



Analysis of Revit 2014 based on the Modeling of a TU Munich Building

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Abstract:

This Bachelor-Thesis will try to give an introduction to Building Information Modeling (BIM), the different existing software and more specifically Revit 2014. All this will be based on the modeling of Building 9 at the Technical University Munich.

The first part of the thesis focuses on the term Building Information Modeling and how/why it gained such popularity in recent times.

In the second part the focus will shift towards Revit 2014 and the main approach when modeling a building with Revit. All this will be made easier to understand with the example of modeling a building at the city campus of TU Munich. In depth explanations and various screen-shots should make the whole process easy to understand.

The last section of this Bachelor-Thesis will first critically analyze Revit and its possibilities and limitations. Second it will give a first look into the MEP section of Revit and what opportunities it gives to the user.

In conclusion the thesis should prove the importance of BIM and the way it can be used to make the construction and maintenance of buildings easier and more efficient.

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I. Introduction:

Since the beginning of human kind up until the second half of the 20th century sketching was a main part of the work of every engineer or architect. Architects used sketches to design and visualize what they were planning to build, while engineers used it to approximate and analyze the physical and mechanical properties of the project. With time the art of sketching improved significantly, but it still required long hours of precise handwork and mistakes were difficult to correct. With the emergence of the industrial revolution in the more developed countries, businessman and investors increased the demand on architects and engineers for efficiency and cost cuts in order to provide better products at a lower price. The increased competition required everyone contributing to a project to coordinate more and better in order to develop and execute the project faster and better. For example engineers had to start their work on the development of the building even before architects have finalized its design and analogically architects had to take into account the mechanical properties and process that a construction will undergo while designing the building. All these represented great challenges to everyone participating in the process of planning and building a commercial or industrial building.

The invention of the computer and the subsequent evolution of the computer technologies provided the perfect opportunity to face all these challenges and make them into possibilities to improve the efficiency and quality of the final product. But in order for this to happen there was the need of a tool, which would allow the user to input and modify his ideas into the computer language, and thus use the capabilities of the hardware. Such software would enable an architect to visualize his ideas better and apply changes to them at any point without having to redo the whole project. Engineers would be able to simulate movements of parts and internal material movements. The 2D representation provided by a sketch would be substituted first by a 3D computer model and later even by a 4D model, showing the processes a model undergoes in time. The software would allow all people involved

in a project to make decisions and predict their consequences, starting from the first conception up until the destruction of the building. The emergence of such software would subsequently lead to the creation of a whole new area of engineering and architecture called Building Information Modeling (BIM).

II. Building Information Modeling:

1. What is BIM and how did it start?

BIM is basically the creation and subsequent use of a four-dimensional computer-based model in order to plan, analyze, build and maintain a building throughout its life. The model contains all elements of the building, the way they are linked together, and all their mechanical and material properties. More precisely it contains all available information for the building. It can also be used to simulate processes that the building undergoes, such as load distribution and earthquake simulation. According to the National Building Information Model Standard Project Committee (NBIMSPC) the official definition of BIM is:

“Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.”

A BIM project is designed to support the work of everyone involved. Starting from the architects and engineers up to the owners and the authorities, everyone can easily overlook the project and do his job faster and more efficiently. Each member of the project can also make changes to the model and they will be immediately available to everyone else involved.

The idea of BIM, as a tool for decision-making throughout the life cycle of a building, started in the 1970's but the exact term was coined first in 1992 in the paper “Modeling multiple views on buildings” by G.A. Van Nederveen and F.P. Tolman.¹ Later on around the turn of the century Autodesk started using the term as nomenclature for their products and Jerry Laiserin popularized the term even further in 2002 with his paper “Comparing Pommes and Naranjas” where he argued that it should become a standard term in the industry.²

¹A Brief History of BIM

²Pommes and Naranjas by Jerry Laiserin

2. Historical Evolution of BIM

Already in 1962 Douglas C. Engelbart predicted the evolution of concepts like parametric modeling, object based design and relational database.³ All these would become in the next decades the core of Building Information Modeling. But the first and most vital development for the emergence of BIM was a graphical interface through which the user can interact with the model. Without such interface BIM would be impossible. The Sketchpad Program by Ivan Sutherland, introduced in 1963, gave the required basis for BIM.⁴ Afterwards appeared the need of methods to record shape information. The first such methods to be developed were construction solid geometry (CSG) and boundary representation (B-rep). Later on the appearance of databases with the most commonly used elements and materials, and the relational database made BIM more attractive and helpful to architects and engineers.

Next in the late 1980's it became clear that BIM would develop in two parallel directions. The first was focused on representing structures better and thus increasing the speed at which they were developed and their efficiency. The second direction was towards performing simulations on constructions in order to test their behavior in case of certain conditions. This was the start of distinguishing BIM not only as a tool that will substitute sketching, but also as an appliance that can perform different simulations on finished constructions.

From this point on it was obvious that BIM would become a major part of the work of every architect, engineer and later on even investors and authorities. In the last two decades the major improvements to the different software performing BIM were the introduction of parametric modeling and the a fourth dimension - time to the models.

³A Brief History of BIM

⁴Wiki page for Sketchpad

3. Advantages and Disadvantages of BIM

The main reason why BIM gained such popularity in the last few decades, and most specifically in recent years, is the enormous amount of advantages it gives to everyone involved in the process of constructing and maintaining a building. Some of the most obvious are the ability to recognize possible conflicts in the design at a very early stage and the ease in making minor, but even major, changes to the model. The early recognition of conflicts and their removal saves both time and money, while the easy introduction of changes allows fast modification without compromising all the work already done by the user. Further advantages that BIM gives to its users are the fact that computer models do not decay with time, unlike paper sketches, and the possibility to apply renovations to the model without having to create a new one. But perhaps the most important advantage of BIM is the possibility for everyone involved in a building project to work simultaneously on a model and thus improve team coordination and efficiency dramatically. Architects, engineers, interior designers, authorities and many others can work at the same time on a 4D model and coordinate their work with the others just by applying changes to the model, which become then visible to everyone else involved. This implementation of the work of many different specialists into one model allows employers to coordinate their work easily and efficiently and at the same time helps contractors to oversee the project better.

Obviously BIM possesses some disadvantages, like the need for powerful enough computers that can support the software and the necessity for employee training on the software being used. Another major disadvantage is the price that the company will have to pay for the software license. One more problem is the reliability of the software and its possibility to interact and operate with other BIM software.

All disadvantages listed above are serious and could stop a particular company from using BIM, but in general the amount of advantages BIM software gives to contractors and employers is so immense that the further expansion of BIM in many industries is inevitable. And this expansion would most probably lead to the

diminishing of some disadvantages like the high price of the software and its “interoperability” with other software.

4. Areas of Use

The previous section gave us a clear idea why the use of BIM is expanding rapidly in numerous industries, throughout the last two decades. It is important to make the distinction that BIM is used by numerous different groups of people involved in the building project but also at several distinct stages of the project.

First it shall be shown who is using BIM and how it improves his work. The first users of it are architects. BIM software allows them to substitute sketching with something more intuitive, simple to manipulate and easier to visualize, in this case a 4D model. The next group of people benefited by the emergence of BIM is mechanical, electrical and other types of engineers. It gives them the possibility to work hand in hand with architects and model their technical constructions around the design specified by the architect. At the same time they can perform simulations like load distribution and earthquake simulation on the building.⁵

Except the technical people involved in a project, BIM simplifies the work of many others taking part in the building and maintenance of a construction. Contractors can easily oversee the project and the progress made on it. Different authorities can also have effortless look on the construction and all its aspects. BIM could also give possible owners of space in the building the possibility to visualize it and thus help the investors sell property. The number of beneficiaries of BIM increases even further when we move to the next stages of the life of a building.

Until now the focus was on the design and construction stages, but BIM facilitates the decision-making throughout the whole life cycle of the building. People involved in the maintenance and renovation of the building will find their work supported and simplified by the BIM model. The existing model will aid even the ones responsible for the demolition of the building at the end of its life, as they

⁵Homepage of Autodesk

will easily analyze and determine the easiest and safest way to demolish the construction. In conclusion it can be stated that BIM is used on one hand by everyone involved in the project and on the other hand it is operated from the early conception of the building until its disposal.

5. Different BIM software

The number of existing BIM software is big but the main ones used by most enterprises can be decreased to a handful. The two biggest players in the BIM industry are Munich-based Nemetschek AG and California-based Autodesk.⁶ A big portion of the BIM software in use is developed or under the control of one of these two conglomerates. Following the four most popular ones will be briefly introduced and compared:

a) Allplan by Nemetschek

Nemetschek was founded in 1963 in Munich and has since then become one of the largest providers of CAD software. Its main product is the Allplan software that started in 1984.⁷ It is a software platform designed to aid the work of architects, civil engineers, contractors and facility managers.

b) Vectorworks by Nemetschek

Vectorworks on the other hand is a CAD software that in recent years started to implement many BIM functions. It was initially developed by Diehl Graphsoft but then acquired by Nemetschek.⁸

c) ArchiCAD by Graphisoft

Graphisoft is a Hungarian company that developed ArchiCAD as a BIM tool for engineers and architects. It was initially established as software for Macintosh and remains compatible with Apple computers.⁹ In contrast several other BIM products are not adaptable with Apple products.

⁶Wiki page of Nemetschek

⁷Homepage of the company Nemetschek

⁸Wiki page of Nemetschek

⁹Homepage of Graphisoft

d) Revit by Autodesk

Revit is a 4D BIM software that gives architects, engineers, contractors and many others the opportunity to design, build and facilitate a building. And as it will be used to model a building at the city campus of TU Munich, Revit will be discussed in detail in the next chapters.

III. Revit:

1. Autodesk

John Walker, one of the inventors of AutoCAD, found Autodesk in 1982.¹⁰ AutoCAD was their first product and remains the most popular one. But in the last three decades they have developed several notable products including Sketchbook, Pixlr and Revit. Except CAD and BIM platforms AutoCAD produce also media and entertainment software like Maya, a 3-D animation software.¹¹

2. Revit

After introducing the most popular BIM software and Autodesk as the company that develops Revit, the spotlight will move now to Revit itself. In 1997 ReonidRaiz and Irwin Jungreis founded the company Charles River Software, which started building Revit.¹² Their main goal was to include parametric modeling to the existing idea of CAD, and to allow the user to determine the parametric components graphically, instead of having to use a programming language. This idea of bi-directional associativity is the concept that distinguished Revit from the other BIM software platforms for a certain period of time, until the competition caught up. Bi-directional associativity means that when you change a certain component of your model (for example a wall) all components in relation with the modified one will automatically adjust themselves to the applied changes. For example if a floor level is moved further up all walls connecting it with the lower level will become higher, the ceiling of the lower lever will move up, walls of the current level will shorten and etc. This concept of bi-directional associativity makes the software more intuitive and therefore easier to work with for the user. It also saves enormous amount of time when applying changes to an existing model.

¹⁰Homepage of Autodesk

¹¹Wiki page of Autodesk

¹²Wiki page of Revit

In order to satisfy the specific needs of the different types of specialist using Revit, Autodesk divided the product into three main branches – Revit Architecture, Revit Structure and Revit MEP.

a) Revit Architecture

As the name suggests this branch of Revit is specifically designed to support the work of architects and building designers. The architecture section is mostly a CAD platform that facilitates building and site planning.

b) Revit Structure

This part is focused on aiding structural engineers and designers. Here the user has the possibility to perform analysis on the structure, plan structural reinforcement and generally perform all necessary actions to guarantee the structural stability and reliability of the building.

c) Revit MEP

The Mechanical Electrical and Plumbing (MEP) section of Revit allows mechanical, electrical and other similar types of engineers to design and simulate different kinds of technical systems. Piping and electrical systems can be modeled and integrated into a building with Revit MEP. Energy analysis of a construction can also be performed in MEP Revit. The MEP section will be discussed further in Chapter V.

3. What's new in Revit 2014

The latest version of Revit for the moment is Revit 2014, which was released in March 2013. There are many new functions and modifications compared to older version and the most important ones will be discussed in the following paragraphs.

The most notable features included in Revit 2014 for the first time are Displaced Views, Room Calculation Point and Split Elevations.¹³Displaced Views allows you to take apart the whole model in order to observe and analyze how each component comes into contact with the others. This feature is very useful as it helps

¹³What's new in Revit 2014

the user not only to understand how the different parts interact but also to recognize possible conflicts. The feature gives you the opportunity to determine the path on which the component will be dislocated and thus allows you to manipulate the model as you wish. An example of a model on which the Displaced Views functions is applied can be seen in Figure 1.

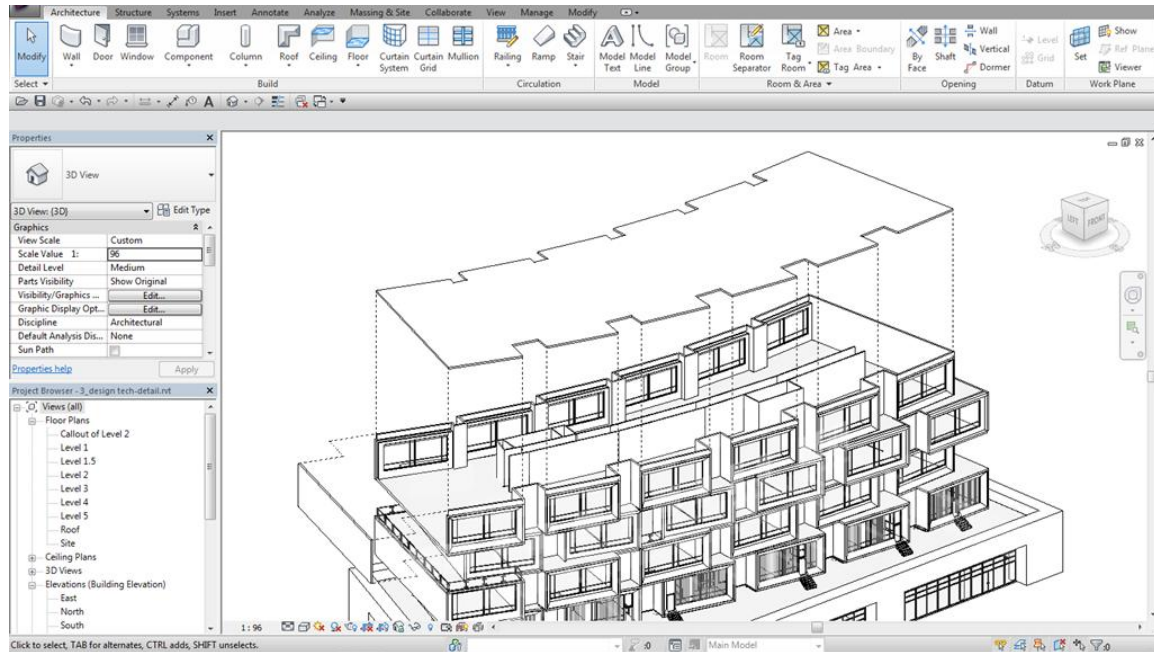


Figure 1 <http://autodesk-revit.blogspot.de/2013/03/whats-new-in-revit-2014.html>

The Room Calculation Point is a feature that gives Revit the ability to make decisions on its own, thus support and simplify the work of the user. It basically analyzes and then decides where specific components can be placed. The main goal is to place families, such as doors, windows and furniture, in meaningful places and thus save time.¹⁴ The function is obviously far from ideal, as it cannot take into consideration personal preferences, but it definitely makes the software smarter and more intuitive.

The last new feature to be discussed is actually more of an extension to an already existing one. It is the possibility to split elevations. In previous versions Revit allowed the user to introduce section to the model in order to have a better view of particular spaces, especially the ones inside a room. The split elevations

¹⁴What's new in Revit 2014

option is actually nothing more than the possibility to use the section function in elevation view. But this function combined with the Displaced View feature, which can be used in all views as good as in the 3D view, gives you a unique chance to see parts of your model that would have been very hard or even impossible to see in previous releases. The list of new functions and modifications is much longer but most of them are minor and not noteworthy.

But it is important to mention that Revit 2014 assesses to some extent one of the disadvantages of BIM software that was discussed earlier. The problem of interoperability with other software is substantial and because of that buildingSMART, formerly known as the International Alliance for Interoperability, has developed the Industry Foundation Classes (IFC) data model.¹⁵ Its main goal is to standardize the file-format in which BIM models are created and distributed. Autodesk provides an IFC Exporter App to further support interoperability and its latest version combined with Revit 2014 guarantees your model will get IFC certification, according to buildingSMART criteria.¹⁶

4. System Requirements for Revit 2014

First of all it should be noted that Revit 2014 is designed only to work with Microsoft Windows and cannot be used on other operating systems. Depending on the size and complicity of the model the system requirements may vary, but Autodesk provide a set of minimal requirements needed to work even on a simple model. The 32-bit version of Windows 7 is required in any of its configurations. 4 GB Random-access memory (RAM) and 5 GB free disk-space are also needed. In case of larger and more detailed models bigger RAM may be necessary. The display or monitor should have a resolution of at least 1'280 x 1'024 pixels and Internet connection is also required in order to register the software license. The newest version of Internet Explorer is also needed.¹⁷

¹⁵BuildingSMART Homepage

¹⁶New version of IFC exporter for Revit

¹⁷System Requirements for Revit 2014

5. User Interface and Main Terms in Revit

In order to explain the basic approach when modeling a building with Revit, first the main terms and the user interface of the software should be introduced.

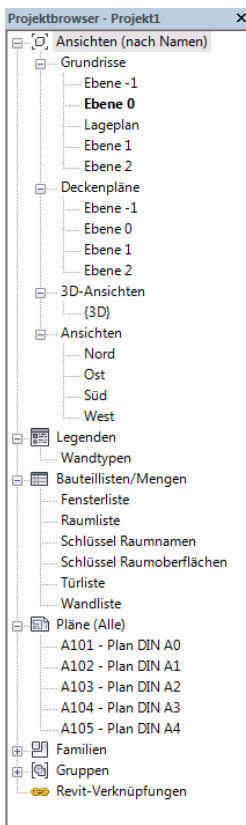
User Interface:



Figure 2: The Purple "R", The QAT and the MFT

The User Interface of Revit can be divided basically into four parts – top, sides and bottom. Starting from the top, in the top left corner the big purple "R" can be found, which gives you access to the application menu. Next to it at the top of the window is located the Quick Access Toolbar (QAT). It contains the most important

Figure 3: Project Browser



and used functions from the application menu, like open, save, undo and etc. Underneath the QAT comes the Multi-Function Table (MFT). From there every function possible in Revit can be selected. All tools needed to create and modify a project can be found there. The different functions are divided into groups according to their type. A specific group can be selected at the top of the MFT and underneath appear all functions from the selected group. The purple "R", the QAT and the MFT can also be seen in Figure 2. Below the functions comes the Options Bar. Initially it is empty, but once a function is selected some of the important options of the function can be viewed and modified there.

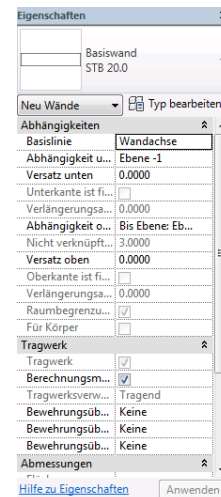


Figure 4.1: Properties Palette

Moving down comes the drawing window, where the model appears in the selected view. On the sides of it are two

important parts of the Revit user interface – the Project Browser (PB) and the Properties Palette (PP). The Project Browser is a very important tool in Revit as it contains all views, lists of components, plans and families. Each view can be selected from the PB and it immediately opens in the drawing window. The Project Browser is basically the main tool for operating and administrating the project. Figure 3 shows the layout of a PB at the beginning of a project. The Properties Palette is usually situated on the left side of the drawing window and it gives the user the opportunity to customize all properties and general parameters of an element. It changes according to the element or function that has been selected. Once you select an element the PP contains the option to open a dialog box where all available properties of it can be manipulated. Through this dialog box new types of elements can be created. An example of the PP for a reinforced concrete wall is shown in Figure 3.1. The last important feature in the drawing window is the Navigation Bar placed in the top right corner. Through the Navigation Bar the current view can be manipulated, which is very important especially in the 3D view.

Finally at the bottom of the Revit window the View Control Bar can be found (Figure 5). It contains functions designed to customize the current view to the preferences of the user. Some of them are scale, level of detail, shades and etc. Underneath the View Control Bar is the last important section in the user interface – the Status Bar (SB). The SB gives hints what action should be performed next and thus supports the user. It is especially helpful when a certain function from the MFT is selected, as the SB helps the user understand what action Revit is expecting from him so that the selected function can be performed.



Figure 5: View Control Bar

Main Terms:

a) Project

The Revit project is the main unit in the software. It is the database where all information about the model is stored. Everything from the different views and components to their relation and function is stored in the project, which is then

stored on a computer as a “.rvt” file. All planes, elements and families used in the model are also stored in the project file.

b) Category

Categories are groups of elements in a model like walls, doors and windows.

c) Family

Families are groups of elements within a category that share similar properties and/or have identical use.¹⁸The different elements within a family can vary in shape, size or material. Revit contains certain families, which come together with the software, but the user has the possibility to load families, download them or even create new ones from scratch. Every category of elements has an empty template designed to support the user when creating a new family. The process of creating a new loadable family will be discussed in detail in the next chapter.

d) Type

Each family can further be divided into different types of elements. Every type would have different size, be composed of a different material or vary in some other way.

e) Element

An element represents a certain component in the model. Elements are, as already revealed, grouped in types, families and categories. But elements can also be differentiated based on their purpose in the model. The differentiation of elements can be seen in the following Figure 6.

f) Planes

Planes are a features designed to give constraints to elements like walls and at the same time specify the location of ceilings, roofs and floors. They basically represent an endless horizontal element. The importance of planes and the exact way in which they are created and used is revealed in Chapter IV.

¹⁸What is a Revit family?

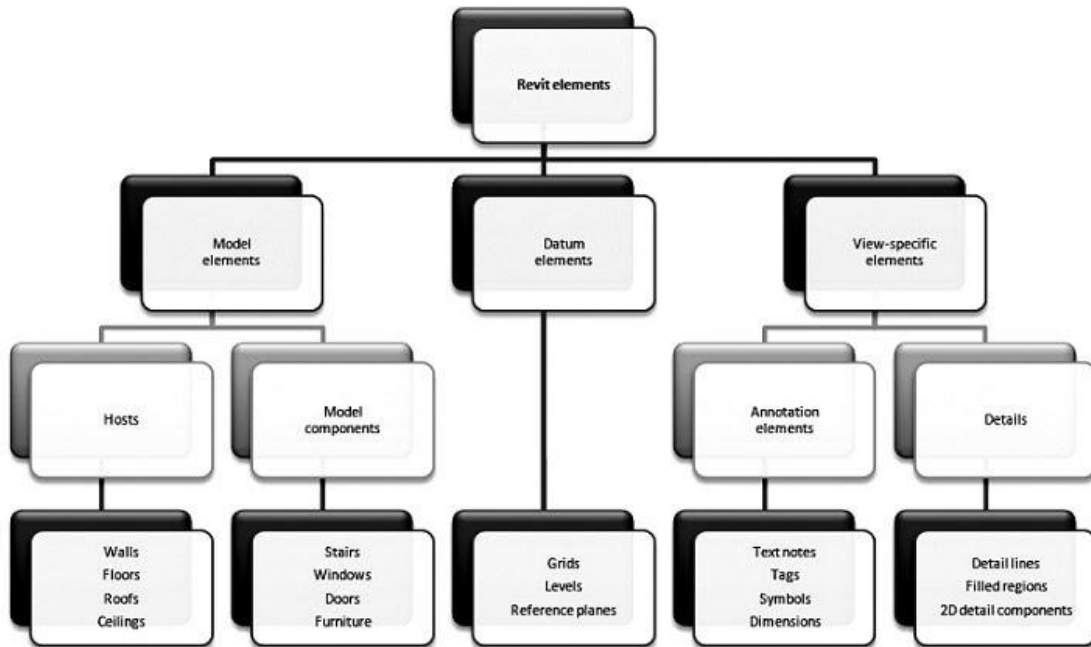


Figure 6: Bachelor-Thesis by Michael Weinholzer (2010)

6. Basic Approach in Architectural Modeling with Revit

Every model to be designed with Revit requires specific steps in order to complete it and create a successful building model. But despite the uniqueness of every structure created with the software, there are several key steps that are to be performed on all models. These steps are vital for the correct modeling of almost every kind of building and because of that they can be described as the main approach to Building Information Modeling with Revit.

In the beginning the required number of planes should be created and the distance between each one of them specified. Planes usually represent the floor levels of a building, but they can also be used to specify the location of roofs and foundations. There is no correct amount of planes in a project, as it depends on the preferences of the user. Their goal is only to simplify the subsequent modeling. Planes are mostly horizontal but vertical ones can also be created using the function “Grid”.

Once the planes have been defined layout plans of the building can be imported into Revit if available. They support mostly the modeling of walls and doors but are not necessary for the successful modeling of the building. The next step is to model the outside and subsequently the inside walls. If the material of the walls is not available in the existing Revit families, new wall types have to be created or existing ones can be modified. Once all walls are in place and their measures specified, the foundation and the roof of the building can be modeled. Roof type and material can be modified analogically to the walls. Foundations and roof can be created also at a later stage of the modeling process. If present, ceilings should also be placed once the room layout is done.

The next step is to place all windows and doors. First the required types should be available in the Revit library and then they can be placed in the model. If a particular window or door can not be found in the available library it should either be downloaded or created as a new family, and then loaded into the project. Stairs and railings are also to be placed between all existing floors. At this point the main parts of the building are in place and all details of the project can be modeled.

IV. Modeling of Building 9 of the TU Munich

1. Introduction to the Building

Building 9 of the TU Munich city campus is located in the inner courtyard of the facility. It is connected with the Audimax building, thus both constructions share similar design and are composed of similar materials. Building 9 houses several chairs from the Faculty of Electrical Engineering and Information Technology and the main campus cafeteria. It has eight floor levels each divided roughly into three sections.

2. Course of Action

The course of action for the modeling of the building involves the following steps, which will be discussed extensively in the next sections:

- i. Creation of Planes
- ii. Building of Outside Walls and their Foundations
- iii. Creation of Sloped Outside Walls
- iv. Support Columns and Beams
- v. Inside Walls
- vi. Introduction of Floors
- vii. Insertion of Doors and Windows
- viii. Development of East and West Wall Profile
- ix. Stairs and Railings
- x. Creation of Two Part Roof

3. Construction of Planes

Planes are a vital tool for the architectural and structural modeling with Revit. They are usually utilized to represent all the floor levels, bottom of wall foundations, top of the roof and other important vertical or horizontal points. The benefit of planes is that once the distance between each one of them is specified, the user can easily insert walls, windows, doors and others just by attaching them to specific planes. This way the height of all this objects does not have to be explicitly indicated every time. And even if a certain object cannot be located exactly between two existing planes, because of its specific height, it can still be attached to the planes by specifying an offset. All this provides for a better and easier overview of the construction. In the case of the TU Munich building the number of required planes at the beginning of the project was set to 12. 8 planes were created representing each floor level, 2 for the bottom of the foundations and the rooftop and two more representing the end of the east and side walls. Later on several additional planes will be created in order to simplify later stages of the construction. The current layout of the planes can be seen in Figure 7.

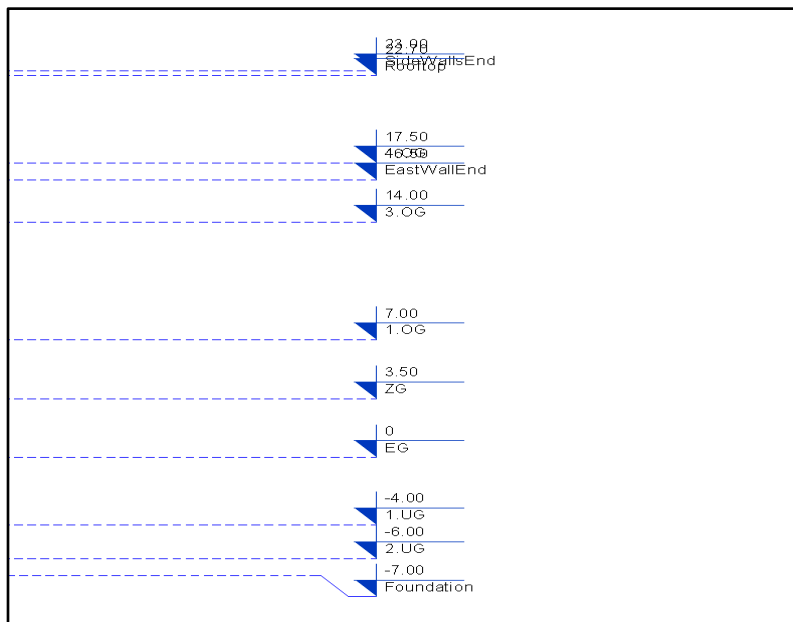


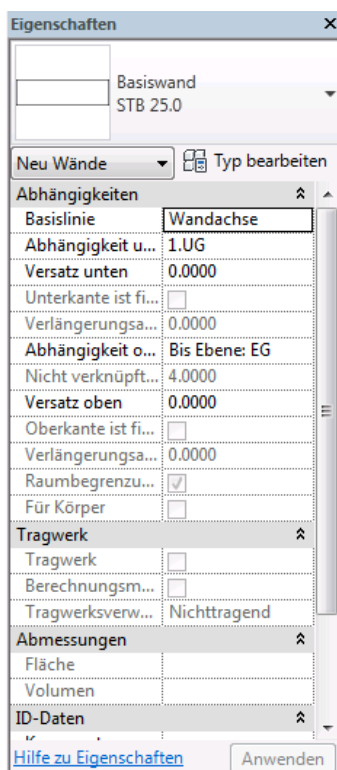
Figure 7: Plane Layout

Each floorlevel is 3.5 meters high with the exception of the first underground floor which is 4 meters high. The foundation is 1 meter below the bottom floor level and the rooftop is 5.2 meters above the fourth floor level. The height of the side walls is 22 meters. The names of the planes were changed in order to simplify their use.

4. Outside Walls and Foundation

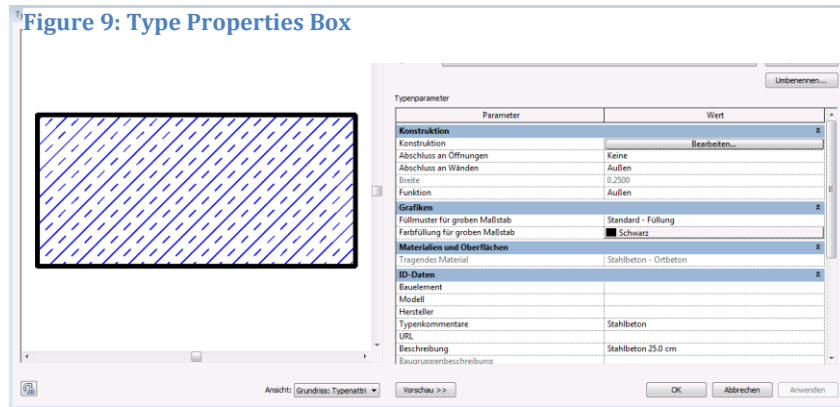
Since the building is complex and lacks symmetry the creation of the outside walls has to be done in several separate steps. The north sidewall will be discussed in the next section, as it is more complicated to build, so in this section the focus will fall on the other three outside walls. First the south sidewall is created since it is the simplest one and is composed from top to bottom from the same material – reinforced concrete. Then for the other three sides the outside wall for the second underground level is created. It is also from reinforced concrete and is entirely underground. At this moment the foundation of the walls can be placed. Each

Figure 8: Properties Box



foundation is one meter tall and one meter wide. Since there is no information about the actual size of the foundations these measures are only an approximation.

Subsequently the focus moves to the east wall. At the first underground level it is composed again from reinforced concrete but only up to the north end of the cafeteria, since only this part is underground. The small part between the north end of the cafeteria and the north wall is above the surface and has the same design as the rest of the wall above ground level. From the ground floor up to its end the east wall is composed partly from aluminum and partly from glass. Since these types of walls are not present in the existing wall types that Revit contains, they have to be created. A new wall type can be



created by going to the “Edit Type” function in the Properties Box (Figure 8). The extended “Type Properties” window appears (Figure9), where the selected wall type can be duplicated and renamed. Then the “Edit” button is used to reach the window where each layer of a wall can be modified and its material can be determined. The user has to click on the material section for the “Material Box” to appear where every possible material can be selected and specified. The “Material Box” can be seen in Figure 10. When the desired material is selected the thickness of the wall has to be specified and the new wall type is ready for use.

For the west and east walls a 10cm aluminum wall and a 3.5cm glass wall are created using the discussed steps. Each floor level consist of one meter high aluminum wall, followed by one meter of glass and then two portions of 50cm aluminum walls divided by 50cm of glass. Every 50cm there is a wall profile, which

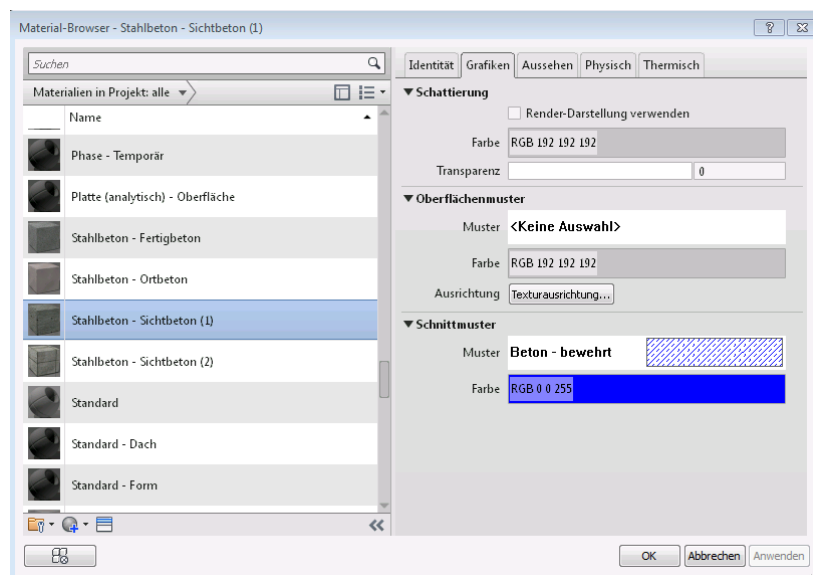


Figure 10: Material Box

will be discussed separately later on. The layout of one floor level of the wall can be seen in Figure 11.

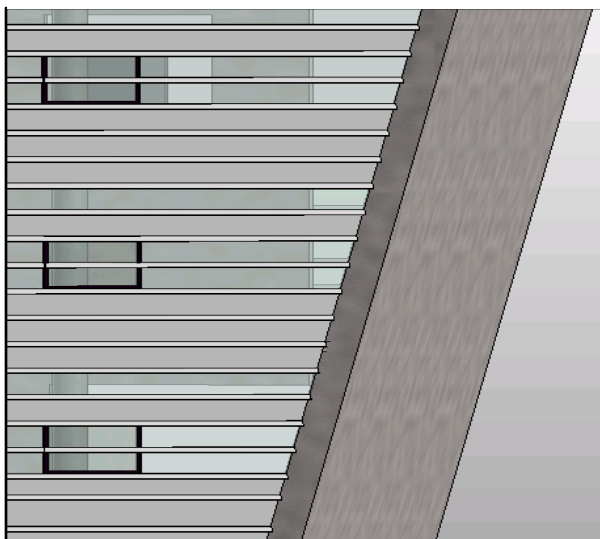


Figure 11: Layout of One Floor Level at The East or West Facade

The same pattern is repeated up to the end of the east wall, which is at 2.5 meters on the third floor.

The next step is to build the west wall. It has the same pattern as the east one, but its span is from the first underground level up to 2.5 meters above the fourth and last floor level. It is also five meters longer at the north end. Once both the east and west walls are in place, the angle which they both have at their north end has to be created. This is done with the function “Edit profile”. Each wall piece is

Figure 12: Angle at The North Edge of The East Facade



selected and then the function is chosen. At this point the wall boundary appears in red and can be manipulated randomly. In our case the north edge is tilted by 10 degrees. After this is done for each part of the wall the result can be seen in Figure 12.

At this point three of the four outside walls are in place with only the north one remaining.

5. Sloped Outside Walls

The north wall has to be addressed separately since it does not have a 90 degrees angle to the east and west walls and at the same time has also an odd angle to the vertical plane. The only way to build sloped walls is through the function “Wall by Face”. But in order to use this function first a project body has to be created. Figure 13 shows where in the Multi-Function Table this two functions can be found.

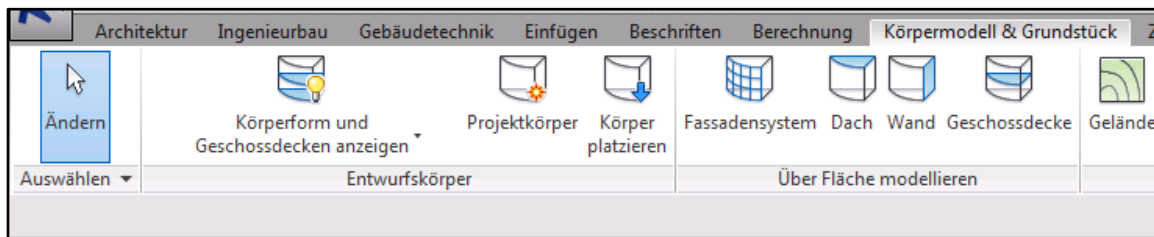


Figure 13: The Functions “Project Body” and “Wall by Face” in the MFT

After the project body function is selected the user has to make a 2D sketch that is then enhanced into a 3D solid. The faces of the solid can then be used for the function wall by face.

In our case a rectangular connecting the ends of the east and west walls was sketched. After the sketch was transformed into a solid body using the function “Create Form”, one of its faces was carefully placed in such a way that it connects the tilted edges of both the east and west walls. Once the face of the body is in the desired position the function wall by face is employed. The user has to select the desired face and the wall is placed at it. Then the project body can be deleted so that only the wall remains in place. This method for creating sloped walls caused several problems in the model that will be discussed in Chapter VI.

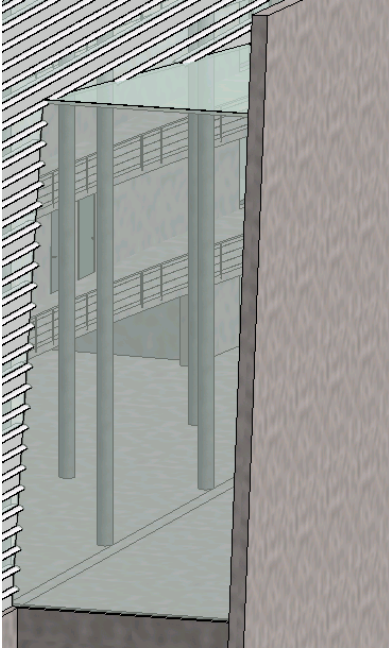


Figure 14: Glass Facade of The Cafeteria

The project body function is then used to create the south glass wall of the cafeteria and its glass roof. But in order to create them first the concrete wall dividing the cafeteria and the Audi Max has to be placed. The wall is placed under an angle to the east facade and its top edge is modified using the “Edit Profile” function. Then the glass wall and roof of the cafeteria are placed. The end result can be seen in Figure 14. At this point all outside walls are in place and the focus moves to the inside of the building.

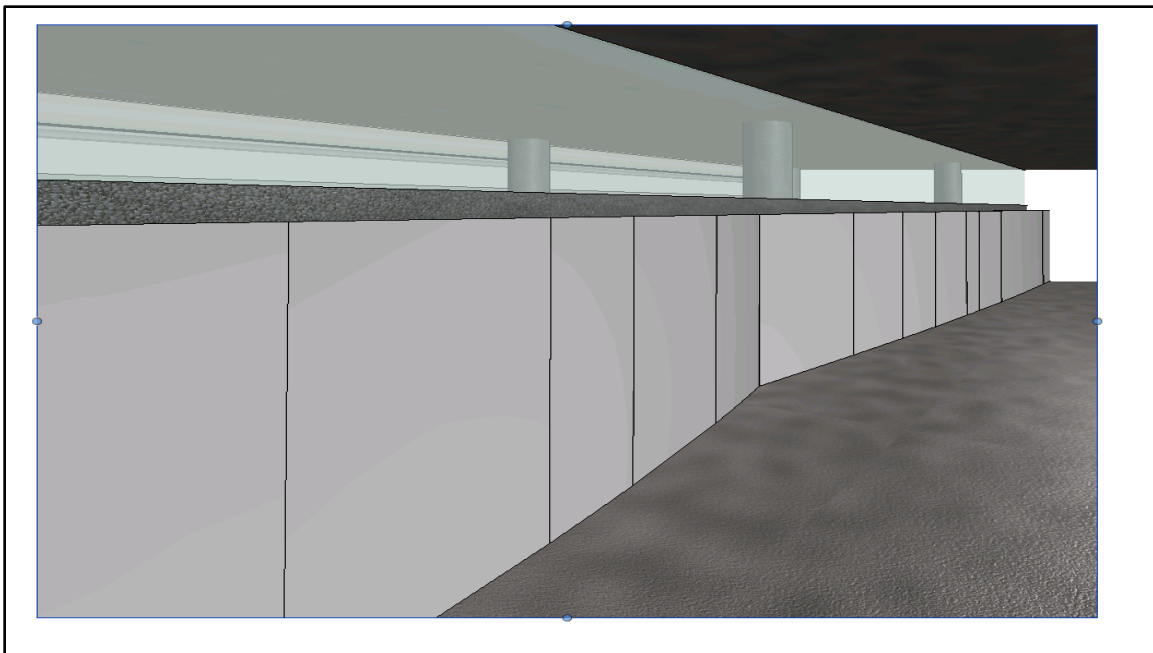
6. Main Inside Walls and Support Columns

On the inside the construction is supported by several concrete walls and numerous concrete columns. The support columns are divided into three groups. Two of them go along the east and west walls, each around 50cm from the respective wall. The third group is placed more or less along the middle of the building but their location varies in some parts. The main support wall that is mostly parallel to the long side of the building is the only support wall going from south to north. All other main support walls are in the direction east - west. They can be divided into three groups of two. Each group consists of two walls placed at an approximately 20 degrees to each other. The space between these two walls is occupied by the three staircases and a lift.

7. Other Inside Walls

The rest of the inside walls are once that do not support the building statically and thus have the only goal to divide the space into rooms and other areas. For almost all non-supporting inside walls a standard 10 or 12cm plasterboard wall was used. The main exceptions are the two arc shaped walls in the two main corridors of the building. They can be found on every floor level except the underground ones. The difficulty in creating these walls is not only their shape but also the fact that they are

Figure 15: Arc Shaped Inside Wall, Support Beam and Glass Wall Seen Using The Camera Function



composed of three parts. For the first 2.2 meters the wall is a thin aluminum one, then we have a 15cm thick and 70cm wide support beam. On top of the beam comes a glass connecting with the next floor level. This construction can be seen with the camera view in Figure 15. The shape of the aluminum part is done by selecting the arc function in the sketch box.

8. Floors

Next the floors of each level were created. For the floors a standard 20cm concrete layer and on top a 10cm default floor material layer were used. Once the floor type is selected its shape has to be sketched using the sketching tools. In the case of Building 9 it is important to take into consideration the fact that all floor levels above the ground floor form a terrace above the cafeteria. Otherwise the floor levels go to each of the outside walls. An example can be seen in Figure 16 where the sketch of the mezzanine floor is shown.

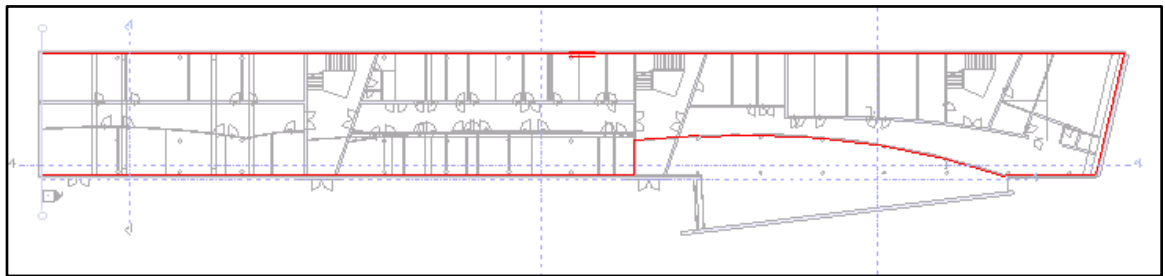


Figure 16: Floor Sketch for The Mezzanine Level

The sketches of the first, second and third floors are identical to the mezzanine one leaving out only the fourth one. The difference in the fourth one is that the terrace above the cafeteria is narrower since the space there is smaller because of the lower part of the roof. The floors of the two underground floors are perfect rectangles and thus fairly simple to sketch.

9. Doors and Windows

The introduction of all doors and windows requires a sufficient amount of effort since none of the ones in the building can be found in the default Revit library. In this case a new family has to be created or an existing one can be modified and then imported into the project. In order to create a new door or window family one of the files “M_Fenster” or “M_Tür” has to be opened. The empty family file represent a template for the sketching of a new element. It provides the user with several view

options. On top of that the file contains diverse planes and lines including set conditions between them all designed to simplify the work of the user. On of the views in the empty “M_Tür” file with all the existing planes and conditions can be seen in Figure 17.

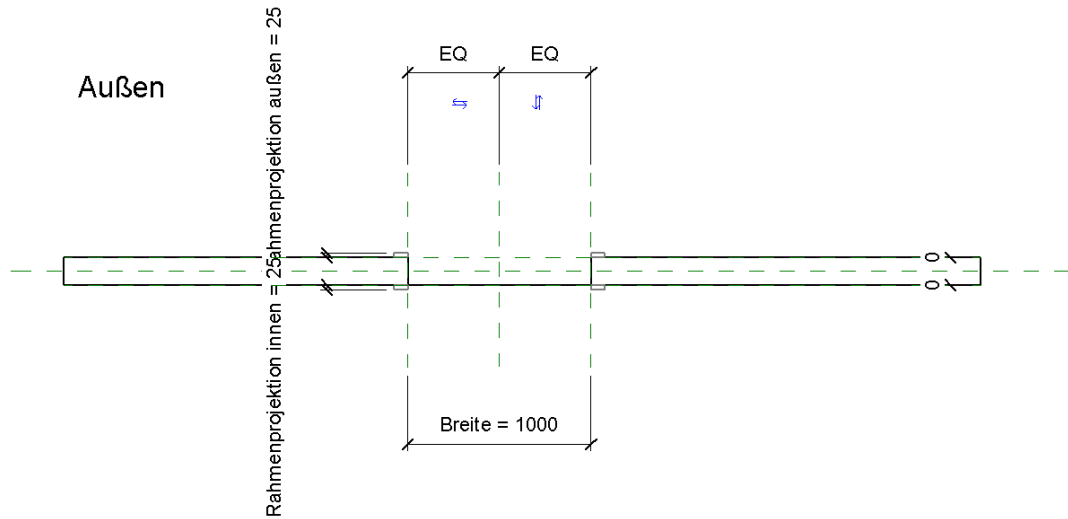


Figure 17: The Empty Template “M_Tür”

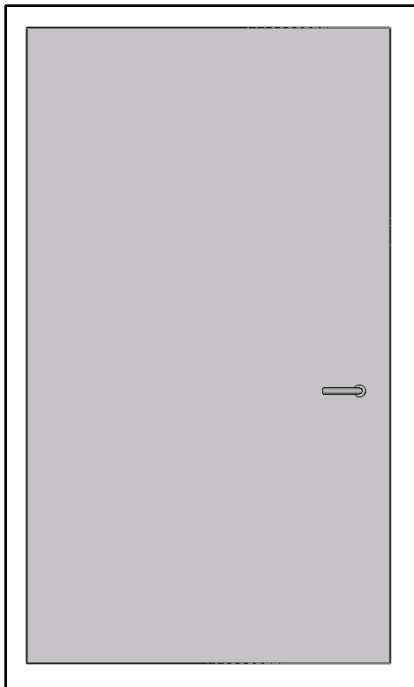


Figure 158: Aluminum Inside Wall

In this section the focus falls on the inside doors, while the outside ones will be discussed in a later section. On the inside there are three types of doors - a glass filled one, a standard block frame one and an aluminum one. From the glass filled and block frame doors double versions are also required. In both cases an existing door family was used and modified to fulfill the specification of the doors in the building. For the aluminum door a new family had to be created since it varies strongly from the existing ones. The door would be 1.2 meters wide, 2.1 meters high and composed of aluminum, thus matching the arc wall on the inside,

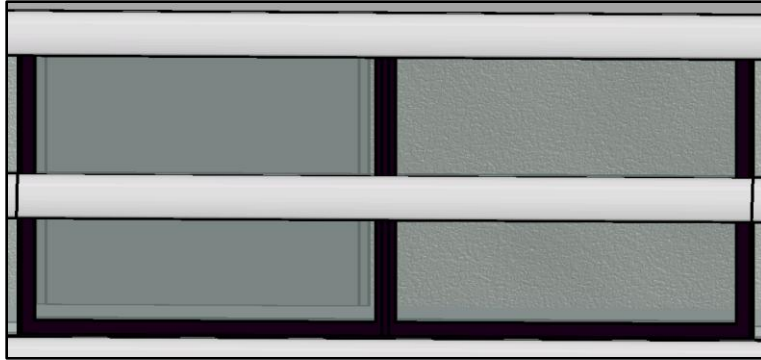
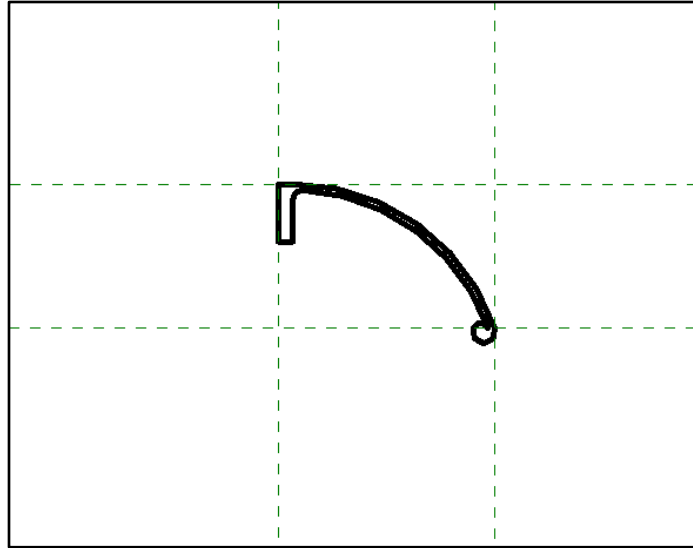


Figure 19: Double Window in The East Wall

on which it will be used. The finished door can be seen in Figure 18. Altogether six different walls were created and loaded into the project in order to have on hand all types of inside doors.

For the windows the procedure is identical but faster since the building has only two types of windows. More precisely one type but available as a single and double window. Again a new family was created where the measurements of the window were sketched and the correct material was selected. The windows of Building 9 have aluminum frame and are one meter high in order to fill in the one-meter tall glass wall at each floor level. The frame is painted in dark purple on the outside. The finished window, which was loaded into the project, can be seen in Figure 19.

Figure 20: Sketch of Wall Profile



10. Wall Profile

The east and west walls have a unique wall profile located in 50cm gaps. In order to develop it a new profile family was developed. The empty template “M_Profil” containing two planes was opened. Here the profile had to be sketched and imported into the project. In order to facilitate the sketching two additional planes were created representing the width and height of the profile, as seen in Figure 20. Once sketched the material was selected – in this case aluminum like most of the walls on which it will be placed. Then the newly created family was loaded into the project and the new wall profile was ready for use. The function “Array” was employed to place all profiles at exactly 50cm gaps, starting from the bottom of the outside facade.

11. Entrance Doors

Building 9 has two different kind of outside doors. One of them follows the pattern of the east and west walls and is composed of aluminum and glass. The two main entrance doors on the other hand are only from aluminum. They are also placed on an additional 3.75 meters aluminum wall outside the building. This wall is connected to the east facade with glass walls. The whole construction can be

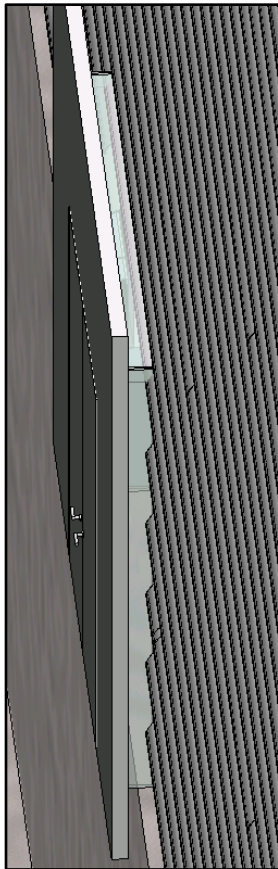


Figure 21: Main Entrance Structure

visualized in Figure 21. Once the aluminum and glass construction is in place the main entrance door was developed. It is a 2.5 meters double door composed of 10cm of aluminum and having a total width of 2.3 meters. The door was developed by modifying an existing double door family. One of the two main entrance walls can be seen in Figure 22.

On the other hand the remaining outside doors had to be created as a new loadable family since their design is unique. It matches the design of the east and west facades. These doors are also 2.5 meters high meaning that they will have first one meter of aluminum, followed by one meter of glass on top of which 50 more centimeters of aluminum will be placed. The thickness of the door also has to match the thickness of the east and west walls and its width is 1.2 meters.

After both types of walls were created they had to be placed on the walls. On the east side all three doors were installed at the ground floor level since the outside terrain is at this level. At the west side of the building the compound is one level lower, so the doors were laid on the first underground level.

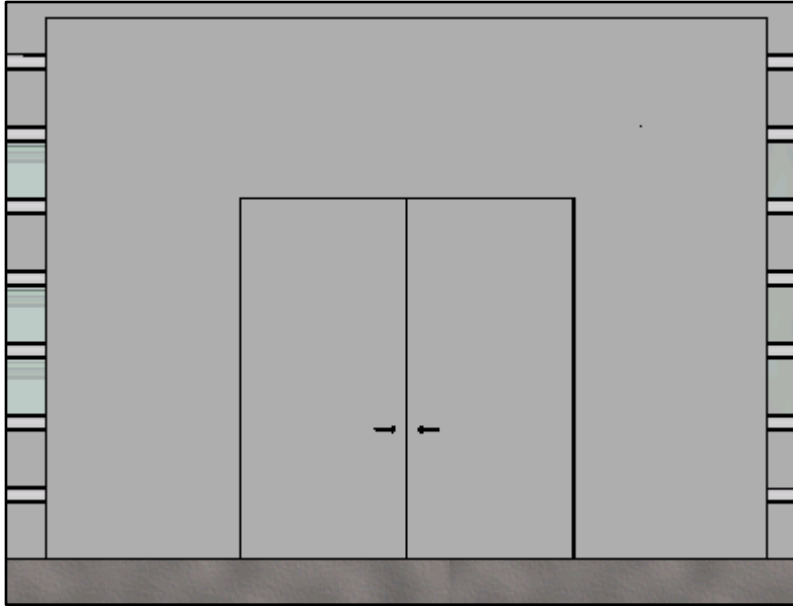


Figure 22: Main Entrance Door

12. Stairs and Railings

Building 9 has three main staircases placed approximately at the same distance from each other and dividing the building in four sections. The south and north staircases span between all existing floor levels, while the middle one does not reach the second underground floor. All three have the same design and are composed of the same material – reinforced concrete.

Before the stairs are modeled into Revit their layout and pattern must be precisely recorded. The length, width and number of stairs was documented. Each stair is 1.9 meters long and 30 centimeters wide. They are divided into two parts separated by a square platform. The first part is composed of 7 stairs and the second one of 12. This pattern varies slightly for the stairs covering the two underground floors since their height is slightly different.

Once all the required information is collected the modeling in Revit can begin. First a vertical shaft, cutting all floor levels except the bottom one, has to be created. This is done with the function “Shaft” where the shape of the vertical hole is sketched. After the vertical shaft is in place the function stairs is employed. It gives you two options to create the stairs, either by connecting it to an existing element of the building or by sketching it. In this case the “Stairs by Sketch” option was chosen. Once selected a sketch box, seen in Figure, appears in the Multi-Function Table. The first step is to use the option “Boundary” (seen in Figure 22) and sketch the boundary of the stairs. It helps you sketch the actual stairs later and informs Revit where they end so that a railing is placed. Next the option “Slope” (also seen in Figure 22) is employed, where the actual sketching of the stairs is done. The finished sketch can be seen in Figure 23, where the green lines represent the boundary and the black ones the stairs.

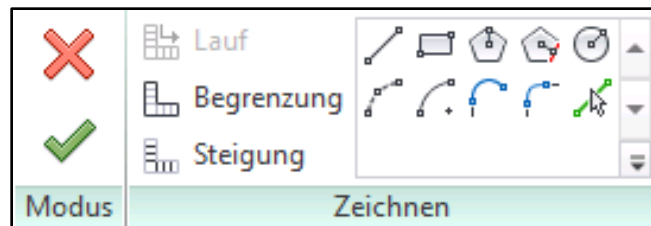


Figure 16: Sketch Box for Stairs

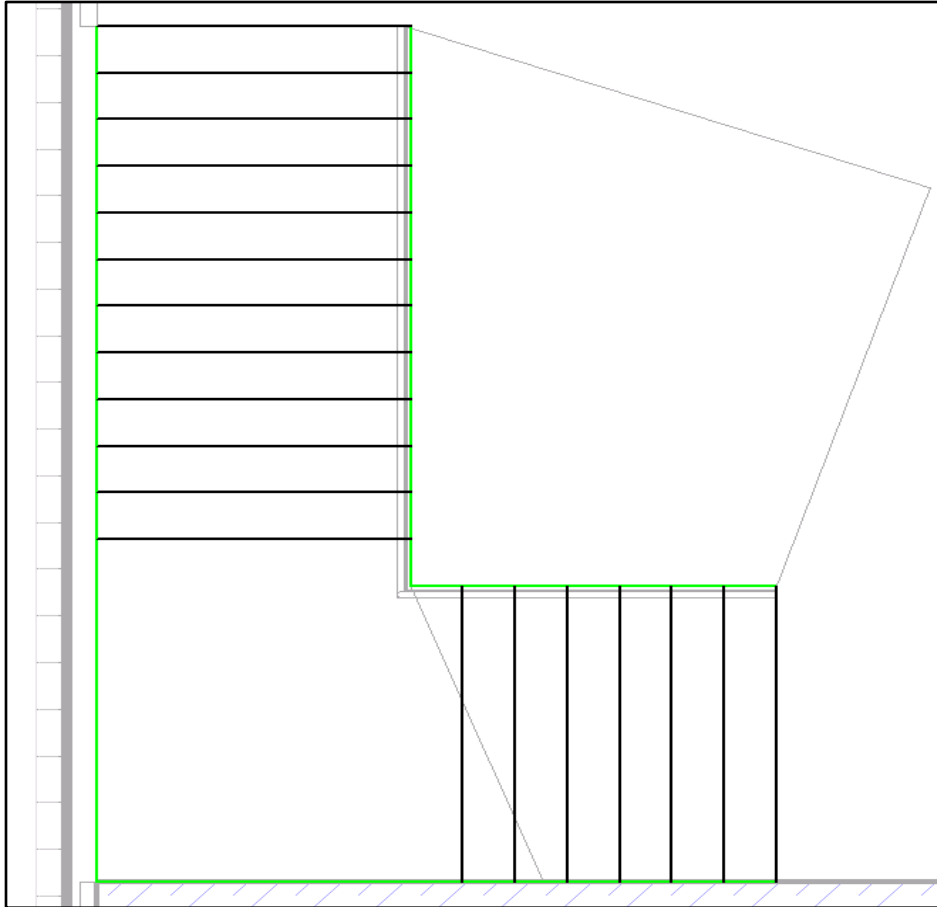


Figure 17: Finished Sketch of The Stairs

When the sketch is finished the railing type has to be selected. In the case of Building 9 a standard horizontal steel railing was chosen and it was edited to match the actual one. At this point the staircase can be created by clicking the green tick. It is important to make sure the box “Solid Stairs” in the stairs property window is checked, since all the stairs in the building are solid. At this point if the created case for one floor is finished it can simply be copied on all the remaining floor planes. For the two underground floors the number of stairs needs to be adjusted so that it fits the height of the floor, while for all other floor levels the copied staircase should fit perfectly. An example of the staircase between the first and second floor is shown in Figure 24.

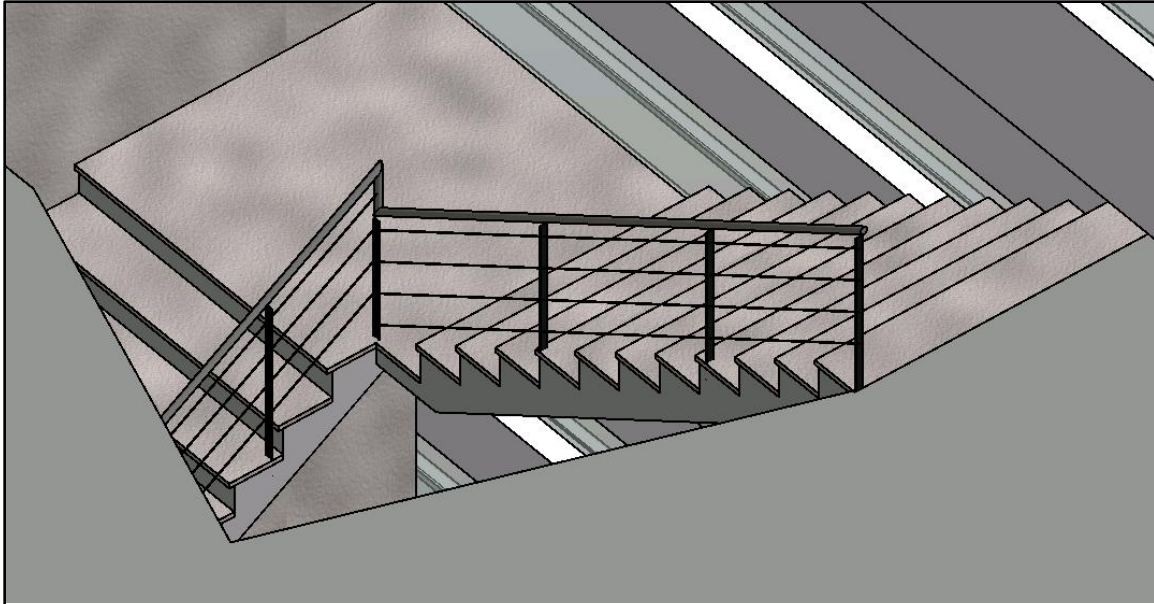


Figure24: Staircase Between First and Second Floor

The terrace that all floor levels above the ground one form on top of the cafeteria and the two vertical shafts above both main entrances also need a railing. The railing type is the same as the one for the stairs and can be inserted using the function “Railing” from the MFT. The path of each railing is sketched matching the edge of the floor. The terrace railings can be seen in Figure from Section 5 of this chapter.

13. Roof

The last step of the modeling process is the insertion of the roof. Building 9 has a two-part, aluminum barrel roof. The two parts are connected with a thin glass wall. The first part covers around 20-25% of the roof starting from the east wall. The second and main part coats the rest and is several meters higher than the first. Since the roof has an unusual form, that cannot be found in the default roof types that Revit contains, the most appropriate function to use in this case is “Roof by Extrusion”. Here the shape of the roof is sketched and subsequently extruded along the length of the building. The first step in applying this function is selecting a

vertical plane on which the roof will be sketched. This plane should match the face of one of the sidewalls because that is the starting point of the roof. In this case the plane should represent the inside face of the south wall. To create such a plane a grid lane was sketched matching the desired wall face. After the vertical plane is selected as reference, an appropriate view in which the sketch will be done must be chosen. Here the most appropriate option is the south view. Now the shape can be carefully sketched. The appropriate roof type is selected and edited, here a 10-centimeter (estimated) aluminum one, and the function is launched. Revit extrudes the solid horizontally to the next vertical wall it contacts. In this case this is the north wall of the building. At this point some problems were encountered but they will be discussed explicitly in Chapter VI. If the user desires to extrude the construction over a specific distance, it can be done manually by entering the aimed value.

Both roof parts were created analogically and the glass wall connecting them was build subsequently. The glass wall was modeled analogically to the glass part of the east and west facade and its windows were also created as separate families as explained in previous sections. The final result is shown in Figure 25.

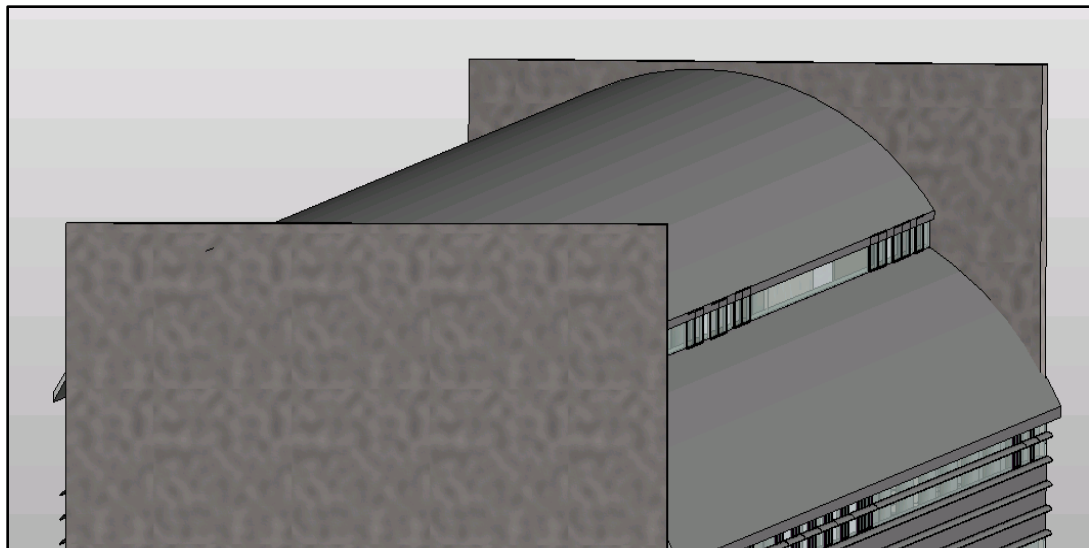


Figure 25: Finished Two-Part Roof

14. Rendering

At this point the model of the building is finished, but the way it looks still varies significantly from the reality. In order to achieve a more realistic image of the building the “Rendering” function is employed. The quality of the rendering can be varied and light and sun setting can be modified, before the actual rendering is applied. In this case a middle quality of rendering was chosen, which needed almost four minutes to complete. The difference before and after the rendering can be seen in Figures 24 and 25.

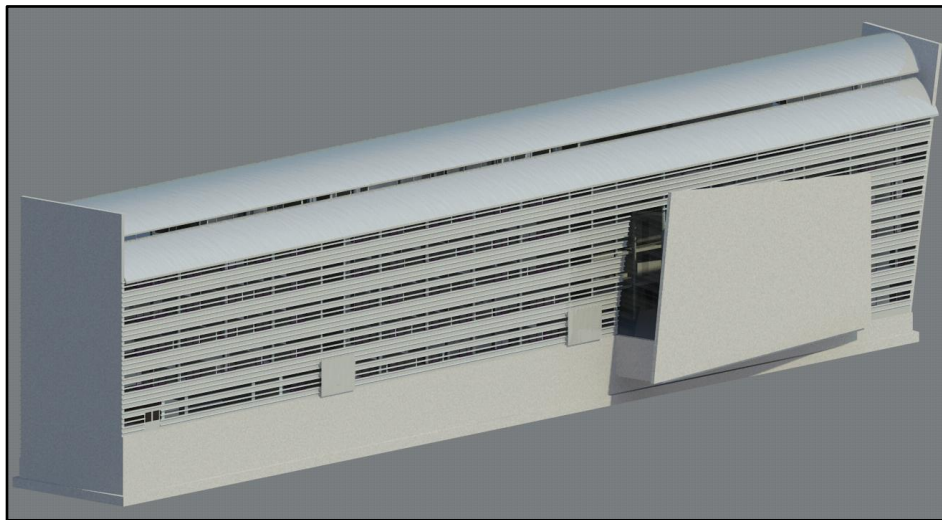


Figure 18: The Model of Building 9 After Middle Quality Rendering

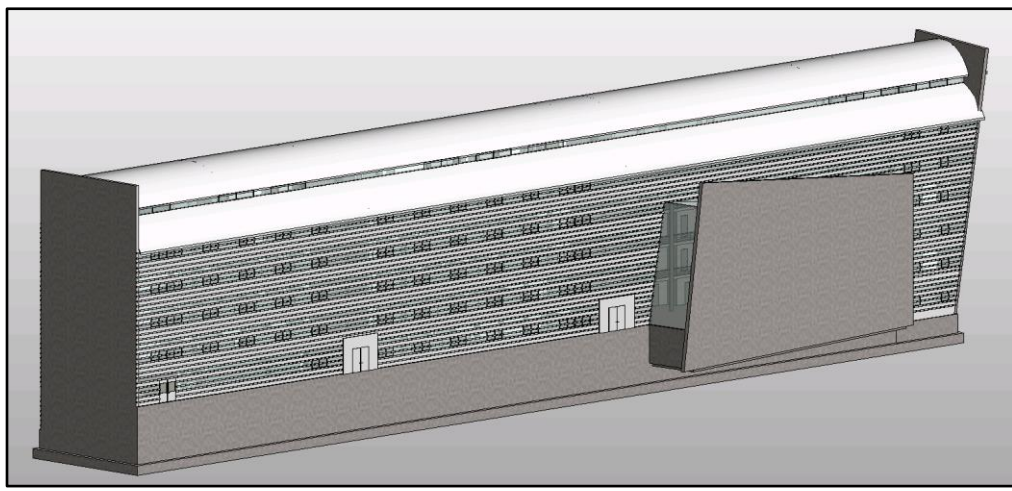


Figure 19: Model Before Rendering

V. Introduction to MEP Revit

Revit MEP is an extension of the software, where everything from modeling duct and piping systems to creating an electrical plan of a building can be done. In this chapter some of the basic features and options in Revit MEP will be discussed. Since there are no electrical or duct plans available for Building 9 and because of the complicated layout of the building, a small duct system will be created in an arbitrary one-floor building. The sole purpose of this exercise is to discuss some of the helpful features of Revit MEP.

1. Modeling a One-Floor Duct System

Once the MEP section is selected from the MFT numerous mechanical, electrical and plumbing components appear (Figure 26).



Figure 20: Multi-Function Table for Revit MEP

For the small duct system that is going to be created the three elements to be used are: mechanical equipment, air terminal and duct. First a mechanical equipment has to be inserted into one of the rooms. Since there is no equipment existing in Revit it has to be loaded from the library. In this case a roof ventilator is loaded into the project. The ventilator is placed at a random location on the roof. The next step is to load some type of an air terminal. Once loaded air terminals are placed in all rooms of the building. After the ventilator and air terminals are in place they are selected and the function “Duct”, shown in Figure 27, is employed. At this point the option “Generate Layout” should be executed. It tells Revit to create a meaningful layout of ducts connecting all selected air terminals with the ventilator. The proposed layout can be modified by the user and once it reaches the desired form the duct system is created. Here the function “Duct Sizing” is very helpful since it modifies the dimension of the system according to the velocity of the flow entered



**Figure 21: Duct
System Function**

by the user. Analogically plumbing and electrical systems of buildings can be created.

VI. Critical Analysis of Revit 2014 and its Limitations

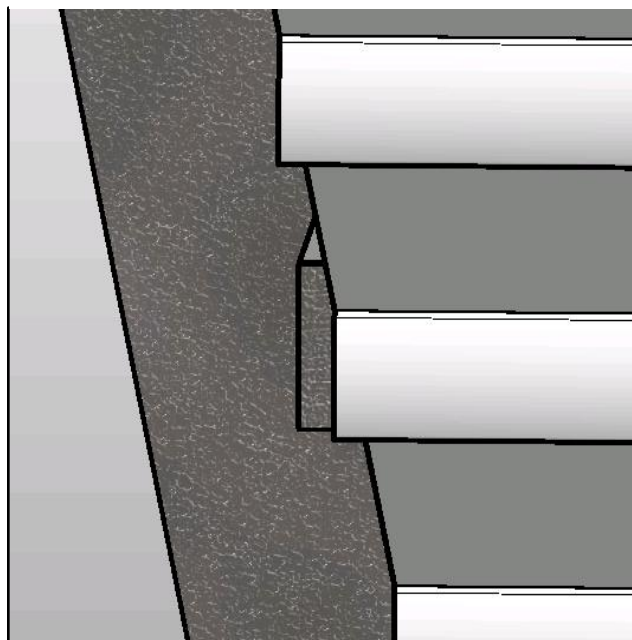
Despite the fact that Revit exists for more than 15 years throughout which it was constantly improved, faults and limitations were addressed and new features introduced, it still possesses some restrictions. The ones that were encountered during the modeling of Building 9 are discussed in the following sections. At the end of the chapter some of the particularly helpful features are also noted.

1. Sloped Walls

The main problem faced by the user while modeling Building 9 was caused by all the sloped walls of the structure. Most notable of which is the north wall, but the sloped glass facade and roof of the cafeteria were also the cause of some complications.

At the moment the only option Revit provides for modeling a sloped wall is by creating a project body and using its face to place a wall. The face is manipulated in the desired way, but it is close to impossible to place it in exactly the wanted position and to make sure it connects perfectly with all neighboring elements. And even if the user manages to place the face in exactly the aimed position and create a wall at it, there are more problems that follow. Firstly the function "Connect", that connects two objects meeting each other at a certain point, never delivers the desired result if one of the elements is a sloped wall. Second all object that meet with the wall, mostly

Figure 22: Overlap Between Sloped Wall and Floor



other walls and floors, have only vertical and horizontal faces meaning at the point of intersection gaps and/or overlaps appear between the two elements. Such faults can clearly be seen at the junction between one of the floor levels and the north wall, which is shown in Figure 28. The same problem applies to the west, east and other inside walls connecting with the north wall. Another place where problems caused by a wall or roof created on a face can be found is the intersection of the south cafeteria wall (also sloped) and the cafeteria glass roof. As shown in Figure 29 the connection between these two objects is not flawless. The junction with the east facade, also seen in Figure 29, contains similar defects.

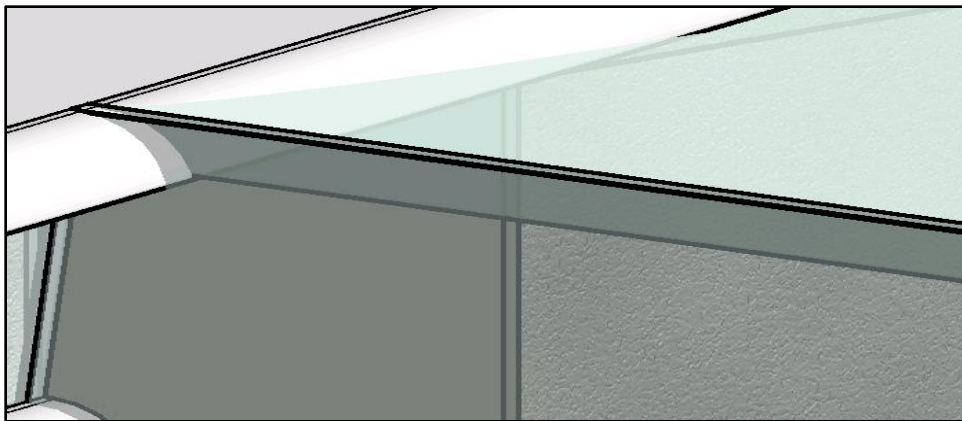


Figure 23: Connection of Cafeteria Glass Facade

On top of all problems that the creation of sloped walls causes in Revit, it must be mentioned that bi-directional associativity does not apply to such objects. This means that if the user decides for example to change the height of a certain floor after such a wall has been placed, he will have to delete the existing one and create a new wall by face matching the modified conditions. This cannot be viewed as a limitation of Revit, since the problem can be eliminated, but it requires unnecessary effort from the user.

2. Roof by Extrusion

The second major limitation of Revit 2014 was encountered during the modeling of the roof. The function “Roof by Extrusion” allows the user to create roofs of all kinds and forms, but the problem arises when the roof construction has to be attached to a wall, that is not perpendicular to the direction of extrusion. In the case of Building 9 the north wall is not parallel to the south one, where the roof extrusion starts, and because of that the construction cannot connect precisely with it. Sketching the roof on the sloped wall and extruding it from there is also not an option since the extrusion happens only perpendicularly to the plane of the sketch,

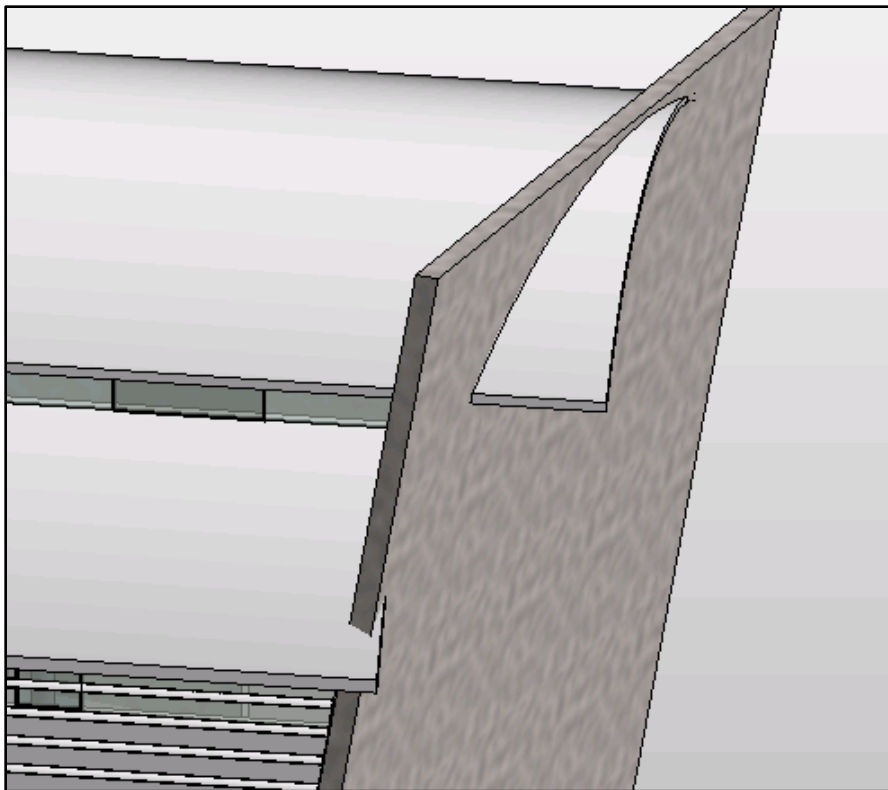


Figure 24: Roof Edge at North Wall

thus it will not reach the south wall. Also the functions “Connect” and “Connect Roof” both do not work in the case of a sloped wall so the result is faulted and does not replicate the reality. An example of how the faulted roof structure can look is shown in Figure 30.

3. Minor Limitations and Complications of Revit 2014

Except the two main limitations of the latest version of Revit, that were discovered during the modeling of Building 9, there is a handful of minor complications noticed throughout the modeling process. One of them is the connection between the walls and the floor on top of them. When the floor is created Revit asks the user if it should connect all adjacent walls to it. This is very useful but works only for walls established before the floor was laid. If the user wants to introduce a new wall at a later stage he has to individually connect it with the floor. The same applies to wall-wall connections. And while this is definitely not a limitation of Revit, in some cases it can lead to severe complications and mostly time loss.

Another small complication is the way Camera Views work. They are very useful since the user is able to see any section on the inside of the construction and have a better understanding of how certain objects and segments of the building look in a 3D space. But the problem with it is that none of the functions can be used while in a camera view. This is again only a possible small complication for the user, but if the use of functions in camera view was made possible, it would definitely become a significant feature of the software. Obviously there are other functions, like “Cut” and “Shift Element”, that facilitate the work of the user in such cases, but there are situations, where the camera view could be more helpful.

4. Noticeable Features

Despite possessing some limitations, the amount of existing helpful features exceeds them vastly, thus making Revit overall an excellent BIM software. The number of valuable functions is probably much greater than the ones actually used during the modeling of Building 9, but there are some particularly valuable ones that should be mentioned.

Unquestionably the most crucial feature of Revit, employed during the modeling of the TU Munich building, is bi-directional associativity. The term was thoroughly explained in Chapter III, so here it should be just mentioned that the amount of time and effort it saves for the user is enormous. Another particularly useful function is “Shift Element”. Once the main outside walls and the roof are in place it is difficult to observe the inside of the construction in the 3D view, but this function allows the user to move objects freely away from their position and then place them back in the initial spot. The “Array” function was also extremely valuable, mostly in the creation and placement of the wall profile, since more than 40 items had to be placed at exactly the same space between each other. Features like “Edit Profile”, “Paste on Plane” and “Project Body” were also especially beneficial during the modeling of Building 9.

VII. Conclusion

The modeling of Building 9 of the TU Munich city campus showed some flaws in the BIM software Revit. And while they can be viewed as limitations to BIM, as a tool for designing and maintaining buildings, the ease with which such a complex construction was modeled proves that Building Information Modeling is definitely a newly created area in engineering that will continue to expand in the coming decades. The constant improvement of computer hardware supports this belief since it will allow BIM software to become much more powerful and thus helpful for the user. All in all it can be concluded that BIM will play an increasingly important role in the work of architects, engineers, contractors, authorities and many others for years to come, and at the moment Revit from Autodesk seems to be in pole-position for the expected expansion of the BIM industry.

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