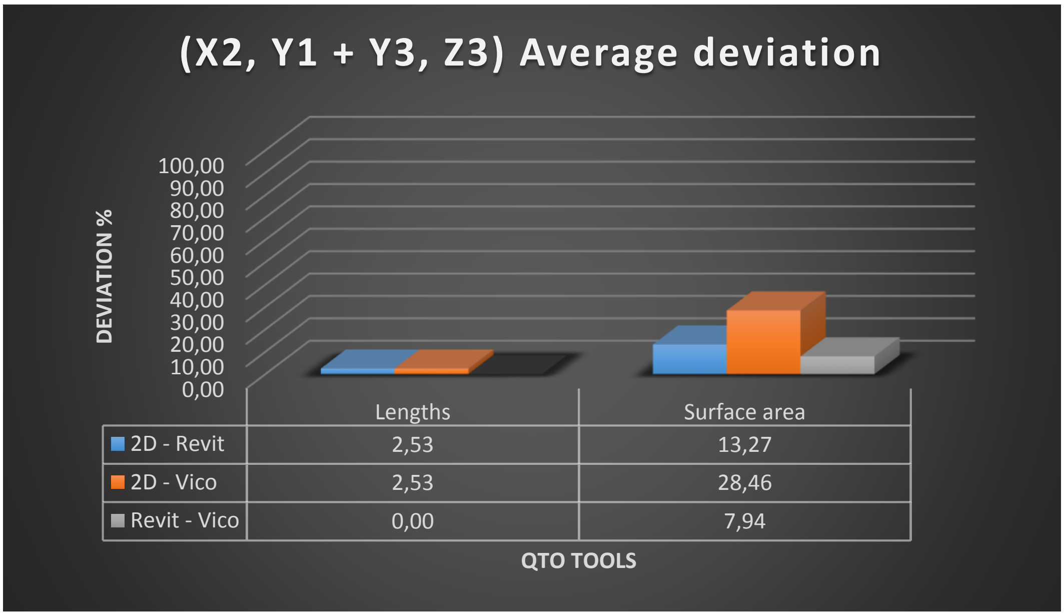
These four graphics illustrate the accuracy extracting quantities from model that simulate two technical solutions: geometrical connection, models (X1, Y1, Z1) and (X1, Y2, Z1), and geometrical intersection, models (X1, Y1, Z2) and (X1, Y2, Z2). It can be observed that there is no deviation when the model is transferred from Revit into Vico (“Revit – Vico”), fact that can show the clear evidence that the deviation detected in Revit is also transferred into Vico. Data that is taken off from these two BIM tool is the same, what can create confusion regarding its accuracy. However, when dimension are contrasted with manual takeoffs clear signs of lack of precision appear (“2D – Revit” and “2D – Vico).

In the case of creating openings in walls, tables 27, 32, 37 and 42 on the appendix, show that both designing procedures offer equal accuracy. Both methods are detected by the two BIM tools and subtract the opening from the total area of the wall in a proper way.

According to the results that are shown on the graphics, the "method 1", that consists in designing each layer of the wall separately, offers more reliability and more details than the "method 2", which only allocated the average length and area to all layers. Therefore, the wider is the wall the more important is the deviation.

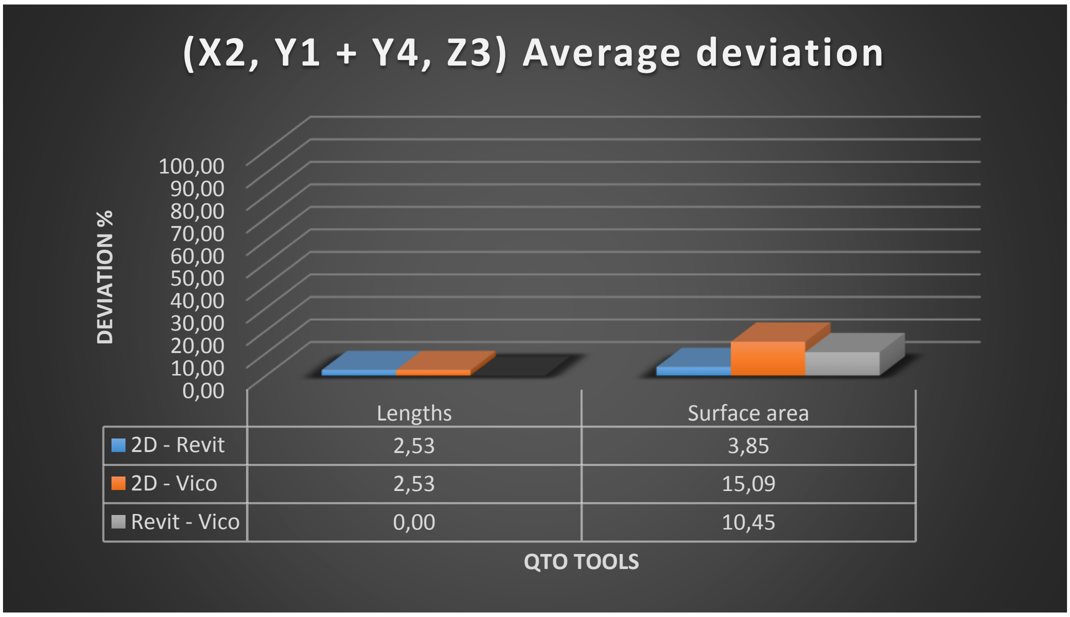
1.4.2. Walls + vertical structural elements

On this analysis are simulated four models that follow the next codification: (X2, Y1 + Y3, Z3), (X2, Y1 + Y4, Z3), (X2, Y2 + Y3, Z3), (X2, Y2 + Y4, Z3). Graphics below show the deviation relating different approaches on the designing process and QTO tools.



	Lengths	Surface area
2D - Revit	2,53	13,27
2D - Vico	2,53	28,46
Revit - Vico	0,00	7,94

Figure 23: (X2, Y1 + Y3, Z3) Average deviation



	Lengths	Surface area
2D - Revit	2,53	3,85
2D - Vico	2,53	15,09
Revit - Vico	0,00	10,45

Figure 22: (X2, Y1 + Y4, Z3) Average deviation

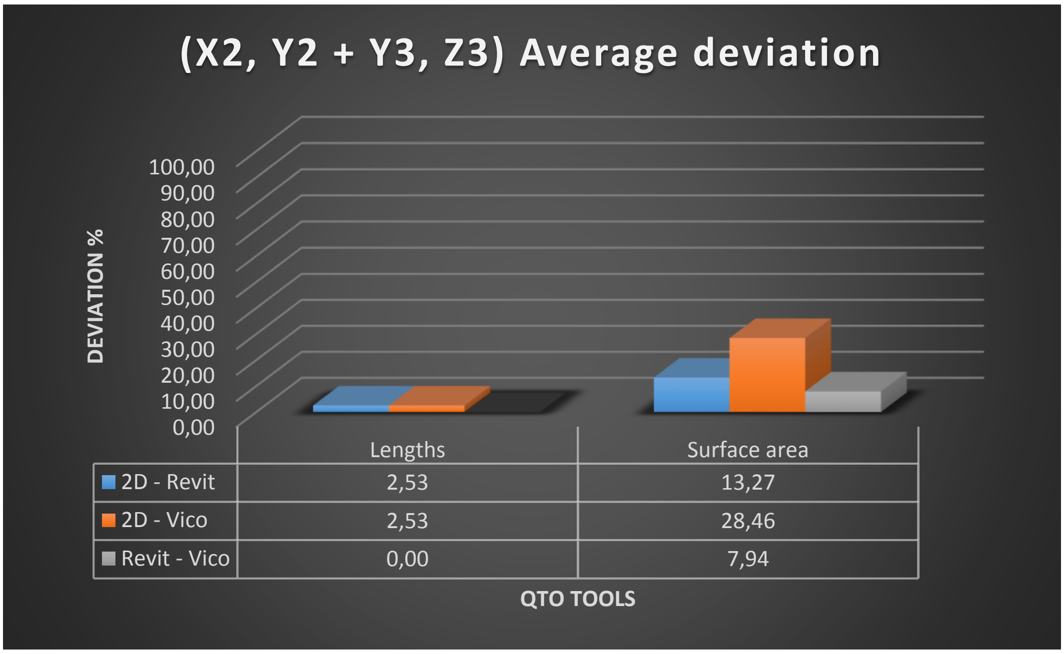


Figure 25: (X2, Y2 + Y3, Z3) Average deviation

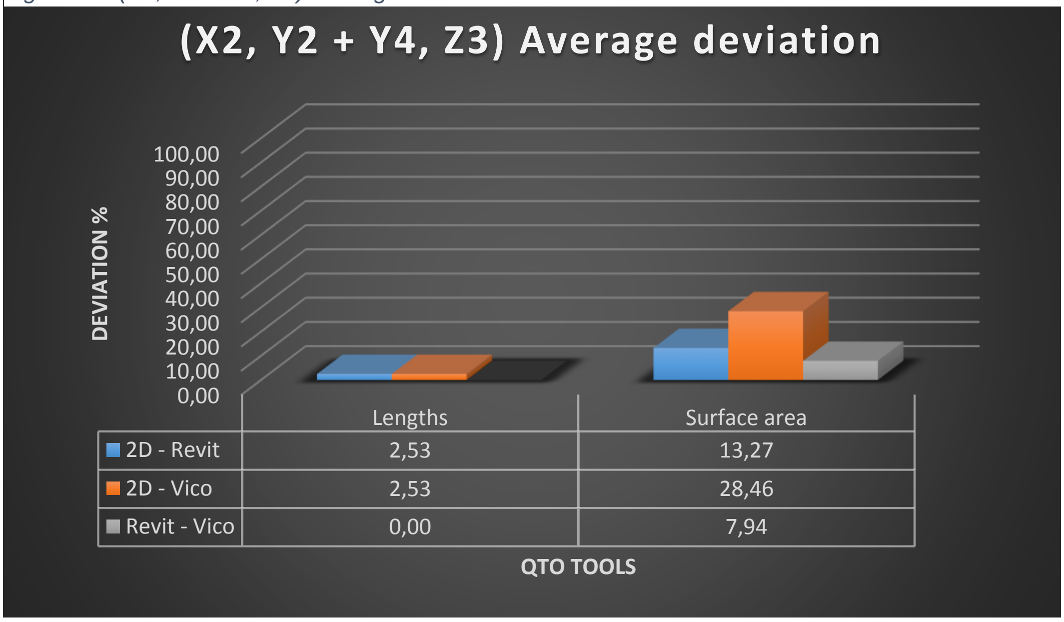


Figure 24: (X2, Y2 + Y4, Z3) Average deviation

Firstly, an important deviation is detected in three models when BIM tools do not subtract the volume that occupy the Structural Wall (STW), fact that happens on the layers M3, M4, M5 of the wall, oversizing the amount of material that composes the wall (surface area). Secondly, if the interior total surface area wants to be measured some divergences appear extracting the total area of the STW. For obtaining this parameter is needed to analyse the model in detail measuring it from the screen. On the contrary, in one model Revit and Vico can subtract the volume of the structural wall (STW) from the multilayer wall (table 20 and 21). Nonetheless, it cannot provide data regarding the surface of each side of the STW. It provides the total surface that is a bit oversized than the number obtained manually.

Studying in detail the average deviation calculated in the case of lengths and areas, the most relevant difference appears on the analysis of “2D – Vico” measures. This distortion on the result is the consequence that Vico measures the total vertical surface of the structural element instead of showing them independently.

According to what superior graphics show, the method of designing that can offer more reliability, in terms of measures, is the one named with the code (X2, Y1 + Y4, Z3). In this case the wall is designed not as a compacted element, layers are modelled separately, and the total 3D wall is joined with the STW.

The deviation when the model is transferred from Revit into Vico (Revit – Vico) is much lower than the results detected when “2D – Revit” and “2D – Vico” are compared. This shows the same trend that happens on models in chapter 4.4.1., the lack of accuracy is transferred from Revit into Vico.

1.4.3. Multilayer walls + horizontal structural elements

Within this group of BIM models is simulated the intersection between horizontal structural elements and multilayer walls. This analysis will show the behaviour of the Revit and Vico QTO depending on the method that the wall has been designed and also according to the type of connection described in Revit. The nomenclatures that are used for naming these specific models are: (X3, Y1 + Y5, Z4), (X3, Y1 + Y6, Z4), (X3, Y2 + Y5, Z4), (X3, Y2 + Y6, Z4).

In this particular solution three combinations demonstrate that have higher deviation than the model (X3, Y1 + Y6, Z4). In the first three cases the error is around the 2.50% whereas the last one shows that the extraction of quantities offer 100% of accuracy, no deviation is noticed. Graphics below show the performance of all simulations.

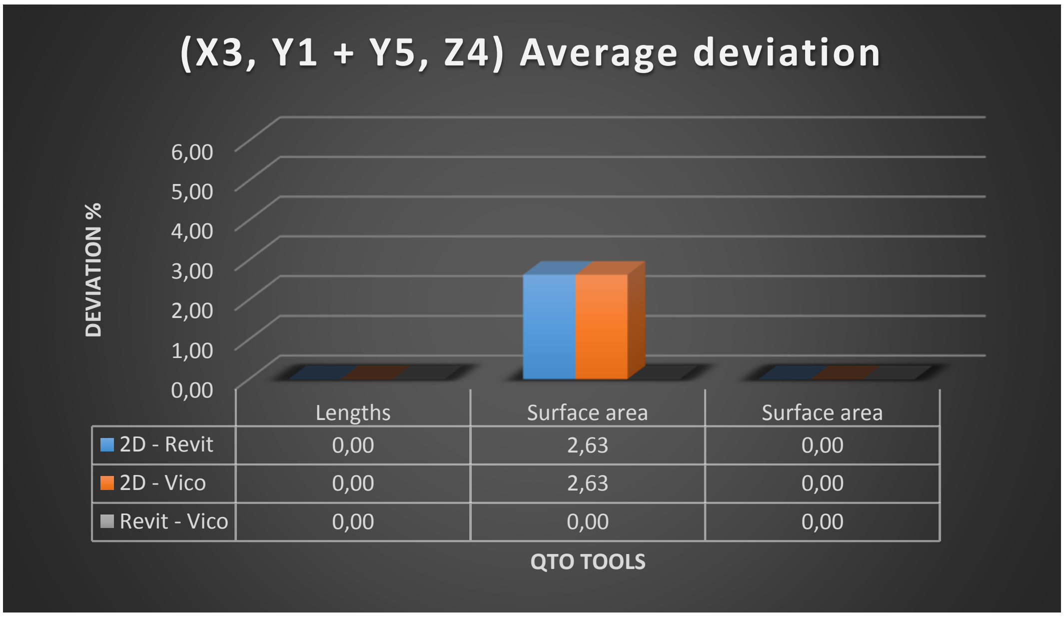


Figure 26: (X3, Y1 + Y5, Z4) Average deviation

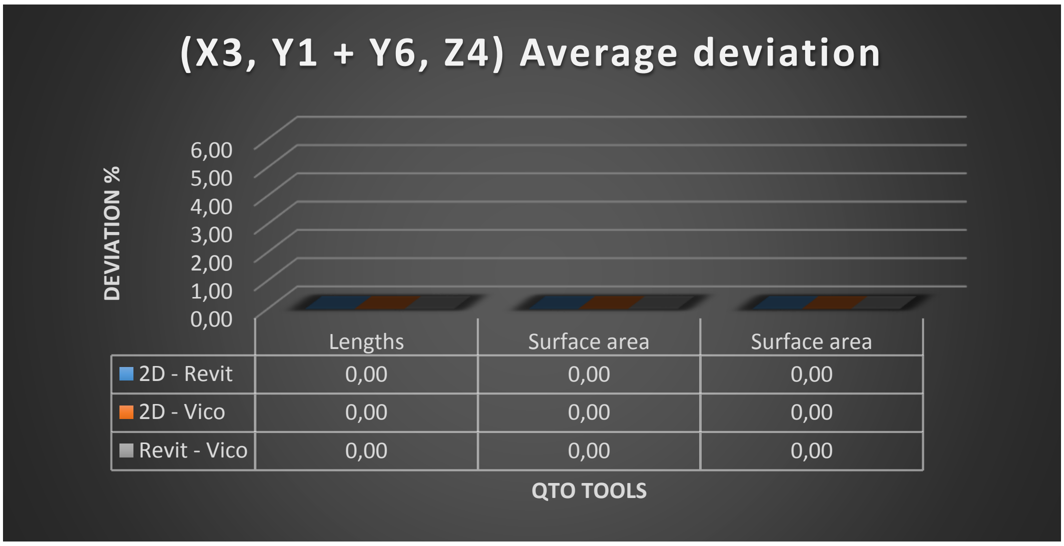


Figure 29: (X3, Y1 + Y6, Z4) Average deviation

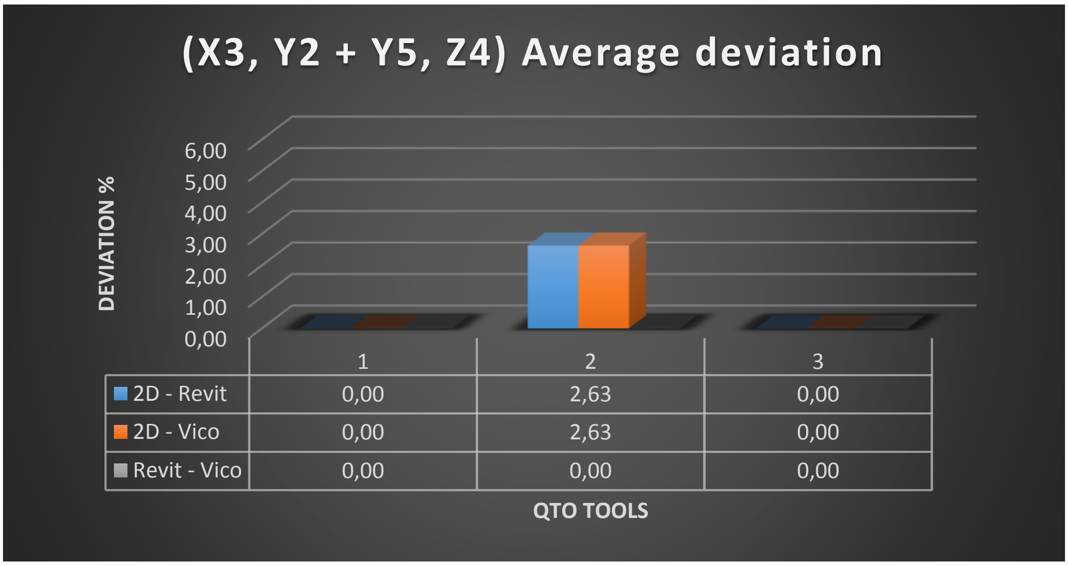


Figure 28: (X3, Y2 + Y5, Z4) Average deviation

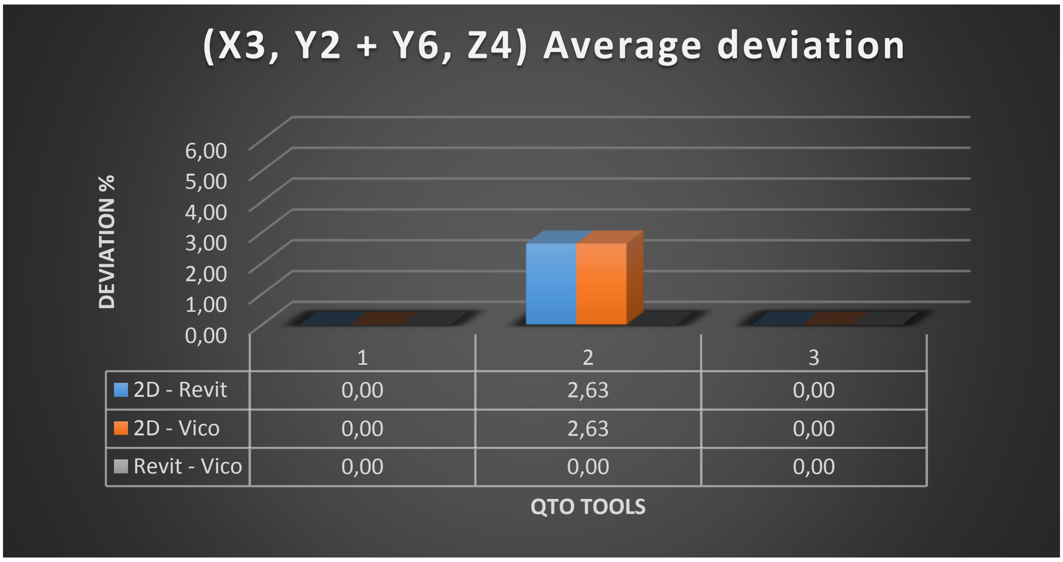


Figure 27: (X3, Y2 + Y6, Z4) Average deviation

In this particular instance that the model offer 100% of reliability, each layer of the wall is defined separately and both slab and multilayer wall are joined. This procedure does not represent deviations when it is analysed by the three procedures proposed in the methodology: “2D – Revit”, “2D – Vico”, “Revit – Vico”.

The analysis of this method of joining and defining the model shows that the deviation is detected comparing manual measures with Revit and Vico takeoff (2D – Revit and 2D - Vico. However, studying the deviation “Revit – Vico” there is no error on the process. This approach makes visible that to be ensured measures are accurate enough, a quick analysis comparing 2D screen dimensions against BIM quantities could demonstrate the real deviation that the process has and also, the behaviour of the specific BIM tools that are being used for the task.

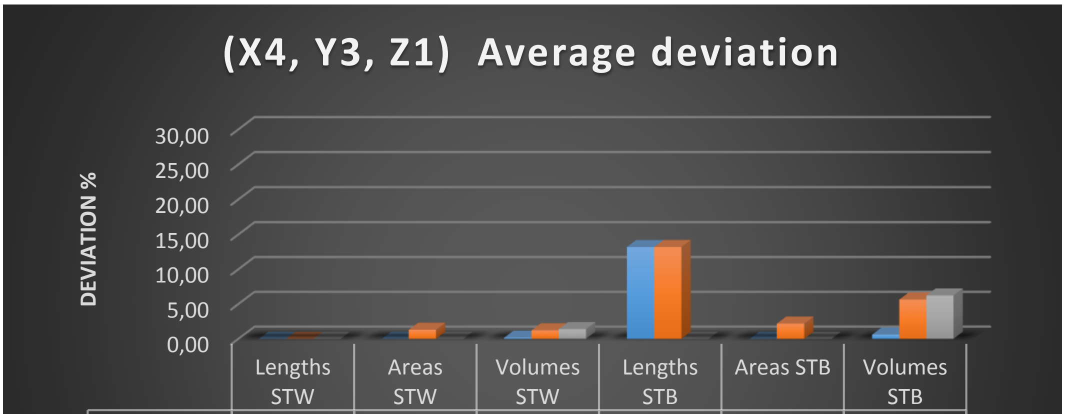
1.4.4. Structural elements

Within this chapter three types of BIM model are simulated in order to offer different combinations and analysing the process of extracting quantities.

Firstly, two BIM simulations represent the joint or connection between the vertical Structural Wall (STW) and the horizontal Structural Beam (STB). This models follow the next codification: (X4, Y3, Z1), (X4, Y4, Z1). Secondly, the STW is connected with a horizontal slab on their top side simulating the hypothetical joint between structural floors and facades. In this case models are codified with the next nomenclature: (X5, Y3, Z1), (X5, Y4, Z1). Finally, the STB in partially embedded in the horizontal slab, simulating a structural floor supported by a skeleton made of pillars and beams. These 3D BIM models are designed using the next combination of variables: (X6, Y3, Z1), (X6, Y4, Z1).

On the first subgroup of models called (X4, Y3, Z1), (X4, Y4, Z1), (Figure 30 and 31) the analysis is focused on calculating the total surface area of the whole structural element. The aim is to obtain the total volume of concrete that performs the structure and besides, it is also analysed the accuracy of the total surface area, which could be and essential data on the estimation of the formwork.

It can be noticed that, on the process of extracting quantities, the higher level of error appear when lengths and volumes want to be obtained. These variations happen dimensioning the STB. The graphics below make visible the average deviation that present each method of modelling these designs.



	Lengths STW	Areas STW	Volumes STW	Lengths STB	Areas STB	Volumes STB
2D - Revit	0,00	0,00	0,18	13,21	0	0,63
2D - Vico	0,00	1,32	1,23	13,21	2,20	5,66
Revit - Vico	0,00	0,00	1,41	0,00	0,00	6,25

Figure 30: (X4, Y3, Z1) Average deviation

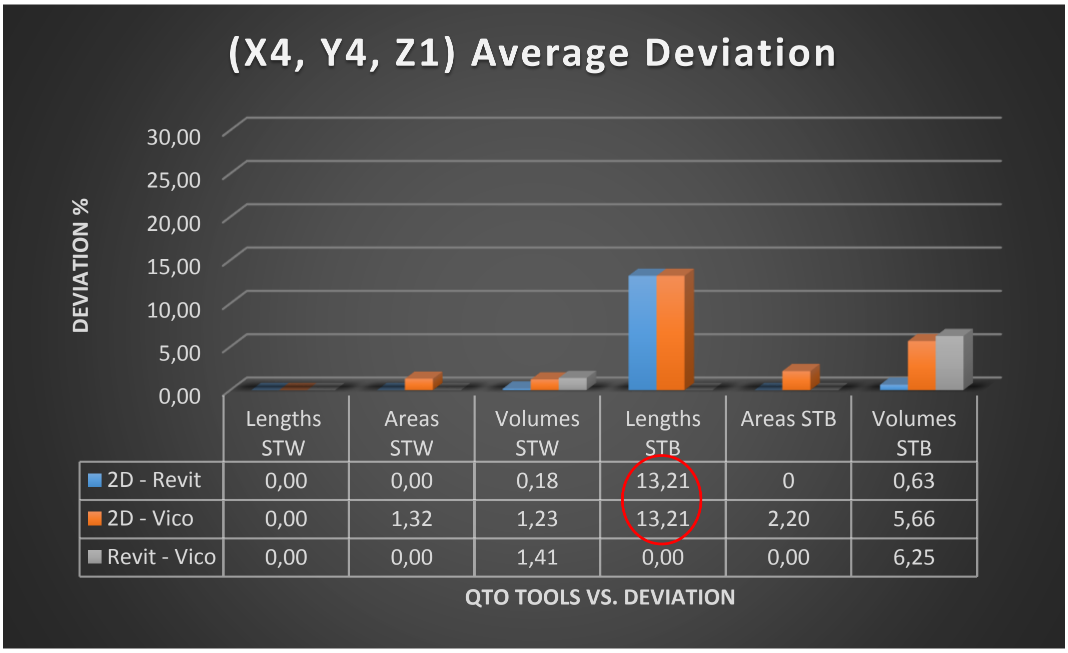


Figure 31: (X4, Y4, Z1) Average Deviation

Concerning the length of the STB, the deviation is the 13.20% ("2D – Revit" and "2D – Vico") of the total. This variation is based on the method that is used for measuring the beam in 2D, which consists in calculating the dimensions that belong to its visual part instead of considering it as whole horizontal element. Following this procedure the longitudinal piece is 2.65 meters length against the 3.00 meters that Revit and Vico extract. These BIM tools identify that the model is made of structural elements and, according to basic structural concepts, pillars support beams on their top part to allow the transference of vertical loads. Therefore, the part that belongs to the connection between both elements is considered as a part of the beam as well. On the one hand, whether this process is done in this way the total area would be oversized by the fact of duplicating the part of the beam embedded in the STW. On the other hand, if accurate measures are strictly required, different dimensional parameters should be obtained in the case of the beam to obtain the total surface area.

Regarding the volume of this structural model, both Revit and Vico calculate it following the rule that is used for measuring this dimension on the 2D process. They measure the total amount of concrete of the vertical element, including the part of the beam embedded, and then calculate the volume that belongs to the span of the beam.

Revit and Vico use two different rules for calculating the surface area and the volume. This can create confusion by the fact of showing a total length of one element but, for measuring its volume it is used another value that is not displayed but can calculated. This demonstrates that these measures need to be checked before being used for other calculations.

Analysing accuracy of measures offered by both Revit and Vico, it is detected, besides the error that belongs to the length, a variation when volumes are calculated. The most important deviation appears comparing "2D – Vico" and "Revit – Vico". In both analysis the error is the 6.90% and the 7.70% respectively, against the 0.80% of error measured in "2D – Revit". These variations, in the first two cases, can be motivated by the accuracy of the spreadsheet, where manual measures are managed and also by the lack of precision that Vico offers when displays volumes (only uses one decimal of precision against the two decimal that are used for the manual process and Revit measures). Secondly, this deviation, that measured in % could be considered really important, could be overestimated by the small size of the model that is studied on this research (only 1.42 m^3), where small variations can represent a significant deviation. Finally, both methods of designing show the same deviation, no differences are detected when the variables are combined, models transferred from Revit into Vico and quantities extracted.

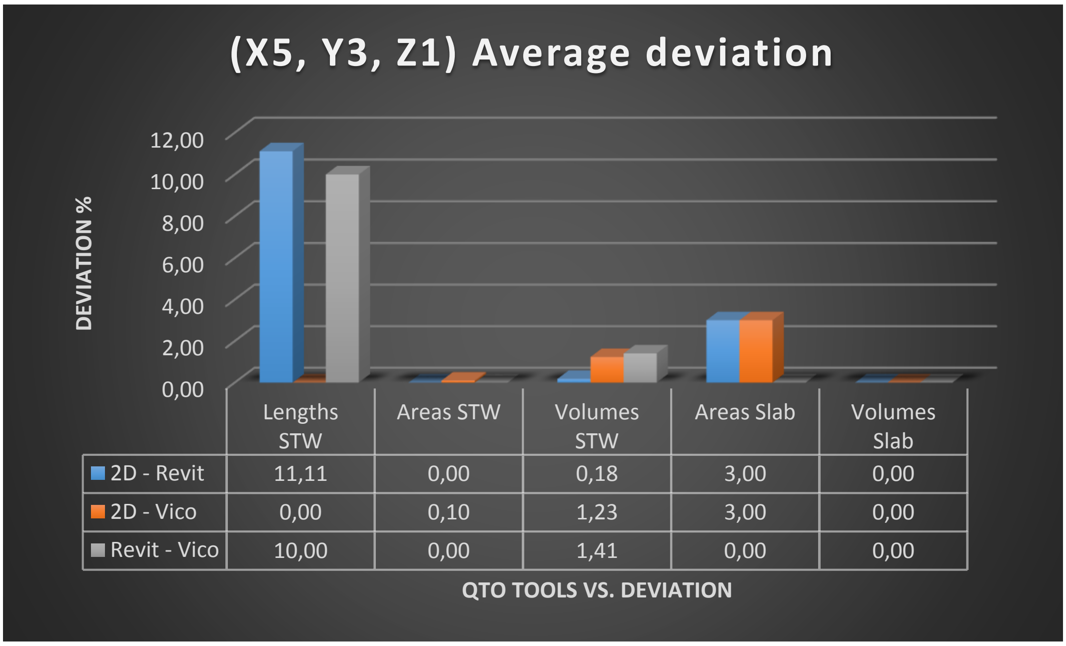
The second subgroup of models analysed in this chapter represent the connection between a structural wall and a slab. On the analysis, the most relevant deviation is detected when heights, surface areas and volumes of material are extracted from the models named following the next codes: (X5, Y3, Z1), (X5, Y4, Z1). Figure 32 and 33.

Firstly, studying in detail the height of the vertical structural element, Revit detects that the column is 3.00 meters height. However, for calculating the volume of concrete it uses 2.70 meters instead of the gross height that displays on the QTO. This procedure can lead confusion, some calculations are hidden on this process and the net height is not displayed. On the contrary, Vico detects and shows the net difference between the bottom and top part of the wall.

Secondly, both Revit and Vico does not distinguish between net surface and gross surface area when the slab is analysed. Comparing both software tools they show the same lack of accuracy whether this parameter is compared with manual measures from the screen.

Finally, the deviation detected on the process of measuring volumes could be motivated by the same reason explained in the previous models. The high accuracy of the spreadsheet against the lack of precision offered by Vico, which only approximates this value until the tenth part whereas Revit shows two decimals but, this precision could be not really important measuring volumes of concrete.

Graphics below show the average deviation that is explained in the previous paragraphs.



	Lengths STW	Areas STW	Volumes STW	Areas Slab	Volumes Slab
2D - Revit	11,11	0,00	0,18	3,00	0,00
2D - Vico	0,00	0,10	1,23	3,00	0,00
Revit - Vico	10,00	0,00	1,41	0,00	0,00

Figure 32: (X5, Y3, Z1) Average deviation

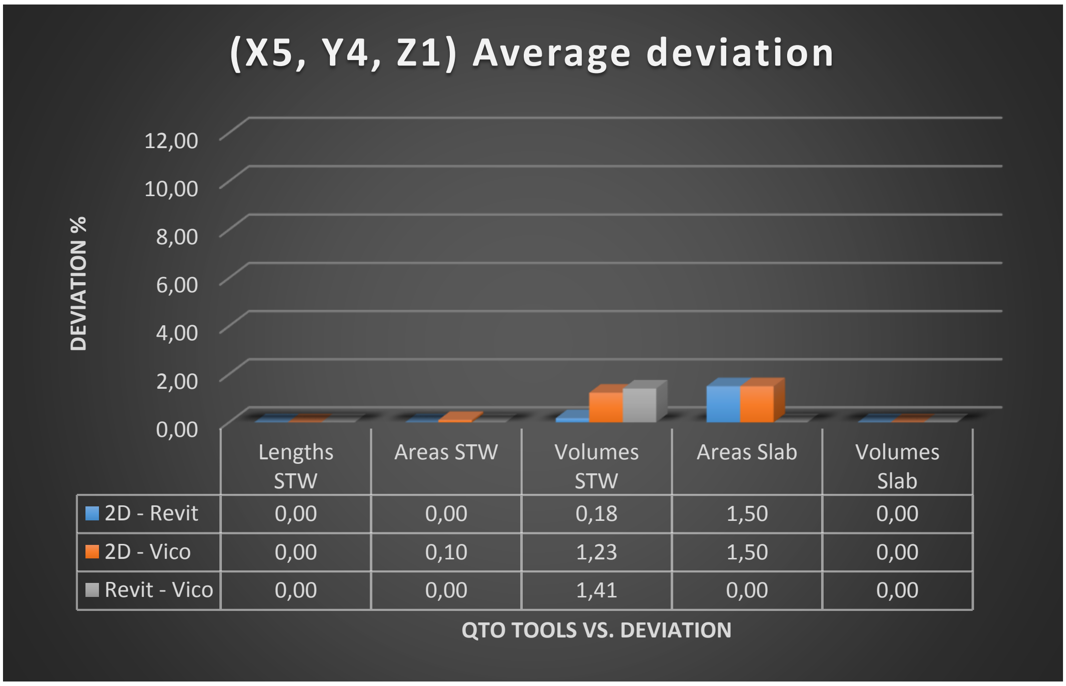


Figure 33: (X5, Y4, Z1) Average deviation

In this specific example, the most accurate method for designing these models is that one where both structural elements are joined, model (X5, Y4, Z1). The total deviation could be oversized by the fact of working with a small portion of structure. In order to have a precise deviation of measures, it would be recommendable the analysis of real technical solutions taking into account the total surface of the building, this approach would proportionate a precise deviation in that real scenario.

The third and final subgroup of models simulates the horizontal beam that is partially embedded in a horizontal slab. These 3D BIM designs are named by the next codes: (X6, Y3, Z1), (X6, Y4, Z1). Figure 34 and 35.

Volume and surface area are the dimensional parameters that offer more deviation in this analysis of QTO, as it is shown on the graphics below:

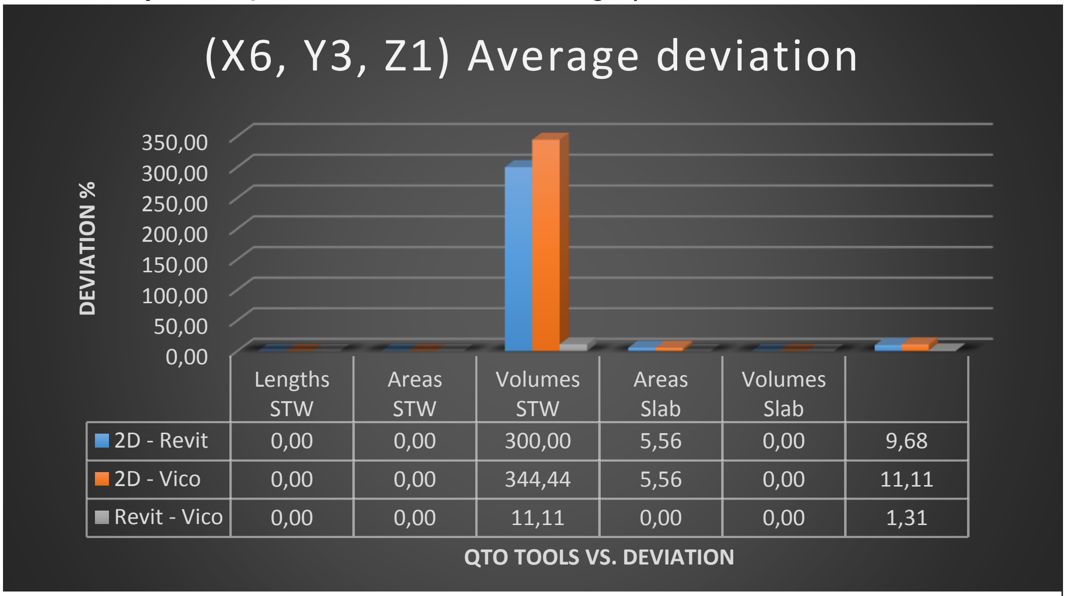


Figure 34: (X6, Y3, Z1) Average deviation

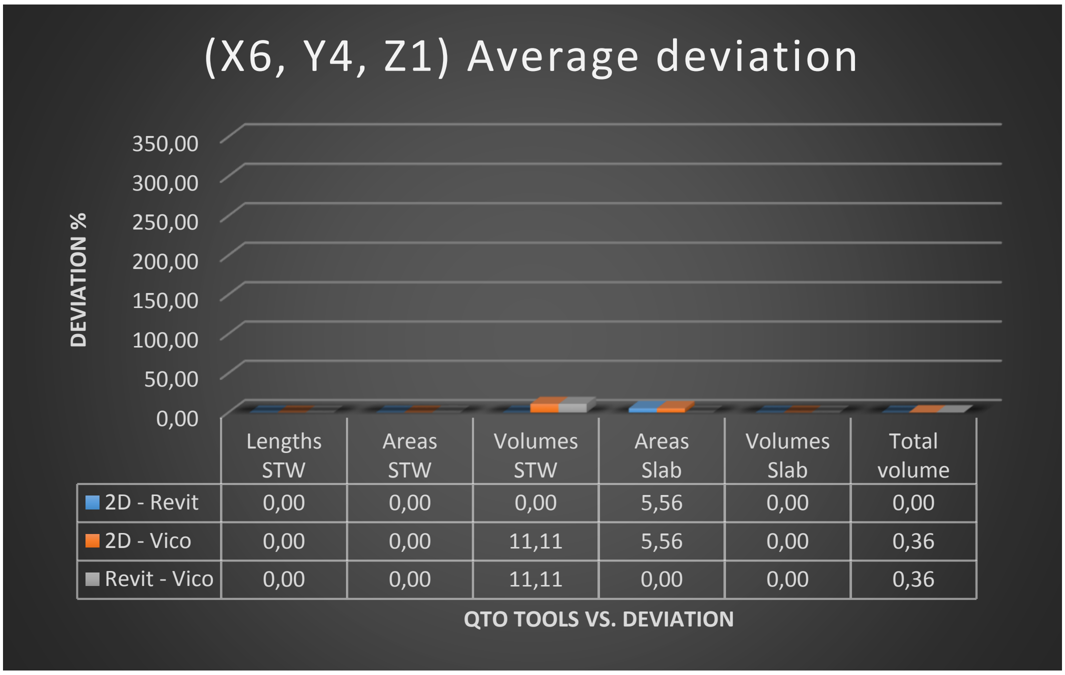


Figure 35: (X6, Y4, Z1) Average deviation

Firstly, the deviation is detected when the total volume of concrete is extracted and the slab and beam are not joined (model (X6, Y3, Z1)). In this model the value of the volume is oversized, Revit and Vico do not detect that the beam is partially embedded in the slab and also, do not subtract the volume that belong to one of the constructive elements, therefore, the volume is measured two times in this part. As a consequence, the total deviation achieve rates of 300% and 345% in comparison with manual measures. This value is also very disproportionate by the fact of modelling a small structural design (3.06 m^3). In order to provide a precise deviation and the real repercussion of this variation it would be compulsory develop the analysis taking as an example a real project, where more different technical solutions would be found and the deviation would be compared with the total surface of the structural skeleton.

The difference that appears on the QTO process between “2D – Revit” and “2D – Vico” follows the same reason explained in the two previous subgroups (lack of decimals when the volume is measured in Vico in comparison with Revit and 2D measures).

Concerning the total surface area of the whole structural element, both BIM tools do not distinguish gross and net surface. By this reason, bottom and top areas have the same dimension. However, Vico recognizes the portion of the beam that is not embedded into the slab and calculates its surface area separately. In addition, when slab and beam are joined, both Revit and Vico detect the volume of concrete that belongs to the not embedded part of the beam.

Different behaviours on the QTO process are shown on these two models. Regarding the accuracy of Vico, the fact of only approximating until the first decimal makes it as a bit lower accurate takeoff solution whether it is compared with Revit. Nonetheless, this extremely precision it could not be needed on the construction industry, it would depend on the specifications of the contract or other requirements. Continuing with this research, the general deviation that is showed in Revit is transferred into Vico, fact that demonstrates that the method used for designing this model would have relevant influence on the QTO process in Vico office.

2. Implementation of BIM in companies.

2.1. Introduction

The aim of this survey is to provide current information concerning the main reasons that firms have for implementing BIM and also to provide recent data concerning how far this technology to manage projects is used in enterprises (dimensions of BIM) in order to corroborate what Eadie et al. (2013) affirm, saying that BIM is more implemented in early stages, on the design phase, than in advanced phases of the project. Furthermore, this questionnaire would be useful to collect data regarding which profile of company is less reluctant to use BIM or, if there is a clear difference on its implementation depending on the type of business they develop. Russell et al. (2014) mention on their recent report that one of the disadvantages of BIM is close related with software issues therefore, by the fact of being this report focused on the analysis of Vico office as a BIM tool, participants are asked for the type of software they use and also for relevant advantages and disadvantages that this technology still presents at this time. This list of benefits would be useful for comparing the whole analysis of positive and negative aspects that are sorted on the section 1.9. in the chapter number one of this report.

2.2. Research methodology

This survey has been addressed directly to companies enclosed in the construction sector (architectural firms, construction companies and any type of engineering consultancies) using a questionnaire which allow them to select between multiple choice question to explain how they manage architectural and construction projects. Thirty surveys have been sent twice to an equal number of firms located in Spain and Denmark initially, providing two methods for answering it: directly on the file or fixing a date to contact them through a phone call. Five surveys have been replied properly. However, having this low rate of participation, at the same time the questionnaire was uploaded on LinkedIn on the most important groups related with BIM: *¡ Contractor BIM, Construction & project managers, Construction Management, g | BIM, Edinburgh Revit User Group, BIM experts and BIM ANZ*. This method for addressing the survey does not allow to obtain a statistical results however, it allows to collect interesting conclusions after comparing the information previously analysed on the state of the art against the data collected from companies engaged in different markets and locations: United States, UK, Australia, Argentina, Mozambique, Egypt, Hungary, Spain, Denmark, Malaysia and United Arabian Emirates. Finally, 25 surveys have been collected during two months providing information regarding companies which use BIM and do not use it. In this case, based on this report focuses its aim on BIM features are only managed the ones that have relation with it (19 out of 25).

Focused on the section of questions related with BIM, participants are asked for the main reasons that have pushed them to adopt it, how far they go on this new technology (3D, 4D, 5D or some combination of dimensions), which software they used and finally for the most highlighted advantages and disadvantages they highlight diary.

2.3. Research findings

2.3.1. Companies

From the interconnection between types of companies and the market where they develop their business can be extracted that there is not a clear signal of relation between them. However, the kind of activity seem to influence or encourage the use of BIM tools. Architectural firms lead the list of companies with the highest number of BIM practitioners with the 52.6% of the total firms engaged in BIM. Secondly, 21% are engineering consultancies and then, construction companies and firms focus on more than one specific activity obtained 15.8% and 10.5% respectively.

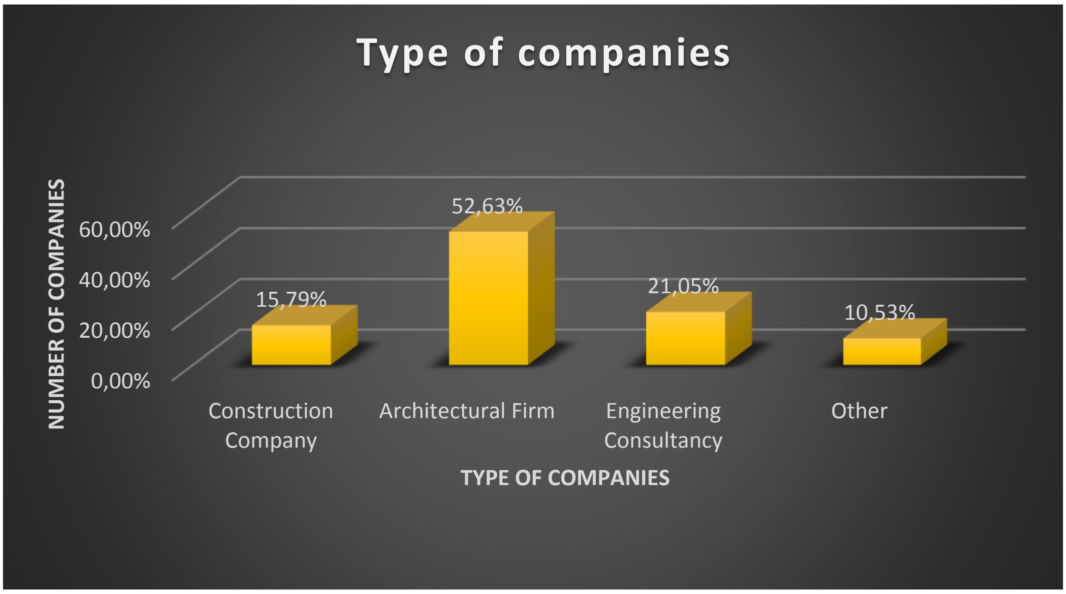


Figure 36: Type of companies took part on this study

Analysing the results it could be affirm that Architectural firms are less reluctant than the other type of companies. Fact that have close relation with the chapter 6.3.2 where it is studied the level of implementation of BIM according to the dimension.

2.3.2. Implementation of BIM and reasons

From this survey can be noticed that BIM is used wider on early stages, during the design process, than on advanced phases like planning and cost estimating are. It can be extracted that around the 85% of companies which use BIM is for 3D modelling, then the 42% for planning and finally the 31% for cost estimating. On the figure below it can be shown the distribution.

Inside this 85% of firms within BIM technology for designing 3D models, the 62% are architectural companies, 19% multidisciplinary enterprises and finally, engineering consultancies and construction companies are the 12.5% and 6% respectively.

37% of companies which are focused on the 4D are architectural and construction firms and then, the 12.5% of enterprises are multidisciplinary and engineering consultancies.

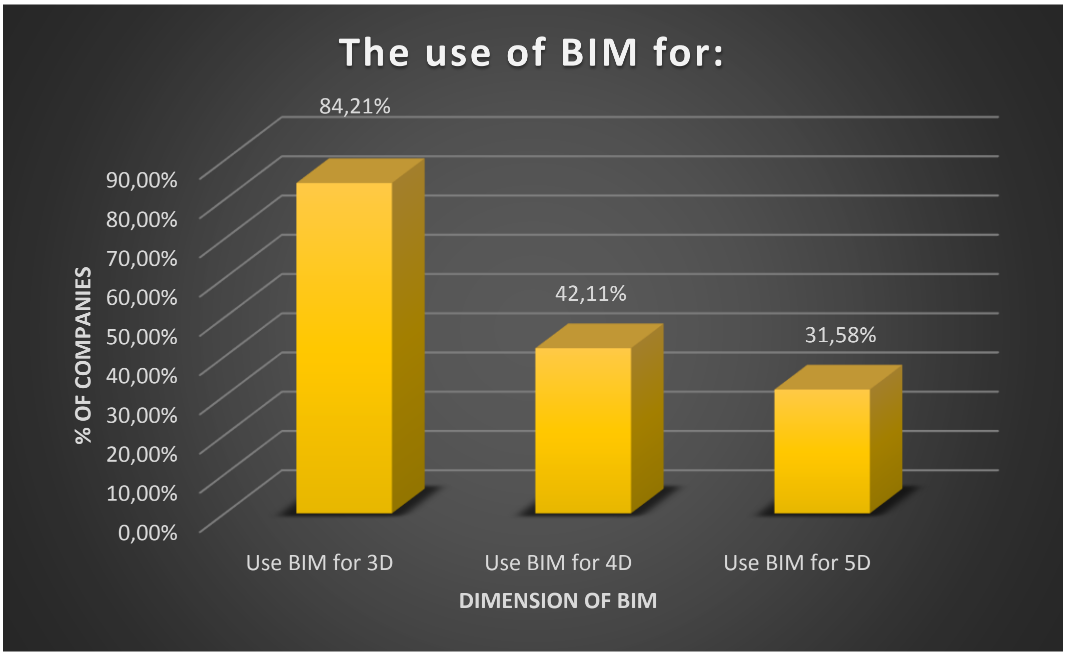


Figure 37: Use of BIM for different dimensions

To conclude, 50% of firms which have between their main tasks the process of costing (5D) are construction companies, then architectural and multidisciplinary firms are placed on the second and third position with the 33% and 16% respectively.

At this point it can be detected the relation between the profile of company which more demands BIM, architectural firms, and the dimension that is more adopted by companies, the 3rd dimension, as Eadie et al. (2013) mention on their investigation.

With regarding the main reasons to implement BIM inside the management system, 69% make reference to the efficiency and competitiveness that BIM provides. The rest of companies, 31%, do not specify an exact reason to justify why they are using it.

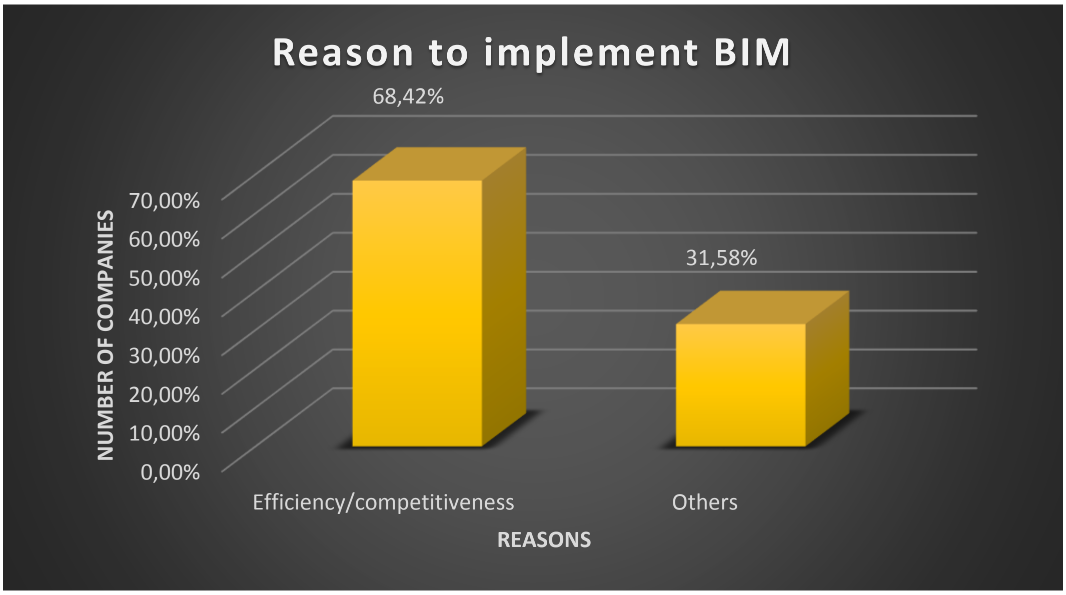


Figure 38: Reason to implement BIM

2.3.3. Software

Regarding the software that is used for the different dimension of BIM a variety of results can be extracted. For 3D designing Autodesk Revit is most required (58%), then Archicad from Graphisoft is used by 12.5% of firms and finally the 4% use Bentley. Architectural firms are the common profile of enterprise which demands this type of software (30%), followed by construction companies and engineering consultancies (12.5% each).

Concerning the software for scheduling projects (4D), Autodesk Navisworks is the most required software (38%), then Autodesk Revit and Synchro are second and third on this list with the 23% and 8% respectively. Along the common profile of company that more demands these tools are: architectural firms (30%), engineering consultancies (15%) and construction enterprises (8%).

Analysing BIM 5D, this dimension is not as implemented as the previous ones. The 33% of companies use Revit for costing and then RIB iTWO and Sigma, 16% each one.

On this analysis, where participants have asked for the type of software they use, Vico office does not appear in the list of tools enumerated by survey respondents.

2.3.4. Advantages and disadvantages

Along the large number of advantages and negative aspects which BIM offers, some of the survey respondents emphasized as the most important feature the possibility of providing more reliable data (37%), then the reduction of time to manage projects combined with the accuracy of data is the second most voted benefit (31%). Thirdly, the isolated feature of BIM to make more efficient some task obtained (15%) and finally, no one underlined the better capability of managing bigger projects using BIM as an advantage as it can be seen on the figure below.

In addition, participants were allowed to add more benefits of BIM. Project coordination and more transparency has been enhanced in BIM with the interface in the design process as well. Participants highlighted also the option of detecting interferences between disciplines, better quality in projects, the fact of producing 3D models as extra documentation and the possibility to save construction costs as very important extras of BIM.

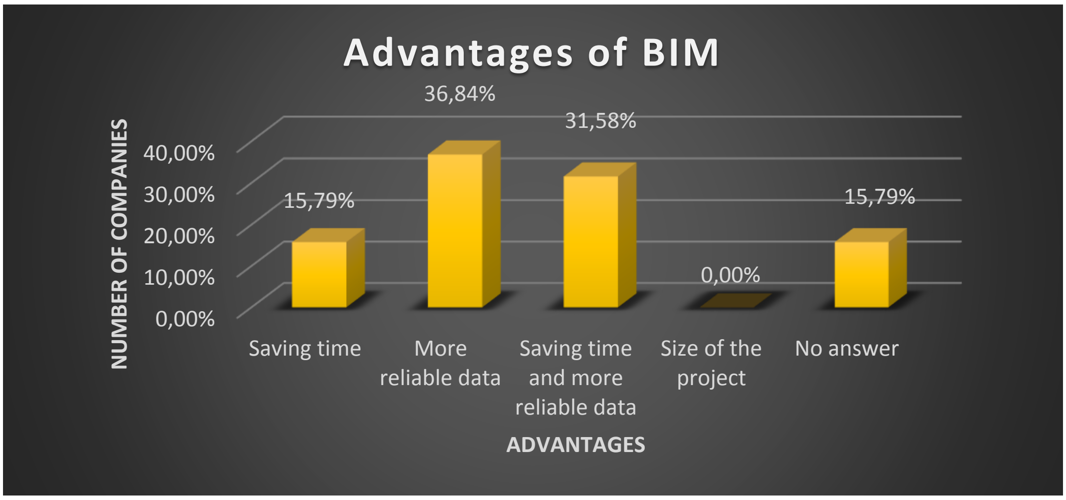


Figure 39: Advantages of BIM

According to the disadvantages selected by participants in this questionnaire, the time required to train employees and acquire enough skills on BIM is the most unfavourable aspect offered by BIM (31%). Then, the initial investment and interoperability issues occupy the second and third position on this scale with the 21% and 5%. At the same time, survey respondents have combined different options offered on the interview and more individual drawbacks to enrich the report. 15% of BIM users see the combined option “initial investment + the training time” is a negative point, followed by the combination of the three options (training time + initial investment + interoperability) with the 10%.

Regarding the individual issues mentioned stands out that one which makes reference to the lack of companies which use BIM, fact that difficult the coordination, and mention also that with BIM the quality of deliveries is worse. In addition to this, BIM forces to manage more information concerning the project in early stages as it has been explained by one respondent:

“*Most consultants and clients do not use BIM software. Difficult to coordinate and integrate with (…) BIM requires a large amount of "front end" information combined (or conflicts) with the traditional design process curve which has information gathering increasing at the "back end", has increased demands/ responsibilities on Architects. Also, the quality of documentation has gone down since implementation of BIM software. Unfortunately, it is difficult to adjust the hardcopy output of BIM software. Mostly, people will just settle with software graphic standards (…).”*

Finally, the difficult to understand how models have been designed is, with the reticence of some member to adopt this technology, another disadvantage mentioned by some members. No one has made reference on this list of issues to the possibility of being the software an important limitation on BIM as Russell et al. (2014) have reported.

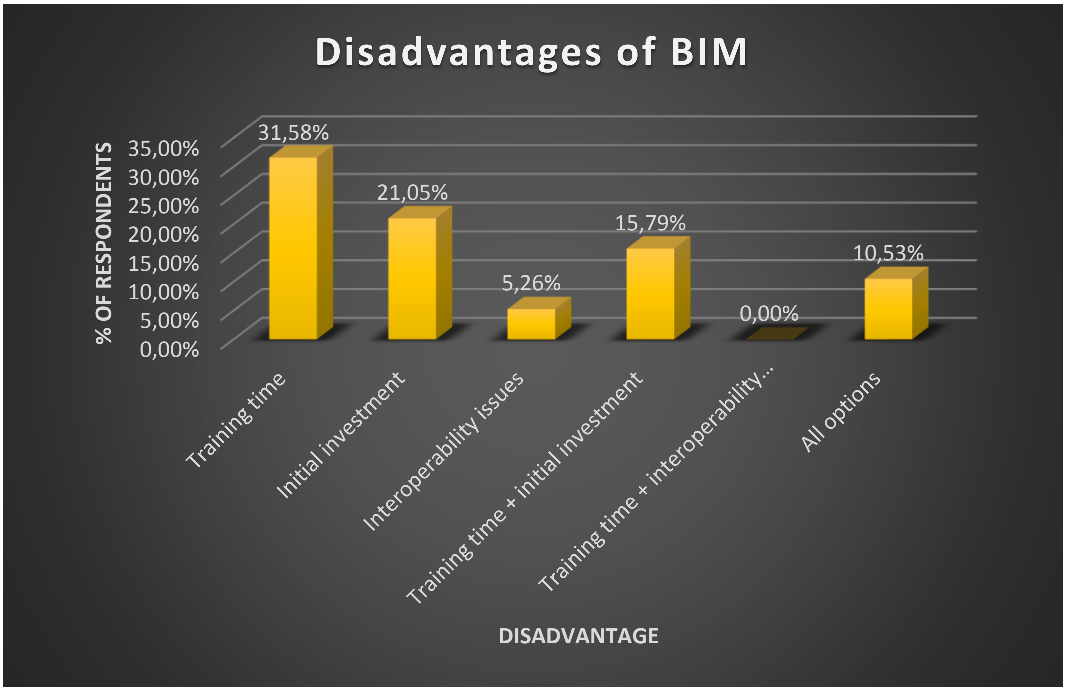


Figure 40: Disadvantages of BIM

Conclusions and further researches

There is a clear influence of the method that is used for designing the model over the accuracy of quantities extracted in Revit and Vico. It has been detected that both BIM software define with different name the same dimensional parameter, height and length are used for naming the same measure. This particular contradiction was found on the analysis of models that simulate technical connections between structural elements. Also in these models, it has been detected incongruity between some measures on the same element. It is the case when the volume is extracted in Revit and Vico but, on the contrary, if this same dimension wants to be deducted, using manual procedures but taking into account the data provided by these both tools, the volume would be oversized.

A clear necessity of checking the automatic quantities from Revit and Vico is required for some reasons: to know the real deviation that, according to the method of designing, the model presents, to obtain, when it is required, more accurate measures and finally, to check partial measures that are used for calculating other dimensions that could be oversized using the automatic data extracted from Revit and Vico.

The survey shows that architectural firms are the companies that more demand this technology on designing process, motivated by the reduction of time and accuracy that BIM tools offer. On the contrary, what is and advantage on this phase is translated in a disadvantage in consultancies and construction companies, when they received the model not well-defined and time is required to understand the design. It is clear that companies live a period of transition, they need to overcome some barriers like the reticent of some companies to implement this technology, that can affect to the teamwork. Training time and initial investment are the most important disadvantages mentioned by companies, what means that enterprises could not find yet the real benefits of this change.

As further researches that could continue this study could be two different topics: the analysis of the economic impact, from the point of view of the main contractor, can cause the lack of accuracy of the QTO in BIM in a real project, that could provide a real sense regarding the necessity or not necessity of precision from early stages on the project. Finally, it would be recommendable the development of a survey targeted on the problems that construction companies receive from previous phased of the project that can affect their profitability.

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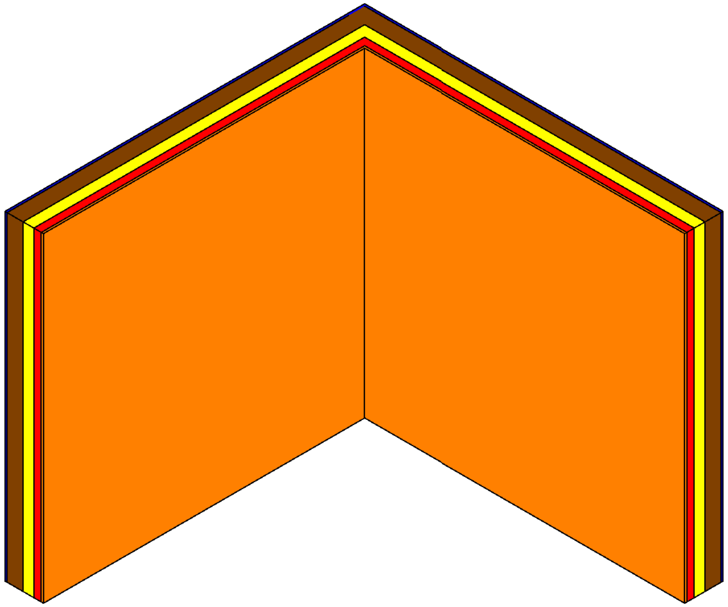
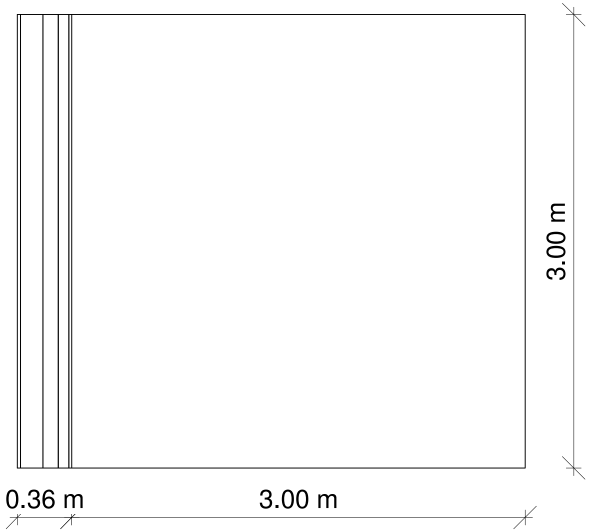
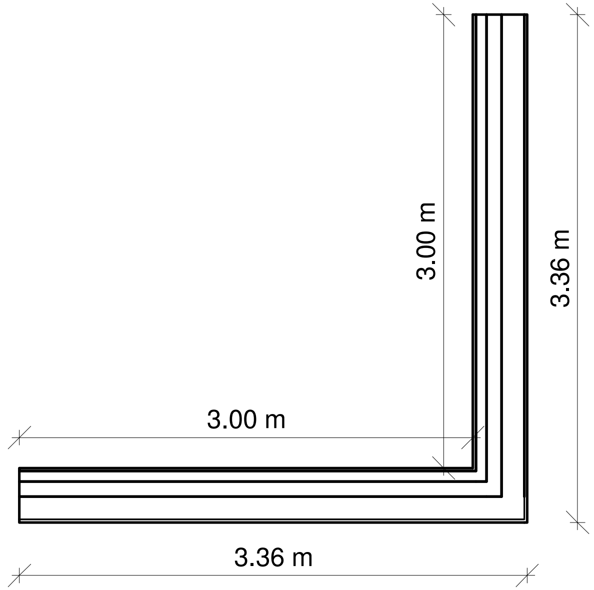
Appendix A: Drawings and measurements



X1, Y1, Z1_3D



X1, Y1, Z1_ELEVATION



X1, Y1, Z1_TOP VIEW

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X1, Y1, Z1**
SUBJECT: **X1, Y1, Z1**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Internal length (m)	Centre length (m)	External length (m)	Interior Area (m^2)	Average surface area (m^2)	Exterior Area (m^2)
M1	6,68	6,70	6,72	20,04	20,10	20,16
M2	6,38	6,53	6,68	19,14	19,59	20,04
M3	6,18	6,28	6,38	18,54	18,84	19,14
M4	6,04	6,11	6,18	18,12	18,33	18,54
M5	6,00	6,02	6,04	18,00	18,06	18,12

Table 3: (X1, Y1, Z1) Manual QTO

Layers	Height (m)	Length (m)	Width (m)	Surface area (m^2)	Volume (m^3)
M1	3,00	6,70	0,02	20,10	0,40
M2	3,00	6,62	0,15	19,59	2,94
M3	3,00	6,28	0,10	18,84	1,88
M4	3,00	6,11	0,07	18,33	1,28
M5	3,00	6,02	0,02	18,06	0,36

Table 4: (X1, Y1, Z1) Revit QTO

Layers	Height (m)	Length (m)	Width (m)	Area (m^2)	Volume (m^3)
M1	X	6,70	X	20,10	0,40
M2	X	6,60	X	19,60	2,90
M3	X	6,30	X	18,80	1,90
M4	X	6,10	X	18,30	1,30
M5	X	6,00	X	18,10	0,40

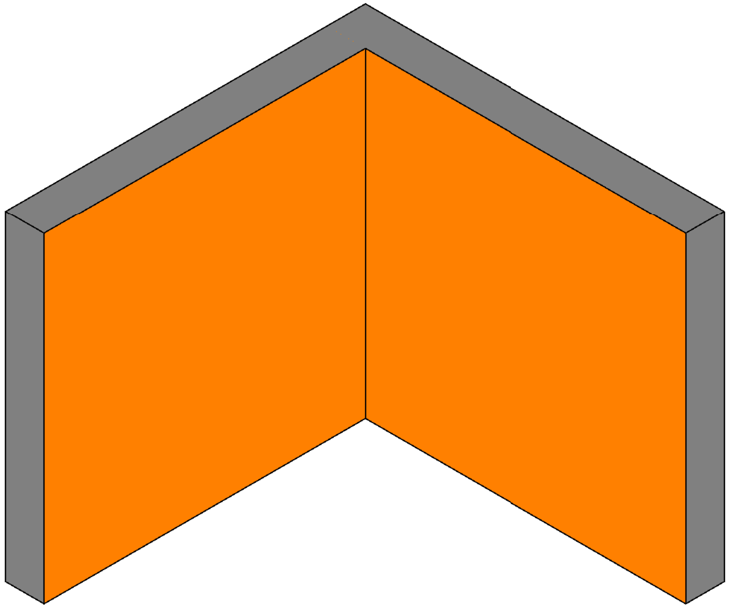
Table 5: (X1, Y1, Z1) Vico QTO

	Lengths (m)		**Surface /Area** (m^2)						
(X1, Y1, Z1)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D	6,00	6,72	20,16	20,10	19,59	18,84	18,33	18,06	18,00
Revit	6,02	6,70	20,10	20,10	19,59	18,84	18,33	18,06	18,06
Vico	6,00	6,70	20,10	20,10	19,60	18,80	18,30	18,10	18,10
	Measurements								

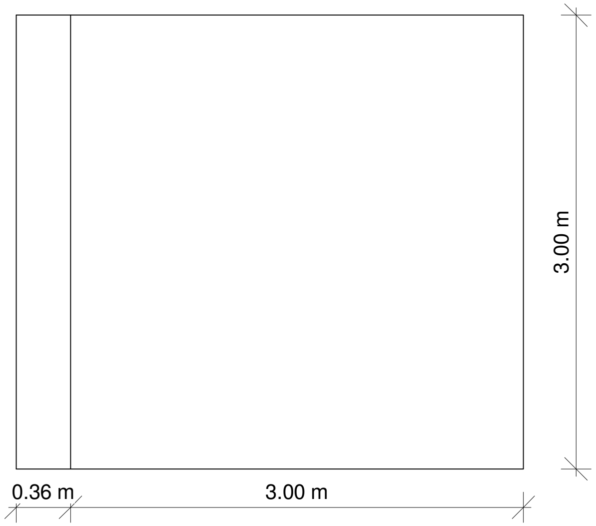
Table 6: (X1, Y1, Z1) Measurements

	Lengths		**Surface /Area**						
(X1, Y1, Z1)	Interior	Exterior	Interior	M1	M2	M3	M4	M5	Exterior
2D - Revit	0,33	-0,30	-0,30	0,00	0,00	0,00	0,00	0,00	0,33
2D - Vico	0,00	-0,30	-0,30	0,00	0,05	-0,21	-0,16	0,22	0,56
Revit - Vico	-0,33	0,00	0,00	0,00	0,05	-0,21	-0,16	0,22	0,22
	Deviation in %								

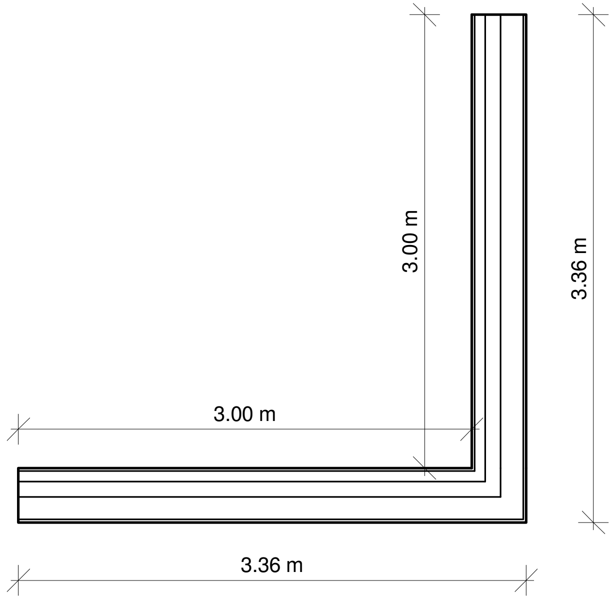
Table 7: (X1, Y1, Z1) Deviation



X1, Y2, Z1_3D



X1, Y2, Z1_ELEVATION



X1, Y2, Z1_TOP VIEW

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X1, Y2, Z1**
SUBJECT: **X1, Y2, Z1**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Height (m)	Internal length (m)	External lent (m)	Centre length (m)	Interior Area (m^2)	Exterior Area (m^2)	Volume (m^3)
M1	3,00	6,68	6,72	6,70	20,04	20,16	0,40
M2	3,00	6,38	6,68	6,53	19,14	20,04	2,94
M3	3,00	6,18	6,38	6,28	18,54	19,14	1,84
M4	3,00	6,04	6,18	6,11	18,12	18,54	1,28
M5	3,00	6,00	6,04	6,02	18,00	18,12	0,36

Table 8: (X1, Y2, Z1) Manual QTO

Layer	Length (m)	Area (m^2)	Volume (m^3)
W1	3,18	9,00	3,24
W1	3,18	10,08	3,63
Total	6,36	19,08	6,87

Table 9: (X1, Y2, Z1) Revit QTO

Layer	Length (m)	Area (m^2)	Volume (m^3)
Wall	6,40	19,10	6,90
Total	6,40	19,10	6,90

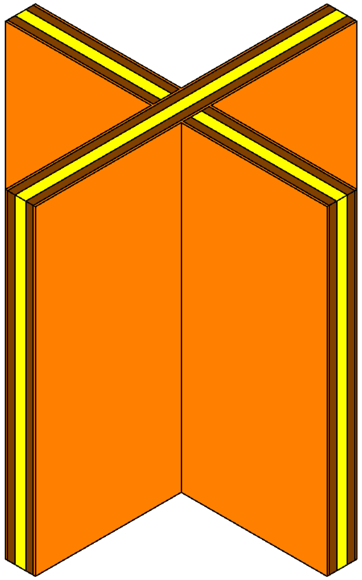
Table 10: (X1, Y2, Z1) Vico QTO

	Lengths (m)		**Surface /Area** (m^2)						
(X1, Y2, Z1)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D	6,00	6,72	20,16	20,10	19,59	18,84	18,33	18,06	18,00
Revit	6,36		19,08						
Vico	6,40		19,10						
	Measurements								

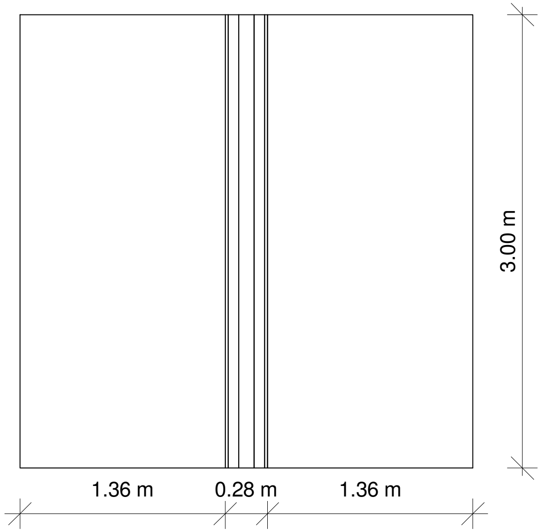
Table 11: (X1, Y2, Z1) Measurements

	Lengths		**Surface /Area**						
(X1, Y2, Z1)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D - Revit	6,00	-5,36	-5,36	-5,07	-2,60	1,27	4,09	5,65	6,00
2D - Vico	6,67	-4,76	-5,26	-4,98	-2,50	1,38	4,20	5,76	6,11
Revit - Vico	0,63		0,10						
	Deviation in %								

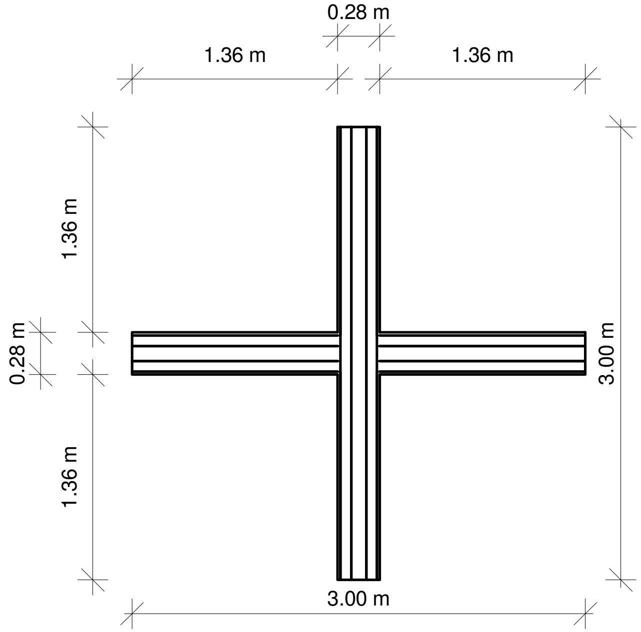
Table 12: (X1, Y2, Z1) Deviation



X1, Y1, Z2_3D



X1, Y1, Z2_ELEVATION



X1, Y1, Z2_TOP VIEW

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X1, Y1, Z2**
SUBJECT: **X1, Y1, Z2**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	External Length (m)	Centre length (m)	Internal length (m)	Exterior Area/Surface (m²)	Average Area/surface (m²)	Interior Area/Surface (m²)	Layers´ Volume (m³)
M5	10,88	10,96	11,04	32,64	32,88	33,12	0,65
M4		11,36			34,56		2,42
M3		5,76			17,28		1,73
Total		28,08			84,72		4,80

Table 13: (X1, Y1, Z2) Manual QTO

Layer	Length (m)	Area (m²)	Volume (m³)
M3	6,00	17,16	1,72
M4	12,00	34,32	2,40
M5	12,00	34,32	0,68
Total	30,00	85,80	4,80

Table 14: (X1, Y1, Z2) Revit QTO

Layer	Length (m)	Area (m²)	Volume (m³)
M3	6,00	17,20	1,70
M4	12,00	34,30	2,40
M5	12,00	34,30	0,70
Total	30,00	85,80	4,80

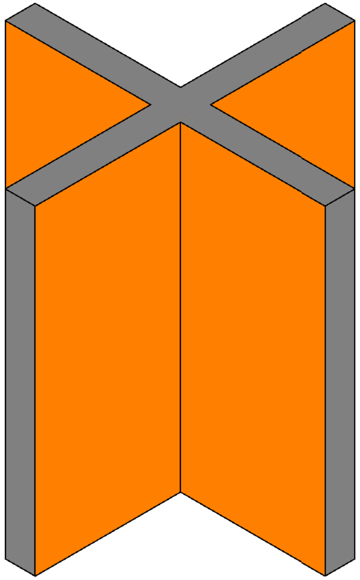
Table 15: (X1, Y1, Z2) Vico QTO

	Lengths (m)		**Surface /Area** (m²)				
(X1, Y1, Z2)	Interior	Exterior	Interior (finishing)	M5	M4	M3	Exterior
2D	10,88	x	32,64	32,88	34,56	17,28	x
Revit	12,00	x	34,32	34,32	34,32	17,16	x
Vico	12,00	x	34,30	34,30	34,30	17,20	x
	Measurements						

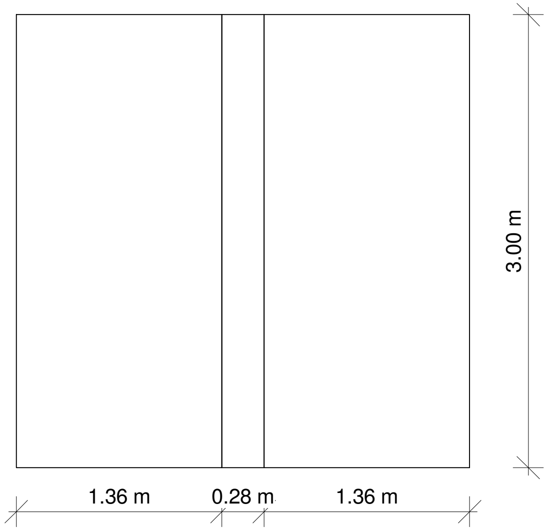
Table 16: (X1, Y1, Z2) Measurements

	Lengths		**Surface /Area**				
(X1, Y1, Z2)	Interior	Exterior	Interior (finishing)	M3	M4	M5	Exterior
2D - Revit	10,29	x	5,15	4,38	-0,69	-0,69	x
2D - Vico	10,29	x	5,09	4,32	-0,75	-0,46	x
Revit - Vico	0,00	x	-0,06	-0,06	-0,06	0,23	x
	Deviation in %						

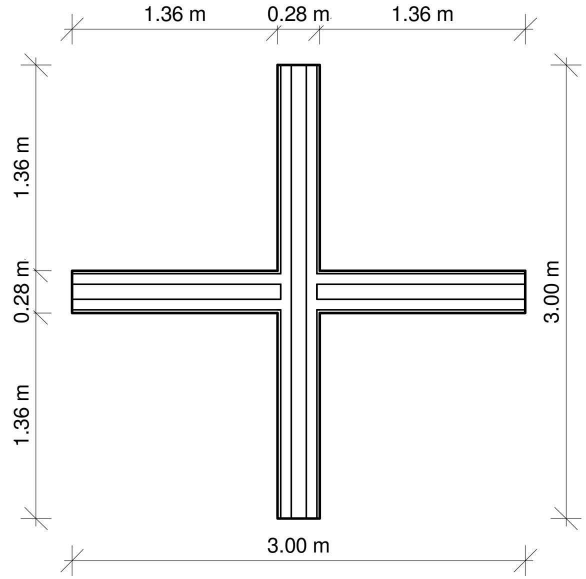
Table 17: (X1, Y1, Z2) Deviation



X1, Y2, Z2_3D



X1, Y2, Z2_ELEVATION



X1, Y2, Z2_TOP VIEW

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X1, Y2, Z2**
SUBJECT: **X1, Y2, Z2**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	External Length (m)	Centre length (m)	Internal Length (m)	Exterior Area (m^2)	Interior Area (m^2)	Volume (m^3)
L5	10,88	10,96	11,04	32,64	33,12	0,65
L4		11,36		34,56		2,42
L3		5,76		17,28		1,73
Total		28,08		84,72		4,80

Table 18: (X1, Y2, Z2) Manual QTO

Layer	Length (m)	Area (m^2)	Volume (m^3)
W1	3,00	9,00	2,52
W1	3,00	8,16	2,28
Total	6,00	17,16	4,80

Table 19: (X1, Y2, Z2) Revit QTO

Layer	Length (m)	Area (m^2)	Volume (m^3)
Wall	6,00	17,20	4,80
Total	6,00	17,20	4,80

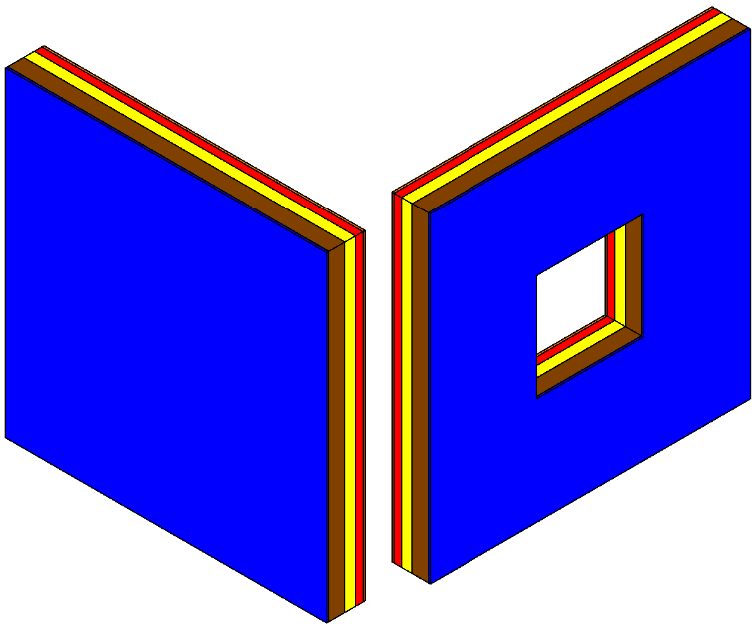
Table 20: (X1, Y2, Z2) Vico QTO

	Lengths (m)		**Surface /Area** (m^2)				
(X1, Y2, Z2)	Interior	Exterior	Interior (finishing)	M5	M4	M3	Exterior
2D	10,88	x	32,64	32,88	34,56	17,28	X
Revit	6,00	x	17,16				X
Vico	6,00	x	17,20				X
	Measurements						

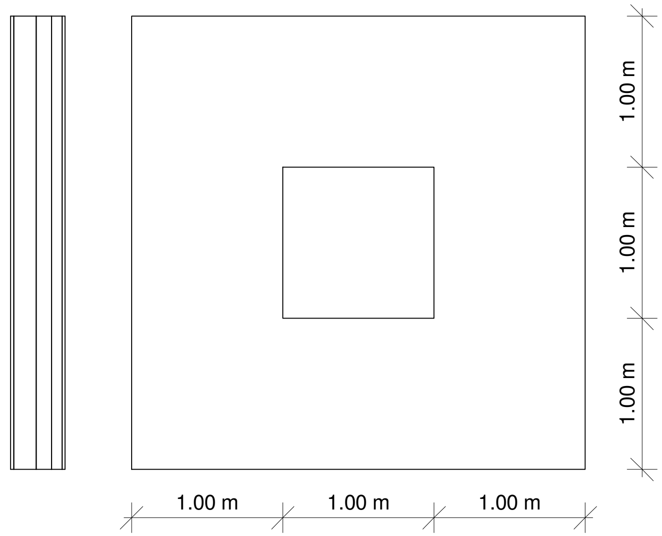
Table 21: (X1, Y2, Z2) Measurements

	Lengths (m)		**Surface /Area** (m^2)				
(X1, Y2, Z2)	Interior	Exterior	Interior (finishing)	M3	M4	M5	Exterior
2D - Revit	-44,85	x	-47,43	-47,81	-50,35	-0,69	X
2D - Vico	-44,85	x	-47,30	-47,69	-50,23	-0,46	X
Revit - Vico	0,00	x	0,23				X
	Deviations in %						

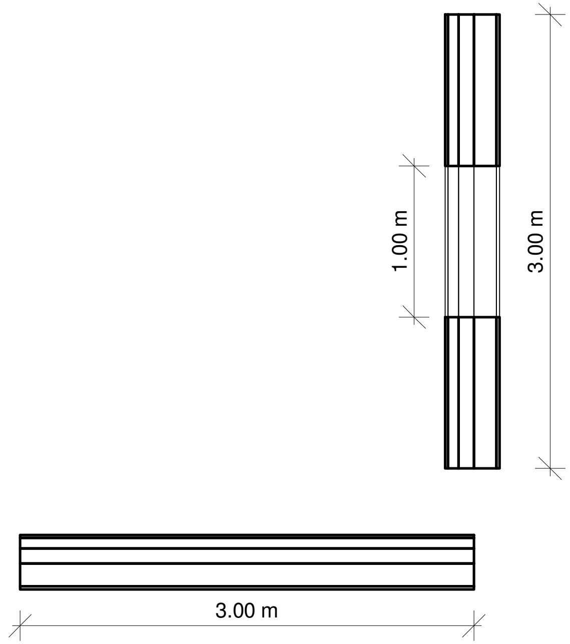
Table 22: (X1, Y2, Z2) Deviation



X1, Y1 + Y7, Z5_3D



X1, Y1 + Y7, Z5_ELEVATION



X1, Y1 + Y7, Z5_TOP VIEW

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X1, Y1 + Y7, Z5**
SUBJECT: **X1, Y1 + Y7, Z5**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Length (m)	Area (m²)	Volume (m³)
M1	6,00	17,00	0,34
M2	6,00	17,00	2,55
M3	6,00	17,00	1,70
M4	6,00	17,00	1,19
M5	6,00	17,00	0,34
Total	30,00	85,00	6,12

Table 23: (X1, Y1 + Y7, Z5) Manual QTO

Layers	Length (m)	Area (m²)	Volume (m³)
M1	6,00	17,00	0,34
M2	6,00	17,00	2,55
M3	6,00	17,00	1,70
M4	6,00	17,00	1,19
M5	6,00	17,00	0,34
Total	30,00	85,00	6,12

Table 24: (X1, Y1 + Y7, Z5) Revit QTO

Layers	Length (m)	Area (m²)	Net volume (m³)	Gross volume (m³)
M1	6,00	17,00	0,30	0,40
M2	6,00	17,00	2,60	2,70
M3	6,00	17,00	1,70	1,80
M4	6,00	17,00	1,20	1,30
M5	6,00	17,00	0,30	0,40
Total	30,00	85,00	6,10	6,60

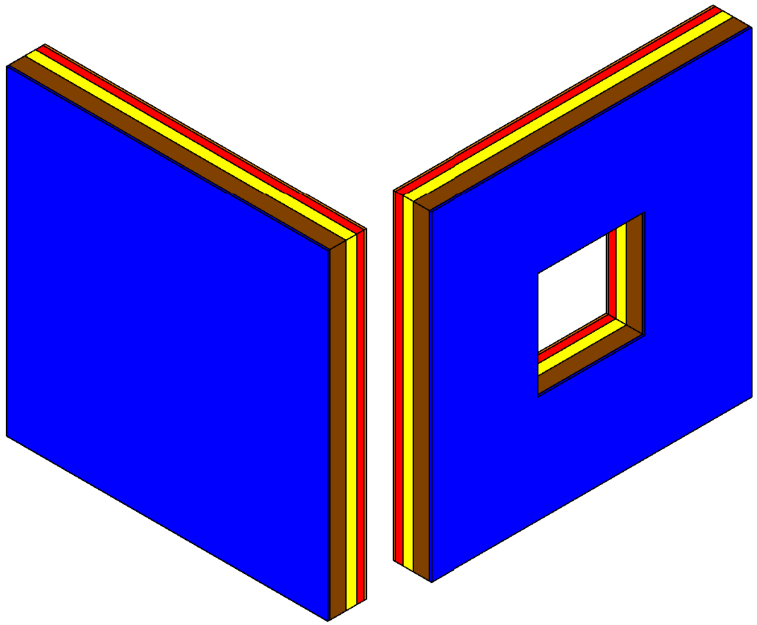
Table 25: (X1, Y1 + Y7, Z5) Vico QTO

	Lengths (m)		**Surface /Area** (m²)						
(X1, Y1 + Y7, Z5)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D	6,00	6,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
Revit	6,00	6,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
Vico	6,00	6,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
	Measurements								

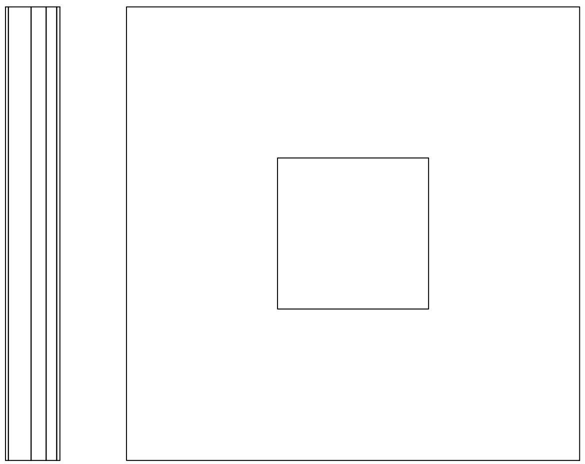
Table 26: (X1, Y1 + Y7, Z5) Measurements

	Lengths		**Surface /Area**						
(X1, Y1 + Y7, Z5)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D - Revit	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2D - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Revit - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Deviations in %								

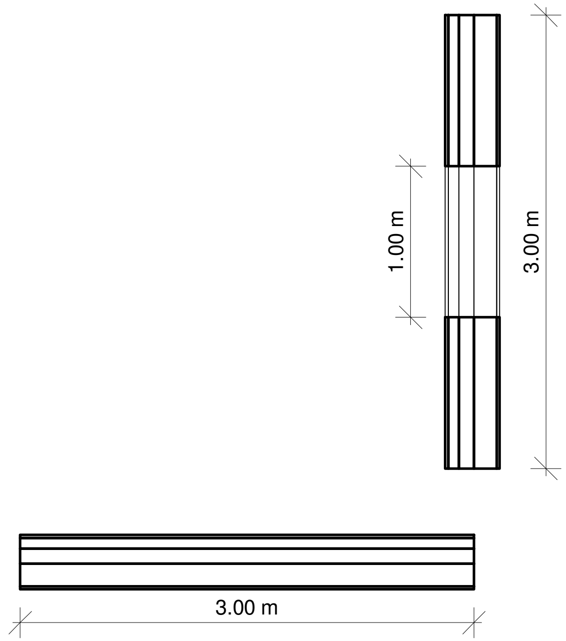
Table 27: (X1, Y1 + Y7, Z5) Deviation



X1, Y1 + Y8, Z5_3D



X1, Y1 + Y8, Z5_ELEVATION



X1, Y1 + Y8, Z5_TOP VIEW

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X1, Y1 + Y8, Z5**
SUBJECT: **X1, Y1 + Y8, Z5**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Length (m)	Area (m²)	Volume (m³)
M1	6,00	17,00	0,34
M2	6,00	17,00	2,55
M3	6,00	17,00	1,70
M4	6,00	17,00	1,19
M5	6,00	17,00	0,34
Total	30,00	85,00	6,12

Table 28: (X1, Y1 + Y8, Z5) Manual QTO

Layers	Length (m)	Area (m²)	Volume (m³)
M1	6,00	17,00	0,34
M2	6,00	17,00	2,55
M3	6,00	17,00	1,70
M4	6,00	17,00	1,19
M5	6,00	17,00	0,34
Total	30,00	85,00	6,12

Table 29: (X1, Y1 + Y8, Z5) Revit QTO

Layers	Length (m)	Area (m²)	Net volume (m³)	Gross volume (m³)
M1	6,00	17,00	0,30	0,40
M2	6,00	17,00	2,60	2,70
M3	6,00	17,00	1,70	1,80
M4	6,00	17,00	1,20	1,30
M5	6,00	17,00	0,30	0,40
Total	30,00	85,00	6,10	6,60

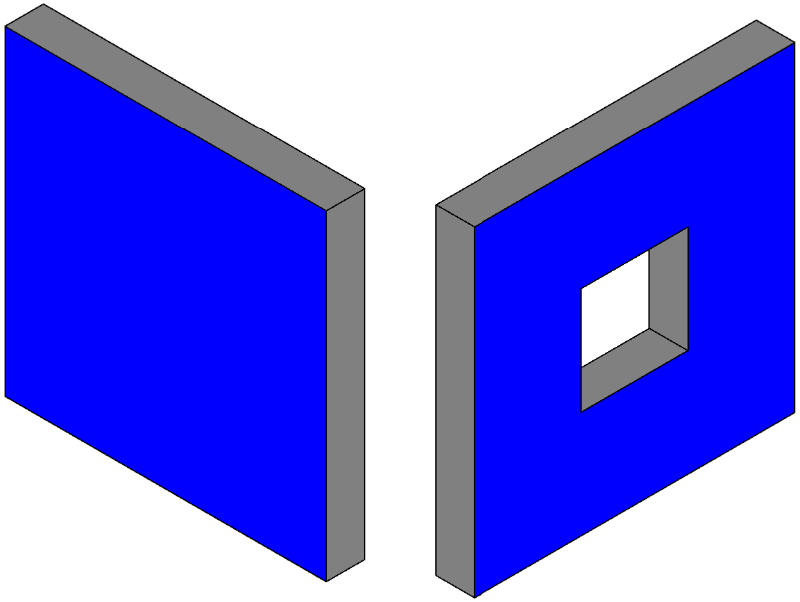
Table 30: (X1, Y1 + Y8, Z5) Vico QTO

	Lengths (m)		**Surface /Area** (m²)						
(X1, Y1 + Y8, Z5)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D	6,00	6,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
Revit	6,00	6,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
Vico	6,00	6,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
	Measurements								

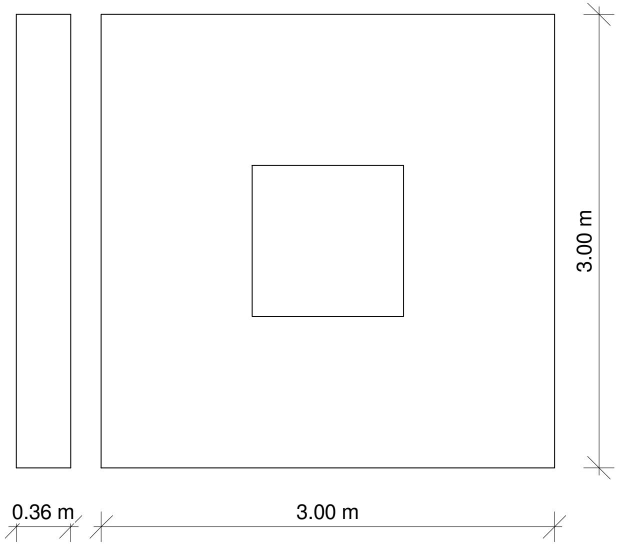
Table 31: (X1, Y1 + Y8, Z5) Measurements

	Lengths		**Surface /Area**						
(X1, Y1 + Y8, Z5)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D - Revit	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2D - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Revit - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Deviations in %								

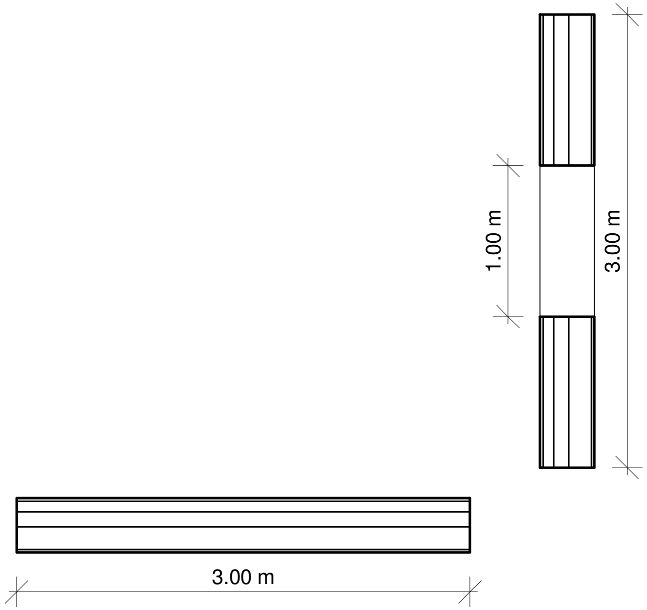
Table 32: (X1, Y1 + Y8, Z5) Deviation



X1, Y2 + Y7, Z5_3D



X1, Y2 + Y7, Z5_ELEVATION



X1, Y2 + Y7, Z5_TOP VIEW

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **TYPE PROJECTNAME**	DATE: **08/14/14**	**X1, Y2 + Y7, Z5**
SUBJECT: **X1, Y2 + Y7, Z5**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	17,00	0,34
M2	6,00	17,00	2,55
M3	6,00	17,00	1,70
M4	6,00	17,00	1,19
M5	6,00	17,00	0,34
Total	30,00	85,00	6,12

Table 33: (X1, Y2 + Y7, Z5) Manual QTO

Layers	Length (m)	Area (m^2)	Volume (m^3)
W1	3,00	8,00	2,88
W1	3,00	9,00	3,24
Total	6,00	17,00	6,12

Table 34: (X1, Y2 + Y7, Z5) Revit QTO

Layers	Length (m)	Area (m^2)	Net volume (m^3)	Gross volume (m^3)
Wall	6,00	17,00	6,10	6,50
Total	6,00	17,00	6,10	6,50

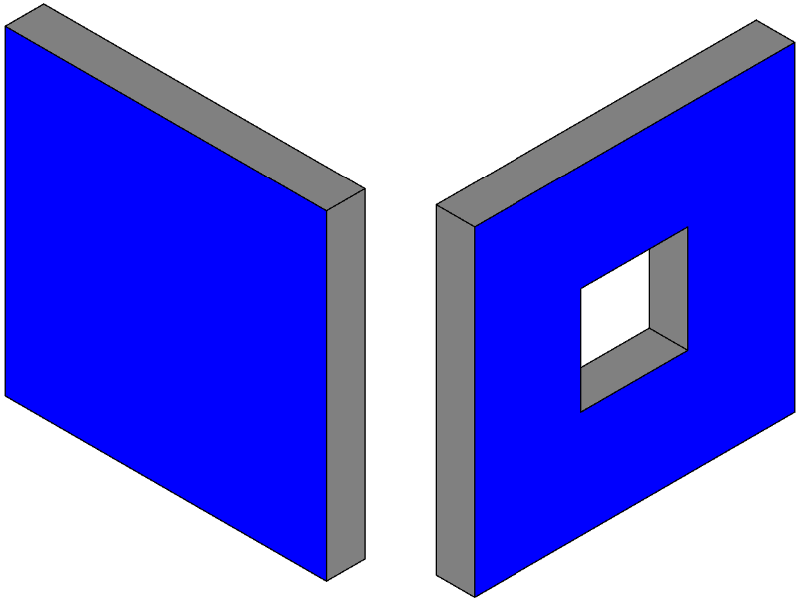
Table 35: (X1, Y2 + Y7, Z5) Vico QTO

	Lengths (m)		**Surface /Area** (m^2)						
(X1, Y2 + Y7, Z5)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D	6,00	6,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
Revit	6,00		17,00						
Vico	6,00		17,00						
	Measurements								

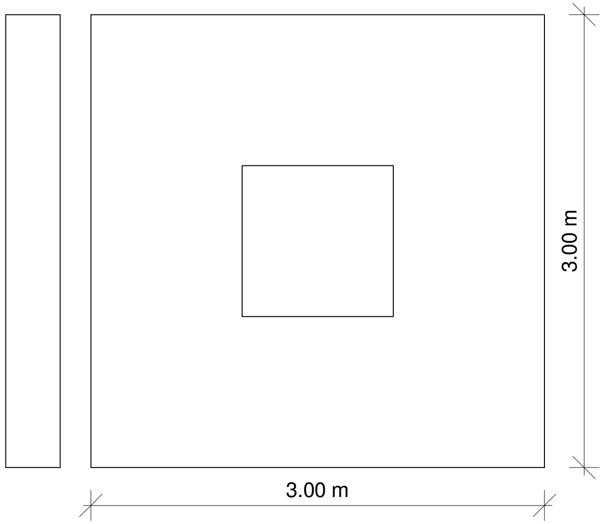
Table 36: (X1, Y2 + Y7, Z5) Measurements

	Lengths		**Surface /Area**						
(X1, Y2 + Y7, Z5)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D - Revit	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2D - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Revit - Vico	0,00		0,00						
	Deviations in %								

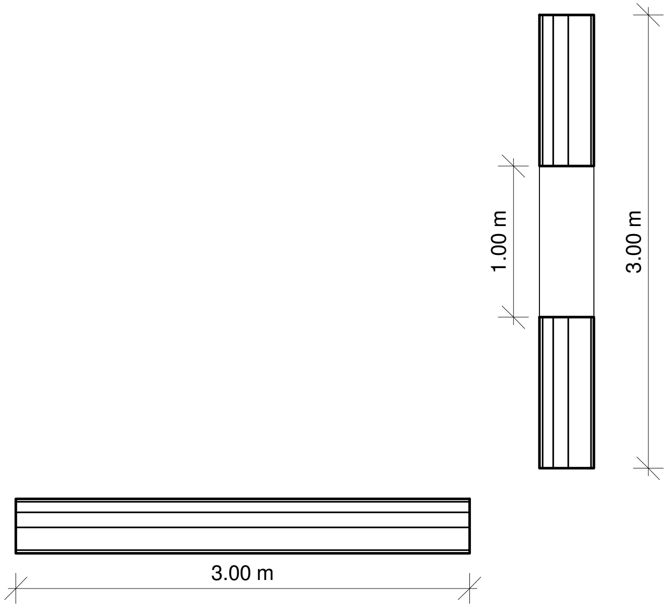
Table 37: (X1, Y2 + Y7, Z5) Deviation



X1, Y2 + Y8, Z5_3D



X1, Y2 + Y8, Z5_ELEVATION



X1, Y2 + Y8, Z5_TOP VIEW

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X1, Y2 + Y8, Z5**
SUBJECT: **X1, Y2 + Y8, Z5**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	17,00	0,34
M2	6,00	17,00	2,55
M3	6,00	17,00	1,70
M4	6,00	17,00	1,19
M5	6,00	17,00	0,34
Total	30,00	85,00	6,12

Table 38: (X1, Y2 + Y8, Z5) Manul QTO

Layers	Length (m)	Area (m^2)	Volume (m^3)
W1	3,00	8,00	2,88
W1	3,00	9,00	3,24
Total	6,00	17,00	6,12

Table 39: (X1, Y2 + Y8, Z5) Revit QTO

Layers	Length (m)	Area (m^2)	Net volume (m^3)	Gross volume (m^3)
Wall	6,00	17,00	6,10	6,50
Total	6,00	17,00	6,10	6,50

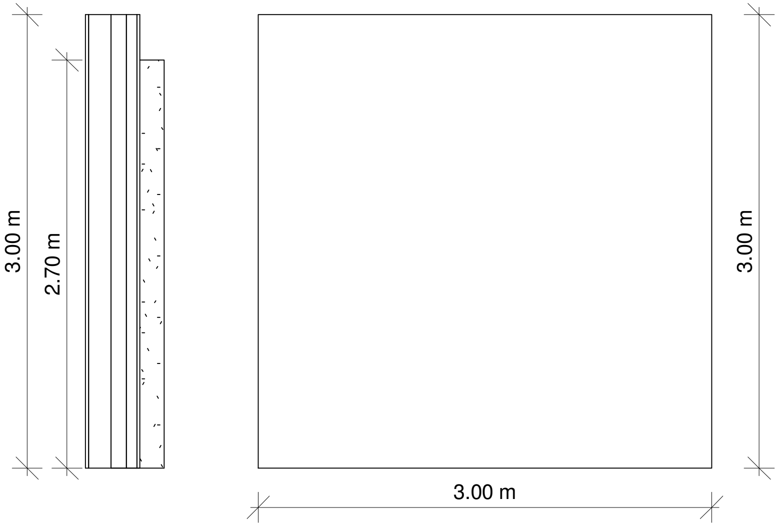
Table 40: (X1, Y2 + Y8, Z5) Vico QTO

	Lengths (m)		**Surface /Area** (m^2)						
(X1, Y2 + Y8, Z5)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior
2D	6,00	6,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
Revit	6,00		17,00						
Vico	6,00		17,00						
	Measurements								

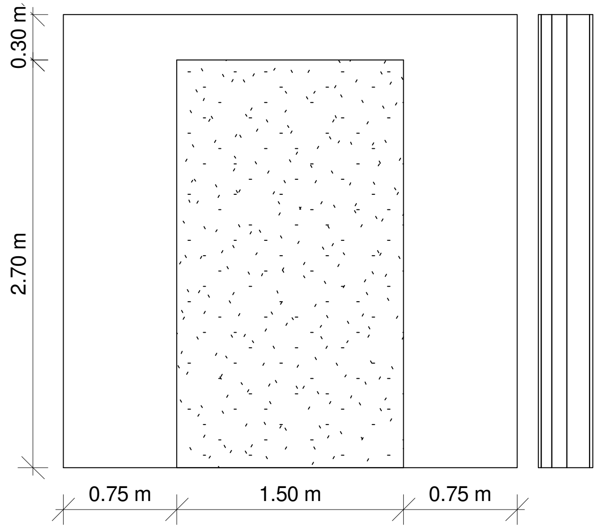
Table 41: (X1, Y2 + Y8, Z5) Measurements

	Lengths		**Surface /Area**						
(X1, Y2 + Y8, Z5)	Interior	Exterior	l Exterior	M1	M2	M3	M4	M5	Interior
2D - Revit	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2D - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Revit - Vico	0,00		0,00						
	Deviations in %								

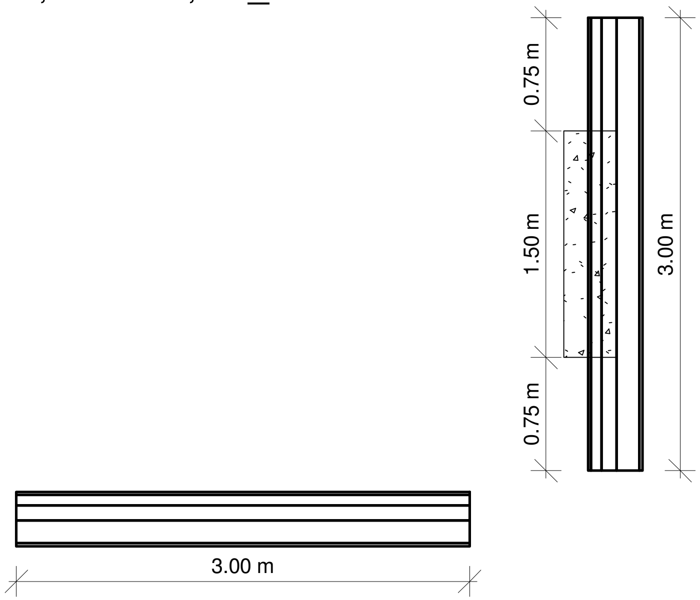
Table 42: (X1, Y2 + Y8, Z5) Deviation



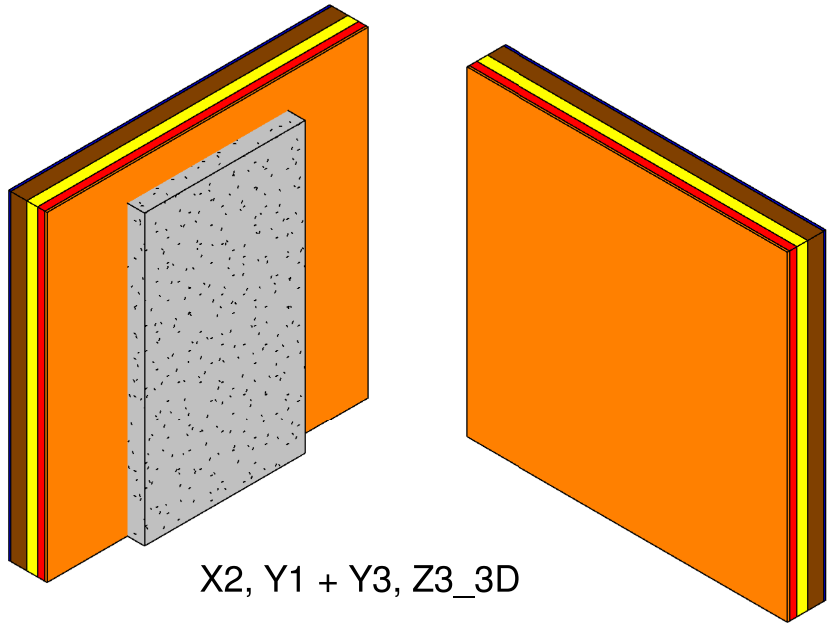
X2, Y1 + Y3, Z3_ELEVATION 1



X2, Y1 + Y3, Z3_ELEVATION 2



X2, Y1 + Y3, Z3_TOP VIEW



X2, Y1 + Y3, Z3_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **TYPE PROJECTNAME**	DATE: **08/14/14**	**X2, Y1 + Y3, Z3**
SUBJECT: **X2, Y1 + Y3, Z3**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	STW Extra length (m)	Surface area (m^2)	STW interior surface (m^2)	Volume (m^3)
M1	6,00		18,00	0,00	0,36
M2	6,00		18,00	0,00	2,70
M3	6,00		13,95	0,00	1,40
M4	6,00		13,95	0,00	0,98
M5	6,00	0,32	13,95	5,15	0,28
Total	30,00		77,85		5,71

Table 43: (X2, Y1 + Y3, Z3) Manual QTO. Multilayer wall

Height (m)	Length (m)	Width (m)	Surface(m^2)	Volume (m^3)
0,00	0,00		0,00	0,00
0,00	0,00		0,00	0,00
2,70	1,50		4,05	0,41
2,70	1,50		4,05	0,28
2,70	1,50	0,32	4,05	0,08

Table 44: (X2, Y1 + Y3, Z3) Manual QTO. Structural Wall

Layer	Length (m)	Area(m^2)	Volume (m^3)
M1	6,00	18,00	0,36
M2	6,00	18,00	2,70
M3	6,00	18,00	1,80
M4	6,00	18,00	1,26
M5	6,00	18,00	0,36
Total	30,00	90,00	6,48

Type	Length (m)	Area(m^2)	Volume (m^3)
Total	2,70	X	1,42

Table 45: (X2, Y1 + Y3, Z3) Revit QTO. Multilayer wall and STW

Layer	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	18,00	0,40
M2	6,00	18,00	2,70
M3	6,00	18,00	1,80
M4	6,00	18,00	1,30
M5	6,00	0,10	0,40
Total	30,00	72,10	6,60

Layer	Height (m)	Area (m^2)	Volume (m^3)
Total	2,70	10,00	1,40

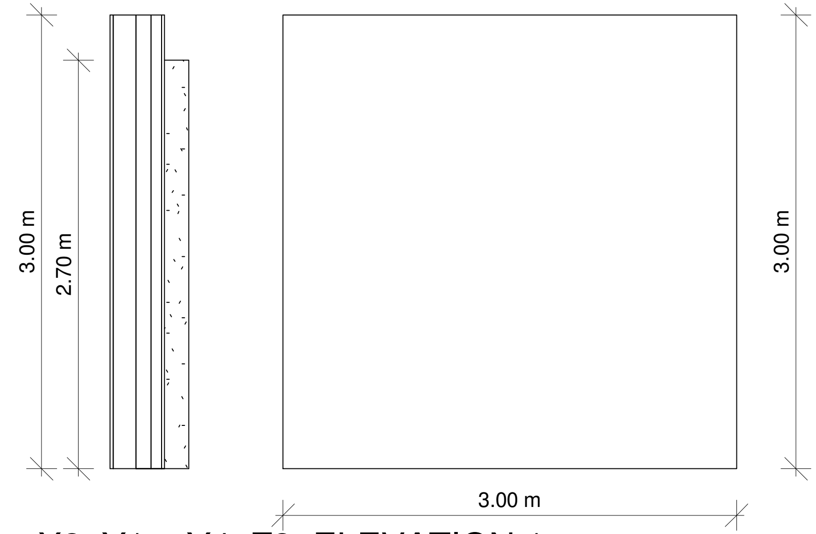
Table 46: (X2, Y1 + Y3, Z3) Vico QTO. Multilayer wall and STW

	Lengths (m)		**Surface /Area** (m^2)							
(X2, Y1 + Y3, Z3)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior structural wall	Interior
2D	6,32	6,00	18,00	18,00	18,00	13,95	13,95	13,95	5,15	19,10
Revit	6,00	6,00	18,00	18,00	18,00	18,00	18,00	18,00	0,00	18,00
Vico	6,00	6,00	18,00	18,00	18,00	18,00	18,00	18,00	10,00	28,00
	Measurements									

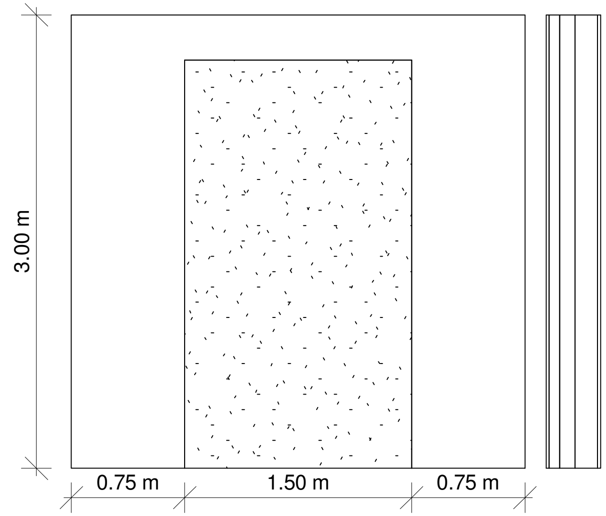
Table 47: (X2, Y1 + Y3, Z3) Measurements

	Lengths (m)		**Surface /Area** (m^2)							
(X2, Y1 + Y3, Z3)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior structural wall	Interior
2D - Revit	-5,06	0,00	0,00	0,00	0,00	29,03	29,03	29,03	-100,00	-5,78
2D - Vico	-5,06	0,00	0,00	0,00	0,00	29,03	29,03	29,03	94,02	46,57
Revit - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	X	55,56
	Deviations in %									

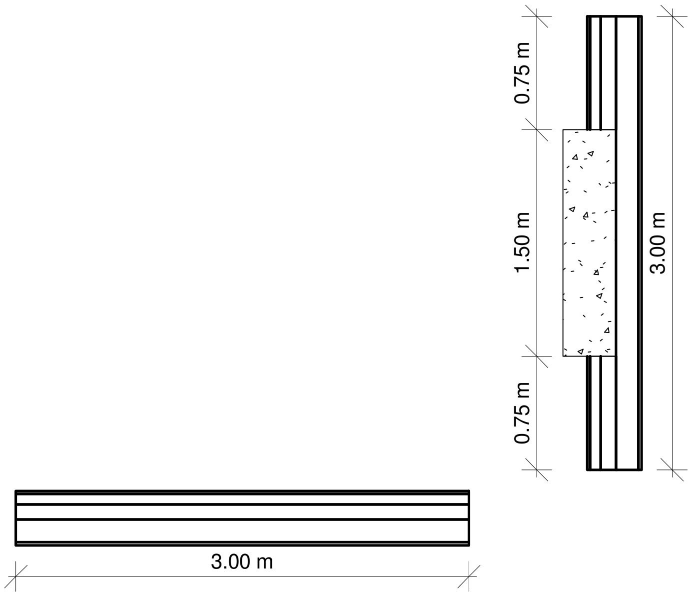
Table 48: (X2, Y1 + Y3, Z3) Deviation



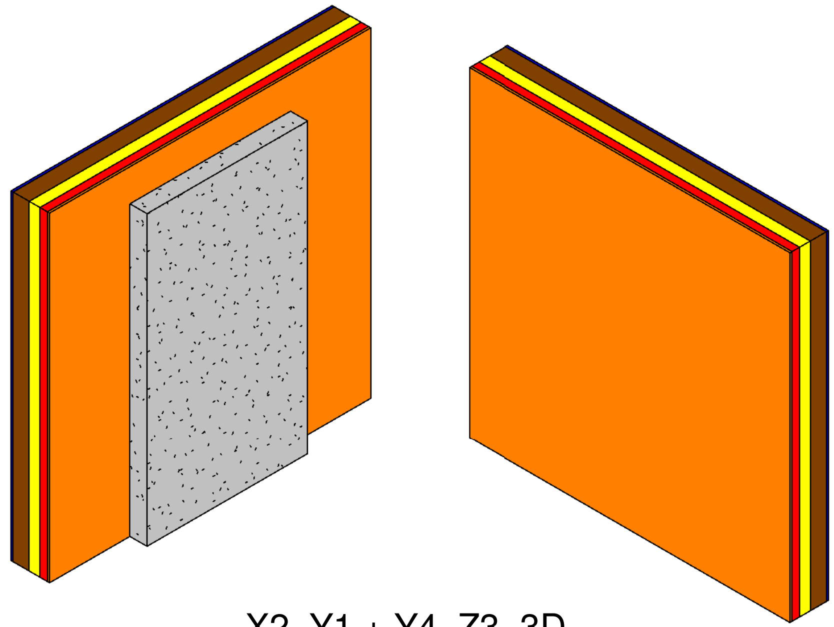
X2, Y1 + Y4, Z3_ELEVATION 1



X2, Y1 + Y4, Z3_ELEVATION 2



X2, Y1 + Y4, Z3_TOP VIEW



X2, Y1 + Y4, Z3_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X2, Y1 + Y4, Z3**
SUBJECT: **X2, Y1 + Y4, Z3**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	STW Extra length (m)	Surface area (m²)	STW interior surface (m²)	Volume (m³)
M1	6,00		18,00	0,00	0,36
M2	6,00		18,00	0,00	2,70
M3	6,00		13,95	0,00	1,40
M4	6,00		13,95	0,00	0,98
M5	6,00	0,32	13,95	5,15	0,28
Total	30,00		77,85		5,71

Table 49: (X2, Y1 + Y4, Z3) Manual QTO. Wall

Height (m)	Length (m)	Width (m)	Surface(m²)	Volume (m³)
0,00	0,00		0,00	0,00
0,00	0,00		0,00	0,00
2,70	1,50		4,05	0,41
2,70	1,50		4,05	0,28
2,70	1,50	0,32	4,05	0,08

Table 50: (X2, Y1 + Y4, Z3) Manual QTO. STW

Layer	Length (m)	Area (m²)	Volume (m³)
M1	6,00	18,00	0,36
M2	6,00	18,00	2,70
M3	6,00	13,95	1,40
M4	6,00	13,95	0,98
M5	6,00	13,95	0,28
Total	30,00	77,85	5,72

Layer	Length (m)	Area (m²)	Volume (m³)
Total	2,70	0,00	1,42

Table 51: (X2, Y1 + Y4, Z3) Revit QTO. Wall and STW

Layer	Length (m)	Surface area (m2)	Net Volume (m3)	Gross volume (m3)
M1	6,00	18,00	0,40	0,40
M2	6,00	18,00	2,70	2,70
M3	6,00	14,00	1,40	1,80
M4	6,00	14,00	1,00	1,30
M5	6,00	14,00	0,30	0,40
Total	30,00	78,00	5,80	6,60

Type	Height (m)	Surface area (m2)	Net Volume (m3)	Volume (m3)
Total	2,70	10,00	1,40	1,40

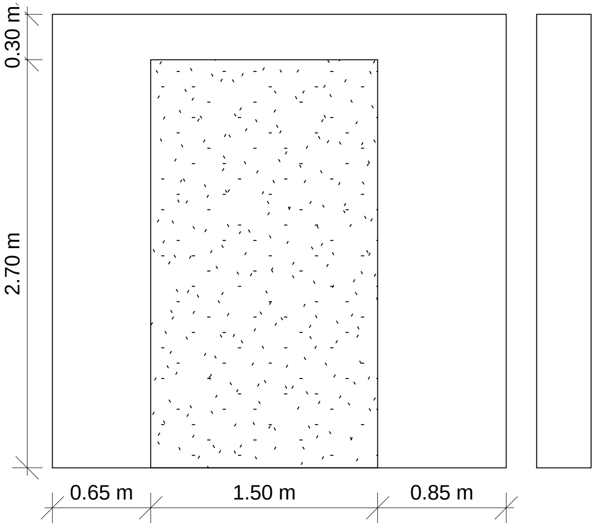
Table 52: (X2, Y1 + Y4, Z3) Vico QTO. Wall and STW

	Lengths (m)		**Surface /Area** (m^2)							
(X2, Y1 + Y4, Z3)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior structural wall	Interior
2D	6,32	6,00	18,00	18,00	18,00	13,95	13,95	13,95	5,15	19,10
Revit	6,00	6,00	18,00	18,00	18,00	13,95	13,95	13,95	0,00	13,95
Vico	6,00	6,00	18,00	18,00	18,00	14,00	14,00	14,00	10,00	24,00
	Measurements									

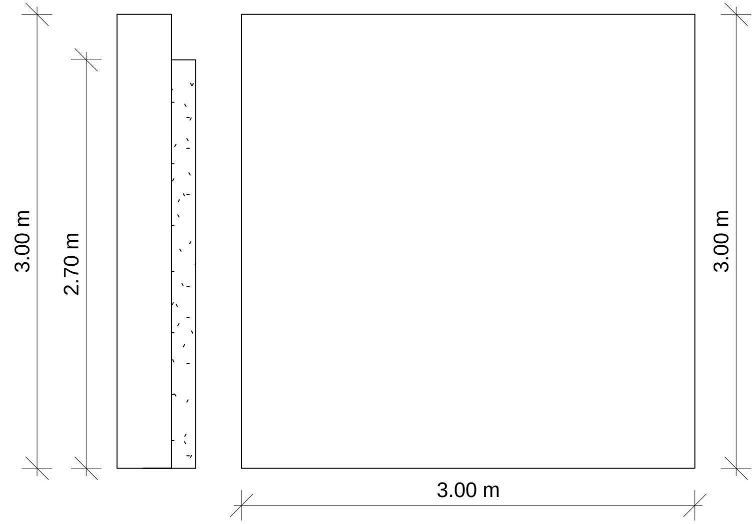
Table 53: (X2, Y1 + Y4, Z3) Measurements

	Lengths		**Surface /Area**							
(X2, Y1 + Y4, Z3)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior structural wall	Interior
2D - Revit	-5,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	X	-26,98
2D - Vico	-5,06	0,00	0,00	0,00	0,00	0,36	0,36	0,36	94,02	25,63
Revit - Vico	0,00	0,00	0,00	0,00	0,00	0,36	0,36	0,36	X	72,04
	Deviations in %									

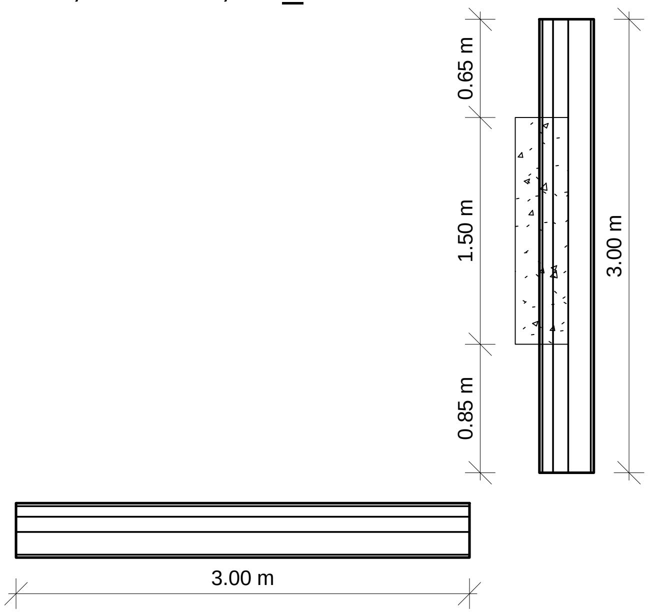
Table 54: (X2, Y1 + Y4, Z3) Deviation



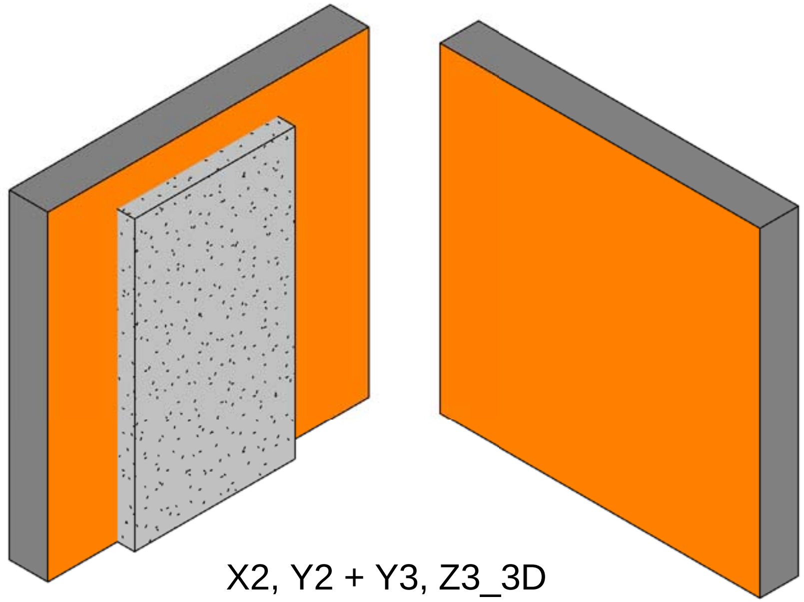
X2, Y2 + Y3, Z3_ELEVATION 2



X2, Y2 + Y3, Z3_ELEVATION 1



X2, Y2 + Y3, Z3_TOP VIEW



X2, Y2 + Y3, Z3_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X2, Y2 + Y3, Z3**
SUBJECT: **X2, Y2 + Y3, Z3**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	STW Extra length (m)	Surface area (m²)	STW interior surface (m²)	Volume (m³)
M1	6,00		18,00	0,00	0,36
M2	6,00		18,00	0,00	2,70
M3	6,00		13,95	0,00	1,40
M4	6,00		13,95	0,00	0,98
M5	6,00	0,32	13,95	5,15	0,28
Total	30,00		77,85		5,71

Table 55: (X2, Y2 + Y3, Z3) Manula QTO. Wall

Height (m)	Length (m)	Width (m)	Surface(m²)	Volume (m³)
0,00	0,00		0,00	0,00
0,00	0,00		0,00	0,00
2,70	1,50		4,05	0,41
2,70	1,50		4,05	0,28
2,70	1,50	0,32	4,05	0,08

Table 56: (X2, Y2 + Y3, Z3) Manual QTO. STW

Layer	Length (m)	Area (m²)	Volume (m³)
W1	3,00	9,00	3,24
W1	3,00	9,00	3,24
Total	6,00	18,00	6,48

Layer	Length (m)	Area (m²)	Volume (m³)
Total	2,70	X	1,42

Table 57: (X2, Y2 + Y3, Z3) Revit QTO. Wall and STW

Layer	Length (m)	Area (m²)	Volume (m³)
W1	6,00	18,00	6,50
Total	6,00	18,00	6,50

Layer	Height (m)	Surface area (m²)	Volume (m³)
Total	2,70	10,00	1,40

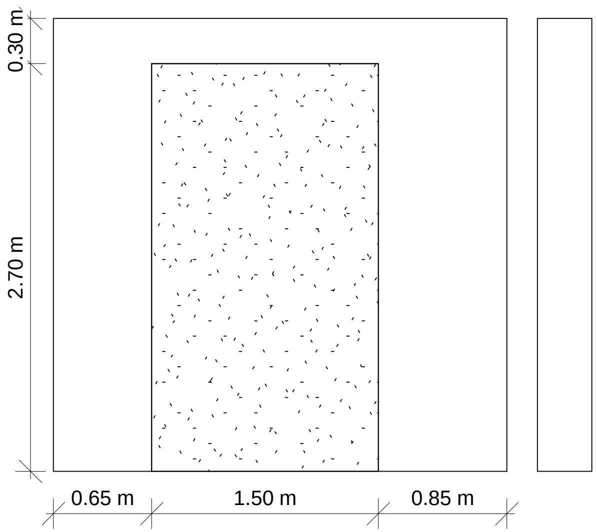
Table 58: (X2, Y2 + Y3, Z3) Vico QTO. Wall and STW

	Lengths (m)		**Surface /Area** (m^2)							
(X2, Y2 + Y3, Z3)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior structural wall	Interior
2D	6,32	6,00	18,00	18,00	18,00	13,95	13,95	13,95	5,15	19,10
Revit	6,00		18,00							
Vico	6,00	6,00	18,00	18,00	18,00	18,00	18,00	18,00	10,00	28,00
	Measurements									

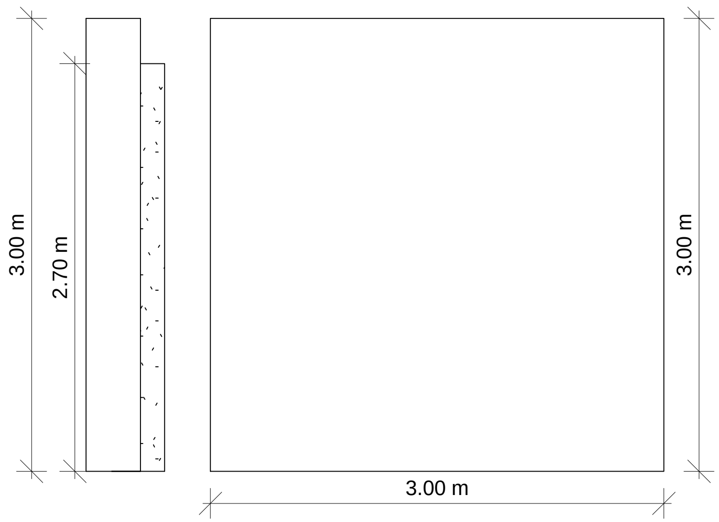
Table 59: (X2, Y2 + Y3, Z3) Measurements

	Lengths		**Surface /Area**							
(X2, Y2 + Y3, Z3)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior structural wall	Interior
2D - Revit	-5,06	0,00	0,00	0,00	0,00	29,03	29,03	29,03	249,24	-5,78
2D - Vico	-5,06	0,00	0,00	0,00	0,00	29,03	29,03	29,03	94,02	46,57
Revit - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-44,44	55,56
	Deviations in %									

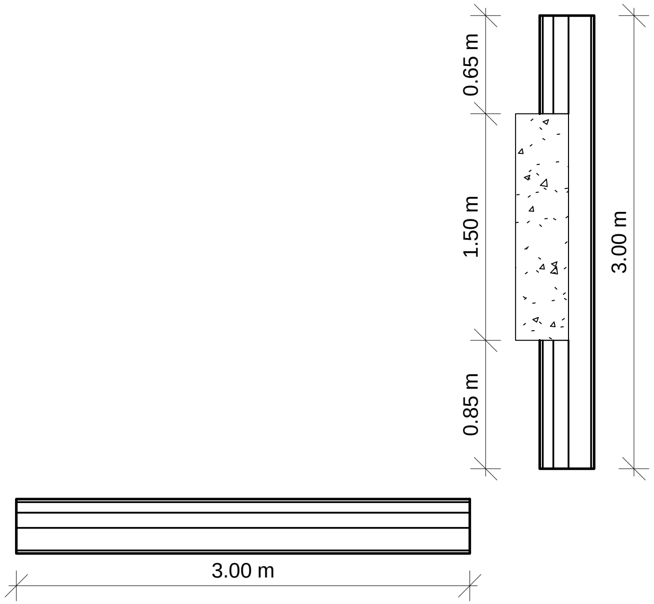
Table 60: (X2, Y2 + Y3, Z3) Deviation



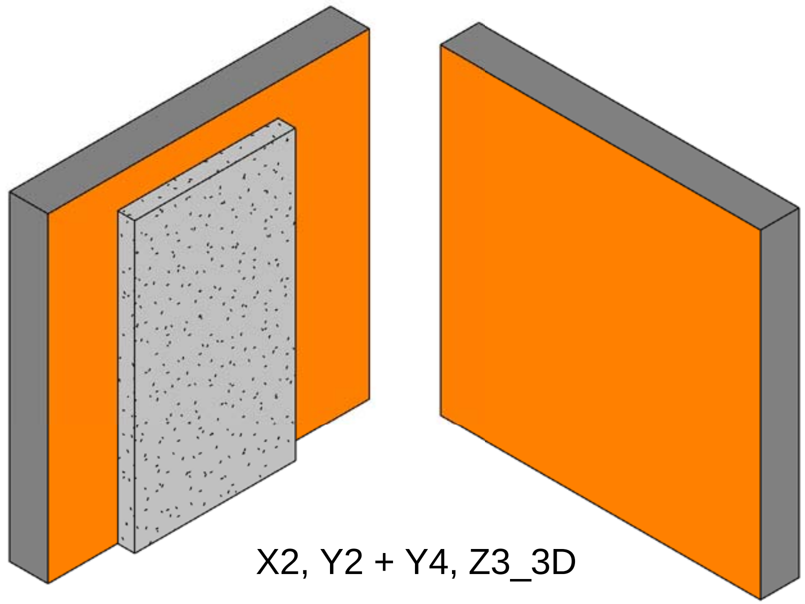
X2, Y2 + Y4, Z3_ELEVATION 2



X2, Y2 + Y4, Z3_ELEVATION 1



X2, Y2 + Y4, Z3_TOP VIEW



X2, Y2 + Y4, Z3_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

UNIVERSIDAD DE CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X2, Y2 + Y4, Z3**
SUBJECT: **X2, Y2 + Y4, Z3**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	STW Extra length (m)	Surface area (m^2)	STW interior surface (m^2)	Volume (m^3)
M1	6,00		18,00	0,00	0,36
M2	6,00		18,00	0,00	2,70
M3	6,00		13,95	0,00	1,40
M4	6,00		13,95	0,00	0,98
M5	6,00	0,32	13,95	5,15	0,28
Total	30,00		77,85		5,71

Table 61: (X2, Y2 + Y4, Z3) Manual QTO. Wall

Height (m)	Length (m)	Width (m)	Surface(m^2)	Volume (m^3)
0,00	0,00		0,00	0,00
0,00	0,00		0,00	0,00
2,70	1,50		4,05	0,41
2,70	1,50		4,05	0,28
2,70	1,50	0,32	4,05	0,08

Table 62: (X2, Y2 + Y4, Z3) Manual QTO. STW

Layer	Length (m)	Area (m^2)	Volume (m^3)
W1	3,00	9,00	2,47
W1	3,00	9,00	3,24
Total	6,00	18,00	5,71

Layer	Length (m)	Area (m^2)	Volume (m^3)
Total	2,70	X	1,42

Table 63: (X2, Y2 + Y4, Z3) Revit QTO. Wall and STW

Layer	Length (m)	Area (m^2)	Volume (m^3)
Wall	6,00	18,00	5,70
Total	6,00	18,00	5,70

Layer	Height (m)	Area (m^2)	Volume (m^3)
Total	2,70	10,00	1,40

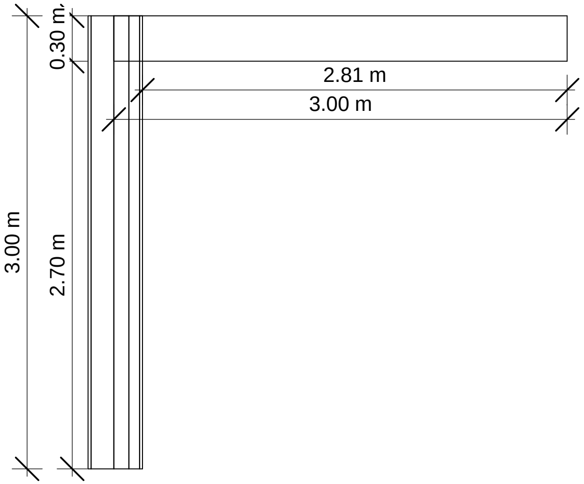
Table 64: (X2, Y2 + Y4, Z3) Vico QTO. Wall ans STW

	Lengths (m)		**Surface /Area** (m^2)							
(X2, Y2 + Y4, Z3)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior structural wall	Interior
2D	6,32	6,00	18,00	18,00	18,00	13,95	13,95	13,95	5,15	19,10
Revit	6,00		18,00							
Vico	6,00	6,00	18,00	18,00	18,00	18,00	18,00	18,00	10,00	28,00
	Measurements									

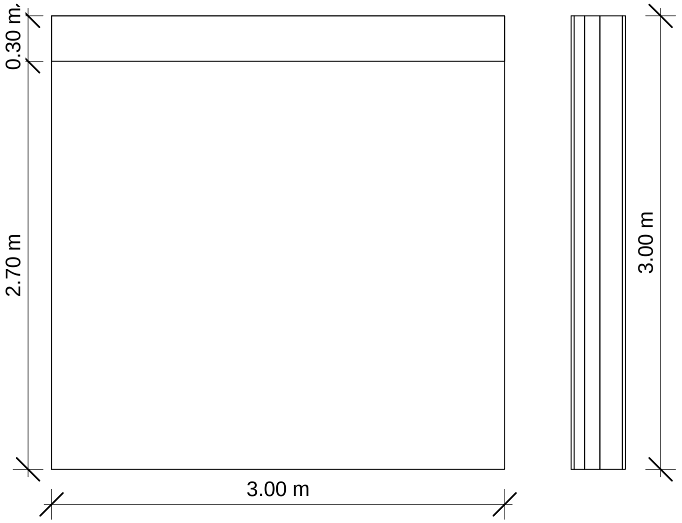
Table 65: (X2, Y2 + Y4, Z3) Measurements

	Lengths		**Surface /Area**							
(X2, Y2 + Y4, Z3)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior structural wall	Interior
2D - Revit	-5,06	0,00	0,00	0,00	0,00	29,03	29,03	29,03	249,24	-5,78
2D - Vico	-5,06	0,00	0,00	0,00	0,00	29,03	29,03	29,03	94,02	46,57
Revit - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-44,44	55,56
	Deviations in %									

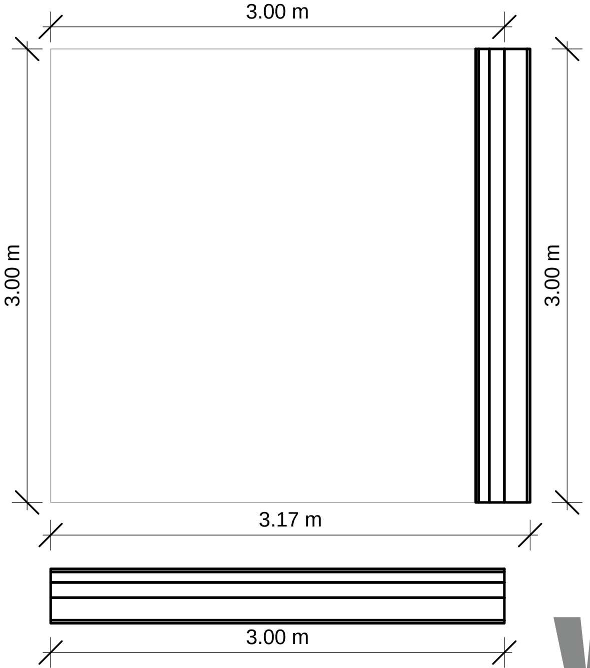
Table 66: (X2, Y2 + Y4, Z3) Deviation



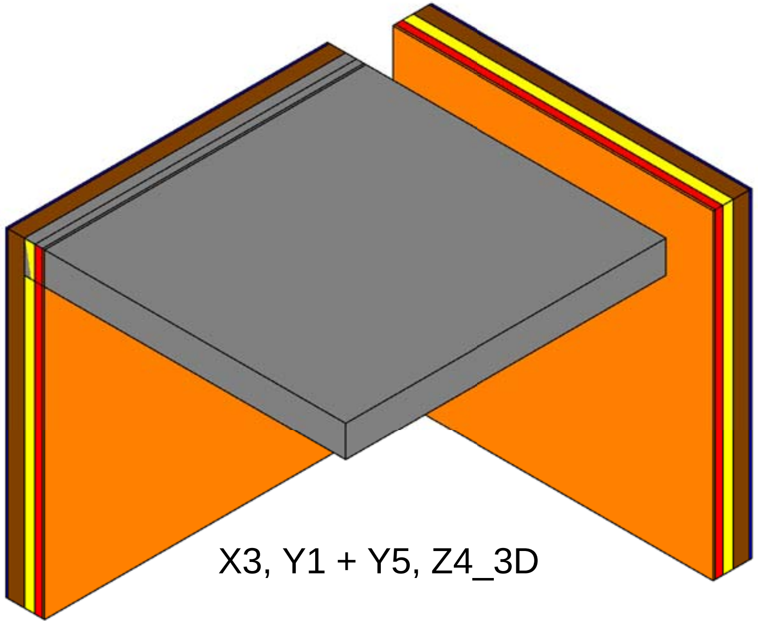
X3, Y1 + Y5, Z4_ELEVATION 1



X3, Y1 + Y5, Z4_ELEVATION 2



X3, Y1 + Y5, Z4_TOP VIEW



X3, Y1 + Y5, Z4_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

UNIVERSIDAD DE CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X3, Y1 + Y5, Z4**
SUBJECT: **X3, Y1 + Y5, Z4**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	18,00	0,36
M2	6,00	18,00	2,70
M3	6,00	17,10	1,71
M4	6,00	17,10	1,20
M5	6,00	17,10	0,34
Total	30,00	87,30	6,31

Table 67: (X3, Y1 + Y5, Z4) Manual QTO. Wall

Height (m)	Lenth (m)	Surface (m^2)	Volume to substract (m^3)
3,00	3,00	9,00	0,00
3,00	3,00	9,00	0,00
2,70	3,00	8,10	0,09
2,70	3,00	8,10	0,06
2,70	3,00	8,10	0,02

Table 68: (X3, Y1 + Y5, Z4) Manual QTO. Slab

Layer	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	18,00	0,36
M2	6,00	18,00	2,70
M3	6,00	18,00	1,80
M4	6,00	18,00	1,26
M5	6,00	18,00	0,36
Total	30,00	90,00	6,48

Layer	Area (m^2)	Volume (m^3)
Slab	9,00	2,70

Table 69: (X3, Y1 + Y5, Z4) Revit QTO. Wall and Slab

Layer	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	18,00	0,40
M2	6,00	18,00	2,70
M3	6,00	18,00	1,80
M4	6,00	18,00	1,30
M5	6,00	18,00	0,40
Total	30,00	90,00	6,60

Layer	Area (m^2)	Volume (m^3)
Slab	9,00	2,70

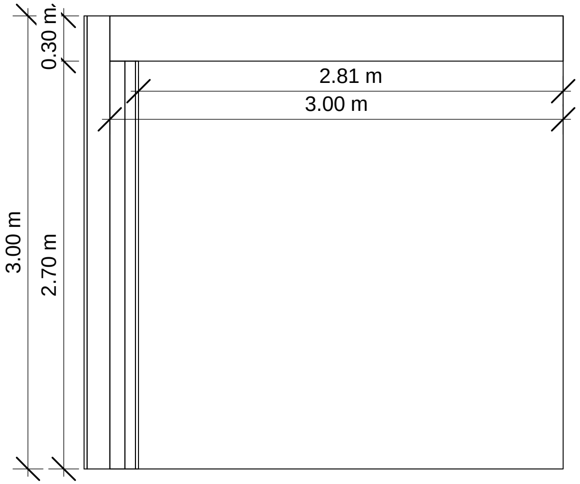
Table 70: (X3, Y1 + Y5, Z4) Vico QTO. Wall and Slab

	Lengths (m)		**Surface /Area (m^2)**								**Volume (m^3)**
(X3, Y1 + Y5, Z4)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior	Slab	Slab
2D	6,00	6,00	18,00	18,00	18,00	17,10	17,10	17,10	17,10	9,00	2,70
Revit	6,00	6,00	18,00	18,00	18,00	18,00	18,00	18,00	18,00	9,00	2,70
Vico	6,00	6,00	18,00	18,00	18,00	18,00	18,00	18,00	18,00	9,00	2,70
	Measurements										

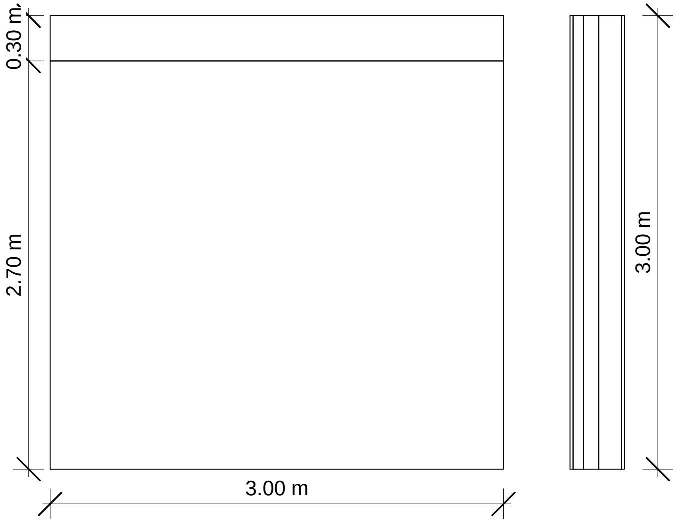
Table 71: (X3, Y1 + Y5, Z4) Measurements

	Lengths		**Surface /Area**								**Volume**
(X3, Y1 + Y5, Z4)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior	Slab	Slab
2D - Revit	0,00	0,00	0,00	0,00	0,00	5,26	5,26	5,26	5,26	0,00	0,00
2D - Vico	0,00	0,00	0,00	0,00	0,00	5,26	5,26	5,26	5,26	0,00	0,00
Revit - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Deviations in %										

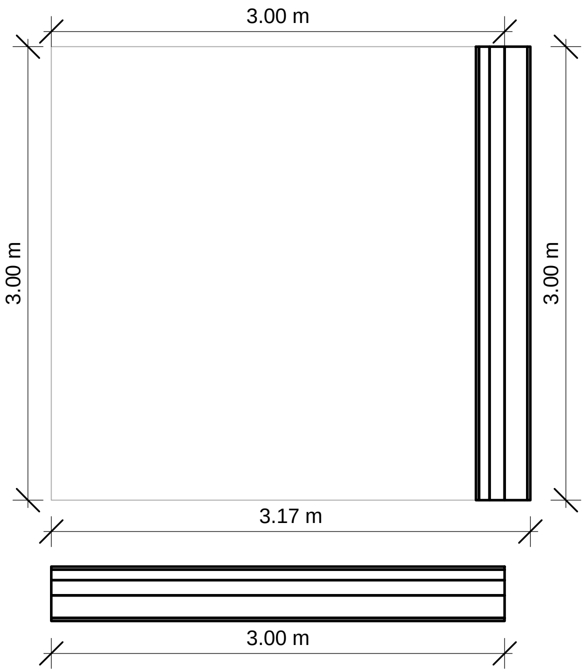
Table 72: (X3, Y1 + Y5, Z4) Deviation



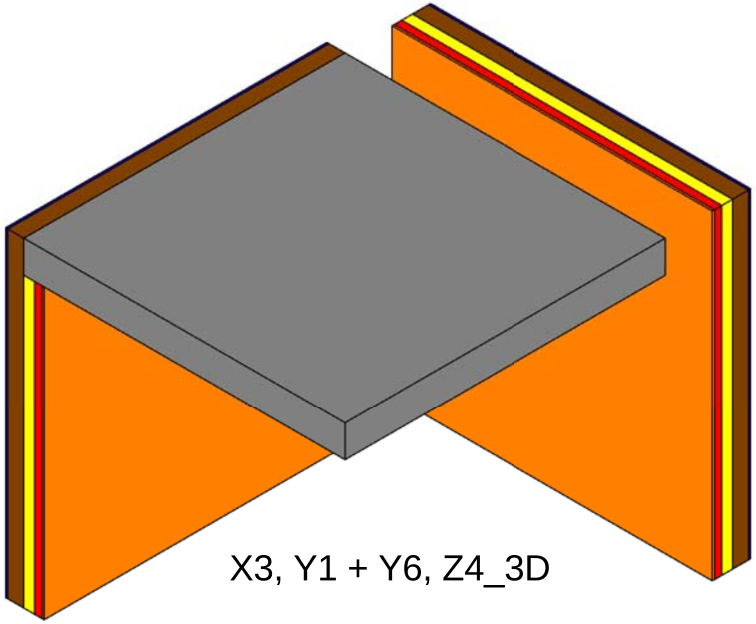
X3, Y1 + Y6, Z4_ELEVATION 1



X3, Y1 + Y6, Z4_ELEVATION 2



X3, Y1 + Y6, Z4_TOP VIEW



X3, Y1 + Y6, Z4_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X3, Y1 + Y6, Z4**
SUBJECT: **X3, Y1 + Y6, Z4**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	Area (m^2)	Volume (m^3)
L1	6,00	18,00	0,36
L2	6,00	18,00	2,70
L3	6,00	17,10	1,71
L4	6,00	17,10	1,20
L5	6,00	17,10	0,34
Total	30,00	87,30	6,31

Table 73: (X3, Y1 + Y6, Z4) Manual QTO. Wall

Height (m)	Length (m)	Surface (m^2)	Volume to substract (m^3)
3,00	3,00	9,00	0,00
3,00	3,00	9,00	0,00
2,70	3,00	8,10	0,09
2,70	3,00	8,10	0,06
2,70	3,00	8,10	0,02

Table 74: (X3, Y1 + Y6, Z4) Manual QTO. Slab

Layer	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	18,00	0,36
M2	6,00	18,00	2,70
M3	6,00	17,10	1,71
M4	6,00	17,10	1,20
M5	6,00	17,10	0,34
Total	30,00	87,30	6,31

Layer	Area (m^2)	Volume (m^3)
Slab	9,00	2,70

Table 75: (X3, Y1 + Y6, Z4) Revit QTO. Wall and Slab

Layer	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	18,00	0,40
M2	6,00	18,00	2,70
M3	6,00	17,10	1,70
M4	6,00	17,10	1,20
M5	6,00	17,10	0,30
Total	30,00	87,30	6,30

Layer	Area (m^2)	Volume (m^3)
Slab	9,00	2,70

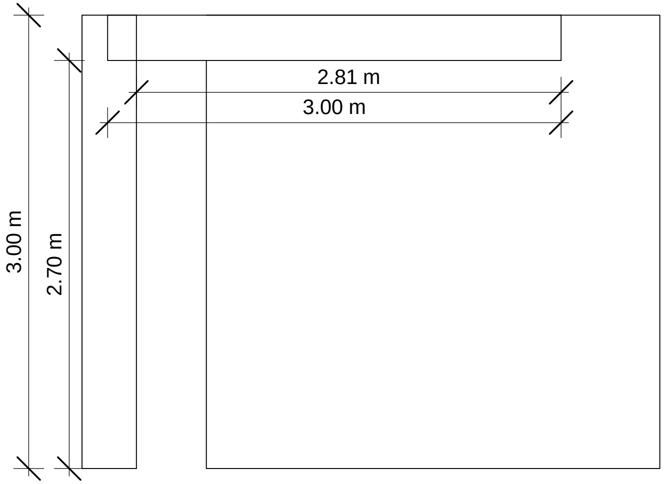
Table 76: (X3, Y1 + Y6, Z4) Vico QTO. Wall and Slab

	Lengths (m)		**Surface /Area (m^2)**								**Volume (m^3)**
(X3, Y1 + Y6, Z4)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior	Slab	Slab
2D	6,00	6,00	18,00	18,00	18,00	17,10	17,10	17,10	17,10	9,00	2,70
Revit	6,00	6,00	18,00	18,00	18,00	17,10	17,10	17,10	17,10	9,00	2,70
Vico	6,00	6,00	18,00	18,00	18,00	17,10	17,10	17,10	17,10	9,00	2,70
	Measurements										

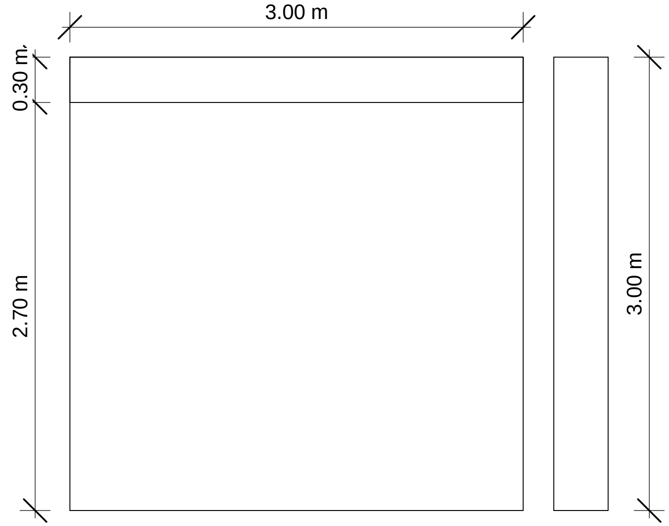
Table 77: (X3, Y1 + Y6, Z4) Measurements

	Lengths		**Surface /Area**								**Volume**
(X3, Y1 + Y6, Z4)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior	Slab	Slab
2D - Revit	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2D - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Revit - Vico	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Deviations in %										

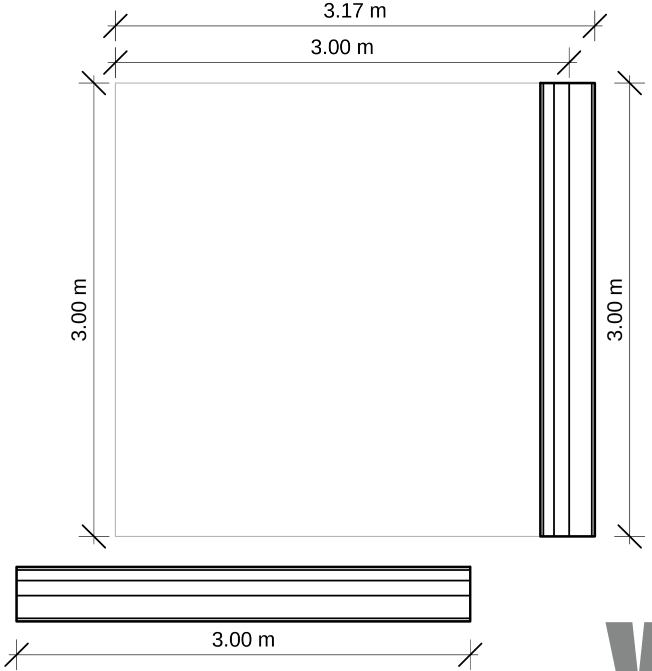
Table 78: (X3, Y1 + Y6, Z4) Deviation



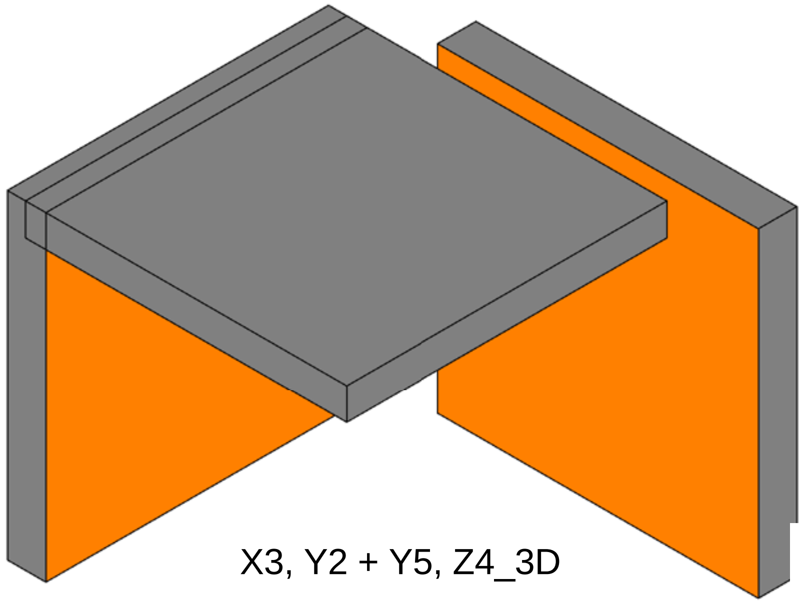
X3, Y2 + Y5, Z4_ELEVATION 1



X3, Y2 + Y5, Z4_ELEVATION 2



X3, Y2 + Y5, Z4_TOP VIEW



X3, Y2 + Y5, Z4_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

UC UNIVERSIDAD DE CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X3, Y2 + Y5, Z4**
SUBJECT: **X3, Y2 + Y5, Z4**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	18,00	0,36
M2	6,00	18,00	2,70
M3	6,00	17,10	1,71
M4	6,00	17,10	1,20
M5	6,00	17,10	0,34
Total	30,00	87,30	6,31

Table 79: (X3, Y2 + Y5, Z4) Manual QTO. Wall

Height (m)	Length (m)	Surface (m^2)	Volume to subtract (m^3)
3,00	3,00	9,00	0,00
3,00	3,00	9,00	0,00
2,70	3,00	8,10	0,09
2,70	3,00	8,10	0,06
2,70	3,00	8,10	0,02

Table 80: (X3, Y2 + Y5, Z4) Manual QTO. Slab

Layer	Length (m)	Area (m^2)	Volume (m^3)
W1	3,00	9,00	3,24
W1	3,00	9,00	3,24
Total	6,00	18,00	6,48

Layer	Area (m^2)	Volume (m^3)
Total	9,00	2,70

Table 81: (X3, Y2 + Y5, Z4) Revit QTO. Wall and Slab

Layer	Length (m)	Area (m^2)	Volume (m^3)
Wall	6,00	18,00	6,50
Total	6,00	18,00	6,50

Layer	Area (m^2)	Volume (m^3)
Total	9,00	2,70

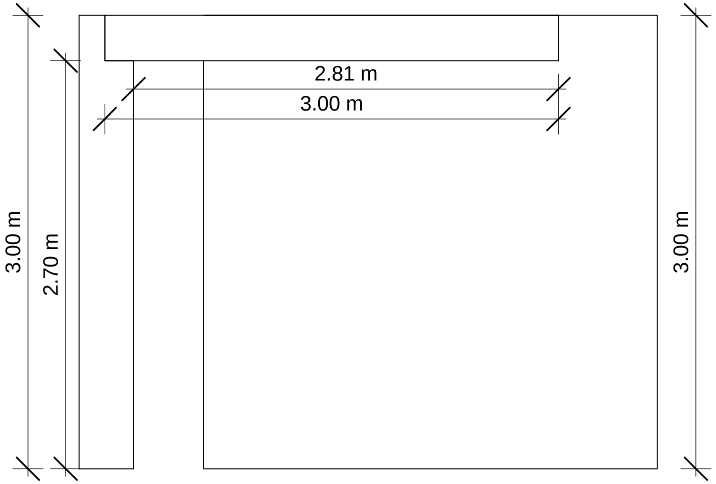
Table 82: (X3, Y2 + Y5, Z4) Vico QTO. Wall and Slab

	Lengths (m)		Surface /Area (m²)								Volume (m³)
(X3, Y2 + Y5, Z4)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior	Slab	Slab
2D	6,00	6,00	18,00	18,00	18,00	17,10	17,10	17,10	17,10	9,00	2,70
Revit	6,00		18,00							9,00	2,70
Vico	6,00		18,00							9,00	2,70
	Measurements										

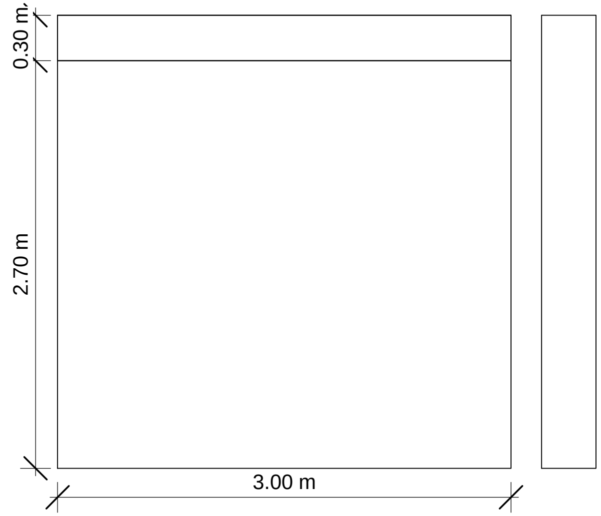
Table 83: (X3, Y2 + Y5, Z4) Measurements

	Lengths		Surface /Area								Volume
(X3, Y2 + Y5, Z4)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior	Slab	Slab
2D - Revit	0,00	0,00	0,00	0,00	0,00	5,26	5,26	5,26	5,26	0,00	0,00
2D - Vico	0,00	0,00	0,00	0,00	0,00	5,26	5,26	5,26	5,26	0,00	0,00
Revit - Vico	0,00		0,00							0,00	0,00
	Deviations in %										

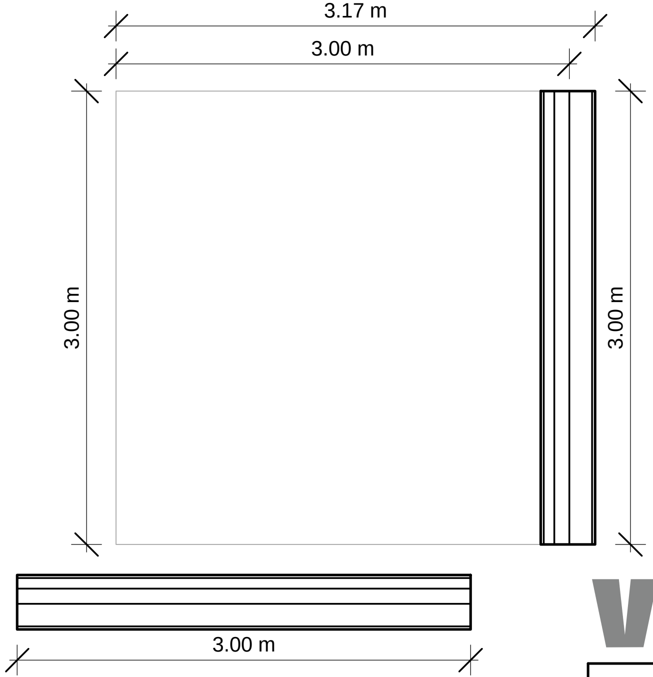
Table 84: (X3, Y2 + Y5, Z4) Deviation



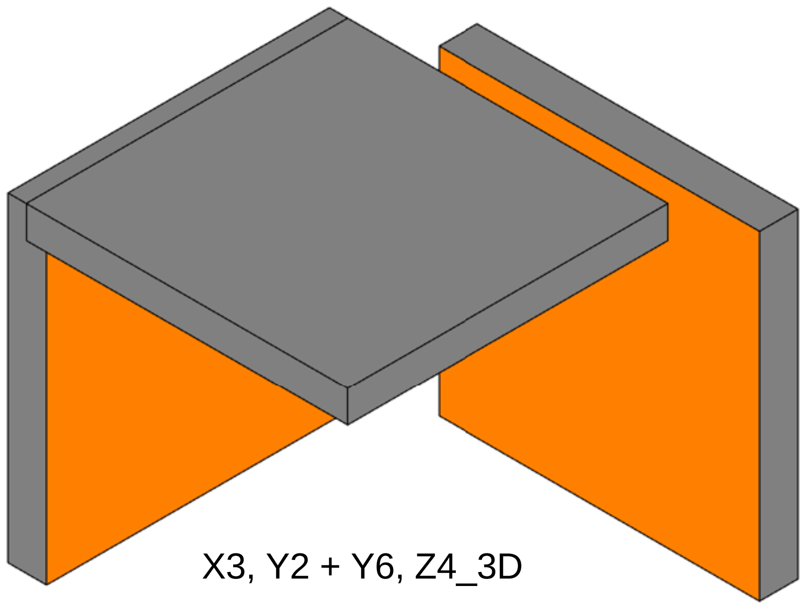
X3, Y2 + Y6, Z4_ELEVATION 1



X3, Y2 + Y6, Z4_ELEVATION 2



X3, Y2 + Y6, Z4_TOP VIEW



X3, Y2 + Y6, Z4_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X3, Y2 + Y6, Z4**
SUBJECT: **X3, Y2 + Y6, Z4**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	Area (m^2)	Volume (m^3)
M1	6,00	18,00	0,36
M2	6,00	18,00	2,70
M3	6,00	17,10	1,71
M4	6,00	17,10	1,20
M5	6,00	17,10	0,34
Total	30,00	87,30	6,31

Table 85: (X3, Y2 + Y6, Z4) Manual QTO. Wall

Height (m)	Length (m)	Surface (m^2)	Volume to subtract ($m^{3)}$
3,00	3,00	9,00	0,00
3,00	3,00	9,00	0,00
2,70	3,00	8,10	0,09
2,70	3,00	8,10	0,06
2,70	3,00	8,10	0,02

Table 86: (X3, Y2 + Y6, Z4) Manual QTO. Slab

Layer	Length (m)	Area (m^2)	Volume (m^3)
W1	3,00	9,00	3,07
W1	3,00	9,00	3,24
Total	6,00	18,00	6,31

Layer	Area (m^2)	Volume (m^3)
Total	9,00	2,70

Table 87: (X3, Y2 + Y6, Z4) Revit QTO. Wall and Slab

Layer	Length (m)	Area (m^2)	Volume (m^3)
Wall	6,00	18,00	6,30
Total	6,00	18,00	6,30

Layer	Area (m^2)	Volume (m^3)
Total	9,00	2,70

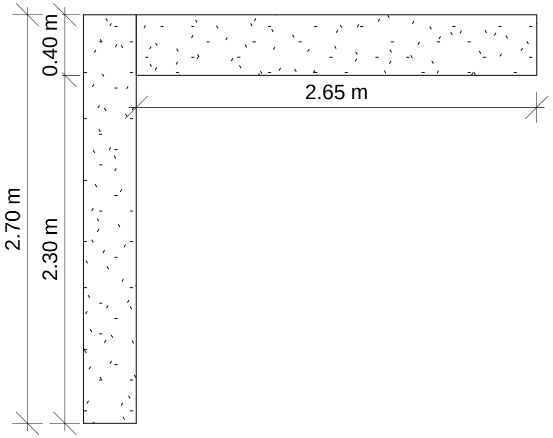
Table 88: (X3, Y2 + Y6, Z4) Vico QTO. Wall and Slab

	Lengths (m)		**Surface /Area (m^2)**								**Volume (m^3)**
(X3, Y2 + Y6, Z4)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior	Slab	Slab
2D	6,00	6,00	18,00	18,00	18,00	17,10	17,10	17,10	17,10	9,00	2,70
Revit	6,00		18,00							9,00	2,70
Vico	6,00		18,00							9,00	2,70
	Measurements										

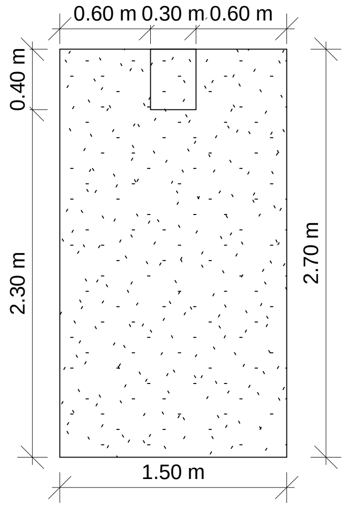
Table 89: (X3, Y2 + Y6, Z4) Measurements

	Lengths		**Surface /Area**								**Volume**
(X3, Y2 + Y6, Z4)	Interior	Exterior	Exterior	M1	M2	M3	M4	M5	Interior	Slab	Slab
2D - Revit	0,00	0,00	0,00	0,00	0,00	5,26	5,26	5,26	5,26	0,00	0,00
2D - Vico	0,00	0,00	0,00	0,00	0,00	5,26	5,26	5,26	5,26	0,00	0,00
Revit - Vico	0,00		0,00							0,00	0,00
	Deviations in %										

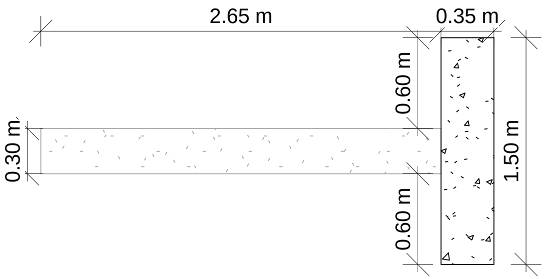
Table 90: (X3, Y2 + Y6, Z4) Deviation



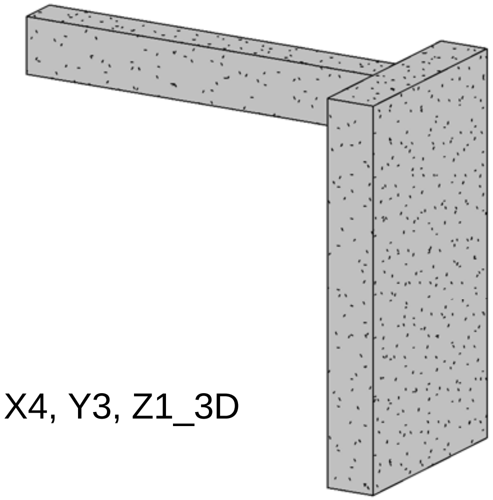
X4, Y3, Z1_ELEVATION 1



X4, Y3, Z1_ELEVATION 2



X4, Y3, Z1_TOP VIEW



X4, Y3, Z1_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X4, Y3, Z1**
SUBJECT: **X4, Y3, Z1**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)
STW - 1,50 x 0,35	1,50	0,35	2,70	4,88	5,00	1,42

Layer	Length (m)	Width (m)	Height (m)	Surface b1 (m^2)	Surface b2 (m^2)	Surface a1 (m^2)	Surface a2 (m^2)	Volume (m^3)
STB - 0,30 x 0,40	2,65	0,30	0,40	0,80	0,80	1,06	1,06	0,32

Table 91: (X4, Y3, Z1) Manual QTO. STW and STB

Layer	Length (m)	Volume (m^3)
STW - 1,50 x 0,35	2,70	1,42

Layer	Length (m)	Volume (m^3)
STB - 0,30 x 0,40	3,00	0,32

Table 92: (X4, Y3, Z1) Revit QTO. STW and STB

Layer	Height (m)	Area (m^2)	Volume (m^3)	Vertical surface a (m^2)	Vertical surface b (m^2)
STW - 1,50 x 0,35	2,70	10,00	1,4	X	X

Layer	Length (m)	Width (m)	Height (m)	Surface b1 (m)	Surface b2 (m^2)	Surface a1 (m^2)	Surface a2 (m^2)	Volume (m^3)
STB - 0,30 x 0,40	3,00	X	X	0,8	0,8	1,1	1,1	0,3

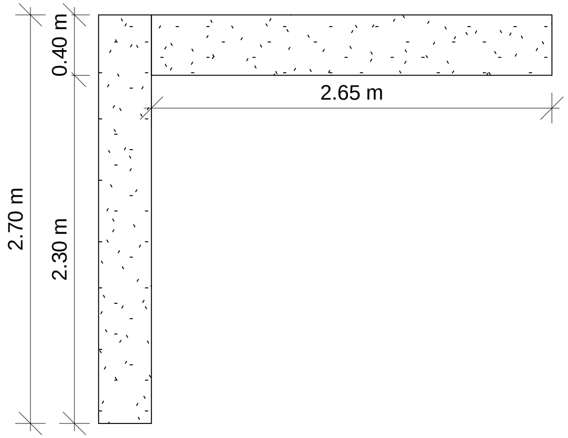
Table 93: (X4, Y3, Z1) Vico QTO. STW and STB

	STW - 1,50 x 0,35						**STB - 0,30 x 0,40**							
(X4, Y3, Z1)	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)	Length (m)	Width (m)	Height (m)	Surface b1 (m^2)	Surface b2 (m^2)	Surface a1 (m^2)	Surface a2 (m^2)	Volume(m^3)
2D	1,50	0,35	2,70	4,88	5,00	1,42	2,65	0,30	0,40	0,80	0,80	1,06	1,06	0,32
Revit	x	x	2,70	x	x	1,42	3,00	x	x	x	x	x	x	0,32
Vico	x	x	2,70	10,00		1,40	3,00	x	x	0,80	0,80	1,10	1,10	0,30
	Measurements													

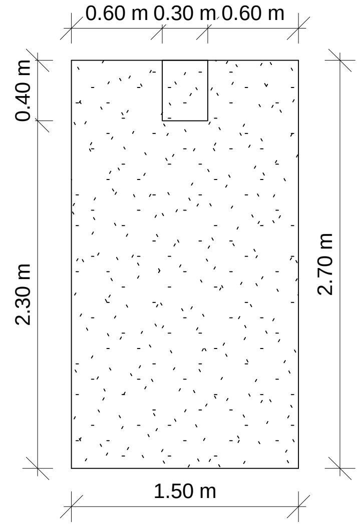
Table 94: (X4, Y3, Z1) Measurements

	STW - 1,50 x 0,35						**STB - 0,30 x 0,40**							
(X4, Y3, Z1)	Length	Width	Height	Surface a	Surface b	Volume	Length	Width	Height	Surface b1	Surface b2	Surface a1	Surface a2	Volume
2D - Revit	x	x	0,00	x	x	0,18	13,21	x	x	x	x	x	x	0,63
2D - Vico	x	x	0,00	1,32	1,32	-1,23	13,21	x	x	0,63	0,63	3,77	3,77	-5,66
Revit - Vico	x	x	0,00	x	x	-1,41	0,00	x	x	x	x	x	x	-6,25
	Deviation in %													

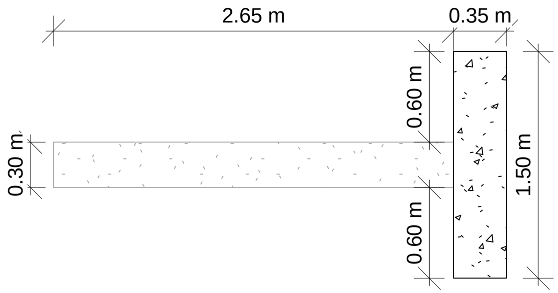
Table 95: (X4, Y3, Z1) Deviation



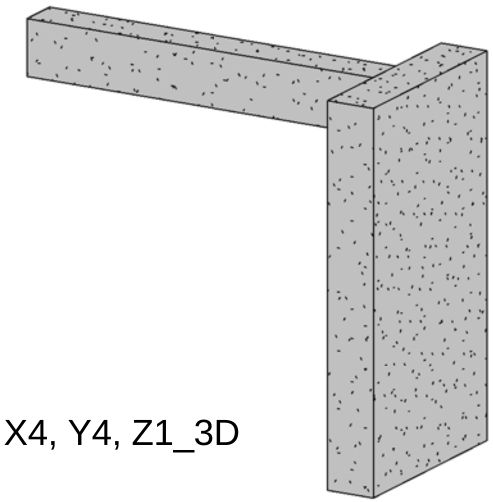
X4, Y4, Z1_ELEVATION 1



X4, Y4, Z1_ELEVATION 2



X4, Y4, Z1_TOP VIEW



X4, Y4, Z1_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X4, Y4, Z1**
SUBJECT: **X4, Y4, Z1**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layer	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)
STW - 1,50 x 0,35	1,50	0,35	2,70	4,88	5,00	1,42

Layer	Length (m)	Width (m)	Height (m)	Surface b1 (m^2)	Surface b2 (m^2)	Surface a1 (m^2)	Surface a2 (m^2)	Volume (m^3)
STB - 0,30 x 0,40	2,65	0,30	0,40	0,80	0,80	1,06	1,06	0,32

Table 96: (X4, Y4, Z1) Manual QTO. STW and STB

Layer	Length (m)	Volume (m^3)
STW - 1,50 x 0,35	2,70	1,42

Layer	Length (m)	Volume (m^3)
STB - 0,30 x 0,40	3,00	0,32

Table 97: (X4, Y4, Z1) Revit QTO. STW and STB

Layer	Height (m)	Area (m^2)	Volume (m^3)	Vertical surface a (m^2)
STW - 1,50 x 0,35	2,70	X	10,00	1,40

Structural Beam Schedule

Layer	Length (m)	Width (m)	Height (m)	Surface b1 (m)	Surface b2 (m^2)	Surface a1 (m^2)	Surface a2 (m^2)	Volume (m^3)
STB - 0,30 x 0,40	3,00	X	X	0,80	0,80	1,10	1,10	0,30

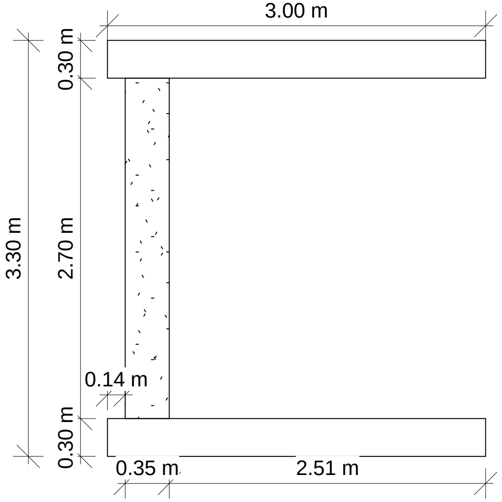
Table 98: (X4, Y4, Z1) Vico QTO. STW and STB

	STW - 1,50 x 0,35						STB - 0,30 x 0,40							
(X4, Y4, Z1)	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)	Length (m)	Width (m)	Height (m)	Surface b1 (m^2)	Surface b2 (m^2)	Surface a1 (m^2)	Surface a2 (m^2)	Volume(m^3)
2D	1,50	0,35	2,70	4,88	5,00	1,42	2,65	0,30	0,40	0,80	0,80	1,06	1,06	0,32
Revit	x	x	2,70	x	x	1,42	3,00	x	x	x	x	x	x	0,32
Vico	x	x	2,70	10,00		1,40	3,00	x	x	0,80	0,80	1,10	1,10	0,30
	Measurements													

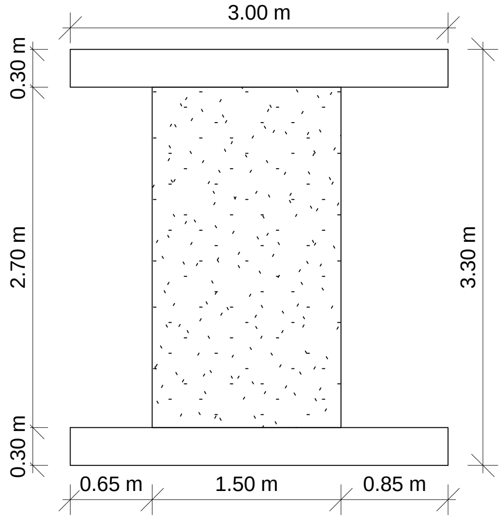
Table 99: (X4, Y4, Z1) Measurements

	STW - 1,50 x 0,35						STB - 0,30 x 0,40							
(X4, Y4, Z1)	Length	Width	Height	Surface a	Surface b	Volume	Length	Width	Height	Surface b1	Surface b2	Surface a1	Surface a2	Volume
2D - Revit	x	x	0,00	x	x	0,18	13,21	x	x	x	x	x	x	0,63
2D - Vico	x	x	0,00	1,32	1,32	-1,23	13,21	x	x	0,63	0,63	3,77	3,77	-5,66
Revit - Vico	x	x	0,00	x	x	-1,41	0,00	x	x	x	x	x	x	-6,25
	Deviation in %													

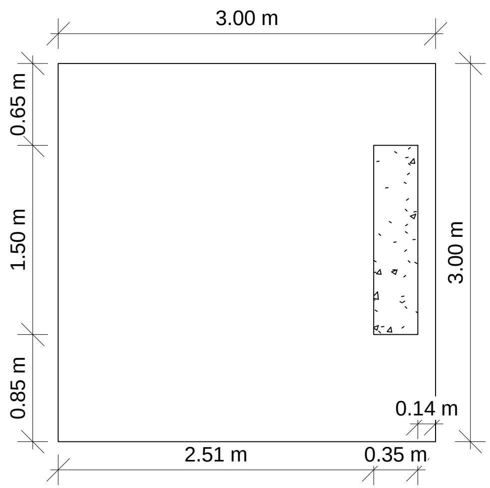
Table 100: (X4, Y4, Z1) Deviation



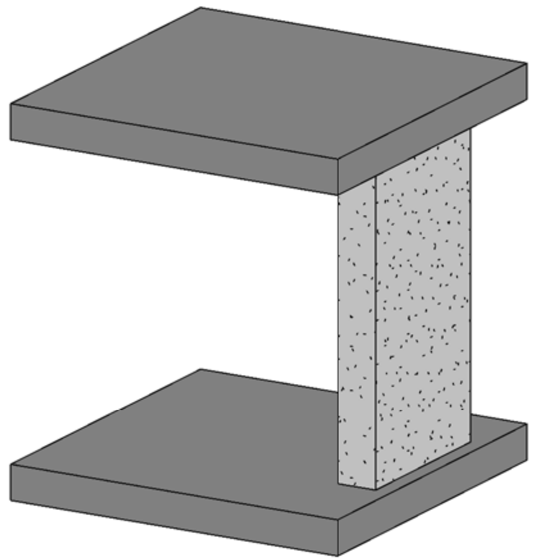
X5, Y3, Z1_ELEVATION 1



X5, Y3, Z1_ELEVATION 2



X5, Y3, Z1_TOP VIEW



X5, Y3, Z1_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	
SUBJECT: **X5, Y3, Z1**	SCALE: **1 : 60**	**X5, Y3, Z1**
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)
STW - 1,50 x 0,35	1,50	0,35	2,70	5,00	5,00	1,42

Layers	Length (m)	Width (m)	Height (m)	Top surface (m^2)	Bottom surface (m^2)	Volume (m^3)
Top slab	3,00	3,00	0,30	9,00	8,48	2,70
Bottom slab	3,00	3,00	0,30	8.48	9,00	2,70
Total	X	X	X	17,48	17,48	5,40

Table 101: (X5, Y3, Z1) Manual QTO. STW and Slab

Layers	Height (m)	Volume (m^3)
STW - 1,50 x 0,35	3,00	1,42

Layers	Surface (m^2)	Volume (m^3)
Top Slab	9,00	2,70
Bottom slab	9,00	2,70
Total	18,00	5,40

Table 102: (X5, Y3, Z1) Revit QTO. STW and Slab

Layers	Height (m)	Width (m)	Vertical surface area (m^2)	Volume (m^3)
STW - 1,50 x 0,35	2,70	X	10,00	1,40

Layers	Edge perimeters (m)	Width (m)	Height (m)	Bottom surface area (m^2)	Top surface area (m^2)	Volume (m^3)
Slab	24,00	X	X	18,00	18,00	5,40

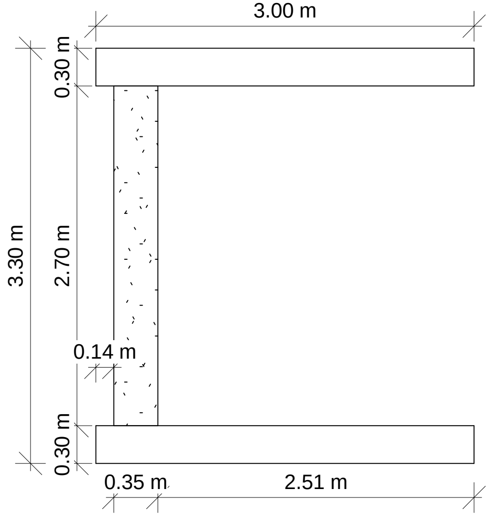
Table 103: (X5, Y3, Z1) Vico QTO. STW and Slab

	STW - 1,50 x 0,35						**Slab**			**STW +Slab**
(X5, Y3, Z1)	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)	Top Surface Area ((m^2)	Bottom Surface/Area (m^2)	Volume ((m^3)	Total Volume (m^3)
2D	1,50	0,35	2,70	5,00	5,00	1,42	17,48	17,48	5,40	6,82
Revit	x	x	3,00	x	x	1,42	18,00	18,00	5,40	6,82
Vico	x	x	2,70	10,00		1,40	18,00	18,00	5,40	6,80
	Measurements									

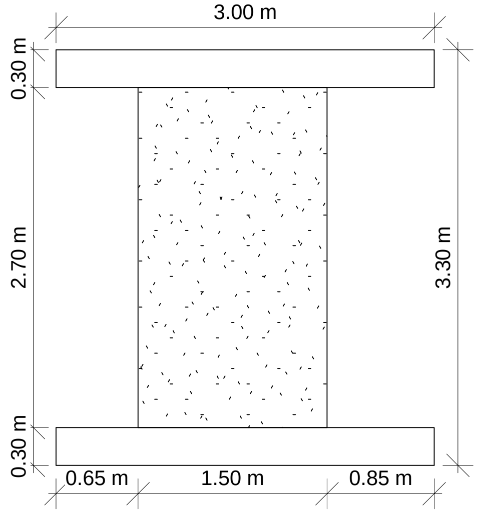
Table 104: (X5, Y3, Z1) Measurements

	STW - 1,50 x 0,35						**Slab**			**STW +Slab**
(X5, Y3, Z1)	Length	Witdth	Height	Surface a	Surface b	Volume	Top Surface/Area	Bottom Surface/Area	Volume	Total Volume
2D - Revit	x	x	11,11	x	x	0,18	3,00	3,00	0,00	0,04
2D - Vico	x	x	0,00	0,10	0,10	-1,23	3,00	3,00	0,00	-0,26
Revit - Vico	x	x	-10,00	x	x	-1,41	0,00	0,00	0,00	-0,29
	Deviation in %									

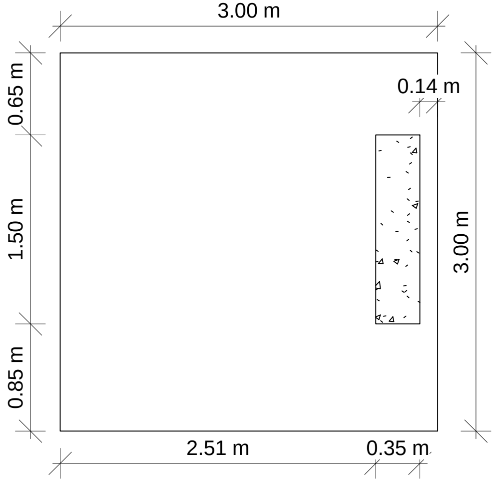
Table 105: (X5, Y3, Z1) Deviation



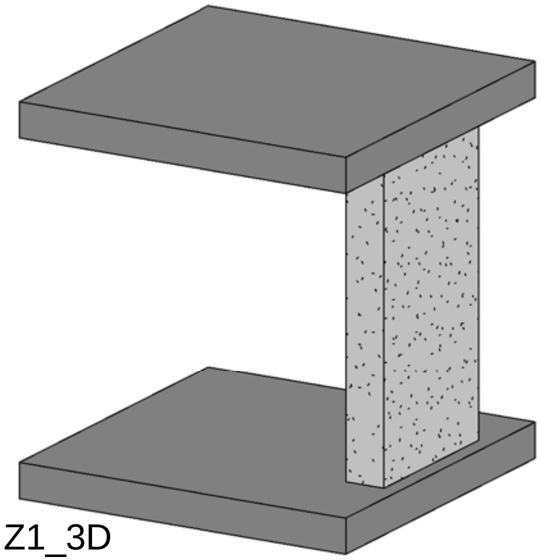
X5, Y4, Z1_ELEVATION 1



X5, Y4, Z1_ELEVATION 2



X5, Y4, Z1_TOP VIEW



X5, Y4, Z1_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

UNIVERSIDAD DE CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X5, Y4, Z1**
SUBJECT: **X5, Y4, Z1**	SCALE: **1 : 60**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)
STW - 1,50 x 0,35	1,50	0,35	2,70	5,00	5,00	1,42

Layers	Length (m)	Width (m)	Height (m)	Surface b1 (m^2)	Surface b2 (m^2)	Volume (m^3)
Top slab	3,00	3,00	0,30	9,00	8,48	2,70
Bottom slab	3,00	3,00	0,30	8,48	9,00	2,70
Total				17,48	17,48	5,40

Table 106: (X5, Y4, Z1) Manual QTO. STW and Slab

Layers	Height (m)	Volume (m^3)
STW - 1,50 x 0,35	2,70	1,42

Layers	Surface (m^2)	Volume (m^3)
Top Slab	9,00	2,70
Bottom slab	9,00	2,70
Total	18,00	5,40

Table 107: (X5, Y4, Z1) Revit QTO. STW and Slab

Layers	Height (m)	Width (m)	Vertical surface area (m^2)	Volume (m^3)
STW - 1,50 x 0,35	2,70	X	10,00	1,40

Layers	Edge perimeters (m)	Width (m)	Height (m)	Bottom surface area (m^2)	Top surface area (m^2)	Volume (m^3)
Slab	24,00	X	X	18,00	18,00	5,40

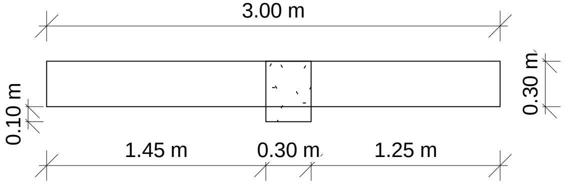
Table 108: (X5, Y4, Z1) Vico QTO. STW and Slab

	STW - 1,50 x 0,35						Slab			STW +Slab
(X5, Y4, Z1)	Length	Witdth	Height	Surface a	Surface b	Volume	Top Surface/Area	Bottom Surface/Area	Volume	Total Volume
2D	1,50	0,35	2,70	5,00	5,00	1,42	17,48	17,48	5,40	6,82
Revit	x	x	2,70	x	x	1,42	18,00	18,00	5,40	6,82
Vico	x	x	2,70	10,00		1,40	18,00	18,00	5,40	6,80
	Measurements									

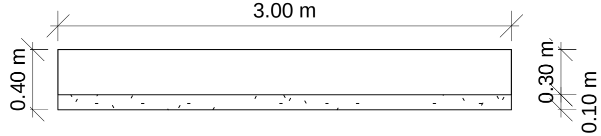
Table 109: (X5, Y4, Z1) Measurements

	STW - 1,50 x 0,35						Slab			STW +Slab
(X5, Y4, Z1)	Length	Witdth	Height	Surface a	Surface b	Volume	Surface/Area	Bottom Surface/Area	Volume	Total Volume
2D - Revit	x	x	0,00	x	x	0,18	3,00	3,00	0,00	0,04
2D - Vico	x	x	0,00	0,10	0,10	-1,23	3,00	3,00	0,00	-0,26
Revit - Vico	x	x	0,00	x	x	-1,41	0,00	0,00	0,00	-0,29
	Deviation in %									

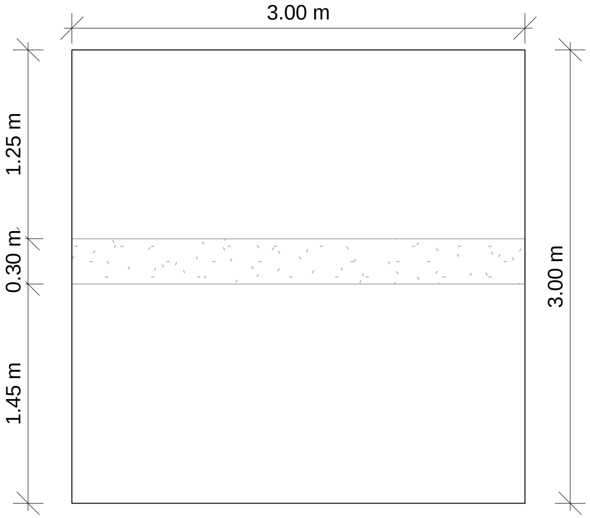
Table 110: (X5, Y4, Z1) Deviation



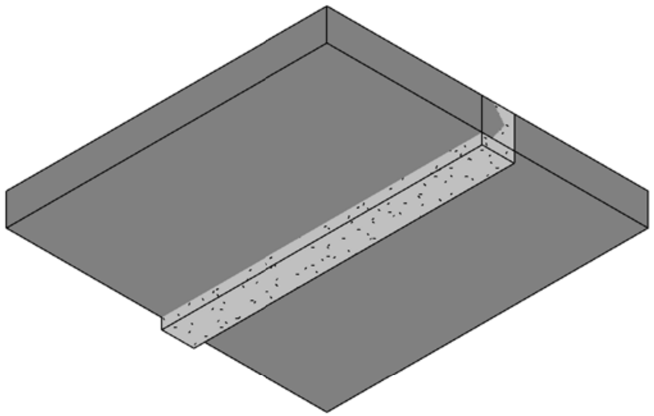
X6, Y3, Z1_ELEVATION 1



X6, Y3, Z1_ELEVATION 2



X6, Y3, Z1_TOP VIEW



X6, Y3, Z1_3D

VIA

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UC UNIVERSIDAD DE CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X6, Y3, Z1**
SUBJECT: **X6, Y3, Z1**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)
Slab	3,00	3,00	0,30	9,00	8,10	2,70

Layers	Length (m)	Width (m)	Height (m)	Surface b1 (m^2)	Surface b2 (m^2)	Surface a1 (m^2)	Surface a2 (m^2)	Volume (m^3)
STB - 0,30 x 0,40	3,00	0,30	0,10	0,90	0,00	0,30	0,30	0,09

Table 111: (X6, Y3, Z1) Manual QTO. Slab and STB

Layers	Area (m^2)	Volume (m^3)
Slab	9,00	2,70

Layers	Length (m)	Volume (m^3)
STB	3,00	0,36

Table 112: (X6, Y3, Z1) Revit QTO. Slab and STB

Layers	Edge perimeter (m)	Width (m)	Height (m)	Bottom surface area (m^2)	Top surface area (m^2)	Volume (m^3)
Slab	12,00	X	X	9,00	9,00	2,70

Layers	Length (m)	Width (m)	Height (m)	Bottom surface (m^2)	Top Surface (m^2)	Reference side surface area (m^2)	Opposite reference side surface area (m^2)	Volume (m^3)
STB - 0,30 x 0,40	3,00	X	X	0,90	0,90	1,20	1,20	0,40

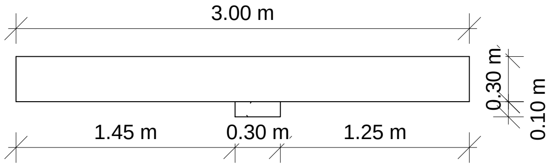
Table 113: (X6, Y3, Z1) Vico QTO. Slab and STB

	STB							**Slab**						**STB + Slab**
(X6, Y3, Z1)	Length	Witdth	Height	Surface b1	Surface a1	Surface a2	Volume	Length	Witdth	Height	Top Surface area	Bottom Surface area	Volume	Volume of concrete
2D	3,00	0,30	0,10	0,90	0,30	0,30	0,09	3,00	3,00	0,30	9,00	8,10	2,70	2,79
Revit	3,00	x	x	x	x	x	0,36	x	x	x	9,00	9,00	2,70	3,06
Vico	3,00	x	x	0,90	1,20	1,20	0,40	x	x	x	9,00	9,00	2,70	3,10
	Measurements													

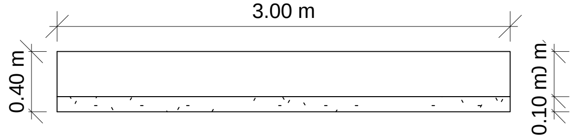
Table 114: (X6, Y3, Z1) Measurements

	STW - 1,50 x 0,35							**Slab**						**STB + Slab**
(X6, Y3, Z1)	Length	Witdth	Height	Surface b1	Surface a1	Surface a2	Volume	Length	Witdth	Height	Top Surface area	Bottom Surface area	Volume	Volume of concrete
2D - Revit	0,00	x	x	x	x	x	300,00	x	x	x	0,00	11,11	0,00	9,68
2D - Vico	0,00	x	x	0,00	x	x	344,44	x	x	x	0,00	11,11	0,00	11,11
Revit - Vico	0,00	x	x	x	x	x	11,11	x	x	x	0,00	0,00	0,00	1,31
	Deviation in %													

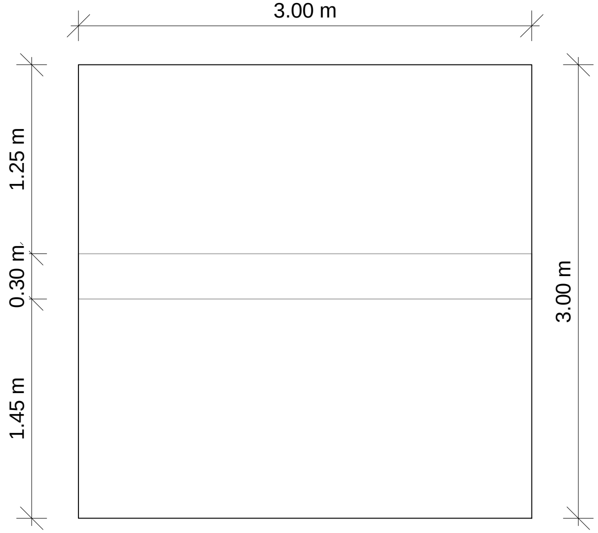
Table 115: (X6, Y3, Z1) Deviation



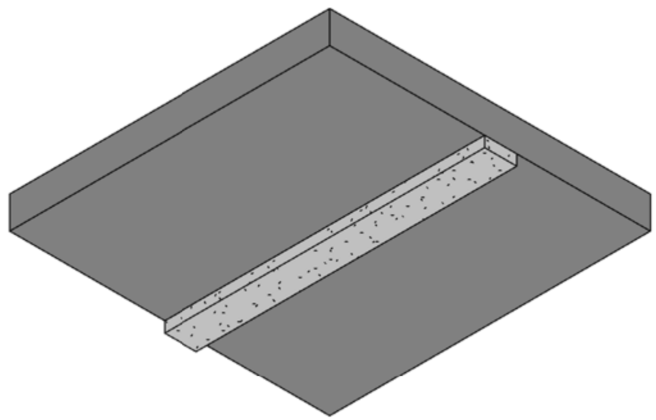
X6, Y4, Z1_ELEVATION 1



X6, Y4, Z1_ELEVATION 2



X6, Y4, Z1_TOP VIEW



X6, Y4, Z1_3D

VIA UNIVERSITY COLLEGE - UNIVERSITY OF CANTABRIA

PROJECT: **Analysis of QTO**	DATE: **08/14/14**	**X6, Y4, Z1**
SUBJECT: **X6, Y4, Z1**	SCALE: **1 : 50**	
DRAWN BY: **David Couto Cerqueiro**	CLASS:	

Layers	Length (m)	Width (m)	Height (m)	Surface a (m^2)	Surface b (m^2)	Volume (m^3)
Top Slab	3,00	3,00	0,30	9,00	8,10	2,70

Layers	Length(m)	Width (m)	Height (m)	Surface b1 (m^2)	Surface b2 (m^2)	Surface a1 (m^2)	Surface a2 (m^2)	Volume (m^3)
STB - 0,30 x 0,40	3,00	0,30	0,10	0,90	0,00	0,30	0,30	0,09

Table 116: (X6, Y4, Z1) Manual QTO. Slab and STB

Layers	Area (m^2)	Volume (m^3)
Slab	9,00	2,70

Layers	Length (m)	Volume (m^3)
STB	3,00	0,09

Table 117: (X6, Y4, Z1) Revit QTO. Slab and STB

Layers	Edge perimeter (m)	Width (m)	Height (m)	Bottom surface area (m^2)	Top surface area (m^2)	Volume (m^3)
Slab	12,00	X	X	9,00	9,00	2,70

Layers	Lenth (m)	Width (m)	Height (m)	Bottom surface (m^2)	Top Surface (m^2)	Reference side surface area (m^2)	Opposite reference side surface area (m^2)	Volume (m^3)
STB - 0,30 x 0,40	3,00	X	X	0,90	0,90	0,30	0,30	0,10

Table 118: (X6, Y4, Z1) Vico QTO. Slab and STB

	STB							Slab						STB + Slab
(X6, Y4, Z1)	Length	Witdth	Height	Surface b1	Surface a1	Surface a2	Volume	Length	Witdth	Height	Top Surface area	Bottom Surface area	Volume	Volume of concrete
2D	3,00	0,30	0,10	0,90	0,30	0,30	0,09	3,00	3,00	0,30	9,00	8,10	2,70	2,79
Revit	3,00	x	x	x	x	x	0,09	x	x	x	9,00	9,00	2,70	2,79
Vico	3,00	x	x	0,90	0,30	0,30	0,10	x	x	x	9,00	9,00	2,70	2,80
	Measurements													

Table 119: (X6, Y4, Z1) Measurements

	STB							Slab						STB + Slab
(X6, Y4, Z1)	Length	Witdth	Height	Surface b1	Surface a1	Surface a2	Volume	Length	Witdth	Height	Top Surface area	Bottom Surface area	Volume	Volume of concrete
2D - Revit	0,00	x	x	x	x	x	0,00	x	x	x	0,00	11,11	0,00	0,00
2D - Vico	0,00	x	x	0,00	0,00	0,00	11,11	x	x	x	0,00	11,11	0,00	0,36
Revit - Vico	0,00	x	x	x	x	x	11,11	x	x	x	0,00	0,00	0,00	0,36
	Deviation in %													

Table 120: (X6, Y4, Z1) Deviation

Appendix B: Survey

General information

Name of the company	Location. (*Country)*

Type of company. *Write "X" in the empty box*

	National Company		Architectural Firm
	International Company		Construction Company
			Structural Consultancy
			Engineering Consultancy
			Other (specify):

Number of employees

Specific information *Write "X" in the empty box*

- Is Building Information Modelling (BIM) implemented in your Company?

  a) Yes
  b) No

A. If **BIM** is **NOT IMPLEMENTED** in your company:

A1) in which software are projects based on to develop the design, cost estimations and schedule plans?

a) AutoCAD + Excel + MS Project
b) AutoCAD + Excel + Primavera Planner
c) Other combination (specify): ______________________

A2) how do you share the information between the different parts involved in the project.

a) E- Mail
b) Others (specify): ______________________

B. If **BIM** is **IMPLEMENTED** in your company

B1) when has BIM been implemented?

Year ____________

B2) what was the main reason to adopt BIM?

a) Size of projects
b) Efficiency/competitiveness
c) Others ______________________

B3) what is the level of implementation of BIM in your company?

a) 3D (modelling design)
b) 4D (planning)
c) 5D (cost estimations)
d) 3D + 4D + 5D (modelling design + planning + cost estimation)
e) Others (specify): ______________________

B4) what is the software used in each dimension of BIM?

- [ ] a) 3D (modelling design) ______________________________
- [ ] b) 4D (planning) ______________________________
- [ ] c) 5D (cost estimations) ______________________________
- [ ] d) Others (specify): ______________________________

B5) what are some of the most important **ADVANTAGES** of using **BIM** to estimate costs and planning against no BIM tools?

- [ ] a) Saving time
- [ ] b) Reliable data
- [ ] c) Others (specify): ______________________________

B6) what are some of the most important **DISADVANTAGES** of using **BIM** to estimate costs and planning against no BIM tools?

- [ ] a) Initial investment
- [ ] b) Interoperability problems
- [ ] c) Training time
- [ ] d) Others (specify): ______________________________

Appendix B.1: Results of the Survey

Company	Type of company	Does your company use BIM?
1	Construction Company	a) Yes
2	Architectural Firm	a) Yes
3	Construction Company	a) Yes
4	Other	a) Yes
5	Construction Company	a) Yes
6	Other	a) Yes
7	Architectural Firm	a) Yes
8	Engineering Consultancy	a) Yes
9	Engineering Consultancy	a) Yes
10	Engineering Consultancy	a) Yes
11	Construction Company	b) No
12	Construction Company	b) No
13	Construction Company	b) No
14	Architectural Firm	a) Yes
15	Architectural Firm	a) Yes
16	Architectural Firm	a) Yes
17	Architectural Firm	a) Yes
18	Architectural Firm	a) Yes
19	Engineering Consultancy	b) No
20	Architectural Firm	b) No
21	Architectural Firm	a) Yes
22	Architectural Firm	a) Yes
23	Construction Company	b) No
24	Engineering Consultancy	a) Yes
25	Architectural Firm	a) Yes

If BIM is NOT implemented		
Company	***Which program does your program use to cost estimating and planning?***	**When has BIM been implemented?**
1	c) Other	2010
2		2010
3		2013
4	c) Other	
5		last 4 yrs
6		2006
7		1997
8	b) AutoCAD + Excel + Primavera Planner	4 years ago
9		2000
10		2008
11	a) AutoCAD + Excel + MS Project	
12	a) AutoCAD + Excel + MS Project	
13	a) AutoCAD + Excel + MS Project	
14		2011
15		
16		2007
17	c) Other	Schematic Design
18		6 years ago
19	b) AutoCAD + Excel + Primavera Planner	
20	c) Other	
21		Been using it since 2006
22		5 years
23	a)AutoCAD + Excel + MS Project	
24		2012
25		2004

If BIM is implemented			
Company	**What has the main reason been to implement BIM**		***What is the level of implementation of BIM in your company?***
1	b) Efficiency/competitiveness		d) 3D + 4D + 5D
2	b) Efficiency/competitiveness		a) 3D (modelling design)
3	b) Efficiency/competitiveness	c) Others	a) 3D (modelling design) + b) 4D (planning) + e) Others
4			
5	b) Efficiency/competitiveness	c) Others	d) 3D + 4D + 5D
6	b) Efficiency/competitiveness		d) 3D + 4D + 5D
7		c) Others	a) 3D (modelling design)
8	b) Efficiency/competitiveness		b) 4D (planning)
9	b) Efficiency/competitiveness		a) 3D (modelling design)
10	b) Efficiency/competitiveness		a) 3D (modelling design)
11			
12			e) Others
13			
14	b) Efficiency/competitiveness		d) 3D + 4D + 5D
15		c) Others	a) 3D (modelling design)
16	b) Efficiency/competitiveness		a) 3D (modelling design)
17	b) Efficiency/competitiveness		a) 3D (modelling design) + b) 4D (planning)
18		c) Others	a) 3D (modelling design)
19			
20	b) Efficiency/competitiveness		
21	b) Efficiency/competitiveness		a) 3D (modelling design)
22	b) Efficiency/competitiveness		a) 3D (modelling design)
23			
24	b)Efficiency/competitiveness		b)4D (planning)
25	b)Efficiency/competitiveness		d)3D + 4D + 5D

If BIM is implemented			
Company	**B4) what is the software used in 3D BIM?**	**B5) what is the software used in 4D BIM?**	**B6) what is the software used in 5D BIM?**
1	Bentley projectwise , Revit	Synchro	RIB iTWO
2	Archicad		
3	Revit	Navisworks	BT2
4			
5	revit, sketchup, navisworks	revit, sketchup, navisworks	revit, sketchup, navisworks
6	Revit	Navis and MS Project	Sigma
7	ArchiCAD	none	none
8	vit, Civil 3D, inventor, Infrawo	Naviswork	
9	autocad, archicad		
10	Revit Structure and Revit MEP		
11			
12			
13			
14	Revit	Revit	Revit
15	Revit		
16	revit	no answer	no answer
17	Revit	Revit	
18	revit		
19	We started to use Revit in a small limitations		
20	vectorworks		
21	Autodesk Revit and Navisworks	Navisworks	
22	Revit		
23			
24	Revit architecture	Revit architecture	
25	Allplan Architecture and Engineering	Naviswork, Primavera, Presto, BIM+	Presto

If BIM is implemented		
Company	***What are some of the most important ADVANTAGES of using BIM***	***What are some of the most important DISADVANTAGES of using BIM***
1	a) Saving time. Project coordination and transparency	a) Initial investment + b) Interoperability problems + c) Training time
2	Interface in design	c) Training time
3	a) Saving time	b) Interoperability problems
4	a) Saving time + b) More reliable data is obtained	a) Initial investment
5	a) Saving time + b) More reliable data is obtained	Need to understand what is modeled and how modeled, does not always conform to the way materials need to be taken off
6	b) More reliable data is obtained	c) Training time
7	a) Saving time + b) More reliable data is obtained	
8	b) More reliable data is obtained + Clash detection, quality, coordination	a) Initial investment + The knowledge Engineer men, are old guys who don't understand softwares
9	b) More reliable data is obtained	c) Training time
10	b) More reliable data is obtained	c) Training time
11		
12		
13		
14	b) More reliable data is obtained	a) Initial investment + c) Training time
15	Visualize in 3D	a) Initial investment + b) Interoperability problems + c) Training time + Most consultants and clients do not use BIM software. Difficult to coordinate and integrate with 3D civil software. Because BIM requires a large amount of "front end" information combined (or confilicts) with the traditional design process curve which has information gathering increasing at the "back end", has increased demands/ responsibilities on Architects. Also, the quality of documentation has gone down since implementation of BIM software. Unfortunately, it is difficult to adjust the hardcopy output of BIM software. Mostly, people will just settle with software graphic standards. This is obvious in symbols, legends & schedules.
16	a) Saving time	c) Training time
17	b) More reliable data is obtained	a) Initial investment + c) Training time
18	a 3D model is the result of using revit to document the building	We dont use BIM for cost estimating or planning
19	a) Saving time	
20	b) More reliable data is obtained	b) Interoperability problems
21	b) More reliable data is obtained	c) Training time
22	a) Saving time + b) More reliable data is obtained + extra content is generated	a) Initial investment + c) Training time
23		
24	a) Saving time + b) More reliable data is obtained	a)Initial investment
25	a) Saving time + b) More reliable data is obtained + Saving construction cost	a)Initial investment

Table 121: Survey