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Analysis and development of a BIM-based workflow in Structural Engineering

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Bachelor's Thesis

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Abstract

Workflows between BIM-based softwares are nowadays becoming a trending topic for the way they have revolutionized the construction sector. Still a lot of research is needed to accomplish the aim of developing the perfect program that allows the tracking of a whole construction.

During my project, the workflow in a big closed BIM (between Allplan and Scia) and in a big open BIM (the usage of the BIM+ platform) has been studied. In order to carry out this workflow, a building has been modeled in Allplan and later a structural analysis in Scia has been done. The needed reinforcement was calculated and added to the model in the end.

The goals of the project are standing out the changes that files can suffer through the workflow and showing how useful can be the open BIM platforms for organizing and transferring files. At first, a whole report of how the transference have been done can be found. In parallel, a real construction between more than one workers has been simulated in order to practice how platforms are used.

The conclusions show that file transference are still not perfect. Some extra work has to be done after it in order to obtain an acceptable result for beginning to work. Although the time saved makes it worth it. The platform has showed good transference results.

Foreword

When I started the civil engineering degree, I was looking forward to learning and take part in interesting and profitable designing projects such as of buildings, bridges or roads. So when I saw the opportunity of getting to know companies related to the sector at the IKOM Bau¹, and in some cases having the chance to work or do the final degree project with them, I thought I could not let the opportunity go. During the job fair, I was lucky and found not only a project matching my interests but also the chance of working with the support of both my exchange university (TUM) and the Nemetschek Company.

As said before, they offered a project related to the design of a building. But the offer had a special feature: being able to work with their products. This meant modelling the building in a BIM-based software. The possibility of using the cutting-edge design software made the project more interesting.

A final talk added two aspects to the project: a structural analysis of the building, carried out with another Nemetschek Group's software, Scia, and a workflow study necessary for the transference of information between the different software.

The main objective of my project is studying how information is transferred between softwares. A practical part will be also done in order to test this workflow: the use of BIM technology to model a building in Allplan, study the structural part in Scia and finally make some variations in the initially modelled building in Allplan for fixing the structural problems according to my results. In parallel, workflow needed in between the programs should be done, as well as using the BIM+ platform for organizing the work as if a real project would have been carried out.

¹ IKOM Bau is a job fair intended for civil engineering students from TUM. Students are able to make their first contact with companies. <http://www.ikom.tum.de/students/bau>

Index

Abstract	2
Foreword	3
List of figures	5
1 Introduction and motivation	6
2 BIM – Building Information Modeling	7
3 The software company	9
3.1 Nemetschek Allplan	9
3.2 Nemetschek Scia	10
4 Workflow	12
4.1 Own workflow.....	13
4.2 BIM+ platform	15
4.3 Industry Foundation Classes (IFC)	17
4.4 Advanced Streaming Format (ASF).....	18
4.5 Workflow from Allplan to BIM+	18
4.6 Workflow from BIM+ to Scia.....	19
4.7 Workflow from Scia to BIM+	21
4.8 Workflow from BIM+ to Allplan.....	22
4.9 Second cycle workflow	23
5 Practical work.....	24
5.1 Modelling in Allplan	24
5.2 Analysis in Scia.....	26
5.3 Reinforcement in Allplan and Scia	33
6 Conclusions	37
Annex A	39
Annex B.....	42
Annex C.....	45
Annex D	46
Bibliography.....	47
Declaration	48

List of figures

Figure 1 - BIM common procedure cycle. Source: http://www.argestek.es/bim	7
Figure 2 - Allplan's main screen.....	10
Figure 3 - Scia's main screen.....	11
Figure 4 – Own workflow	13
Figure 5 – First screen in BIM+	15
Figure 6 – BIM+ viewer.....	16
Figure 7 – Detail of the IFC file export in Allplan.....	19
Figure 8 – Detailed view of the terrace in Allplan and after the transfer and after the align in Scia.....	20
Figure 9 – View of the topic creator in BIM+.....	21
Figure 10 - Detail of how to do the file import	22
Figure 11 - Detail of the templates available in Allplan	24
Figure 12 - Detail with the structure created with their corresponding heights and their layers	25
Figure 13 - Detail of the aesthetical figures given directly by Allplan	26
Figure 14 - Check structure data characteristics	27
Figure 15 - Chacking member/nodes characteristics	27
Figure 16 - Types of loads applied.....	29
Figure 17 - Column and slab studied	30
Figure 18 - Stress results for the column.....	31
Figure 19 - Displacement results for the column	31
Figure 20 - Displacement results from the slab.....	32
Figure 21 – Stress results from the slab	32
Figure 22 – View of the required reinforcement in Scia.....	33
Figure 23 – Result view of the file transference from Scia to Allplan.....	34
Figure 24 – Detailed view of the reinforcement	35
Figure 25 – View of the needed reinforcement after the bars location.	36

1 Introduction and motivation

Since the computer industry was created years ago its developing and interference in other industries has been constant and it is nowadays a really important part of them. This applies in particular to the construction area. Building analysis, calculations and later 2D planning were the first help introduced by computer technologies (Madsen, 2012). But that was not sufficient, the ambition of creating a virtual model was notorious.

The last computer-aided technology for the construction industry was first named by (van Nederveen & Tolman, 1992). The Building Information Modelling (BIM) was from them a reality.

2 BIM – Building Information Modeling

A totally new concept of building has been introduced by BIM. All that has to be done in a building life can be done with this revolutionary software.

The modelling can be done in a powerful 3D viewer. Construction elements such as doors or walls can be designed in a high detailed way. Also, the esthetical part is not left apart. All the designs can be now conceptualized in a faster and more visual way, really useful for exposing the projects to clients. The recreation of views can be easily made.

The possibility of using multiple programs allows an accurate structural analysis. The high performance makes them versatile enough for testing the most creative building shapes. Simulations of light and shadows, the recreation of heat needed or illumination can also be performed.

More recently the concept of 4D and 5D has been developed while adding the possibility of scheduling the construction time or even creating a cost estimation. So the program goes beyond

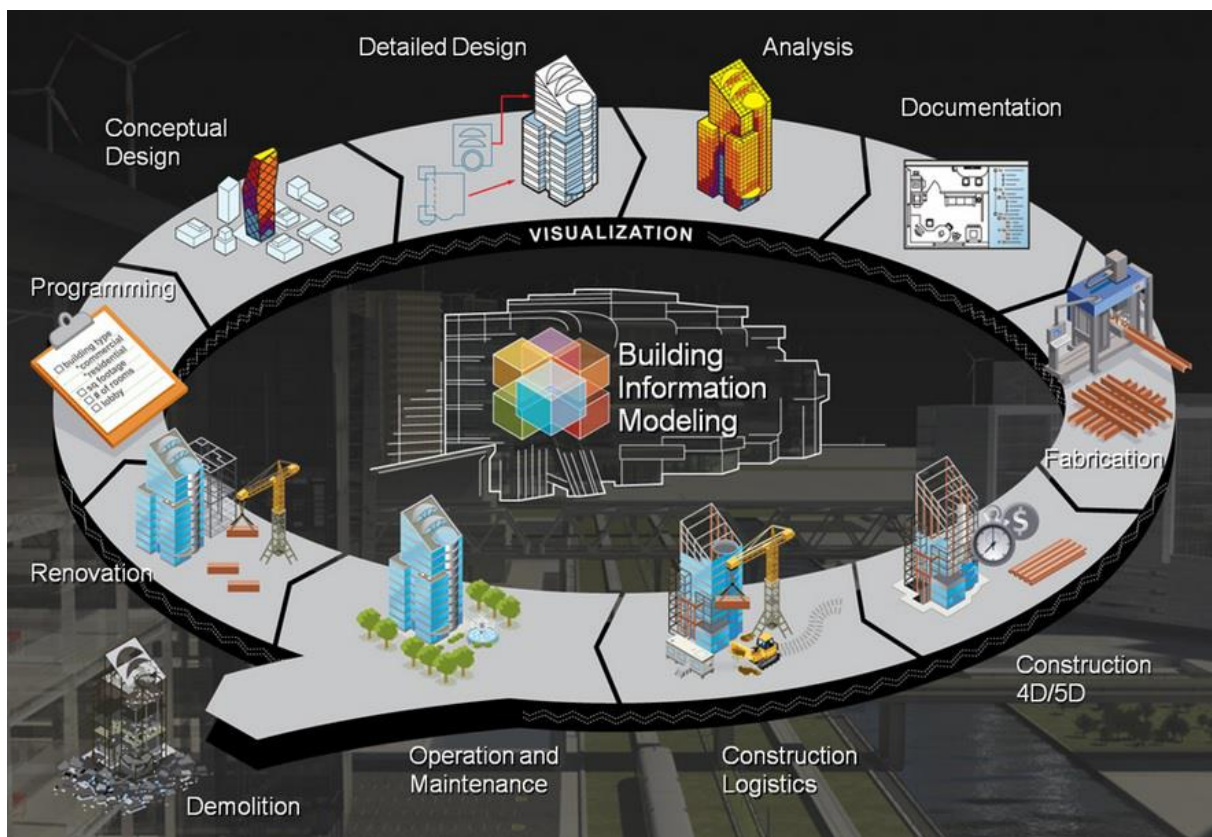


Figure 1 - BIM common procedure cycle. Source: <http://www.argestek.es/bim>

the mere design. During the construction, information coming from the program will be still useful: the normally tight schedule that a construction has, the prefabrication of elements like beams, etc.

Furthermore, the program can be used for getting information after the construction. The cost of maintenance or reforming the building after the useful life can be also calculated.

Also, the implementation of a totally new way of information exchange has been one of the main advantages. The different stakeholders can not only work in powerful softwares but also exchange this information with others in a fast and safe way.

The triumph of the BIM technology can be noticed in the always increasing number of companies considering this way of working as the most efficient for now and the near future.

3 The software company

The Nemetschek company was founded in 1963 in Munich by Prof. Georg Nemetschek. In their foundation was an office for technical construction studies. But after focusing on the software development, they presented their first software in 1977 named *Programmsystem Statik 97/77*.

The company was one of the pioneers of the Building Information Modelling (BIM) and the initiator of the Open BIM initiative. The Open BIM is an online platform based in the collaborative buildings design through the usage of workflows.

Nemetschek group became a holder in 2008. Since then the group consists of 13 totally independent branch companies. Between them, the main one is Nemetschek Allplan. Other important ones are Nemetschek Vectorworks, Nemetschek Scia or Graphisoft.

With the company reorganization, they could expand and reach more market segments: Media and 3D Software (Maxon), Office solutions (Bluebeam). Nowadays their programs are used by 1.8 million users in 142 countries².

3.1 Nemetschek Allplan³

Allplan is a BIM software, a program mainly used by architects and engineers in order to carry out the conceptual as well as the detailed designing. They launched their first program in 1984 under the name Allplan V1. Since then, 18 versions of the program have been created till the newest one, the Allplan 2016. Its high performance allows high-quality results and presentations as well as keeping a full creativity. It allows the 2D and 3D computer-aided design, working with topography, the realization of infographic and films, exchange with other budget applications and the compatibility with other calculation software. Because of this interoperability between softwares, the most common digital formats are available as import and export. Ones of the main formats are IFC and CAD files⁴.

² Source: <http://www.nemetschek.com/en/company/ueber-nemetschek>

³ Home page: <http://www.allplan.com/en>

⁴ For more information about the possible import and export Allplan files: http://www.allplan.com/fileadmin/user_upload/corp/Home/Services/CAD_Downloads/Systemvoraussetzungen/DE/Allplan_2014_Austauschformate.pdf

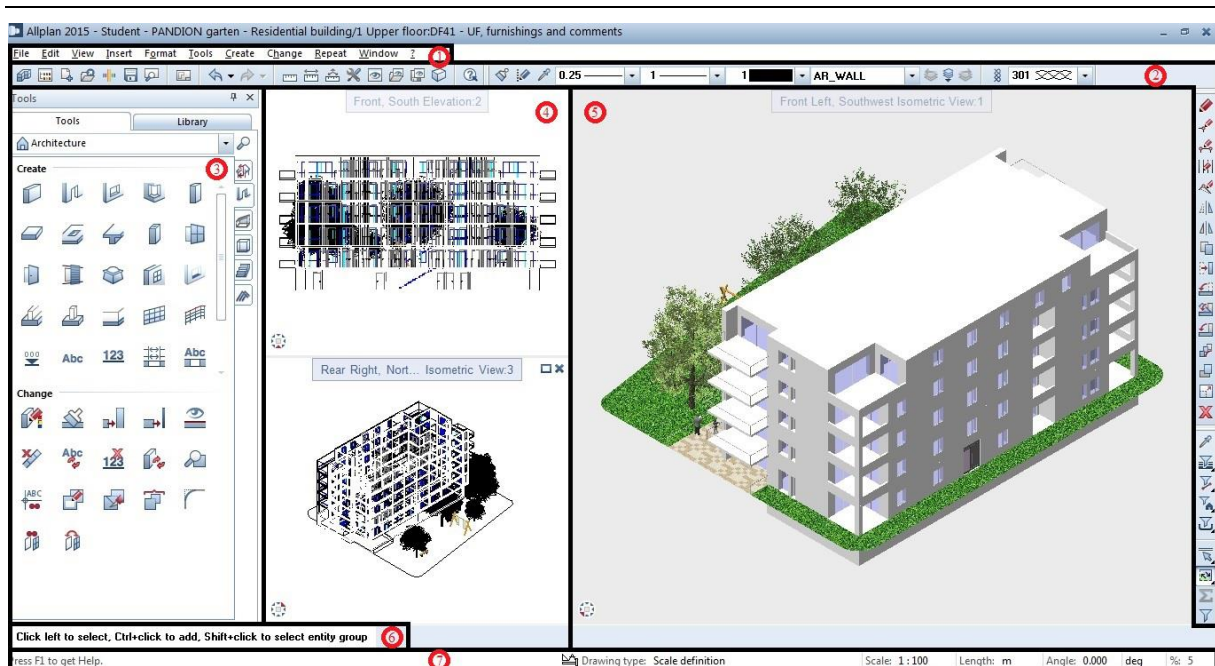


Figure 2 - Allplan's main screen

- | | | |
|----------------------|----------------|------------------|
| 1- Menu bar | 2- Toolbar | 3- Palettes |
| 4- Secondary windows | 5- Main window | 6- Dialogue line |
| 7- Status bar | | |

3.2 Nemetschek Scia⁵

Scia, as well as seen with Allplan, is also an open BIM software founded in 1974 by the Nemetschek Group. The main field of work is the structural and analysis part in the construction industry. The versatility of the program allows the users to test their most creative structures and to see the model in a powerful 3D viewer. Also international codes (localized software with the specific building code in the country, nowadays available in 16 countries) have been integrated for the technical design. Due to the necessity of working with other BIM programs in most of the cases, a large range of formats are available, and it is the only analysis software

⁵ Home page: <http://www.scia.net/en>

IFC 2x3 certified. The results verify their quality: being worldwide top 3 in the specific marked and distributing the product in more than 50 countries and in 8 different languages⁶.

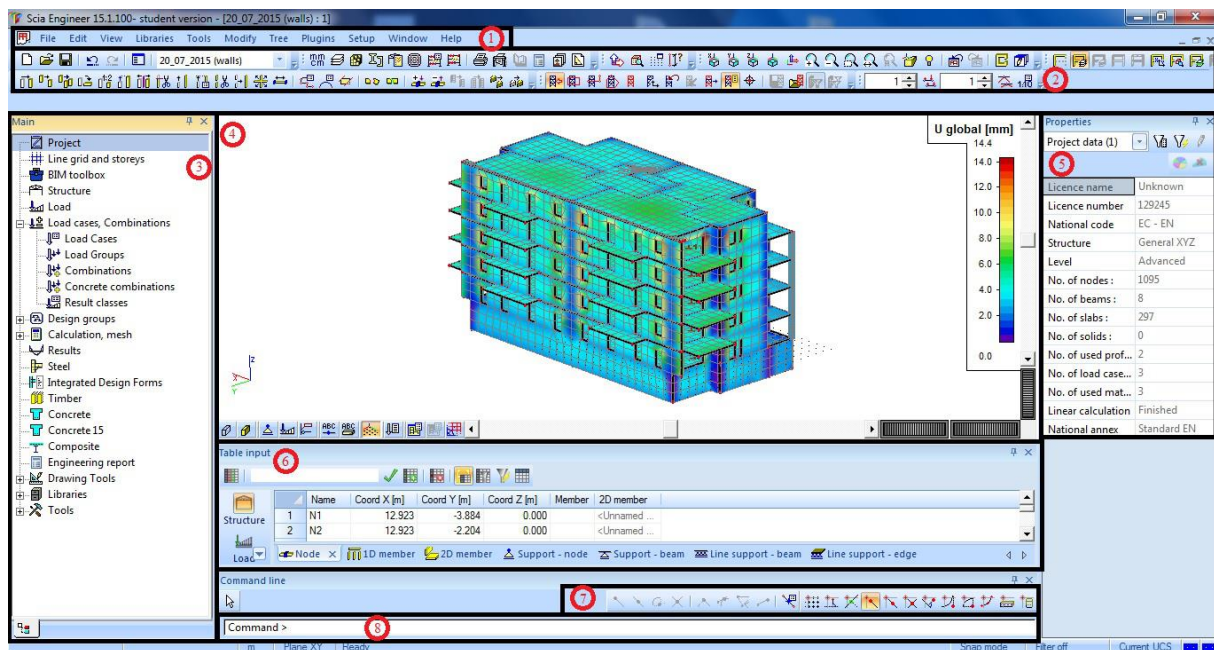


Figure 3 - Scia's main screen

1- Menu bar

2- Toolbar

3- Tree window

4- Working window

5- Properties window

6- Table input

7- Snap settings bar

8- Command line

⁶ Source: <http://www.scia.net/en/about-scia>

4 Workflow

Workflow is nowadays becoming more important as a consequence of how the world is being transformed into more global. The fact that not a single product is anymore created by a single person or company, and in most of the cases, not in the same place or with the same method, has created the necessity of developing a way in which all this parts have to be processed and joined smartly. While talking on the production of goods, a reference of how they are produced separately and joined afterward creating the final product has to be mentioned. It has to be developed a way of doing it fast, cheap and productive. On a digital stage, the procedure does not differ too much. People working in many places, with different programs and in different times have to be able to join their work in order to create a common result. This way of how information is transferred is going to be defined as the workflow.

As said before, the workflow is becoming important, and because of that, the progress gaining has been notorious in the last years. While talking about workflow progress in a construction way BIM cannot go unnoticed. Apart from having introduced a totally new way of modelling a building, it has revolutionized the workflow concept.

BIM related programs have been lately more used since their release (Barison & Santos, 2010). The workflow developed solves the actual needs between designers, architects, engineers, draftsmen and all other people involved in the same project. The information can be exchanged in an easy, safe and fast way, which is really important due to the multiple times that have to be treated. Although this BIM concept shelter lots of different software companies (Autodesk, Nemetschek or RhinoBIM), or even different software in the same companies (Allplan and Scia, both from Nemetshek), the workflow has to be guaranteed and able between them. This is possible thanks to having the same files as inputs and outputs. IFC or CAD files are common in all of them. Another improvement on the workflow is the creation of certain platforms, like BIM+, that allows the exchange in an organized and accurate way.

The workflow can be done in some different ways. The fact of using a BIM-aided program, but not involving the information or files obtained in a workflow, is known as “little BIM”. If a workflow with this information between different softwares is created, we will talk about “BIG BIM”. These concepts were introduced by (Jernigan, 2008). Closed BIM is defined as the workflow established between same company products, and open BIM if the softwares used

are from different companies (Borromann, König, Koch, & Beetz, 2015). Also, an online platform can be used for expediting and organizing the workflow.

The big closed BIM can be created directly from one to the other without the usage of a file or a platform in between, but the usage of this platforms is more common, due to this aim of sharing everything and in most of the cases being different people the ones that are going to work in the different programs. There is a direct linkage between a program and its same-company-platform. That makes the user is not having to export the file from a program and uploading at the platform.

In the case of working with big open BIM the direct transference solution is not existing. The file will have to be exported in a compatible format for both, and imported directly on the other program or in a platform after. Also there's the possibility also of not being able to import the file directly from the program to the platform if the platform is also not from the same company. In this case, again a file will have to be exported and imported in the platform.

4.1 Own workflow

For our own workflow, a platform in between our same-company-programs is used. The possibility of using a local workflow exists. With that, to study a nowadays building project and analyse the process between the different projectors is going to be able.

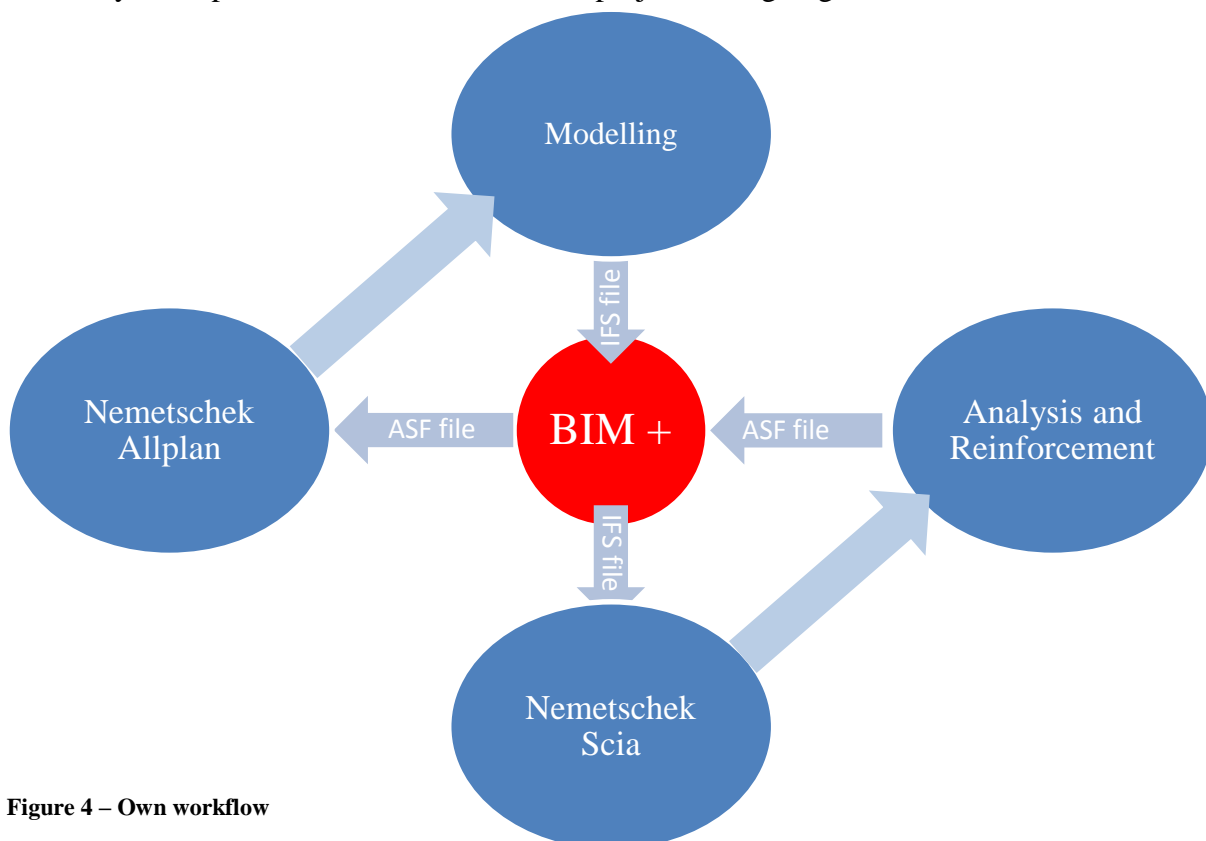


Figure 4 – Own workflow

The different blue rounds show us the two programs used: Nemetschek Allplan and Nemetschek Scia; and their corresponding tasks: the building modelling and the analysis and reinforcement. The red round in the middle shows us the platform used for carrying out all the workflow, the BIM+ platform. The arrows are pointing out the path followed. Next to them the file for transferring the information between software and platform are named. In order to prove different ways of import and export, the files have been treated differently in that way. The transference between Allplan and BIM+ has been done directly from the program, without creating any file in between. Also, it has been tried to import the IFC file to BIM+. For the other three cases, a file has been generated and imported to the platform, or downloaded from the platform and imported to the program.

The figure of the BIM+ platform will be used for transferring the files between same project workers. The program will be useful for organizing the way the project must be done. On the other hand, the programs will be used for developing the design or analysis itself. Every worker will have to take the initial information from the files in BIM+, work with them in the most appropriate software depending on what each one has to do and export the results in a compatible way for BIM+ and the other available software.

As it is shown in figure 4, the cycle has not a beginning point as well as an ending one. That means that the model can be improved always after a structural analysis if a model modification is done.

In the studied case, Allplan software will be used for creating the building model, extracting the IFC file and importing it to BIM+ platform. Once there, a prove of the model view in the platform will be done, and the IFC file will be downloaded. After importing the file to Scia, the analysis will take place, as well as calculating the reinforcement needed with the corresponding ASF file creation. A linkage between this ASF file with an advice in the platform will be performed again and after the file download for making the readjustment. Till here the cycle has been completed one time. From here on, changings will be done in order to reach a better structural analysis. The ASF file will be used for the readjustment of the model, the IFC file will be outputted, and changed again on the platform, but in a second model. The final step will be downloading it, importing it again to Scia and doing the analysis. Verifying that the displacements are lower than in the before analysis will be the final checking for knowing that the procedure has been correct.

4.2 BIM+ platform

The BIM+ platform was created by the Nemetschek group as a result of the nowadays necessity of having same project workers installed in different places and not able to have a personal communication. Also, it can be used as a smart organization method, and not as a result of large distances between co-workers. BIM+ offers an easy way of data exchanging between people working on the same project.

It's as easy as creating a shared folder where all users can share and exchange information. This shared folder will be accessible “anytime-anywhere”, so the workers will know in a real time how the project is progressing by just accessing to the platform in the cloud. Of course, this folder will have some special characteristics and options referring to the projects they are going to contain; the design and analysis of the building.

The platform has two main screens available and showed down here.

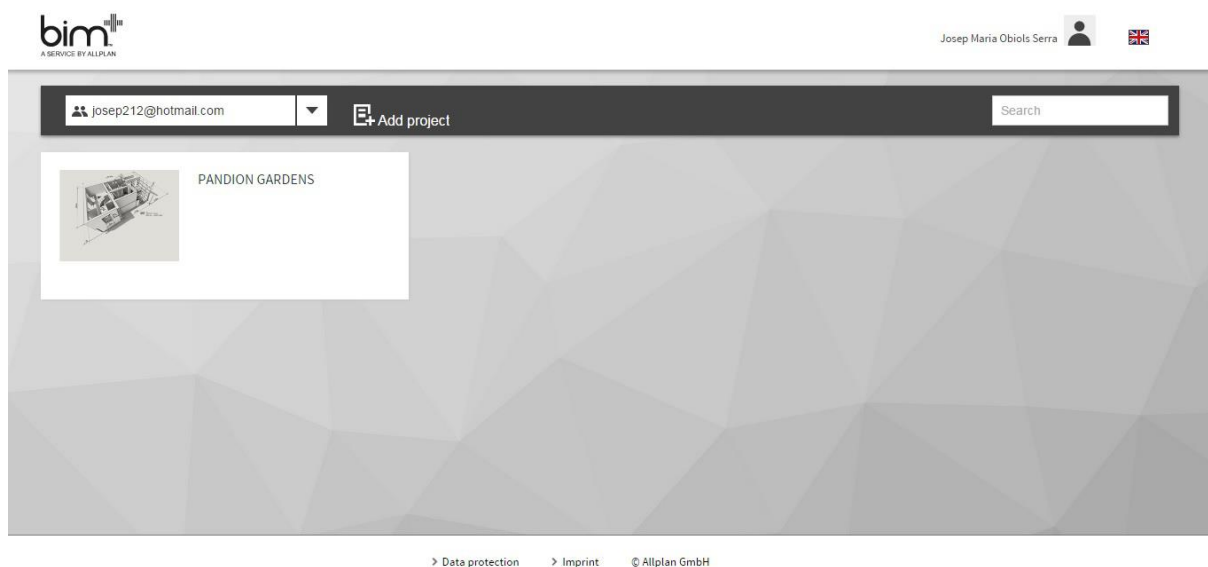


Figure 5 – First screen in BIM+

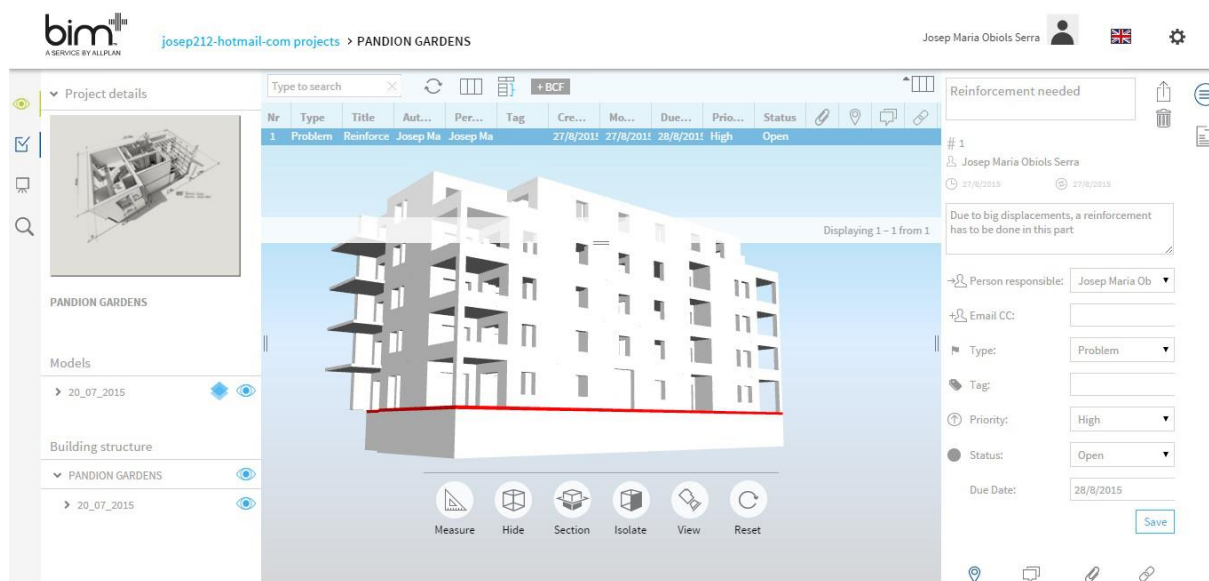


Figure 6 – BIM+ viewer

In the first one, the own menu can be seen. In this screen, the currently working on projects will be allocated, as well as the old ones. Also, the possibility of adding new projects or deleting some of them is available.

For accessing the second screen, a selection of a project is needed. Ones in the screen will be divided into 4 areas. The project information can be found on the left, as well as the models that have been entered for each project and the layers imported for each model. A layer viewer allows us deciding which layers want to be seen. All the layers switched on will be visible on the centre of the screen. Also in the lower part some options are offered for being able to look in more detail or take more information about the building.

On the top of the viewer, a list of topics, work to do or another type of advice is showed. This is the part where the interaction of all members is showed. Everyone can identify problems and report them, hang information or files for others in order to make their work easier, hang out results, consider tasks that have to be done, assign work to others or even hang pictures to solve some details. In order to create one of this advices, formulae found on the right of the screen will have to be filled. Some information will have to be added such as the person or people advised or put in charge of the work, add a description of the advice, set a priority and a date and link some picture or web page for a better comprehension or even a file that has to be used for some reason. In the end, the attribution of this advice to a certain element of the building

will have to be done by linking both of them. All this information will be saved in a BCF file format⁷.

Once the advice is done, the main receivers will be noticed and will be able to deal with it. Once done, they will do the same: posting a result, confer a work to a next worker, etc. Keeping working like that, the building project will be created by a lot of people doing small parts of the project and joining them in a unique platform till getting the wanted result.

During the workflow, some advices have been created as they can be done during the accomplishment of one project. The example can be seen during the workflow explanation between software and platform.

The files used in this platform can not be randomly selected. As the centre platform of the workflow, the usage of files able for the platform as well as for the software used will have to be considered. In order to have a possible view typical BIM files such as CAD model formats and IFC files will have to be imported. As said before, the linkage of some files in the advices can be created. This files will not have to be compatible with the platform itself, but obviously with the software that will be used afterward.

4.3 Industry Foundation Classes (IFC)

The Industry Foundation Class file was introduced in 1994 by a group of companies. Its aim was creating a common and neutral format for the architecture, engineering and construction industry used in building information modelling projects.

IFC has been presented in different formats during its development. The newest was presented in March 2013 under the name of IFC4.

IFC2x3 files (February 2006) will be exported from Allplan for being imported in BIM+ and Scia. Both, the platform and the software, are able to read it. For the case of the platform, the view of the building created in Allplan can be directly viewed on the cloud, and for the Scia case, it is going to be seen with some esthetical modifications.

⁷ For more information about BCF files: <http://www.buildingsmart-tech.org/specifications/bcf-releases>

4.4 Advanced Streaming Format (ASF)

The Advanced Streaming Format was created by Microsoft and is mainly used for streaming videos or music.

ASF files will be useful for transferring the reinforcement from Scia to Allplan for being able to do the model adjustment. As always the file will have to be transferred through BIM+, but, in this case, the platform will only serve as a shared folder because it is not able to open them. The transference is going to be made by creating a topic and linking it. The receiver will be able to download the file directly from the cloud and importing it to the program.

4.5 Workflow from Allplan to BIM+

This first workflow is done by an IFC file. This IFC allows us saving a wide range of information. Before creating it, the way it is going to be used in the future is relevant. In this case, viewing it in BIM+ and doing an analysis in Scia is the objective. Because of that the selection showed will be the one chosen. No esthetical elements like furniture or stairs are selected because just the elements that will take part in the structural analysis are important.

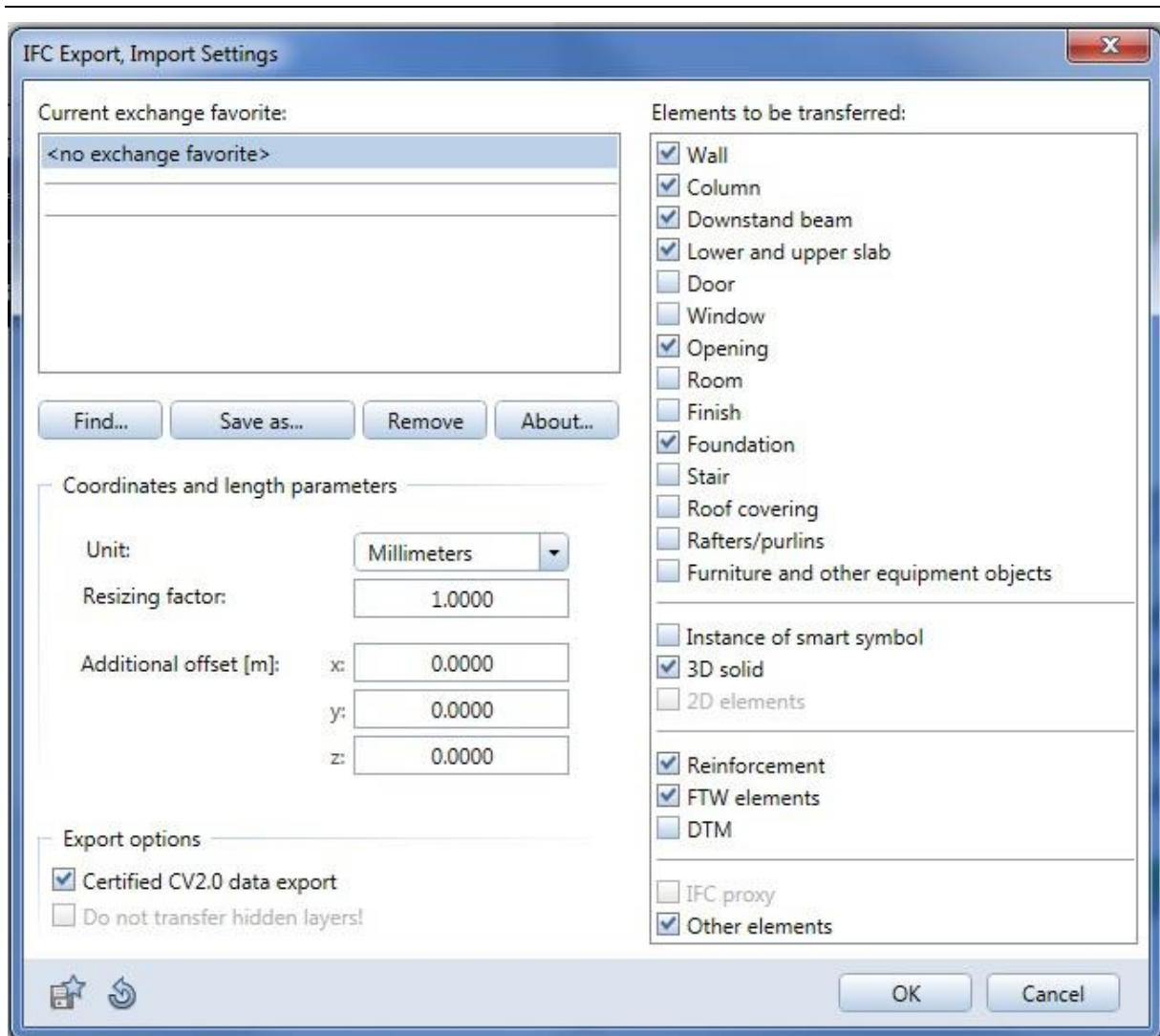


Figure 7 – Detail of the IFC file export in Allplan

After the IFC is created, a new project in BIM+ must be done, and then the IFC would be able to be imported. As it is the first time that the IFC is imported, the first model will be created. All the layers exported from Allplan will be imported in BIM+ and will be able to check if everything is correct in the viewer part.

From that moment on, after the platform creation, all the possible workers added, can upload information to the project as well as modifications and suggestions.

4.6 Workflow from BIM+ to Scia

The workflow between BIM+ and Scia is done by downloading the IFC file imported from Allplan to BIM+ (explained above) and importing it to Scia. This IFC can be easily imported to Scia. When introducing it, a windows will ask what kind of information should be imported.

As long as the information was already selected while exporting it from Allplan, the import is quasi-direct. There are some options that can be interesting, like having a certified data import.

With that, it can be noticed that the IFC file with all the information can be created in the beginning and then use the same IFC importing different layers. For example, if the estimated budget has to be calculated and a structural analysis done, an IFC file with all the possible information can be created. After that, the import of only the layers regarding the budget calculation in the specific program will be done, as well as the layers regarding to the structural analysis in another program.

So the appropriate elements for the structural analysis are the ones selected during the IFC exportation. After opening it some changes will be noticed, and not only because of the missing elements that were not imported, also the ones imported will suffer some changes.

The main changes can be noticed in the next comparison. The picture shows the building in Allplan, and the one in the middle in Scia after direct import. The most changed part is the aesthetic one. The

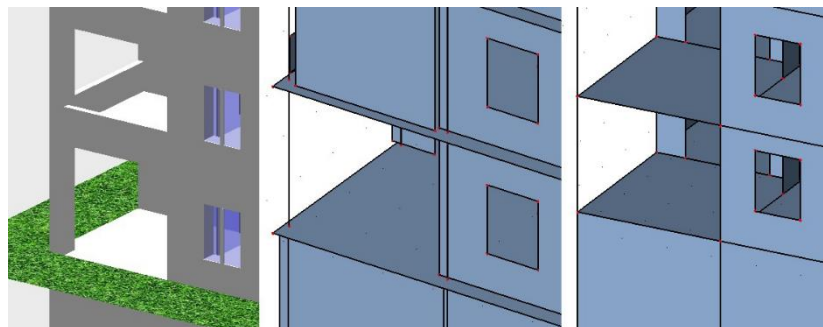


Figure 8 – Detailed view of the terrace in Allplan and after the transfer and after the align in Scia.

colour of the walls and floors, the missing of the grass or the lack of designed windows are the main ones. But other things have also changed. During the process, walls and slabs have become 2D planes as well as the doors, windows and other openings. The columns became lines, and some nodes have been created in order to be the junction points between all this planes and lines.

Despite the creation of this nodes, the junction between all the elements is not exact. In order to get a good analysis, a modification of the structure is needed. For fixing the building, some steps must be followed for having in the end a good result. The easiest way is to follow the BIM toolbox commands. First of all a structural alignment, then connect the members and nodes and finally check the structure data.

The align command allows us to join the nodes with the planes and columns. For doing a correct align a node by node selection must be done, check that the automatic planes are given by the

program and in which nodes will collide are right for us and keep doing it for all the nodes in the building. Once a point where all the nodes are aligned and planes and slabs are forming rooms a successful import can be considered.

4.7 Workflow from Scia to BIM+

Once the analysis is done and the reinforcement is projected, it is time to go back to Allplan in order to model the changes. For that, some instructions of how the changes should be done are needed. This information should be given by the same person who analysed and determined the change. The best way to give that information is directly from a Scia file that can be imported to Allplan in order to visualize the changes there. For that, an ASF file is used. For the communication between both the usage of the platform is required and again creating a topic.

This topic is going to advice that some tasks have to be done and that someone has to be responsible for doing it. But the important part of creating the topic is adding the ASF file and a pin placed in a part of the building where this file is going to be useful for. The file is no compatible with BIM+, so the result will not be able in the platform. The users who want to see the information will have to download the file and use it from their own PC. In this case the platform will be used as a shared folder.

The screenshot shows the 'View of the topic creator in BIM+'. The interface includes a title field containing 'reinforcement file', a description field with the text 'Attachment of reinforcement file for remodeling the slab in Allplan', and several metadata fields: 'Person responsible' (Josep Maria Ob), 'Email CC', 'Type' (Task), 'Tag', 'Priority' (High), 'Status' (Solved), and 'Due Date' (30/8/2015). A 'Save' button is located at the bottom right of the form. Below the form, there are icons for location, comments, and attachments. At the bottom of the page, a file 'reinforcement 1.asf (82.49 kB)' is shown as attached.

Figure 9 – View of the topic creator in BIM+

4.8 Workflow from BIM+ to Allplan

The first step will be downloading the ASF file from the platform. Not like the IFC file, the ASF can not be imported directly. It will have to be imported as a layer, as a FEA file. A layer where the file wants to upload will have to be selected.

But the information will not be seen as like as seen in other layers. In this case, only a coloured diagram along the slab will be seen. This diagram shows us the quantity reinforcement area needed. It's a similar view of the one in Scia, but colours are defining different intervals. The next step is drawing the bars.

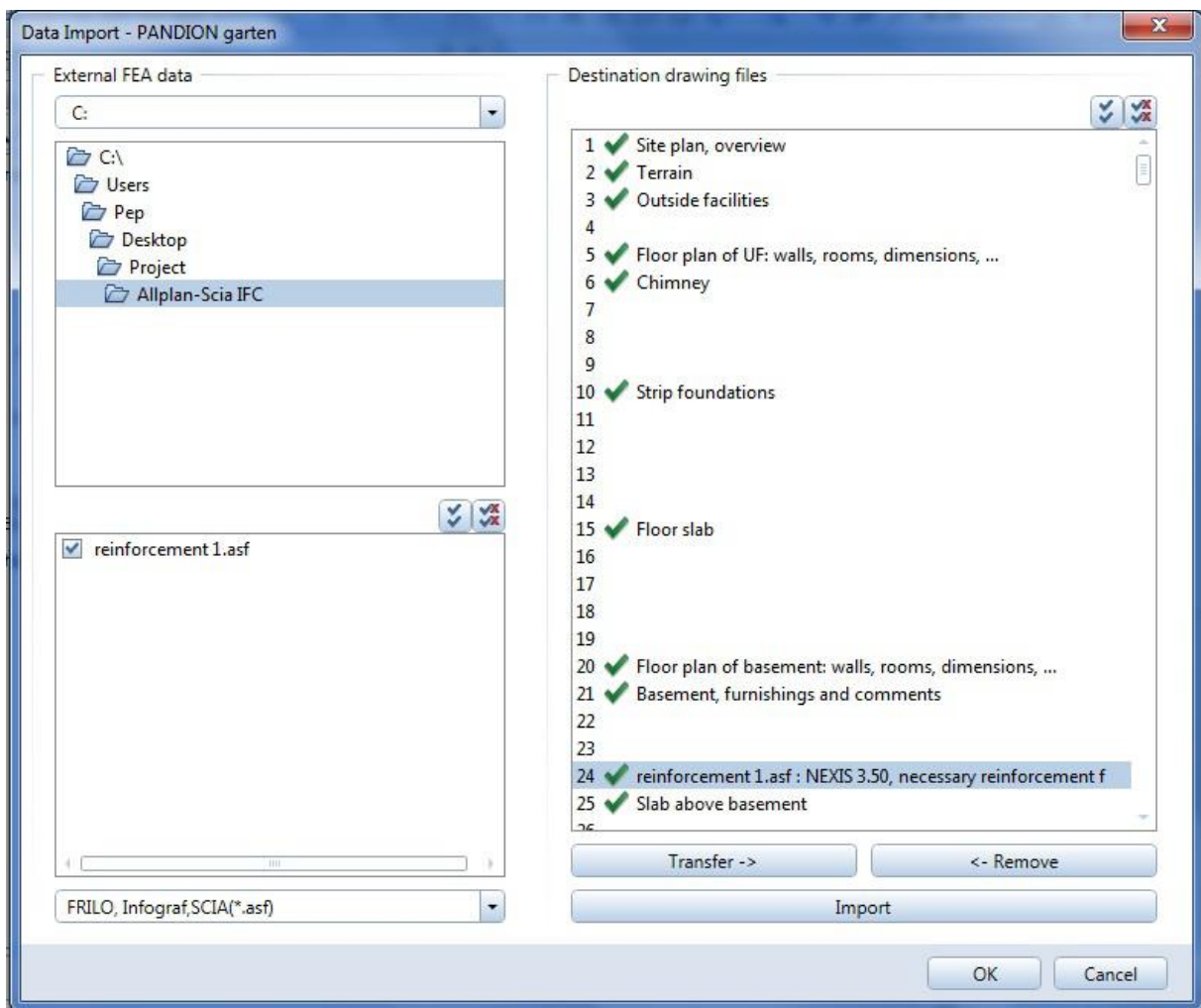


Figure 10 - Detail of how to do the file import

4.9 Second cycle workflow

If a second cycle is needed in this procedure, it is going to be for improving the reinforcement or for adding reinforcement in other structural elements. In this case, the procedure used till now has to be followed. The IFC files will be used for the bars transference and AFS files for transferring the reinforcement needed from Scia to Allplan as a layer.

5 Practical work

To put in practice all this workflow study, a practical work has to be done in order to have the required data to make the study. For that, a building has been chosen for being, at first modelled, then structurally analysed and in the end adding the reinforcement needed. The building chosen is a part of the PANDION Gardens⁸. It's located in the Neuhausen-Nymphenburg district in Munich, close to the city centre. This residential building will combine the comfort of living next to the city and the privacy of living in a non-congested and nature surrounded environment. The flats will variate their area between 37m² and 154m² as well as the number of bedrooms between 1 and 4. Modelling in Allplan.

5.1 Modelling in Allplan⁹

The building has been modelled in concordance with the planes given by my supervisors as well as the ones that can be found in the main Pandion garden web. Due to taking in care the main purpose, the study of workflow and the structural analysis, furniture as well as detailed esthetical things have not been taken in consideration.

In the initial part, some templates are available. There are several, and depending on the intentions it will be useful to choose one or another. The number of floors or the usability of the building will determinate the template.

A residential building with garage template has been selected for the practical case. With this option, the

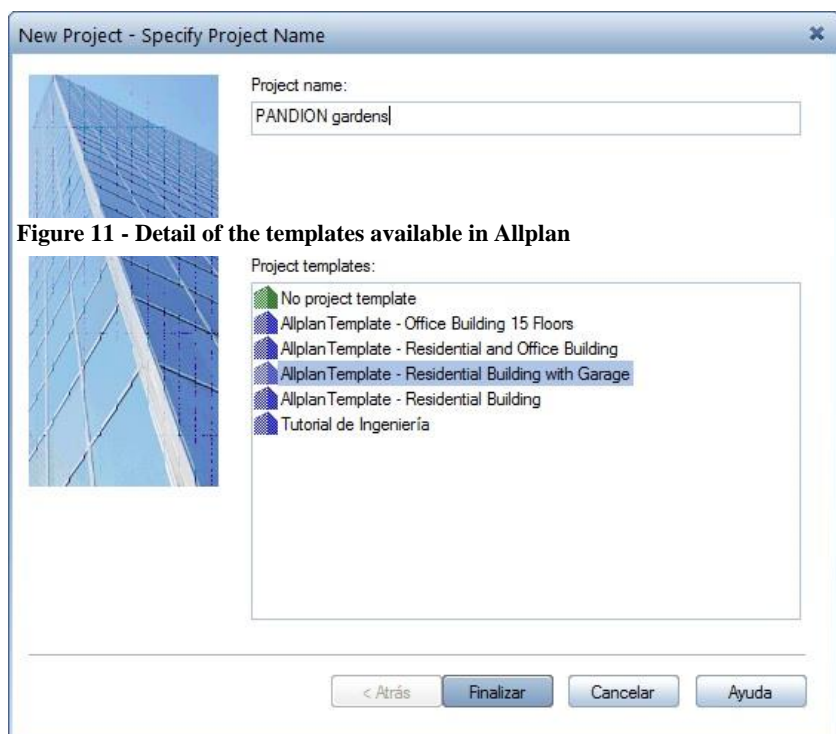


Figure 11 - Detail of the templates available in Allplan

⁸ Source: <http://gardens.pandion.de>

⁹ Final layouts of the modelled building can be found in Annex A.

program has created some different layers defined by their floor and usability. So each layer is compressed between two heights, and the name shows us their usability. The default layers are for the slab, the floor plan and the furnishing. From this point on, the drawing of the building will begin floor by floor, selecting the corresponding layer in each case and following the planes.

Building structure		Height at bottom	Height at top
PANDION garten			
1	Site plan, overview	-	-
2	Terrain		
3	Outside facilities		
4			
Residential building			
5	Floor plan of UF: walls, rooms, d...	-3.000	14.100
6	Chimney		
7			
8			
9			
Foundation		-3.800	-3.200
Basement		-3.000	-0.400
Ground floor		-0.200	2.400
30	Floor plan of GF: wal...		
31	GF, furnishings and ...		
32	Balcony		
33	Garten		
34			
35	Slab above GF		
36			
37			
38			
39			
1 Upper floor		2.600	5.200
2 Upper floor		5.400	8.000
3 Upper floor		8.200	10.800
Top floor		11.000	13.600
Garage		-1.400	2.500

Figure 12 - Detail with the structure created with their corresponding heights and their layers

As the important point for us is the structural analysis, the default walls, doors and windows given by the program in the wizard tab from the palettes window will be used. The main fixation should be the heights of the walls, doors and windows, the width of the slabs and the coincidence between floors.

Finally, and in order to show the possibilities that the program has, some esthetical stuff has been added. The walls have been painted in white and some personal tiled floors for the terraces and grass for the garden has been added. The Allplan library has been used for adding some people and trees and a swing in the garden. Some surrounding changes are also important for giving to our building a more idyllic aspect.

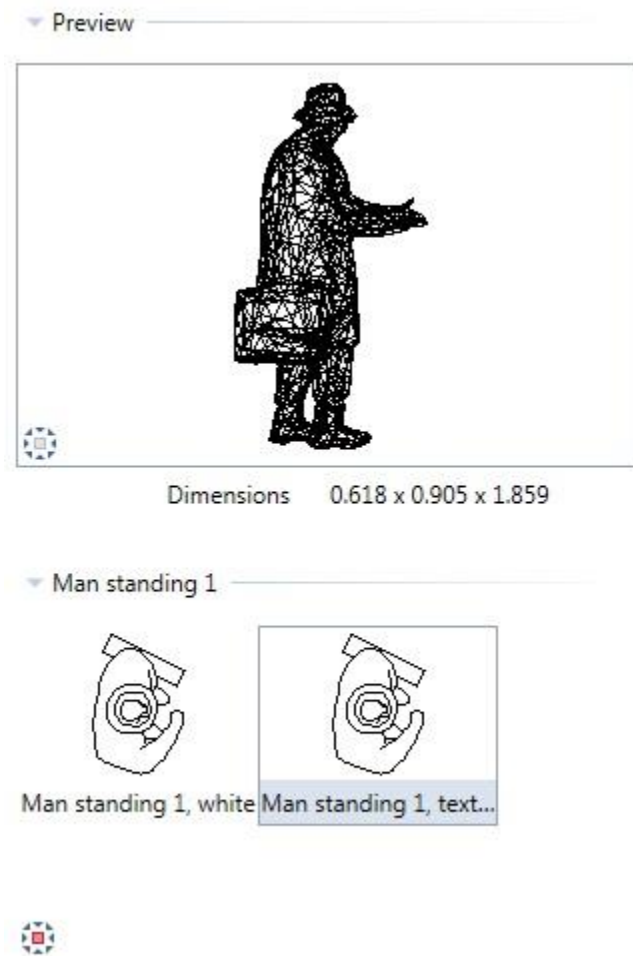


Figure 13 - Detail of the aesthetical figures given directly by Allplan

- Workflow between Allplan and Scia through the BIM+ platform using the IFC file

5.2 Analysis in Scia

Once the building is fixed after the transferring, everything is ready for performing the analysis. Before it the building will be adequate following some steps.

First of all, a building check will be needed. With this, double walls or nodes will be deleted, or nodes which are not joining other parts. Also, the different members or nodes will have to be connected, so the program will know between which elements there will be stress interaction. Both works are automatically done by the program under the commands Check structure data and Connect member/nodes.

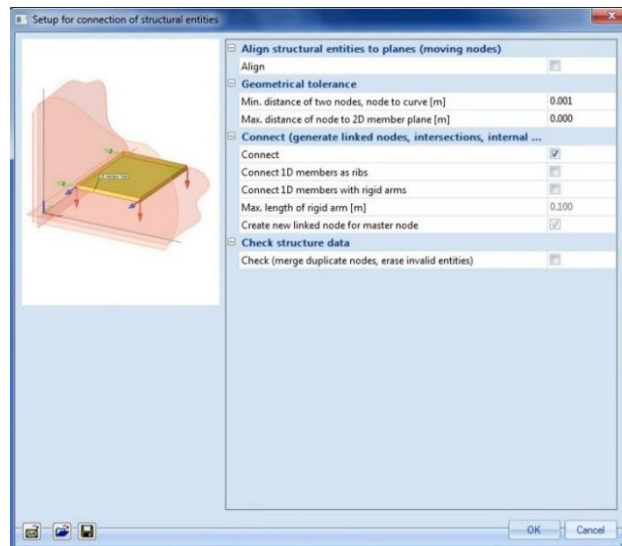


Figure 15 - Chacking member/nodes characteristics

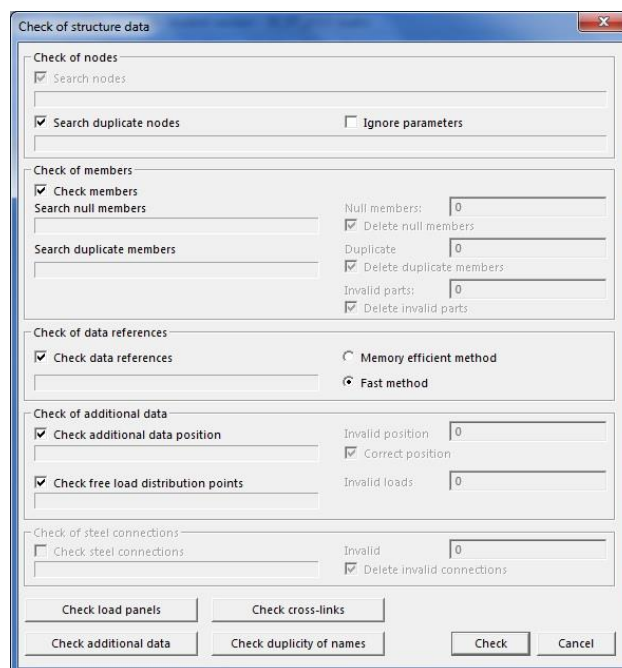


Figure 14 - Chack structure data characteristics

After that, the model is ready and loads and load cases can be added. Thinking about the loads that should be added is an important point. Sufficient loads in order to put the structure in its critical case should be added, and designing it to support it. The main loads will be self-weight, permanent loads and variable loads. Self-weights are referring to the weight of the structure, so the weight of the masonry walls and the weight of the concrete slabs and columns. Permanent and variable loads are referring to all that kind of stuff that can be placed inside de building.

Also punctual loads, wind loads or earth pressure can be added in order to have a more realistic model. Punctual loads can be added in some strategical points, like in the edge of the terrace

for seeing how much can it resist. Wind loads are especially important for slender constructions. Earth pressure is important when we have some part of the building buried, and it is referred to the load that the earth is directly producing to our walls.

All this loads have to be selected from the load command, define them with a type of load, a direction and an amount, and after that place them in a 2D element. For the punctual loads, only a point will have to be selected.

In order to define the magnitude of all the loads, the norms will be followed. The norm used in this case is the EUROCODE 2¹⁰. The values have been taken from the Schneider book “*Bautabellen für Ingenieure: mit Berechnungshinweisen und Beispielen*” (Schneider, 2012). Other considerations for the election had to be made.

A value of 0.22 kN/m² was decided as a permanent load in the different floors after supposing that ceramic floors will be installed. In the case of the roof, this permanent load rises up to 0.50 kN/m². In the case of the variable loads, what is really important is how the building is going to be used. In our case, as a residential building, the norm fixes us to use a load of 1.5 kN/m². In the case of the garage, and because it is expected to be used for parking cars, the default load is going to be of 2.5 kN/m². The last load fixed by the norm is the wind one. In this case is important the location of the building (Munich in our case) and the height of the building, which is 14m. Joining this information, the wind load is projected with a value of 0.80 kN/m²¹¹.

The last case of load to be commented is the one made by the earth pressure. The difference with the previous ones is that is not given by a norm, it is depending by the ground characteristics. A ground with 16 kN/m³ of weight and a friction angle of 30° with no cohesion has been chosen. These characteristics provide to the wall a load of $q(H)=8H$. As the buried wall goes from H=0m to H=-3m, a triangular load going from 0 kN/m² (in H=0) till 24 kN/m² (in H=-3) in a triangular way¹² will have to be considered.

Once all the loads have been created and placed, the definition of the load cases has to be done. For this point is really important to give the correct functionality to the loads before mentioned. The different cases will be studied separately and the worst case has to be taken in order to design the building for resisting. Each case will consider the different forces with a different

¹⁰ <http://www.eurocode-online.de/de/eurocode-inhalte/eurocode-2>

¹¹ Tables with the corresponding values can be found in Annex B

¹² A more detailed earth pressure explanation can be found in Annex C

coefficient, given directly for the program. Basically two cases will be defined, the service limit state (SLS) and the ultimate limit state (ULS). The SLS is useful for knowing if the structure is not exceeding some deformations that can guarantee the usability of the structure. On the other hand, the ULS informs us about the maximum stress that the construction can support before collapsing.

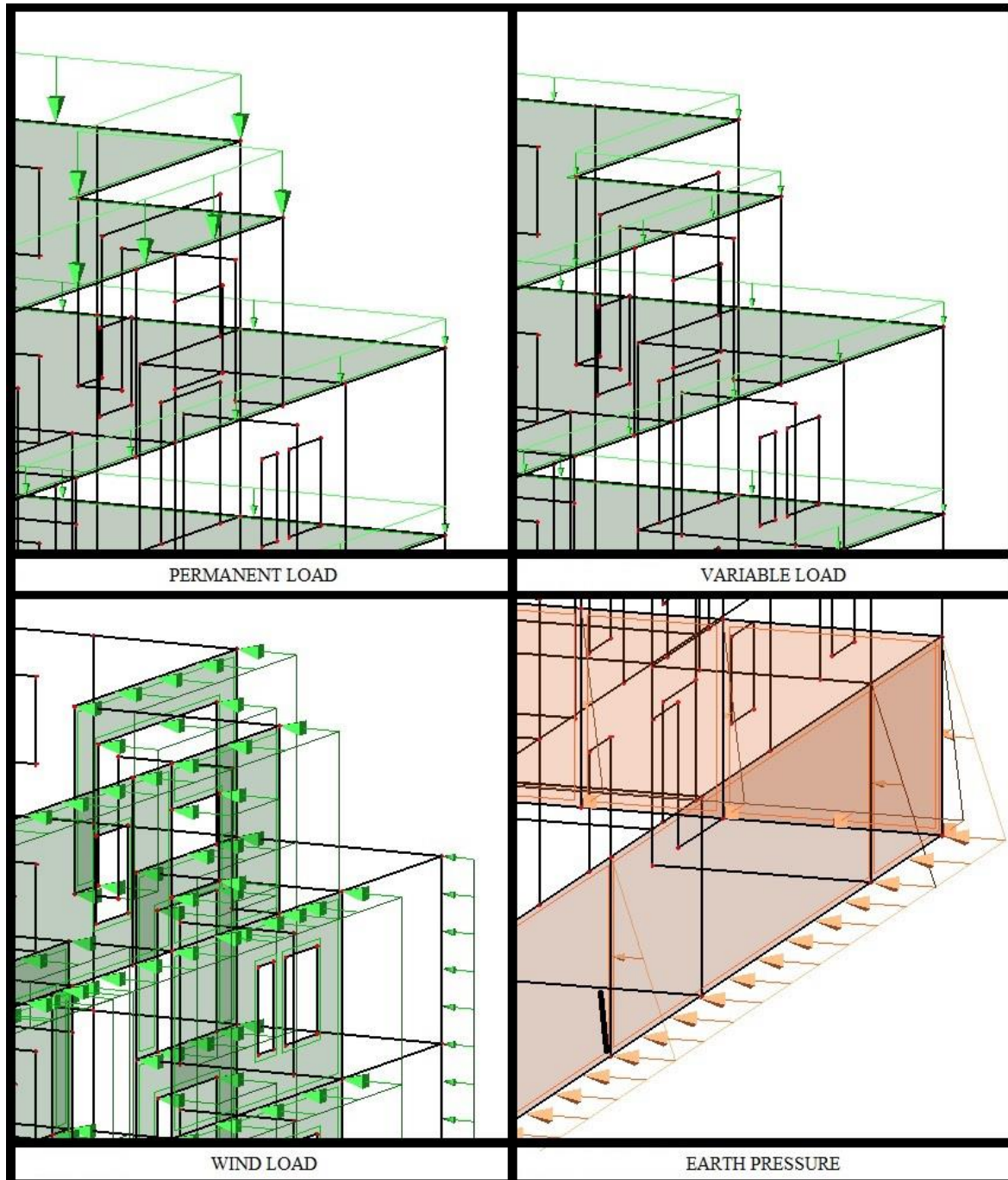


Figure 16 - Types of loads applied

After introducing to the program all the information and the kind of combinations wanted, it has automatically created the different combinations and envelopes with both, as a result, 11 different combinations are obtained:

NAME	S.W.	PERM.	VARIABLE	WIND X	WIND Y	E. PRESS.
SLS - Freq	1	1	1	1	1	1
ULS - set B	1	1	1	1	1	1
SLS - Freq1	1	1	-	-	-	-
SLS - Freq2	1	1	0.5	0.8	0.8	0.8
SLS - Freq3	1	1	0.3	0.9	0.9	0.9
ULS - set B1	1.35	1.35	-	-	-	-
ULS - set B2	1	1	-	-	-	-
ULS - set B3	1.35	1.35	1.5	1.5	1.5	1.5
ULS - set B4	1	1	1.5	1.5	1.5	1.5
ULS - set B5	1.35	1.35	1.05	1.5	1.5	1.5
ULS - set B6	1	1	1.05	1.5	1.5	1.5

Table 1 - Coefficients given to the different loads in the different envelopes.

From all this combinations, the worst one will be showed by the program as the result for both cases, SLS and ULS.

In order to solve the problem that the structure has shown, a study case would have to be done and a reinforcement placed. In order to



Figure 17 - Column and slab studied

simplify but to show how it should be done, two parts of the building have been considered for being studied and in the end one will be reinforced. The two parts are one of the columns in the terrace and de slab between the garage and the ground floor.

Study case of the column:

Columns are always an important building point to take in consideration. Loads tend to be higher there, and as a slender element it can have important displacements. For our study, the columns have been provided with two main loads, the self-weight and the wind load. Also, the self-weight and the main and permanent loads used in the slab around will have some effect in the column result.

The following result shows how stress and displacements are affecting the column. The results are logical, in the higher part of the column there is fewer stress due to not having to support so much weight, but the displacements are larger. The higher stress is 3.5 MPa and the lower -5.8 MPa, reached both in the bottom of the column. The higher displacement is reached in the top with a value of 2.1 m.

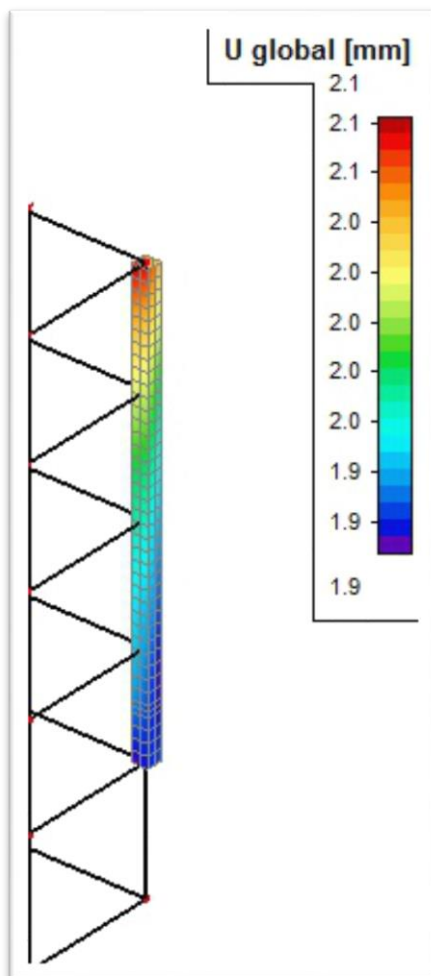


Figure 19 - Displacement results for the column

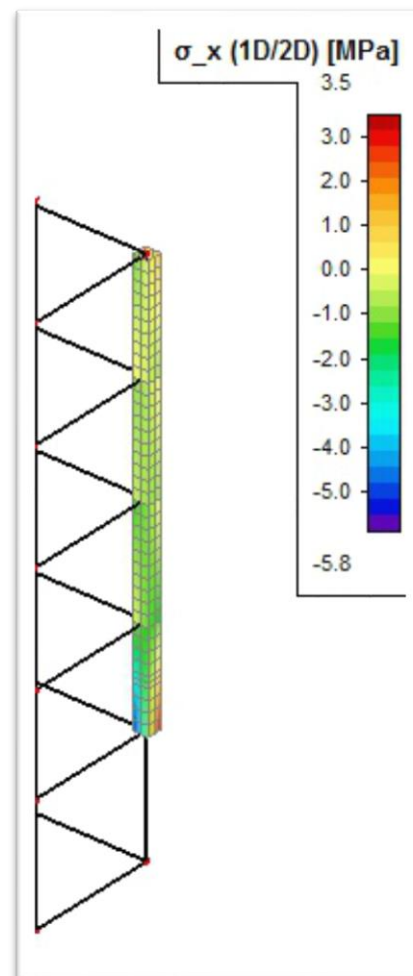


Figure 18 - Stress results for the column

Study case of the ground floor slab:

The ground floor slab is always an important piece of the structure to study. As a result of having to stand the stress of almost the whole building and not having the ground support as the garage floor has. Due to it, big stresses around the contacts with the walls, and less stresses in the points where there is no contact will be expected. In the other way, displacements will be bigger in the places where no walls are, and bigger as further as the nearer wall is. Points in contact with the walls will almost not have displacement. In the same case as with the column, some loads have been added to the slab in order to make the analysis realistic. The self-weight has been taken in account. So it means that the material used C25/30 and the width will be used to determinate this value, which is going to be around $2,3\text{kN/m}^2$.

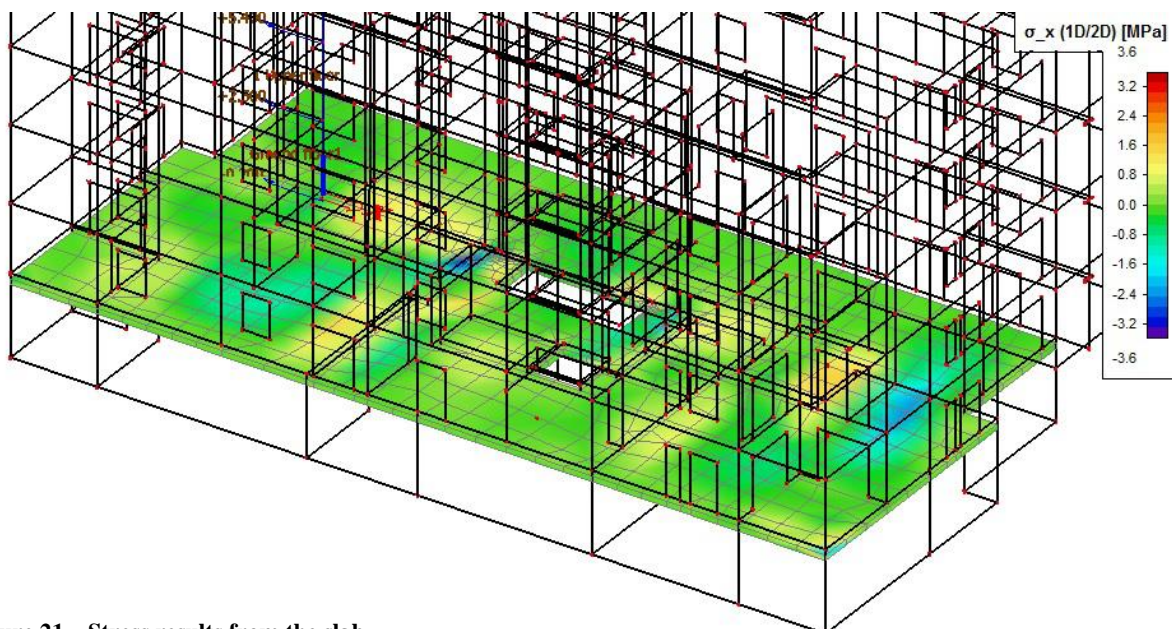


Figure 21 – Stress results from the slab

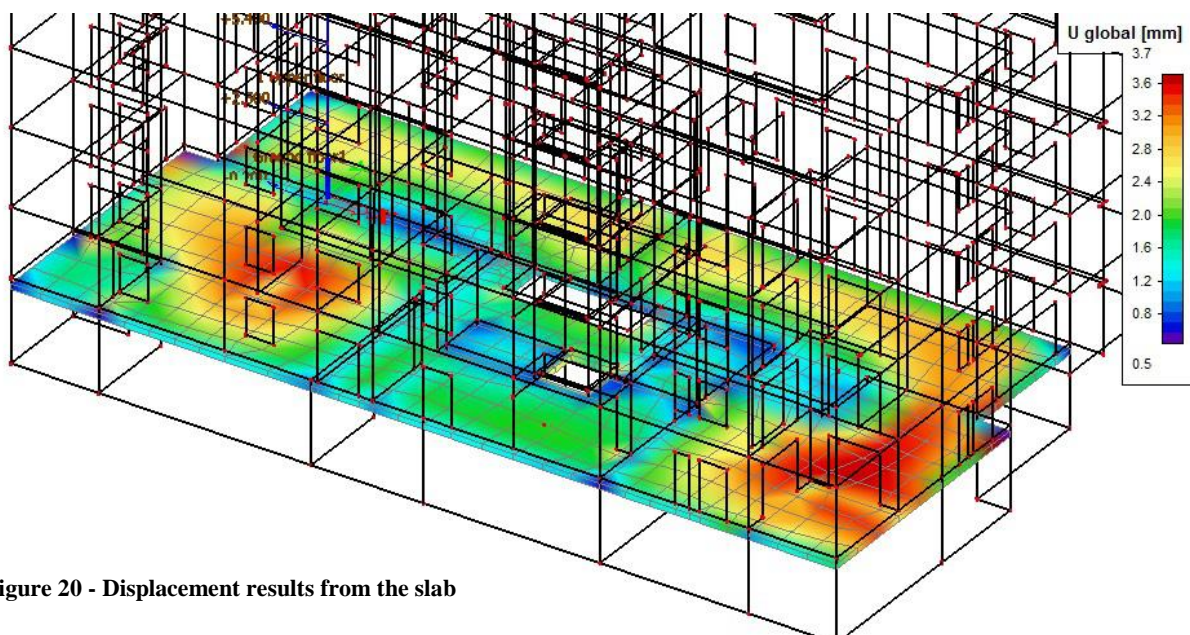


Figure 20 - Displacement results from the slab

As the results show, the predictions have been accomplished. In the displacement figure, can be seen that the biggest displacement (3.7 mm) is reached in the point found further from any wall. When closer to a wall, the displacement is being reduced till arriving at the walls. But also on the walls there are some minimum displacements of value 0.5mm. It can be attributed to the general displacement that the building will have because of the self-weight.

5.3 Reinforcement in Allplan and Scia

A reinforcement is always needed when the deformations because of the loads are higher than what the norm for SLS allows. Due to having exceeded this number, a reinforcement will be needed in our case. The first step that has to be followed is calculating the amount of reinforcement needed. Scia can do it by itself, and gives us the results in an image like this.

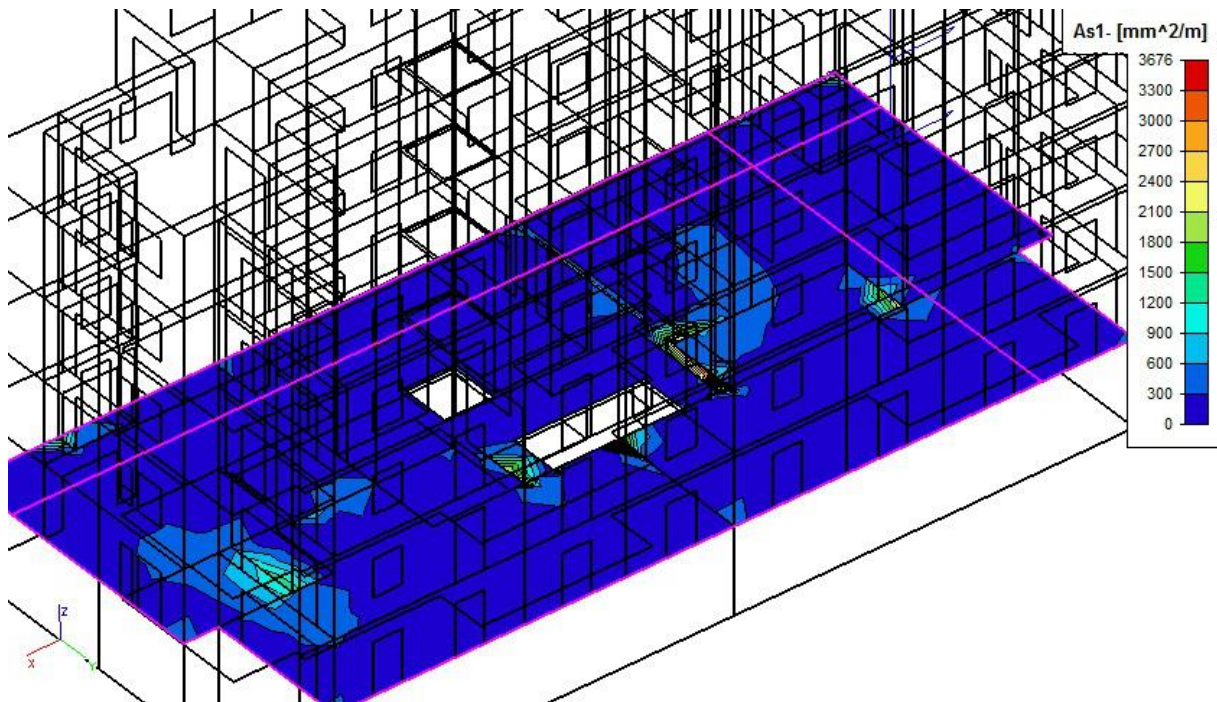


Figure 22 – View of the required reinforcement in Scia

As shown in the picture, a reinforcement between 0 and 3 cm²/m is going to be needed. Also, there are some points in which this reinforcement should be much higher. An advanced result output shows us the default amount of reinforcement that the program has calculated as an estimation of what would be needed.

Member	elem	Case	n1- [kN/m]	z- [mm]	x- [mm]	ϵ_s - [1e-4]	ϵ_c - [1e-4]	σ_{sz} - [MPa]	σ_c - [MPa]	$A_{s,calc}$ - [mm ² /m]	$A_{s,min}$ - [mm ² /m]	$A_{s,max}$ - [mm ² /m]	E/W _s -
<Unnamed Element>311	4251	ULS - set B	1295.63	141	49	79.1	-35.0	352.44	-16.67	393	3283	3676	101

Once calculated, the program has the automatic option for allocating the bars. Standard diameter bars will be placed, as many as necessary, in each meter in order to accomplish the steel area needed (which is 3,93 cm² in our case). The way of allocating the bars is explained also by the DIN EN 1992 norm. Some distance has to be left between the border of the slab and the placement of the bars, as well as the distance between bars.

In my case, bars of 10 mm of diameter will be used, separated a distance of 200 mm. That makes the total amount of steel area equal to the 393 mm². The distance between the concrete border and the steel bars is 30 mm for the cross ones, and 30 mm plus the diameter of the cross ones (10mm) so a total of 40 mm, for the longitudinal¹³.

- Workflow between Scia and Allplan through the BIM+ platform using the ASF file.

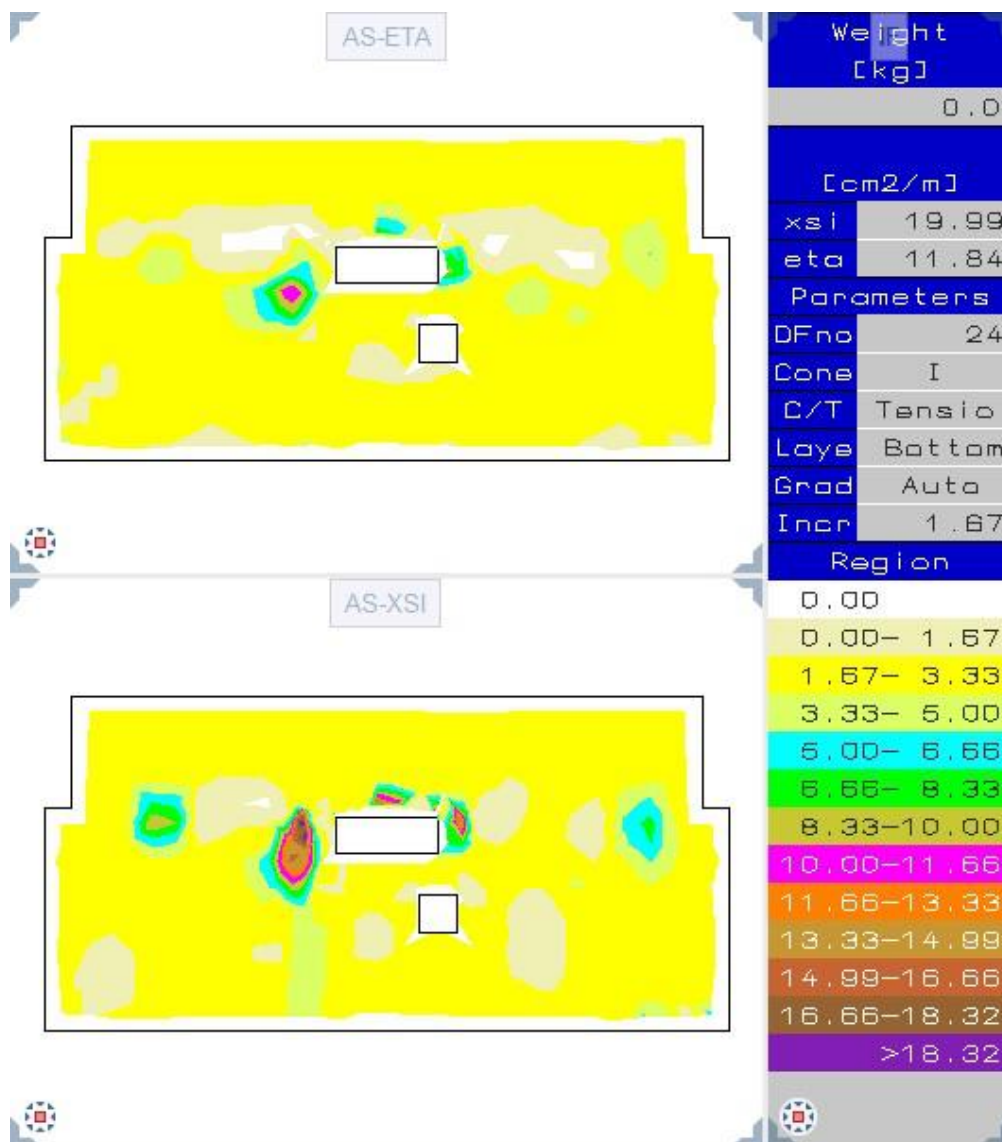


Figure 23 – Result view of the file transference from Scia to Allplan

¹³ A better explanation of the reinforcement allocation can be found in Annex D

As shown in the figure, the slab is needing a global reinforcement but suck different values are displayed. In this case, the value that Scia program gave us, $3.93 \text{ cm}^2/\text{m}$, is accepted. Also, the same bar diameter and its disposition is going to be used.

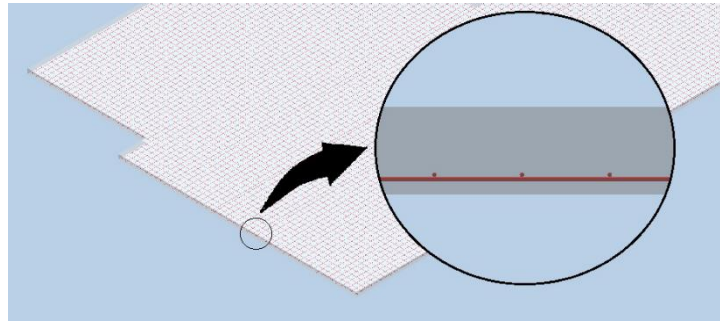


Figure 24 – Detailed view of the reinforcement

For the bars displacement, the Allplan procedure will be used. First of all, some profiles of the slab will be made. As many profiles as different they can be will have to be done. So the beginnings and endings of the openings, or width variation will be inflection points for beginning-ending one profile. 13 profiles are needed and were added to the model. Ones the profiles are done, the bar reinforcement have to be added in the profile, and the possibility of extending the same reinforcement to the same profile area will be able, just the distance between bars will have to be described. Other inputs like the concrete recovery. In the end, a B500S mesh like the one shown in the picture will be obtained.

Now, once again the reinforcement needed visor can be turned on, and it can be seen that the quantity of reinforcement needed in all the surface has decreased a constant value of $3.93 \text{ cm}^2/\text{m}$.

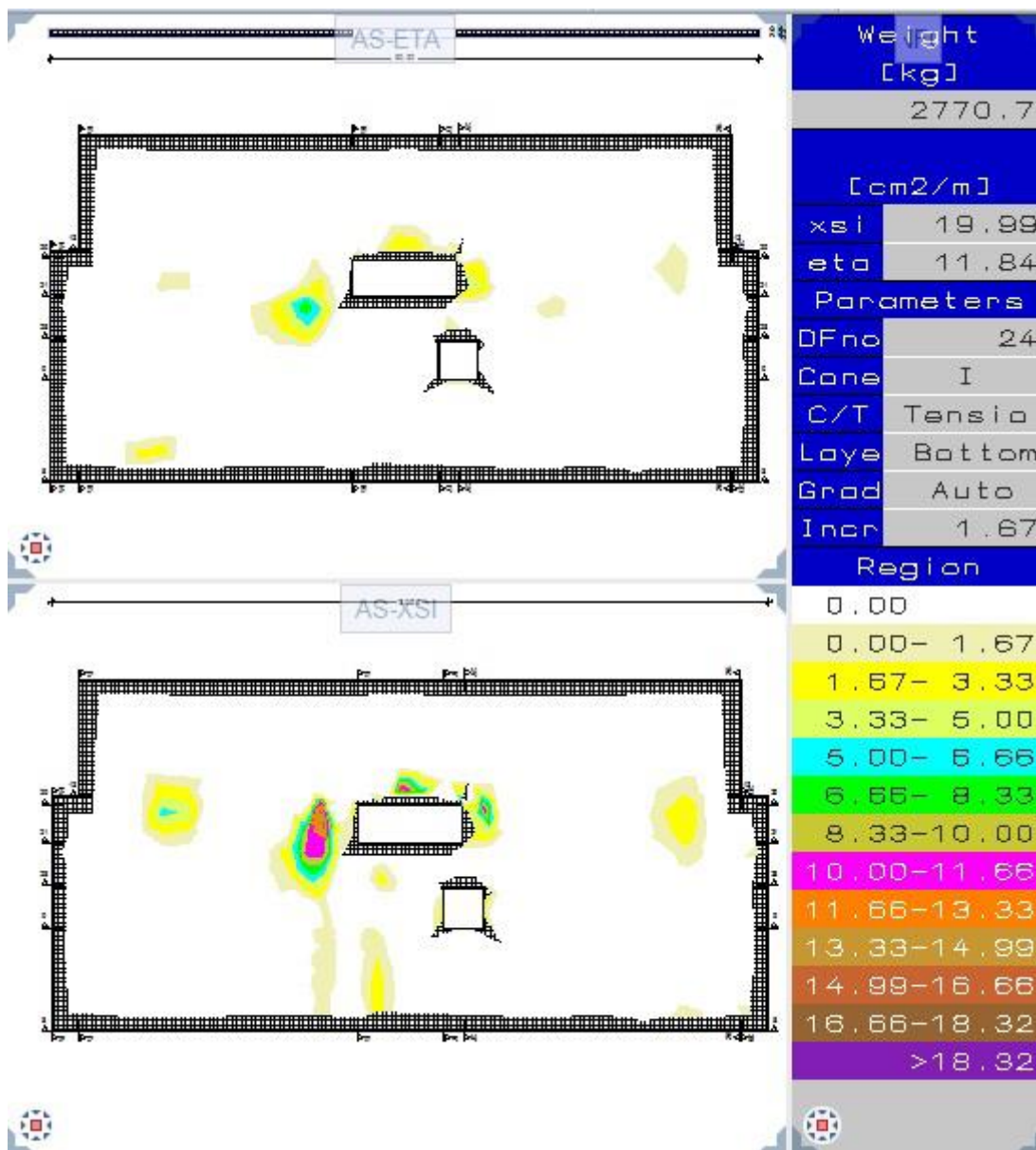


Figure 25 – View of the needed reinforcement after the bars location.

6 Conclusions

After three months of working with the BIM software, the platform and the workflow in between I can now extract some conclusions of what I have learned, what have been the work done by the BIM community to bring this technology till this point and what should the BIM offer in a nearly future from my point of view.

When I began this project, looking for BIM information as well as its way of exchanging information, I could not understand the magnitude of its meaning. Now I can say that designing and constructing a building nowadays is like building it two times, the first time is going to be digitally, and after that, the real one. BIM software can be so accurate that can show where electricity cable holes will have to be made, or even the switches placement can be discussed with the client before beginning the construction. Having the chance to show a “real” finished product avoids problems during the construction, having changes, and helps in reducing the delivery time. Also other options, like the analysis calculation or self-reinforcement calculation are a great help, Second time construction, the real one, will be just a copy of what have been “constructed” using the BIM software.

The workflow is an essential part of the whole. Is the linkage between all the other parts. Without it, different parts of a same project could have been done separately, but the possibility of joining them would be unthinkable. Input data (the geometry of the structure, the loads, the decoration elements or the reinforcement bars for example) would have to been done multiple times making us loose time and veracity of considering all the buildings exactly the same. The triumph of the creation of a same building file was a completely success for the workflow. Having to change multiple times the format is tedious, but what is more important, unsafe for the information, being that a possible cause of damage or modification of it.

Now thinking on the future of what workflow can bring us, I think there is still a lot to do. I would bet on the developing on this just born online platforms. I see on them a lot of potential. Till now, only files can be viewed, hanged or shared, as well as creating advices of what have been done ore what is still for doing. It can be said that till now they are mainly used for organizing. In the future this platforms would have to be able to contain the whole files as well as the different software, would have to contain the whole elements for being able to all the “digital construction”. The creation of a place with such aim has to contain certain characteristics.

The whenever-whenever philosophy should continue, so we are talking about a platform that can be accessed by anyone allowed from internet. Everyone would have his own account, and in this account, the projects involved in. At the same platform, the user will be able to open the different projects in the different software available. For that, a different concept of files or software will have to be contrived. On one hand a file made of multiple layers can be devised. With that, the different software would be able to open just the layer of its interest. On the other hand, a totally new software joining the functions in the different programs can be joined in order to work just in one program.

There are some points for and against this idea. With it, the creation of files and importation of them to the platform would not be needed. In fact, and as remarked in the workflow paragraph, there is the possibility to do that between Allplan, Scia and the BIM+ platform. Also the advantage of having everything on the cloud will allow us being mobile without having to carry our laptop or files in an external memory, or having to go on installing the software in new computers every time we want to work. Some against arguments can be the fact of working directly on the original file, having the possibility of erasing or modifying it in a bad and irreversible way. For that I would suggest the creation of a new model everyone saves the work done. I also would design the creator of the model as the only one able to save directly over or even erase it. Also the requirement of having to be connected to internet is a handicap, so would reduce this requirement to the charge of the program and file as well as in the end for its saving.

And what happens in the case of wanting to link with some other software or platform companies? An e-mail service can be added to the platforms in order to send and receive files from other platforms. For making it possible, and then having the possibility to open the received information with another company program, the formats will have to be compatible, as it is happening now with the IFC or CAD files.

Of course the possibility of the import and exportation of files from the platform will continue active, as well as all the organization method.

The principal aim of all this evolution is concentrating all the needs during the design in one screen in order to save time during the transactions between programs with the creation of files as well as ensuring a better treatment of this files during the workflow.

Annex A

Allplan views



Illustration II – Location of the haus into the PANDION gardens

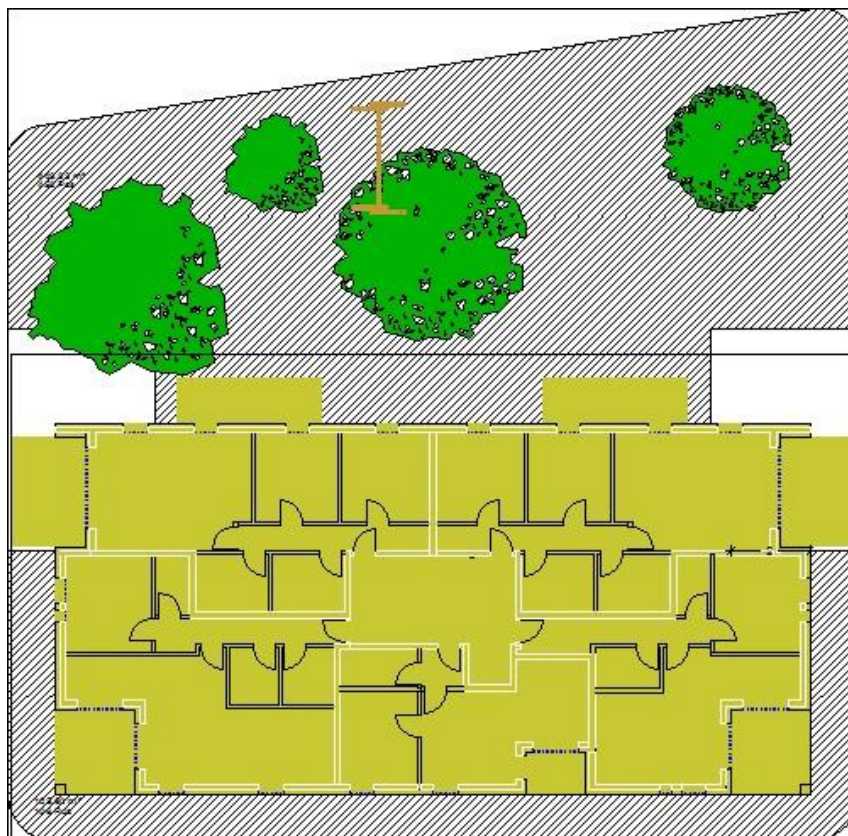


Illustration I – Plan view of the building



Illustration III – Front view



Illustration IV – Back view



Illustration VI - Side view



Illustration V - Corner view

Annex B

Default forces

In order to know where exactly the different values are taken from, the corresponding tables are presented.

6 Fußboden- und Wandbeläge (EC1-1-1, Tab. NA.A.18)

Gegenstand	Flächenlast je cm Dicke in kN/m ²
Asphaltbeton	0,24
Asphaltmastix	0,18
Gussasphalt	0,23
Betonwerksteinplatten, Terrazzo, kunstharzgebundene Werksteinplatten	0,24
Estrich	
▪ Calciumsulfatestrich (Anhydritestrich, Natur-, Kunst- und REA ¹⁾ -Gipsestrich)	0,22
▪ Gipsestrich	0,20
▪ Gussasphaltestrich	0,23
▪ Industrieestrich	0,24
▪ Kunstharzestrich	0,22
▪ Magnesiaestrich nach DIN 272 mit begehrbarer Nuttschicht bei ein- oder mehrschichtiger Ausführung	0,22
▪ Unterschicht bei mehrschichtiger Ausführung	0,12
▪ Zementestrich	0,22
Glasscheiben	0,25
Gummi	0,15
Keramische Wandfliesen (Steingut einschließlich Verlegemörtel)	0,19
Keramische Bodenfliesen (Steinzeug und Spaltplatten, einschließlich Verlegemörtel)	0,22
Kunststoff-Fußbodenbelag	0,15
Linoleum	0,13
Natursteinplatten (einschließlich Verlegemörtel)	0,30
Teppichboden	0,03

¹⁾ Rauchgasentschwefelungsanlagen.

Illustration VII – Permanent loads for the floors and garage

5 Dachdeckungen

Die Flächenlasten gelten für 1 m² Dachfläche ohne Sparren, Pfetten und Dachbinder.

Deckungen aus Dachziegeln, Dachsteinen und Glasdeckstoffen (EC1-1-1, Tab. NA.A.21)

Gegenstand	Flächenlast ¹⁾ in kN/m ²
Dachsteine aus Beton mit mehrfacher Fußverrippung u. hoch liegendem Längsfalz	0,50
▪ bis 10 Stück/m ²	
▪ über 10 Stück/m ²	0,55
Dachsteine aus Beton mit mehrfacher Fußverrippung u. tief liegendem Längsfalz	
▪ bis 10 Stück/m ²	0,60
▪ über 10 Stück/m ²	0,65
Biberschwanzziegel 155 mm × 375 mm und 180 mm × 380 mm und ebene Dachsteine aus Beton im Biberformat	
▪ Spließdach (einschließlich Schindeln)	0,60
▪ Doppeldach und Kronendach	0,75
Falzziegel, Reformpfannen, Falzpfannen, Flachdachpfannen	0,55
Glasdeckstoffe	bei gleicher Dachdeckungsart wie in Zeilen 1 bis 6
Großformatige Pfannen bis 10 Stück/m ²	0,50
Kleinformatige Biberschwanzziegel u. Sonderformate (Kirchen-, Turmbiber usw.)	0,95
Krempziegel, Hohlpfannen	0,45
Krempziegel, Hohlpfannen in Pappdocken verlegt	0,55
Mönch- und Nonnenziegel (mit Vermörtelung)	0,90
Strangfalzziegel	0,60

¹⁾ Die Flächenlasten gelten, soweit nicht anders angegeben, ohne Vermörtelung, aber einschließlich der Lattung.

Illustration VIII – Permanent loads for the roof

III Nutzlasten für Hochbauten

nach DIN EN 1991-1-1 (12.2010) und DIN EN 1991-1-1/NA (12.2010)

Prof. Dipl.-Ing. Klaus-Jürgen Schneider

1 Lotrechte Nutzlasten für Decken, Treppen und Balkone

Tafel 3.16 Lotrechte Nutzlasten für Decken, Treppen und Balkone; charakteristische Werte
(vgl. EN 1991-1-1/NA, Tab. 6.1 DE)

Kategorie	Nutzung	Beispiele	q_k kN/m ²	Q_k kN
A	A1	Spitzböden	1,0	1,0
	A2	Wohn- und Aufenthaltsräume	1,5	–
	A3	wie A2, aber ohne ausreichende Querverteilung der Lasten.	2,0 ¹⁾	1,0
B	B1	Büroflächen, Arbeitsflächen, Flure	2,0	2,0
	B2	Flure in Krankenhäusern, Hotels, Altenheimen, Internaten usw.; Küchen u. Behandlungsräume einschl. Operationsräume ohne schweres Gerät.	3,0	3,0
	B3	wie B1 und B2, jedoch mit schwerem Gerät	5,0	4,0
C	C1	Flächen mit Tischen; z. B. Schulräume, Cafés, Restaurants, Speisesäle, Lesesäle, Empfangsräume.	3,0	4,0
	C2	Flächen mit fester Bestuhlung; z. B. Flächen in Kirchen, Theatern oder Kinos, Kongresssäle, Hörsäle, Versammlungsräume, Wartesäle.	4,0	4,0
	C3	Frei begehbare Flächen; z. B. Museumsflächen, Ausstellungsflächen usw. und Eingangsbereiche in öffentlichen Gebäuden und Hotels, nicht befahrbare Hofkellerdecken; Flure in den Kategorien C1 bis C3.	5,0	4,0
	C4	Sport- und Spielflächen; z. B. Tanzsäle, Sporthallen, Gymnastik- und Kraftsporträume, Bühnen.	5,0	7,0
	C5	Flächen für große Menschenansammlungen; z. B. in Gebäuden wie Konzertsäle, Terrassen und Eingangsbereiche sowie Tribünen mit fester Bestuhlung.	5,0	4,0
	C6	Flächen mit erheblichen Menschenansammlungen; Tribünen ohne feste Bestuhlung.	7,5	10,0
D	D1	Flächen von Verkaufsräumen bis 50 m ² Grundfläche in Wohn-, Büro- und vergleichbaren Gebäuden.	2,0	2,0
	D2	Flächen in Einzelhandelsgeschäften und Warenhäusern.	5,0	4,0
	D3	Fläche wie D2, jedoch mit erhöhten Einzellasten infolge hoher Lagerregale.	5,0	7,0

¹⁾ Für die Weiterleitung der Lasten in Räumen mit Decken ohne ausreichende Querverteilung auf stützende Bauteile darf der angegebene Wert um 0,5 kN/m² abgemindert werden.

Illustration IX – Variable load for the floors

Tafel 3.24a Windzonenkarte mit zug. Basiswindgeschwindigkeiten $v_{b,0}$ und Basisgeschwindigkeitsdrücken $q_{b,0}$ nach DIN EN 1991-1-4/NA, Anhang NA-A

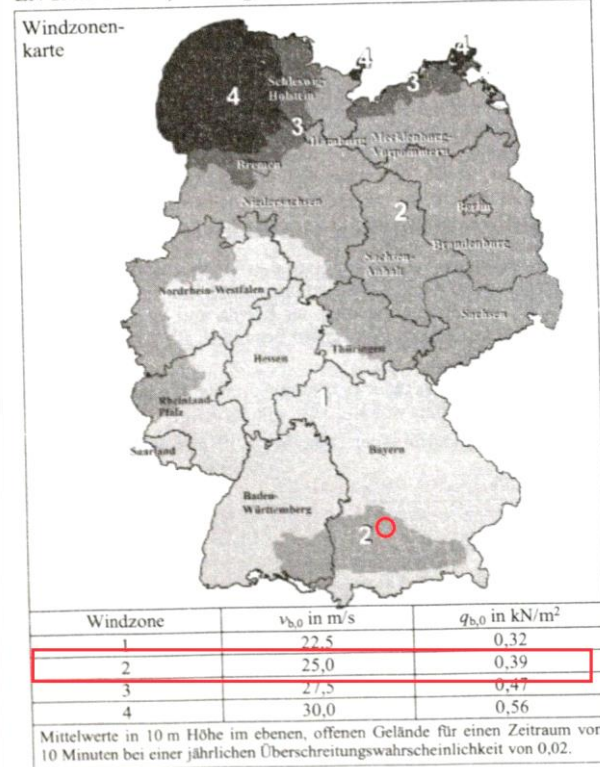


Illustration XI – Determination of the wind zone

5.3 Vereinfachte Böengeschwindigkeitsdrücke für Bauwerke bis 25 m Höhe

Bei Bauwerken bis 25 m Höhe darf der Böengeschwindigkeitsdruck vereinfachend nach Tafel 3.25 konstant über die gesamte Bauwerkshöhe angesetzt werden. Der Böengeschwindigkeitsdruck ergibt sich für die Bauwerkshöhe, eine Abstufung über die Bauwerkshöhe wie in der alten Windlastnorm (DIN 1055-4, Ausg. 1986) ist nicht mehr vorgesehen. Für höhere Bauwerke sowie für Bauwerke auf den Inseln der Nordsee mit mehr als 10 m Höhe ist der Böengeschwindigkeitsdruck nach Abschnitt 5.4 zu berechnen.

Tafel 3.25 Vereinfachte Böengeschwindigkeitsdrücke für Bauwerke bis 25 m Höhe

Windzone		Geschwindigkeitsdruck q_p in kN/m ² bei einer Gebäudehöhe h in den Grenzen von		
		$h \leq 10$ m	$10 \text{ m} < h \leq 18$ m	$18 \text{ m} < h \leq 25$ m
1	Binnenland	0,50	0,65	0,75
2	Binnenland	0,65	0,80	0,90
	Küste ¹⁾ und Inseln der Ostsee	0,85	1,00	1,10
3	Binnenland	0,80	0,95	1,10
	Küste ¹⁾ und Inseln der Ostsee	1,05	1,20	1,30
	Binnenland	0,95	1,15	1,30
4	Küste ¹⁾ der Nord- und Ostsee und Inseln der Ostsee	1,25	1,40	1,55
	Inseln der Nordsee ²⁾	1,40	–	–

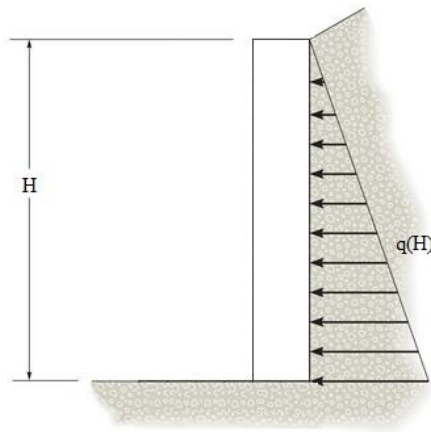
¹⁾ Zur Küste zählt ein 5 km breiter Streifen, der entlang der Küste verläuft und landeinwärts gerichtet ist.
²⁾ Auf den Inseln der Nordsee ist der Böengeschwindigkeitsdruck für Bauwerke über 10 m Höhe nach Abschnitt 5.4 zu ermitteln.

Illustration X – Wind load

Annex C

Earth pressure

In order to obtain the earth pressure loads a simple calcul has been done. The necessary information of the soil and equations for finding the necessary load are show:



Information needed:

$$\gamma = \text{soil weight} \left[\frac{\text{kN}}{\text{m}^3} \right]$$

$$H = \text{height} \text{ [m]}$$

$$c = \text{friction coefficient}$$

$$\phi = \text{friction angle} \text{ [}^\circ\text{]}$$

Equations:

$$q(H) = \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K0 - 2 \cdot c \cdot H \sqrt{K0}$$

$$K0 = 1 - \sin \phi$$

In our case we will consider a typical soil with the following characteristics. We also have also supposed that there is not a floated zone.

$$\gamma = 16.5 \frac{\text{kN}}{\text{m}^3}$$

$$\phi = 30$$

$$c = 0$$

So the final loads applied will follow the next leial equation:

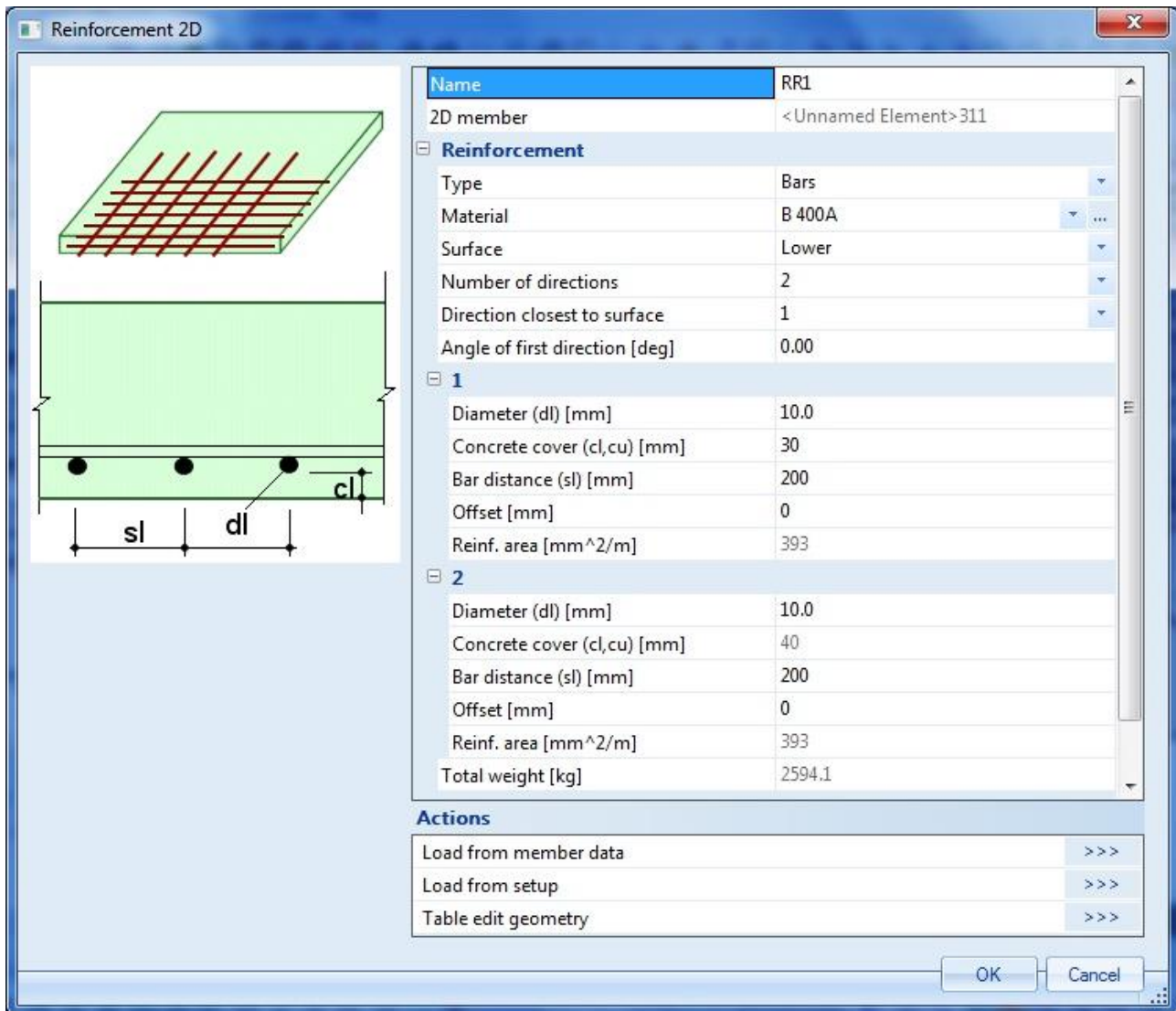
$$q(H) = H \cdot 16 \cdot (1 - \sin 30) = 8H$$

$$q(0) = 0 \frac{\text{kN}}{\text{m}^2}$$

$$q(-3) = 24 \frac{\text{kN}}{\text{m}^2}$$

Annex D

Reinforcement specification



If we place bars of 10 mm of diameter separated 200 mm, means that we are going to have 5 bars in each meter. If we calculate the total bar-area we obtain the reinforcement area proposed by Scia.

$$5 \frac{\text{bars}}{\text{m}} * 5^2 \pi \frac{\text{mm}^2}{\text{bars}} = 392.7 \frac{\text{mm}^2}{\text{m}} \approx 393 \frac{\text{mm}^2}{\text{m}}$$

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Declaration

With this statement I declare, that I have independently completed this Master's thesis. The thoughts taken directly or indirectly from external sources are properly marked as such. This thesis was not previously submitted to another academic institution and has also not yet been published.

München, 21. September 2015

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