UNIVERSITY OF MARIBOR
FACULTY OF CIVIL ENGINEERING, TRANSPORTATION ENGINEERING AND ARCHITECTURE

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# INTEROPERABILITY BETWEEN ARCHITECTURAL AND STRUCTURAL BIM SOFTWARE IN THE CASE OF A MALL PROJECT

Master Thesis

Maribor, December 2017

Univerza v Mariboru

Fakulteta za gradbeništvo,
prometno inženirstvo in arhitekturo

Smetanova ulica 17
2000 Maribor, Slovenija

# INTEROPERABILITY BETWEEN ARCHITECTURAL AND STRUCTURAL BIM SOFTWARE IN THE CASE OF A MALL PROJECT

Master's thesis submitted to the University of Maribor in partial fulfillment of the requirements for the degree of

Master of Science in

Civil Engineering

Student: Drilon RRACI

Study program: Master Degree, Civil Engineering

Department: Structures

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Co-supervisor: red. prof. dr. Danijel REBOLJ, univ. dipl. inž. grad.

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2000 Maribor, Slovenija

Številka: G2004099
Maribor, 14.07.2017

Na osnovi 330. člena Statuta Univerze v Mariboru (Ur. l. RS, št. 29/2017 – UPB12) izdajam

**SKLEP O MAGISTRSKEM DELU**

**Drilon Rraci,** študentu-ki študijskega programa 2. stopnje GRADBENIŠTVO, se dovoljuje izdelati magistrsko delo.

MENTOR(ICA): doc. dr. Milan Kuhta
SOMENTOR(ICA): red. prof. dr. Danijel Rebolj

**Naslov magistrskega dela**:

INTEROPERABILNOST BIM PROGRAMSKE OPREME V PRIMERU PROJEKTA TRGOVSKEGA CENTRA

**Naslov magistrskega dela v angleškem jeziku:**

INTEROPERABILITY BETWEEN ARCHITECTURAL AND STRUCTURAL BIM SOFTWARE IN THE CASE OF A MALL PROJECT

Magistrsko delo je potrebno izdelati skladno z "Navodili za izdelavo magistrskega dela" in ga oddati v treh izvodih do 12.07.2018 v referatu za študentske zadeve. Hkrati se odda tudi izjava mentorja-ice (in morebitne-ga somentorja-ice) o ustreznosti zaključnega dela.
V skladu z Navodili o pripravi in oddaji e-diplom je potrebno magistrsko delo oddati v Digitalno knjižnico Univerze v Mariboru.

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DEKAN
red. prof. dr. Miroslav Premrov

Obvestiti:

- kandidata -ko,
- mentorja-ico,
- somentorja-ico,
- odložiti v arhiv.

UNIVERZA V MARIBORU FAKULTETA ZA GRADBENIŠTVO, PROMETNO INŽENIRSTVO IN ARHITEKTURO 1

**GRATITUDE**

To my beloved family, especially to my MOM,
who gave everything she had to support me at any time!

`

***Quote***

*"At its heart, engineering is about using science to find creative solutions. It's a noble profession"* – ***Queen Elizabeth II***

**Acknowledgment**

*Firstly, I am grateful to* ***JoinEU-SEE>PENTA Programme,*** *for their support and opportunity to carry out my master degree at the University of Maribor. To me, the impact of JoinEU-SEE>PENTA project has been indicated, both on an individual and institutional level.*

*I express my deep sense of gratitude to my University supervisor* **doc. dr. Milan Kuhta, univ. dipl. inž. grad.,** *for his guidance and support in completing this work. He and his teaching assistants gave me the motivation I needed to successfully finish my grads with merits in the Department of Structural Engineering.*

*I would also like to thank my thesis co-supervisor* **red. prof. dr. Danijel Rebolj, univ. dipl. inž. grad.,** *building information modeling (BIM) researcher at FGPA, for his valuable encouragement and guidance during my master thesis.*

*Last but not least, I would like to thank* **Gravitas,** *design and engineering company Ltd***.,** *for their willingness to cooperate in this project.*

*Finally, I would like to thank my family members and my colleagues who have been a constant source of support and encouragement in all respects during my entire thesis work.*

*-**Drilon Rraci***

**INTEROPERABILITY BETWEEN ARCHITECTURAL AND STRUCTURAL BIM SOFTWARE IN THE CASE OF A MALL PROJECT**

**Keywords:** Building Information Modeling **(**BIM), Interoperability, Data, Direct link, IFC, DSTV (*.stp), Tekla, RFEM, Modeling, A&D, Mall Project.

**UDK:** 624.04:004.9(043.2)

**Abstract**

*This master thesis deals with the effect of interoperability between architectural and structural BIM software in the case of a Mall project. The research and most of the work was performed on a BIM model of the Mall project that was modeled using Tekla BIM software.*

*Since there is still a lack of investigations addressing interoperability issues in the structural engineering domain, this thesis pretends to show the collaboration between architectural and structural BIM software, taking into account a real and complex project.*

*A general overview and research regarding building information modeling (BIM) and interoperability issues were done in this project. Various case studies were conducted, where the entire BIM model and partial models of the Mall project were transferred from BIM to FEM software using different data exchange methods. Structural analysis and design in the case of the relevant partial models of the Mall project were performed with the help of Dlubal-Structural Engineering Software for Analysis and Design. Such analyses were made in the structural analysis program RFEM, to investigate if those partial models are imported correctly.*

*The general conclusion based on the used case studies is that data exchange between BIM and FEM software can be useful, but the ease of use depends on both the data exchange method and the way how the relevant model has been created in Tekla BIM software. Referring to these case studies, the most successful data exchange was achieved by using the direct link between BIM and FEM software.*

**INTEROPERABILNOST BIM PROGRAMSKE OPREME V PRIMERU PROJEKTA TRGOVSKEGA CENTRA**

**Ključne besede:** BIM, Interoperabilnost, Informacije, Direct link, IFC, DSTV (*.stp), Tekla, RFEM, Modeliranje, Analiza in Dimenzioniranje, Projekta trgovskega centra.

**UDK:** 624.04:004.9(043.2)

**Povzetek**

*Magistrsko delo obravnava interoperabilnost med BIM programom za arhitekturo in BIM programom za računsko analizo konstrukcij. Interoperabilnost je analizirana na primeru nakupovalnega centra, za katerega je bil izdelan BIM model s programom Tekla BIM Software.*

*Analiza sodelovanja med arhitekturnim in računskim programom, s povdarkom na računski analizi, je bilo izbrano za temo magistrske naloge, ker je še zmeraj pomanjkanje tovrstnih raziskav. V nalogi je prikazan splošni pregled in raziskave, ki se nanašajo na BIM in interoperabilnost. Analiziral se je prenos posameznih delov in celotne konstrukcije nakupovalnega centra iz BIM modela v MKE modele. Statična analiza in dimenzioniranje se je izvedlo s programskim orodjem Dlubal RFEM.*

*Glavna ugotovitev naloge je, da je izmenjava med BIM in MKE programi lahko koristna, odvisna pa je od možnih metod izmenjave in od tega kako je bil BIM model pripravljen. V obravnavanem primeru se je kot najprimernejša metoda izmenjave iskazala direktna API povezava.*

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**INTEROPERABILITY BETWEEN ARCHITECTURAL AND STRUCTURAL BIM SOFTWARE IN THE CASE OF A MALL PROJECT**

**INTEROPERABILNOST BIM PROGRAMSKE OPREME V PRIMERU PROJEKTA TRGOVSKEGA CENTRA**

**Daljši povzetek v slovenščini**

## UVOD

### Ozadje in splošni pregled teze

Magistrsko delo obravnava sodelovanje in izmenjavo podatkov med BIM pregramom za arhitekturo in BIM programom za računsko analizo konstrukcij. Interoperabilnost (izmenjava informacij med BIM in FEM programi) je analizirana na primeru nakupovalnega centra, za katerega je bil izdelan BIM model s programom Tekla BIM software.

Tekla BIM software je 3D BIM program, ki se v gradbeništvu uporablja predvsem za konstruiranje in modeliranje jeklenih ter betonskih konstrukcij. Z uporabo Tekla BIM lahko kreiramo in upravljamo tudi z 3D arhitekturnimi in računski BIM modeli pri sovprežnih konstrukcijah. Program je bil uporabljen tudi za izdelavo fizikalnega in analitičnega modela trgovskega centra.

V delu, kjer smo analizirali zmožnosti interoperabilnosti med arhitekturnim in računskim programom smo nadaljno obravnavali različne metode izmenjave podatkov. Za praktično ponazoritev izmenjave podatkov smo s programom Dlubal-Structural Engineering Software for Analysis and Design izdelali računsko analizo in dimenzioniranje za modele posameznih konstrukcijskih elementov in celotni model trgovskega centra. Uporabljena je bila trenutno zadnja študentska verzija obeh programov.

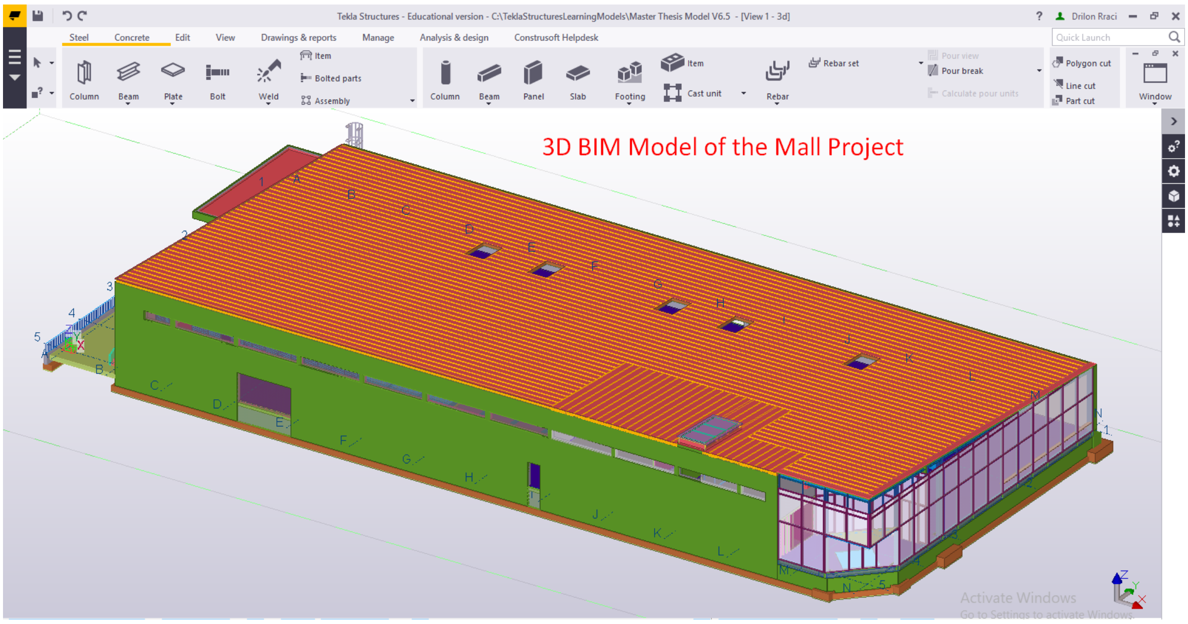
## MODELIRANJE TRGOVSKEGA CENTRA Z UPORABO TEKLA BIM SOFTVER

Namen magistrske naloge je bil analizirati Tekla BIM program.

Tekla BIM program ponuja tudi verzijo za študente, ki se imenuje Tekla Structures Learning (TSL) in je bila uporabljena.

### Opis modeliranja trgovskega centra

Celotni model zajema arhitekturne in konstrukcijske elemente trgovskega centra, lociranega v Murski Soboti (Slika 1-1).




*Slika 1-1: 3D Model trgovskega centra, narejen v TSL*

Vse faze projekta so bile obravnavane. Večina elementov je bila obravnavana kot konstrukcijski, nosilni elementi, kar je bilo nujno za ustrezno računsko analizo. Elementi vsebujejo geometrijo, vozlišča elementov, podatke o materialih, geometrijske karakteristike, podpore in tip načrtovane analize.

Ostali elementi, zajeti v modelu, kot so leseni in aluminijasti elementi fasade so bili obravnavani kot arhitekturni elementi. Ti arhitekturni elementi so bili v TSL modelirani kot nenosilni elementi.

### Modeliranje trgovskega centra

Pri modeliranju trgovskega centra so bila uporabljena naslednja orodja znotraj TSL:

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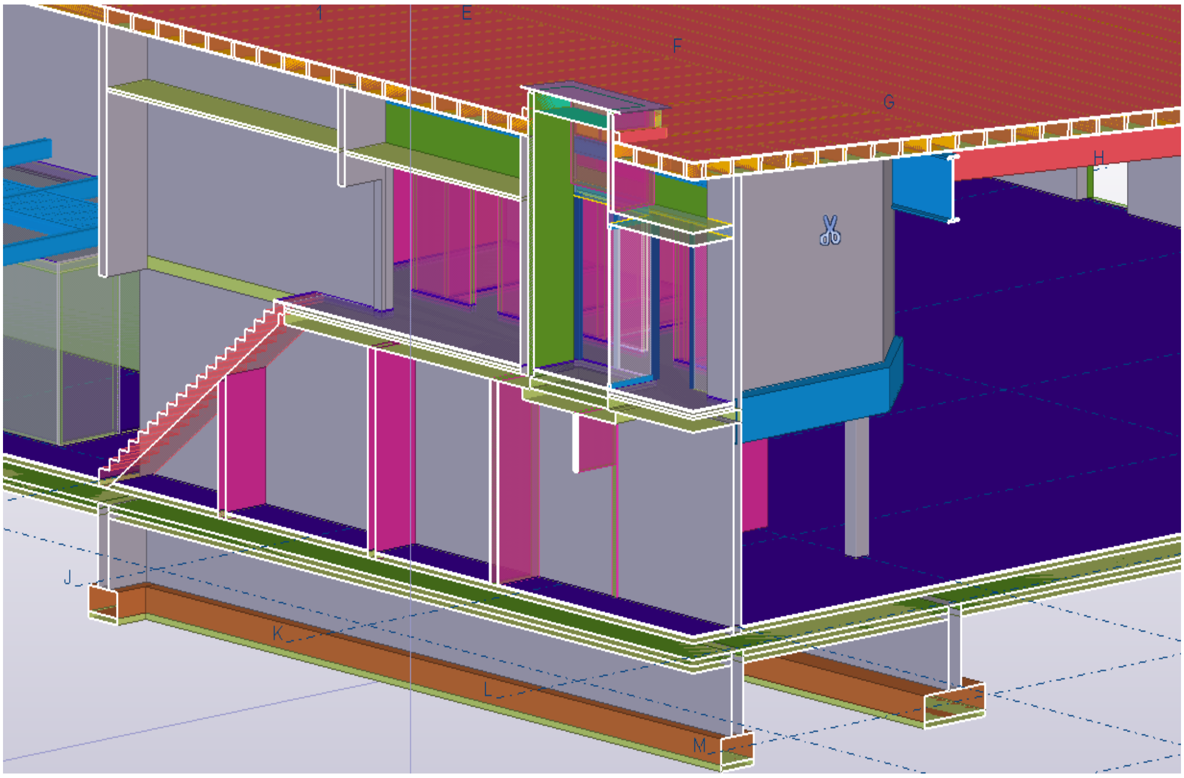
- Tekla Structures Learning Environments,
- Tekla Structures Learning standards and settings,
- Uvoz CAD datotek iz projekta podjetja Gravitas (Gravitas d.o.o, 2017),
- Tekla Warehouse.

**Izdelava risb**

Ker je dokumentacija še zmeraj zahtevana in potrebna na uradih, v projektivnih podjetjih, na gradbiščih in v proizvodnih obratih ohranjajo risbe na papirju v gradbeništvu še zmeraj pomembno vlogo. Zmeraj je torej nujno izdelati risbe, ki podajajo natančne informacije. Z uporabo TSL je možno izdelati risbe posamezno, v skupinah ali pa avtomatično vse. Risbe, ki so bile izdelane v okviru magistrske naloge so dodane v Prilogah.

**Vizualizacija**

Uporaba BIM modelov je v namen vizualizacije že skoraj običajna. V primerjavi z tradicionalnimi risbami 3D BIM vizualizacija projekta pomaga k boljšemu razumevanju koncepta objekta in njegovih detajlov. Primer vizualizacije v TSL je podan na sliki 1-2.



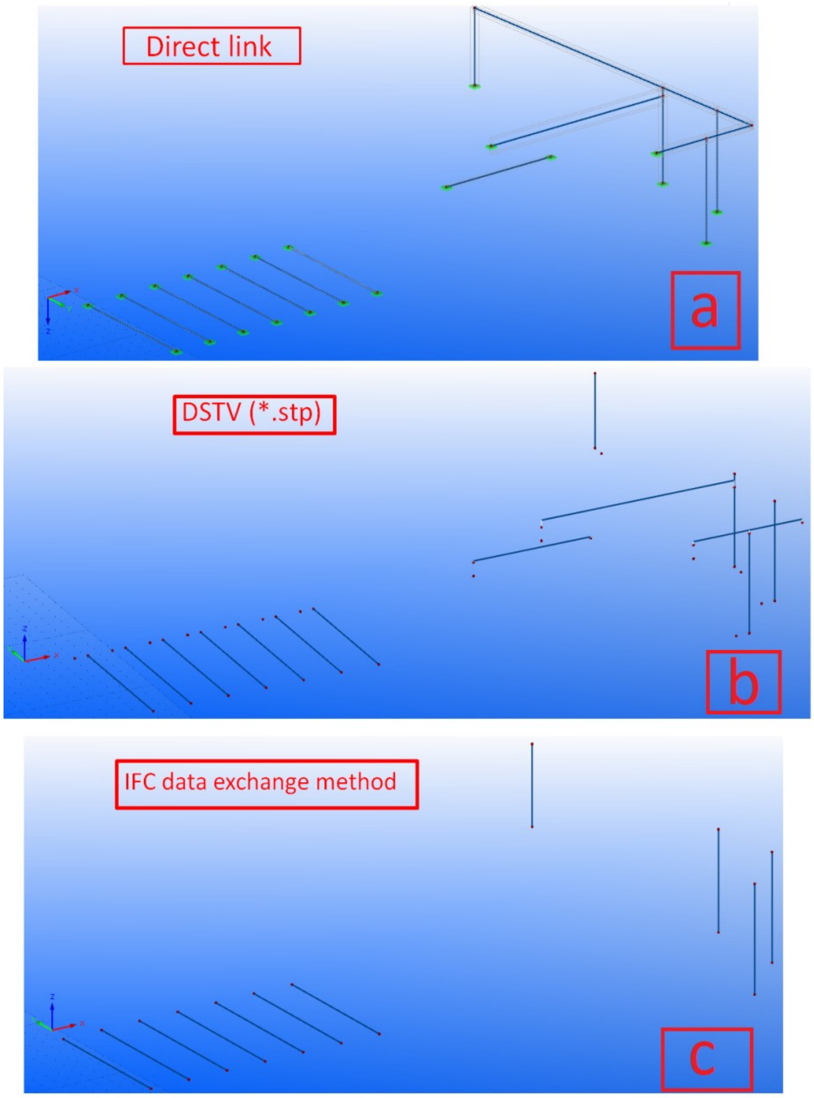

*Slika 1-2: Vizualizacija - delni pogled na trgovski center.*

**INTEROPERABILNOST MED TSL IN RFEM**

To poglavje magistrske naloge opisuje splošne principe izmenjave podatkov med BIM in MKE programi. V okviru magistrske naloge smo za analizo interoperabilnosti izbrali Tekla Structures Learning (TSL) kot BIM program in Dlubal RFEM kot MKE program. Prikazan je postopek izdelave različnih tipov analitičnih modelov v programu TSL.

Poleg tega so bile uporabljene različne metode izmenjave podatkov, kot so »direct link«, »DSTV (*.stp) in »IFC data model exchange«, ki so bile podrobno analizirane in opisane.

Izmenjava podatkov na primeru prenosa konstrukcijskih jeklenih elementov iz TSL v RFEM  je prikazana na Sliki 1-3




*Slika 1-3: Izmenjava podatkov pri prenosu analitičnega modela jeklenih konstrukcijskih elementov iz TSL v RFEM.*

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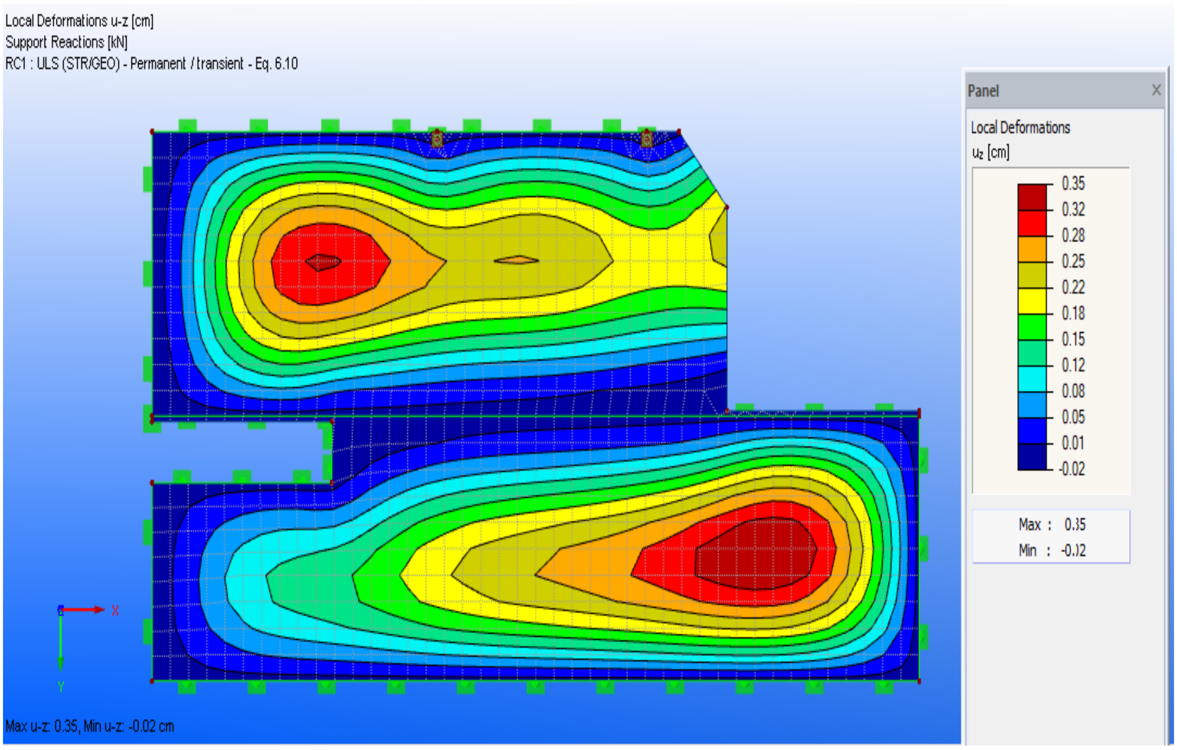
## STATIČNA ANALIZA IN DIMENZIONIRANJE Z DLUBAL SOFTWARE

V tem poglavju je prikazana statična analiza in dimenzioniranje na primeru dveh različnih delnih modelov projekta trgovskega centra. Zasnovano na raziskavi interoperabilnosti med BIM in RFEM v tretjem poglavju naloge, sta bila za nadaljno analizo izbrana dva delna modela in sicer betonska plošča v medetaži in jeklena nosilna konstrukcija. Slika 1-4 prikazuje rezultate statične analize, in sicer pomike, betonske plošče. Za betonsko ploščo je bilo v predelu spuščene plošče potrebno narediti poenostavitev.




*Slika 1-4: Pomiki plošče – program RFEM.*

## OPIS PO POGLAVJIH IN UGOTOVITVE

Z namenom celotne predstqavitve magistrske naloge je v prvem delu tega poglavja podan kratek opis magistrske naloge po poglavjih, v drugem delu pa so opisane glavne ugotovitve.

Začetek naloge vsebuje splošni pregled  o informacijskem modeliranju objektov (BIM) in interoperabilnosti. Namen teh uvodnih poglavij je bil raziskati in prikazati osnovne informacije tega pomembnega področja. Za nadaljne delo se je to izkazalo kot zelo koristno. V nalogi sta se z namenom raziskave interoperabilnosti uporabila dva programa.

TSL je bil uporabljen za modeliranje in pripravo analitičnih modelov, ki so bili uporabljeni v nadaljevanju. Dlubal RFEM je bil uporabljen za uvoz analitičnih modelov in za statično analizo in dimenzioniranje posameznih kosntrukcijskih elementov. V poglavju 4 je prikazan splošni opis in pregled obeh programov.

Modeliranje trgovskega centra je bilo izvedeno s splošnimi funkcijami in nastavitvami, ki jih ponuja TSL. Postopek modeliranja, izdelave risb in vizualizacija so prikazani in komentirani v poglavju 5. Povdariti je potrebno, da je bilo modeliranje izvedeno na osnovi projektne dokumentacije podjetja Gravitas (Gravitas d.o.o, 2017).

Najpomembnješi del naloge, ki se nanaša na bistvo naloge – na interoperabilnost, je zajet v poglavju 6. Za različne analitične modele so prikazani splošen opis, postopek, zapleti in njihova rešitev. Prikazane in analizirane so tudi različne metode izmenjave informacij in posodabljanje modela na osnovi teh izmenjav.

Z namenom nadaljnih raziskav zmožnosti izmenjave podatkov in pomena uvoza analitičnega modela iz TSL je bila narejena statična analiza in dimenzioniranje posameznih konstrukcijskih elementov v programu RFEM. Kratek opis rezultatov statične analize in rezultatov je podan v poglavju 7.

V zaključku naloge so podane ugotovitve, ki vsebujejo pregled glavnih ugotovitev in priporočil iz analize interoperabilnosti na primeru obravnavanega trgovskega centra.

Za analizo interoperabilnosti med BIM in MKE programoma je bila nujna izdelava visoko kvalitetnega BIM modela, ki je zajela vsak posamezen del projekta trgovskega centra. Po uvozu v MKE program je bila nujna temeljita analiza uvoženega, neizogibna je bila tudi izpeljava modifikacij pred statičnim izračunom. Po izvedbi omenjenih procesov je bila izmenjava podatkov z interoperabilnostjo dobro izvedena in manj zahtevno statično analizo in dimenzioniranje v pogramu RFEM je bilo možno izvesti z zadovoljivimi rezultati.

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**CONTENTS**

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**ACRONYMS**

| | |
|---|---|
| BIM | Building Information Modeling (Building Information Model) |
| CAD | Computer-Aided Design |
| 2D | Two-dimensional |
| 3D | Three-dimensional |
| IFC | Industry Foundation Class |
| API | Application Programming Interface |
| FEA | Finite Element Analysis |
| ISO | International Standards Organization |
| SAS | Structure and Architecture Synergy Framework |
| BDS | Building Description System |
| AEC | Architecture, Engineering, and Construction |
| B-rep | Boundary Representation |
| CSG | Constructive Solid Geometry |
| IEC | International Electrotechnical Commission |
| IAI | International Alliance for Interoperability |
| DXF | Drawing eXchange Format |
| IGES | Initial Graphic Exchange Specification |
| STEP | STandard for the Exchange of Product |
| CIS/2 | CIMsteel Integration Standard, Version 2 |
| CIMsteel | Computer Integrated Manufacturing in Constructional Steelwork |
| NBIMS | National BIM Standard |
| SAT | Standard ACIS Text |
| ACIS | Alan, Charles, Ian's System |

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| | |
|---|---|
| BPMN | Business Process Modeling Notation |
| XML | Extensible Markup Language |
| LCIM | Levels of Conceptual Interoperability Model |
| OSI | Open System Interconnect |
| PDF | Portable Document Format |
| NASA | National Aeronautics and Space Administration |
| SQL | Structured Query Language |
| IDM | Information Delivery Manual |
| IFD | International Framework for Dictionaries |
| SI | International System of Units (French: Système international (d'unités)) |
| ICIS | International Construction Information Society |
| COBie | Construction Operations Building Information Exchange |
| O&M | Operations & Maintenance |
| CMMS | Computerized Maintenance and Management System |
| FM | Facility Management |
| HTML | Hypertext Markup Language |
| DTD | Document Type Declaration |
| XSD | XML Schema Definition |
| RDF | Resource Description Framework |
| OWL | Web Ontology Language |
| GIS | Geographic Implementation Specification |
| gbXML | Green Building XML |
| agcXML | Associated General Contractors XML |
| BCF | BIM Collaboration Format |
| GML | Geographic Markup Language |

| | |
|---|---|
| DWF | Design Web Format |
| SDNF | Steel Detailing Neutral Form |
| GUI | Graphical User Interface |
| LOD | Level of Detail/Development |
| MEP | Mechanical, electrical, and plumbing |
| A&D | Analysis and Design |
| RC | Reinforced Concrete |
| TSL | Tekla Structures Learning |
| UDA | User-Defined Attributes |
| EXC | Execution Classes |
| OSB | Oriented Strand Board |
| GA | General Arrangement |
| DSTV | Deutscher STahlbau-Verband |
| NC | Numerical Control |
| DIN | (German: Deutsches Institut für Normung) or (English: German Institute for Standardization) |
| FE | Finite Element |
| EN | European Standards |

`

# 1 INTRODUCTION

## 1.1 Background and overview of the thesis

In this thesis, the collaboration and exchange of data between architectural and structural BIM software have been reflected. The procedure is mainly made based on the modeling of a Mall project. Mall project represents a composite structure made of concrete, steel, timber, aluminium, glass and other relevant insulation materials. It contains all main architectural and structural elements such as beams, slabs, columns, walls, covering and aesthetic elements.

The Architecture, Engineering and Construction (AEC) sector is gradually evolving away from the use of two-dimensional (2D) computer-aided design (CAD) and paper for design towards three-dimensional (3D), semantically rich, digital models. Traditionally, information has been exchanged in the form of drawings and documents. Nowadays, the use of BIM software within a construction industry provides a significant incentive to instead use digital design models as the medium for exchanging information (Steel, Drogemuller and Toth, 2009).

Therefore this thesis considers the use of BIM as a technology for supporting the interoperability (exchange of information between BIM modeling and FEM analysis software) on the example of a Mall project.

Tekla BIM software has been chosen as BIM software to be used in the case of modeling architectural and structural elements of this project. Tekla BIM software is 3D building information modeling (BIM) software mostly being used in the building and construction industries for steel and concrete detailing. Thus, using Tekla BIM software we could create and manage 3D architectural and structural BIM models in composite engineering materials. It was also used to create physical and analytical models, relevant to this project.

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In the section of analyzing the capabilities of the interoperability between architectural and structural BIM software, different data exchange methods have been considered and discussed further. To explain practically the results of such capabilities, relevant structural analysis and design (A&D) in the case of partial analytical models of the Mall project were performed with the help of Dlubal-Structural Engineering Software for Analysis and Design.

The latest available student versions of the above-mentioned software (Tekla Structures Learning 2017 and RFEM 5.10.01), were used in this project.

Various terms have been used to address the main purpose of this thesis. The main terms applied in the project are presented and explained in Table 1.1.

*Table 1.1: Representation of the most important terms used in this project.*

| | |
|---|---|
| **BIM Model** | An integrated information model, including structural and architectural aspects of the building. To create a relevant BIM model in the case of the Mall project, both architectural and structural models have been used at the same time. |
| **Structural Model** | A structural model has been created by modeling different structural elements such as RC walls, RC columns, structural steel elements, etc., in Tekla BIM software. Such elements are then exported as load-bearing elements to RFEM, through an IFC export created in Tekla BIM software. |
| **Architectural Model** | A model created by architectural elements such as wood coverings, ladder, etc., which are modeled as non-load bearing elements in Tekla BIM software, is considered as an Architectural model. It is not directly connected with the structural model but belongs more to the aesthetic role of the building |
| **Analytical Model** | A model created in Tekla BIM software, which has been used to investigate the data exchange capabilities in the case of this project, as well as for structural analysis and design purposes in RFEM. |

| | |
|---|---|
| **Physical Model** | A model which is created in Tekla BIM software using different structural elements, where every structural element could be supported with a point support. |

## 1.2 Motivation and purpose

Interoperability challenges are associated with the export and import capabilities of data models among different software. Insufficient interoperability represents one of the barriers to BIM advancement. From this point of view, we have been motivated to make a research, aiming to present the collaboration between architectural and structural BIM software, based on a real and complex project. Principally, this represents a connection between the conversion challenge of architectural and structural model, using various analytical models generated in the project. Thesis objectives are related with the following issues: to explore best practice for the use of 3D BIM tools in collaboration and exchange of data between BIM and FEM software, and to identify appropriate collaboration workflows and additional information required to support them. Thus, these goals lead to the presentation of various case studies in models-based interoperability, since the collaboration and the exchange of data are deliberated as a vital part of the project and its whole implementation process.

The thesis aims to identify, analyze, and discuss the basic issues of model-based interoperability through exchanging building information models between relevant BIM and FEM software, particularly using the ISO standardized IFC data format.

## 1.3 Structure of the thesis

After the introduction, in the second and third section, a literature review is used to give a general overview regarding BIM and interoperability issues and to identify current research trends within the topic of the thesis.

Hereto, considering Tekla BIM software as the appropriate tool to create various architectural and structural models in the case of a Mall project, general overview and basic features of this program are presented further in Section 4.

`

Afterwards, a general description of the Mall project and modeling of a BIM model relevant to this project, are presented and elaborated in details in Section 5. The BIM model of this project was created and detailed with the help of 2D CAD architectural drawings as the input (reference drawings in Tekla BIM software), which were created by Gravitas, design and engineering company Ltd (Gravitas d.o.o, 2017).

Some of the 2D CAD architectural drawings, which were used to prepare the entire BIM model of the Mall project, can be found in the Appendices. Moreover, a general description of creating different types of drawings and 3D visualization in Tekla BIM software, relevant to this project has also been discussed in Section 5.

To provide the technical capabilities of the data exchange methods between BIM and FEM software, several case studies made with increasing levels of structural complexity and varying materials were considered in Section 6. The purpose of these case studies was to examine what kind of data can be transferred from Tekla BIM software to RFEM software and provide a general assessment regarding different methods of data exchange in terms of technical and practical capability.

A general overview of each data exchange method used in the case of this project is first presented and afterwards the encountered issues are discussed individually for each case. An evaluation of each data exchange method is offered at the end of each study case, relevant to BIM model of the Mall project.

In the last part of the thesis, some of the most important structural parts of the building have been reviewed and structurally analyzed. It has been noted that in the case of preparing the finite element analysis (FEA), which deals with two different partial models of the Mall project, RFEM has been perceived as powerful and appropriate software for quick and easy collaborating with Tekla BIM Software. Using different data exchange methods we could import different analytical models from Tekla BIM software to RFEM software, make necessary modifications and then calculate and show basic results including global and local displacements, support reactions, basic internal forces, etc.

Given these points, a reflection of the basic issues of BIM standard development and mostly the nature of collaboration and data exchange methods dealing with different case studies, is offered as a conclusion of this project.

# 2 BUILDING INFORMATION MODELING

## 2.1 BIM Overview

Building structures have always been considered essential components of building design. Basically, this refers to the roles and meanings of safety, economy, and performance of structures to the society at large (Eastman *et al.*, 2011).

Nowadays, the strategy of structural engineers is to communicate and store knowledge in an easy and efficient way. Furthermore, the relationship between structure and architecture essentially represent the beauty of the building. With various BIM softwares, engineers and architects have great opportunity to use smart tools, in the case of being able to model and analyze artistically efficient structural forms and demonstrate how load combinations affect the stability and behavior of a structure. Thus, BIM (Building Information Modeling) has the right potential to provide solutions to the issues related to the conceptual linking and integration between architectural and structural engineering principles and make progress in different types of structural knowledge-sharing objectives without compromising their distinct requirements.

BIM shall be described as a process that fundamentally changes the role of computation in structural design, since it has prepared a database of the building objects to be used for its all structural aspects, from design to construction, operation, and maintenance. So, referring to this collaborative environment, a new framework is proposed, aiming to advance structural design education. This framework is based on the Structure and Architecture Synergy Framework (SAS Framework), which is described referring to the following Figure 2.1.

Furthermore, the structure and architecture synergy framework (SAS framework) basically can be explained as a useful language for understanding the structure as a whole in connection with its close relationship with architecture (Nawari and Kuenstle, 2015).

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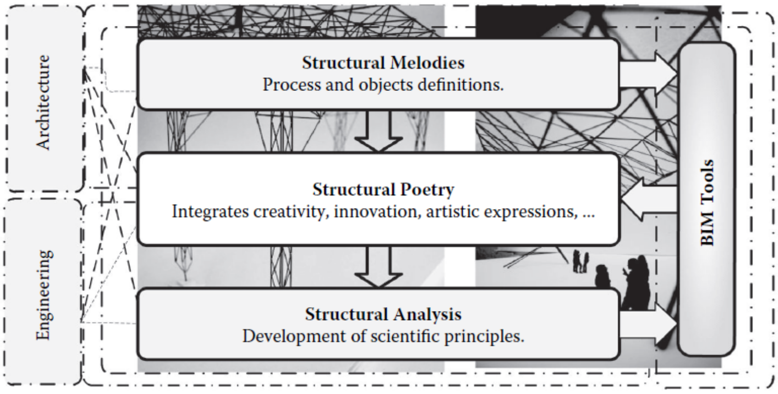


*Figure 2.1: Structure and architecture synergy framework* (Nawari and Kuenstle, 2015).

Creating a BIM model means the creation of three-dimensional (3D) objects library of the physical building. Thus, in essence, BIM provides the ability to construct a building virtually before building it in the real world. BIM gives the opportunity to model with structural components such as walls, columns, beams, doors, windows, ceilings, and roofs, instead of using the primitives CAD form (points, lines, curves) (Nawari and Kuenstle, 2015).

When we look back to history, one of the first projects to successfully create a building database was the Building Description System (BDS) which was the first software to describe individual library elements which could be viewed and added to a model. Furthermore, this program uses a graphical user interface, orthographic and perspective views and a sortable database that allows the user to view information categorically by attributes including material type and supplier. ArchiCAD was developed by Gábor Bojár 1982 in Budapest. While using similar technology as the Building Description System, the software Radar CH was released in 1984 for the Apple Lisa Operating System. Later on, this became ArchiCAD, which makes ArchiCAD the first BIM software that was made available (Quirk, 2012).

Building information modeling (BIM) is one of the most encouraging advancements in the architecture, engineering, and construction (AEC) industries. With BIM softwares, an exact virtual model of a building is built digitally. Whenever finished, BIM software generated models contain exact geometry and data needed to bolster the construction, fabrication, and procurement activities based on which the building is realized (Eastman *et al.*, 2011).

## 2.2 BIM Concept and AEC Industry

Building information modeling represents the process that fundamentally changes the role of computation in building design. Thus, creating a BIM is different from making a drawing in 2D or 3D computer-aided design (CAD). Unlike 2D or 3D CAD drawings, when we make a revision or change in any element of the model, we have to change it only once and all the views and details in the model are automatically updated (Nawari and Kuenstle, 2015).

On the other hand, BIM is still a relatively new technology in an industry typically slow to adopt change, but it is keen to rapidly change the way the construction industry produces and communicates construction information. Anyway, today, BIM technology can be found in the AEC industry everywhere through the world.

Building Information Modeling (BIM) concept and process have been described in Figure 2.2.

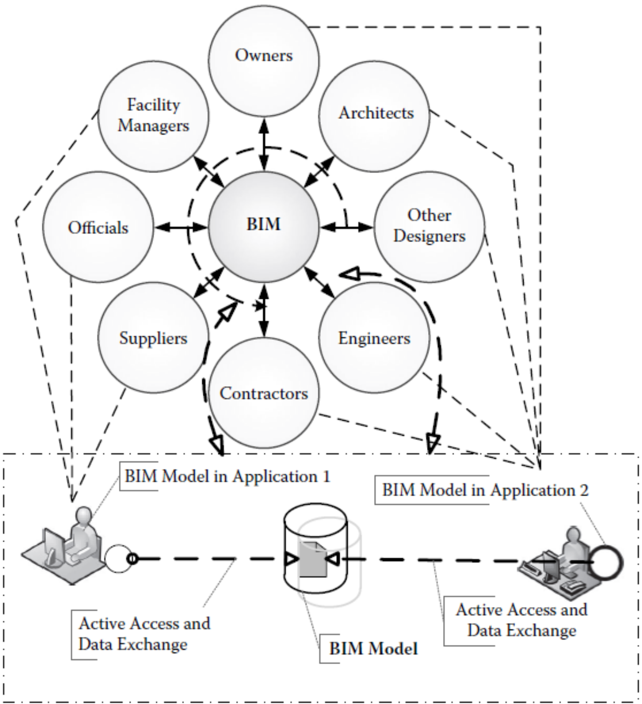


*Figure 2.2: BIM Concept and process* (Nawari and Kuenstle, 2015).

Referring to Figure 2.2, BIM means a shared digital representation of a facility founded on open standards for practical interoperability (Nawari and Kuenstle, 2015).

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One of the most common problems related to 2D-based communication amid the design stage is the significant time and cost required to generate data about a proposed design, cost estimates, energy-use analysis, structural details, etc. These analyses are typically done last, when it is already too late to make vital improvements (Eastman *et al.*, 2011).

The concept of organizational boundaries according to an AEC project team by a typical diagram has been graphically illustrated in Figure 2.3.

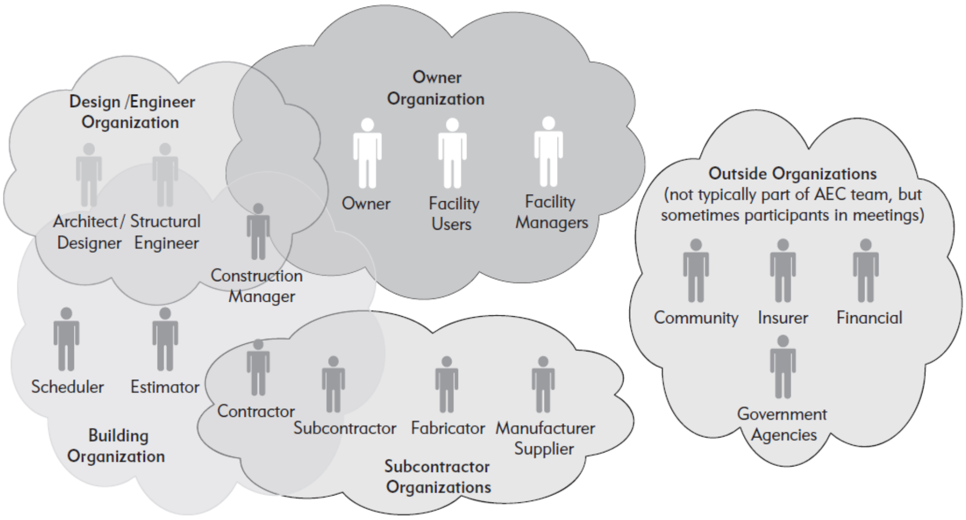



*Figure 2.3: Typical diagram concept of organizational boundaries based on AEC project team* (Eastman *et al.*, 2011).

## 2.3 Definition of Design Tools and Parametric Objects

1980 was the year when object-based parametric modeling was developed in manufacturing technology. It does not represent objects with fixed geometry and properties. In the case of willing to model complex geometries, then custom parametric objects make this possible, while those were previously not possible or not implementable. When we look at how objects like a wall, slab, or roof can interact with other objects, this shall be predefined by system-provided object classes. In this case, object attributes represent a necessary parameter, which is needed to interface with structural analysis and other applications, but these attributes must be firstly defined by the firm or software user. On the other hand, current BIM design applications means carrying out specific tasks as a tool, while they also give or represents a platform as a good way in case of managing the data within a model for different uses (Eastman *et al.*, 2011).

Graphical 3D Modeling in its early stages of development, notifies basically two different approaches, the (B-rep) approach which represented shapes as a closed, oriented set of bounded surfaces in one hand, and on the other hand Constructive Solid Geometry (CSG) as an alternative approach to define shapes as a set of functions (Figure 2.4). While taking an overview at which approach is represented a better one, it was recognized that both of them should be combined, allowing for editing within the CSG tree (sometimes called the unevaluated shape) (Eastman *et al.*, 2011).

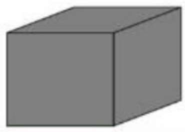
| | Constructive Solid Geometry (CSG) | Boundary Representation (B-Rep) |
|---|---|---|
| |  |  |
| Geometric Description | volumetric object | a (set of) polygon(s) |
| Standard Volumetric Primitive | block | surface |
| Operations | union, intersection, difference | connection of faces |
| Inner core | solid | void |

*Figure 2.4: Comparison of B-Rep and CSG paradigms* (Saygi *et al.*, 2013).

Furthermore, parametric object modeling represents a strong way to create and edit geometry. On the other hand, most BIM softwares provide the means for extracting a drawn section at the level of detail to which they are defined in the 3D model.

## 2.4 BIM for Architects and Engineers

Building information modeling is progressive in the way it changes architectural representation by replacing drawings with 3D virtual building models. It transforms the way that a representation is constructed, generally changing the line-by-line layout of old and the idea processes that go with it. A project's realization includes enormous levels of coordination and collaboration. Coordination and collaboration involve different levels of communication. At one level, it involves communication between people with respect to values, context, and procedures. At another level, it likewise involves diverse device tool representations and the need for data exchange between tools (Eastman *et al.*, 2011).

Basically, in the case of using BIM in design processes for both Architectural and Structural aspects, three major viewpoints shall be taken into consideration, as follows:

- Conceptual design,
- Design and analysis of structural systems using BIM,
- BIM use in developing construction-level information.

## 2.5 The Future of BIM

BIM is changing the way structures look, the way they function, and the ways in which they are constructed (Eastman *et al.*, 2011). BIM is being considered as the catalyst for innovation in the construction industry (Brad Hardin, 2015).

BIM is a work in progress, which means BIM will contribute to a higher degree of prefabrication, greater flexibility and variety in building methods and types, fewer documents, far fewer errors, less waste, and higher productivity (Eastman *et al.*, 2011).

The way the BIM is making progress, it is not very far that BIM will completely replace CAD systems. Since the use of Cloud technology is growing, it would be easier for project stakeholders to quickly access BIM model virtually everywhere (Azhar, Khalfan and Maqsood, 2015).

On the other hand, there are several technological and managerial challenges ahead. The technological challenges can be broadly classified into three categories (Azhar, Khalfan and Maqsood, 2015), as follows:

- The need for well-defined transactional construction process models to eliminate data interoperability issues,
- The requirement that digital design data be computable, and
- The need for well-developed practical strategies for the purposeful exchange and integration of meaningful information among the building information model components.

# 3 INTEROPERABILITY

## 3.1 Interoperability overview

Interoperability is a characteristic of a product or framework, whose interfaces are totally understood, to work with other products or frameworks, present or future, in either implementation or access, with no confinement (GDT Interop, John McCreesh, 2017). Interoperability is utilized to describe the capability of various programs to exchange data via a common set of exchange formats, to read and write the same file formats, and to utilize the same protocols (Wikipedia, 2016).

According to ISO/IEC 2382-01, Information Technology Vocabulary, Fundamental Terms, interoperability is defined as follows: "The capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units" (ISO/IEC JTC 1, 2015).

BuildingSMART, formerly the International Alliance for Interoperability (IAI), is an international organization, which intends to improve the exchange of information between software applications used in the construction industry. It has created Industry Foundation Classes (IFCs) as a neutral and open specification for Building Information Models (BIM) (buildingSMART, 2016).

Interoperability is the ability to exchange information between applications, which smoothes workflows and sometimes facilitates their automation. Interoperability has traditionally relied on file-based exchange formats limited to geometry, for instance, DXF (Drawing eXchange Format) and IGES (Initial Graphic Exchange Specification). Direct links based on the Application Programming Interfaces (APIs) are the oldest and still important route to interoperability. Beginning in the late 1980s, data models were developed to bolster product and object model exchanges within different industries, led by the ISO-STEP international standards effort (Eastman *et al.*, 2011).

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The two principal building product data model schemas are the Industry Foundation Classes (IFC) – for building planning, design, construction and management, and CIMsteel Integration Standard Version 2, (CIS/2) – for structural steel engineering and manufacture. A related STEP schema is ISO-15926, for lifetime modeling of process plants. All of these schemas represent different kinds of geometry, relations, procedures and material, performance, fabrication, and different properties required for design and production. The National BIM Standard (NBIMS) is being undertaken to standardize the data required for particular exchanges. Interoperability, at the base, eliminates the need to manually copy data already created in another application. Manual copying of partial project data enormously discourages iteration during design, as required for discovering best solutions to complex issues, such as structural design. People are used to geometry exchanges between applications, utilizing translators such as DXF, IGES, or SAT. An integrated model must carry much more information than a CAD file. This is an extensive change and the supporting information technology methods and standards for achieving it are only incrementally being set up (Eastman *et al.*, 2011).

Interoperability supports different capabilities and addresses different problems in exchanges of data across three types of BIM applications, as tools (manipulates a building model for some defined purpose and produces a specific outcome), as platforms (generates data for multiple uses and incorporates different tools directly or through interfaces with varying levels of integration), and as environments (the functional capability embedded in a BIM Server). Platform-to-tool exchange is the most basic type of interoperability and is supported by both direct application-to-application exchange and furthermore through shared neutral exchange formats, such as IFC. On the other hand, platform-to-tool data exchange can be complex. While creating an analytical model by extracting the stick and node model for further structural analysis and determining the adequate loads is not yet a common automated translation, as it requires human expertise and judgment. More direct are tool-to-tool exchanges. These are limited because of the limited data available within the exporting tool (Eastman *et al.*, 2011).

Furthermore, the real challenge of interoperability is a platform-to-platform exchange. This includes platforms, for example, ArchiCAD, Revit, and Digital Project and fabrication model platforms such as Tekla, SDS/2 Structureworks, and StruCad, CADPipe, and CAMduct. Platforms not just incorporate a broad spectrum of data, they likewise incorporate rules that manage the integrity of the objects. It should be emphasized that the exchange of fixed shape objects, as well as some simple extrusions, are not problems. At some point in the future, a standard vocabulary of rules might be prepared, which could prompt solving this platform-to-platform exchange of parametric models. More generally, an issue related to interoperability is the need to manage the various representations of a project, at the platform and tool levels. The need is, however, not to simply translate an architectural model to another format, but to modify or extend the model information so that it represents the design for different uses. Thus, referring to structural design aspect, it indicates the knowledge required to translate a physical model of a structural design into a model for structural analysis. In this case, derivation of a structural model from a physical model involves many specialized considerations, dealing with structural codes, spans, depth of beams, the behavior of connections, and especially loading conditions. Computer scientists can, and have implemented the technological framework for interoperability, by supplying the languages (e.g. EXPRESS[1], BPMN, XML) that support exchange protocols (Eastman *et al.*, 2011).

The recent and current usage in BIM is the practice of the 'exchange model.' This especially refers to the interoperability between different software packages that architects, engineers, and contractors each use. In this case, it is more than important to verify the interoperability of BIM software between working groups. In the past, interoperability issues required a lot of software pieces and many workarounds that took much more time. It is relatively clear that in the future we will see more success stories with open standards, such as the IFC schema.

In summary, interoperability represents the process and the methods, which allow different systems and organizations to work together without losing information. Thus, creating 3D models defined in one system to be used in another is possible through interoperability. In this thesis, interoperability is applied based on the Architectural model being used within a structural modeling system in the case of a Mall project.

[1] EXPRESS is a data specification language as defined in ISO 10303-1. It consists of language elements that allow an unambiguous data definition and specification of constraints on the data defined (ISO 10303-11, 2004).

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## 3.2 Levels of Conceptual Interoperability (LCIM)

The International Organization for Standards (ISO)/Open System Interconnect (OSI) reference model introduced seven layers of interconnection, each with well-defined protocols and responsibilities (Tolk, Bair and Diallo, 2013). The LCIM was proposed as a reference model with well-defined layers of interoperation to better deal with challenges of interoperability of simulation systems and composability of simulation models (Tolk, Bair and Diallo, 2013). LCIM has been originally proposed by (Tolk and Muguira, 2003). After continuous evolution, it forms the latest version illustrated in Figure 3.1.

According to (Tolk, Bair and Diallo, 2013) and (Tolk, Diallo and Turnitsa, 2007), the current version of the LCIM exposes seven layers of interoperation as follows.

- **Level 0 – No Interoperability:** Stand-alone systems have *No Interoperability*. Thus, information is used within each system in a proprietary way with no sharing.
- **Level 1 – Technical Interoperability:** On this level, a communication protocol exists, enabling systems to exchange carriers of information. This layer is the domain of integratability.
- **Level 2 – Syntactic Interoperability:** This level provides a common structure to exchange information, for instance, a common protocol to structure the data is used. In other words, this layer belongs to the domain of interoperability
- **Level 3 – Semantic Interoperability:** Introduces a common understanding of the information exchange. On this level, the content of the information exchange requests are defined. It describes the aligned static data.
- **Level 4 – Pragmatic Interoperability:** This level is reached when the interoperating systems are aware of the methods and procedures that each other are employing. In this context data are exchanged as applicable information. Thus, this level represents the aligned dynamic data.
- **Level 5 – Dynamic Interoperability:** This layer recognizes different system states, including the possibility for agile and adaptive systems. As a system operates on data over time, the state of that system will change, and this includes the assumptions and constraints that affect its data interchange.

- **Level 6 – Conceptual Interoperability:** Finally, on this level, assumptions, constraints, and simplifications need to be captured. This layer represents the harmonized data.

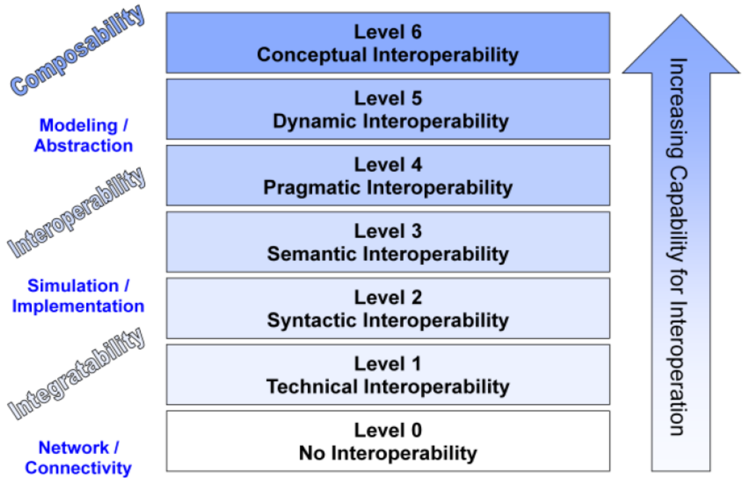


*Figure 3.1: The Levels of Conceptual Interoperability Model* (Wang, Tolk and Wang, 2009).

## 3.3 Data sharing and collaboration

BIM as an advanced modeling process provides building information data which are attached to each building object, thus creating comprehensive architectural and structural content libraries plus mechanical, electrical, plumbing, landscape, and other libraries (Nawari and Kuenstle, 2015).

According to (Nawari and Kuenstle, 2015), an internal collaboration between members of one company can be established as follows:

- Prepare a central database file where all the virtual building data can be stored,
- Group members work on local copies,
- Team members must have the intended workspaces,
- Team members send and receive changes regularly using the previously created centralized database file.

On the other hand, an external collaboration between various companies, which collaborate in a project can be established by sharing the BIM data via different data formats that most BIM tools support (Nawari and Kuenstle, 2015):

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- IFC (Industry Foundation Classes),
- DXF/DWG[2] (AutoCAD Drawing Exchange Format/Drawing),
- PDF (Portable Document Format),
- XML (Extensible Markup Language).

## 3.4 Exchange formats background

Even in the earliest days of 2D CAD in the late 1970s and early 1980s, the need to exchange data between various applications was apparent. The most generally utilized AEC CAD system at that time was Intergraph (Eastman *et al.*, 2011). Later, in the post-Sputnik period, NASA found that they were expending significant amounts of money paying for interpreters among all their CAD engineers. Thus, resulting exchange standard was reviewed, extended, and christened IGES (Initial Graphics Exchange Specification) (Eastman *et al.*, 2011). In general, data exchanges between applications depend on two levels of definition, characterized in Figure 3.2.

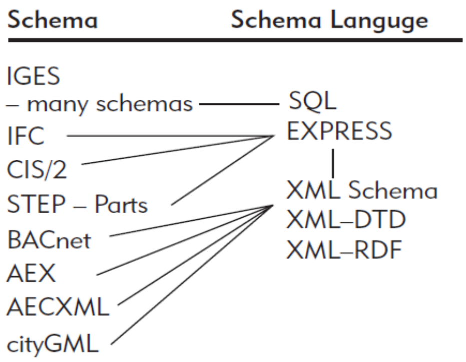


*Figure 3.2: Presentation of modern exchange formats which are based on a schema defined in a schema language* (Eastman *et al.*, 2011).

Structured Query Language (SQL) is a prime example and the dominant schema definition language for databases. The ISO-STEP-developed data modeling language, EXPRESS, is the basis for a range of product modeling technologies and schemas, including Industry Foundation Classes (IFC) and CIMsteel Integration Standard, version 2 (CIS/2). Another

[2] DWG refers to both a technology environment and .dwg files, the native file format for Autodesk's AutoCAD® software (Autodesk, 2017).

substantial set of exchanges is bolstered by XML (eXtensible Markup Language). The different XML schemas support the exchange of many types of data between applications. On the other hand, direct links use the Application Programming Interface (API) of one system to extract data from that application and write the data using the receiving application's API. Direct links are implemented as programming level interfaces, typically relying on C++[3] or C#[4] languages (Eastman *et al.*, 2011).

A summary of the most widely recognized exchange formats in the AEC area is listed in Table 3.1. Table 3.1 groups file exchange formats with respect to their principal use. Furthermore, below-listed formats represent information on very different semantic levels.

*Table 3.1: Common Exchange Formats in AEC Applications* (Eastman *et al.*, 2011).

| | |
|---|---|
| **Image (Raster) Formats** | |
| JPG, GIF, TIF, BMP, PNG, RAW, RLE | Raster formats vary in terms of compactness, number of possible colors per pixel, transparency, compression with or without data loss |
| **2D Vector Formats** | |
| DXF, DWG, AI, CGM, EMF, IGS, WMF, DGN, PDF, ODF, SVG, SWF | Vector formats vary regarding compactness, line formatting, color, layering and types of curves supported; some are file-based and others use XML. |
| **3D Surface and Shape Formats** | |
| 3DS, WRL, STL, IGS, SAT, DXF, DWG, OBJ, DGN, U3D PDF(3D), PTS, DWF | 3D surface and shape formats vary according to the types of surfaces and edges represented, whether they represent surfaces and/or solids, material properties of the shape (color, image bitmap, and texture map), or viewpoint information. Some have both ASCII and binary encodings. Some include lighting, camera, and other viewing controls; some are file formats and others XML. |
| **3D Object Exchange Formats** | |
| STP, EXP, CIS/2, IFC | Product data model formats represent geometry according to the 2D or 3D types represented; they also carry object type data and relevant properties and relations between objects. They are the richest in information content. |
| AecXML, Obix, AEX, bcXML, AGCxml | XML schemas developed for the exchange of building data; they vary according to the information exchanged and the workflows supported. |
| V3D, X, U, GOF, FACT, COLLADA | A wide variety of game file formats vary according to the types of surfaces, whether they carry hierarchical structure, types of material properties, texture and bump map parameters, animation, and skinning. |
| SHP, SHX, DBF, TIGER, JSON, GML | Geographical information system formats vary in terms of 2D or 3D, data links supported, file formats and XML. |

[3] C++ is a general-purpose programming language. It has imperative, object-oriented and generic programming features, while also providing facilities for low-level memory manipulation (Stroustrup, 1997).

[4] C# is a multi-paradigm programming language encompassing strong typing, imperative, declarative, functional, generic, object-oriented (class-based), and component-oriented programming disciplines (Novák, 2010).

## 3.5 buildingSMART and IFC

In late 1994, an industry consortium was initiated by Autodesk to advise the company on the development of a set of C++ classes that could support integrated application development. Initially defined as the Industry Alliance for Interoperability, changed its name in 1997 to the International Alliance for Interoperability (Eastman *et al.*, 2011).

The goal of the new Alliance was to publish the Industry Foundation Class (IFC) as a neutral AEC product data model responding to the building lifecycle. In 2005, it was thought that the IAI name was quite long and complex for people to understand. Thus, at a meeting in Norway of the IAI Executive Committee, IAI was renamed buildingSMART (Eastman *et al.*, 2011).

The Industry Foundation Class (IFC) is a schema developed to define an extensible set of consistent data representations of building information for exchange between AEC software applications. It is based on the ISO-STEP EXPRESS language and concepts for its definition, with a couple of minor restrictions on the EXPRESS language (Eastman *et al.*, 2011).

Since IFC was designed as an extensible "framework model", its developers intended it to provide broad, general definitions of objects and data from which more detailed and task-specific models supporting particular exchanges could be defined. According to this, the IFC has been designed to address all building information, over the whole building lifecycle, from feasibility and planning, through design (including analysis and simulation), construction, to occupancy and building operation (Eastman *et al.*, 2011).

IFC's are the international openBIM standard (buildingSMART, 2016). As of 2010, a new version of the IFC has been released, Version 2x4 (Eastman *et al.*, 2011), while in March 2013 the long expected new edition of the main buildingSMART standard IFC has been officially released: IFC4 (buildingSMART, 2016).

The current version of IFC is the IFC4 Add2, which is published on 15th July 2016 as a buildingSMART Final Standard.

IFC data files are exchanged between applications using the following formats as shown in Figure 3.3 and should be indicated by the published icons.

| | | |
|---|---|---|
| .ifc | IFC data file using the STEP physical file structure according to ISO10303-21. The *.ifc file shall validate according to the IFC-EXPRESS specification.<br><br>This is the default IFC exchange format. | |
| .ifcXML | IFC data file using the XML document structure. It can be generated directly by the sending application, or from an IFC data file using the conversion following ISO10303-28, the XML representation of EXPRESS schemas and data.<br><br>Note: an .ifcXML file is normally 300-400% larger then an .ifc file. | xml |
| .ifcZIP | IFC data file using the PKzip 2.04g compression algorithm (compatible with e.g. Windows compressed folders, winzip, zlib, info-zip, etc.). It requires to have a single .ifc or *.ifcXML data file in the main directory of the zip archive.<br><br>Note: an .ifcZIP files usually compress an .ifc down by 60-80% and an .ifcXML file by 90-95%. | zip |

*Figure 3.3: IFC Data File Formats and Icons* (buildingSMART, 2016).

The conceptual organization of IFC can be considered in several ways (Eastman *et al.*, 2011), while the data schema architecture of IFC defines four conceptual layers, each individual schema is assigned to exactly one conceptual layer (buildingSMART, 2016). The schema architecture perspective is diagrammed in Figure 3.4.

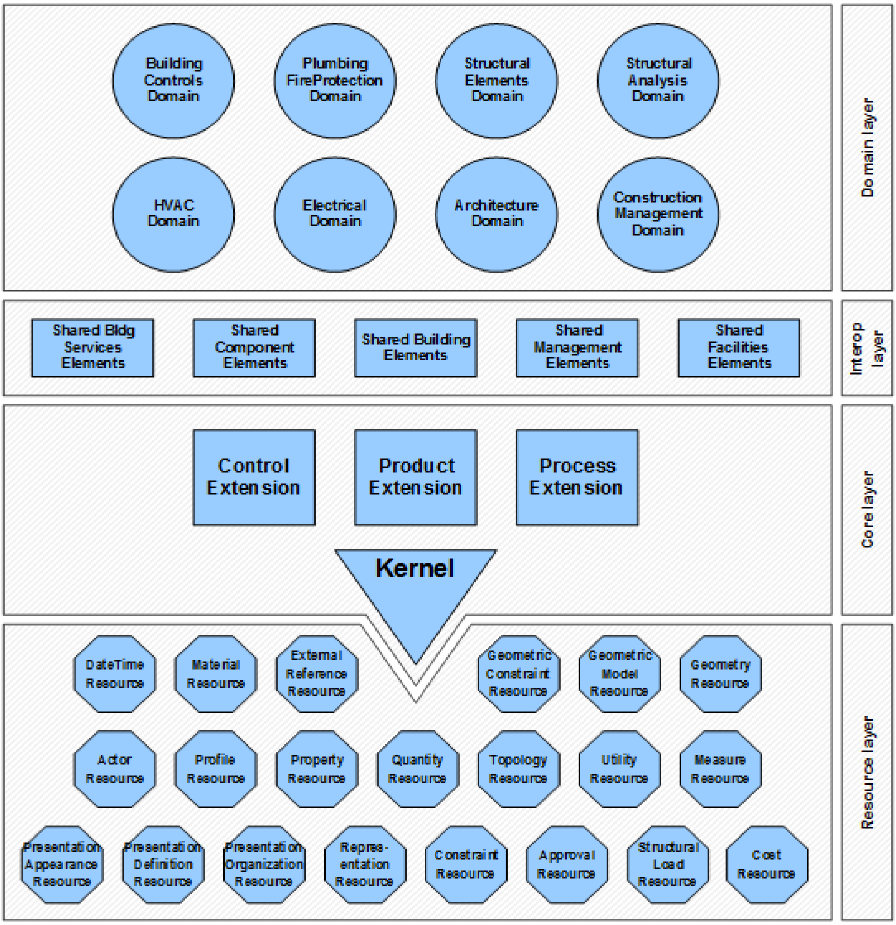


*Figure 3.4: Data schema architecture with conceptual layers* (buildingSMART, 2016).

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According to (buildingSMART, 2016), each layer diagrammed in Figure 3.4, is described as follows:

1. **Resource layer**: The lowest layer includes all individual schemas containing resource definitions, those definitions do not include a globally unique identifier and shall not be used independently of a definition declared at a higher layer.
2. **Core layer**: The next layer includes the kernel schema and the core extension schemas, containing the most general entity definitions, all entities defined at the core layer, or above carry a globally unique id and optionally owner and history information.
3. **Interoperability layer**: The next layer includes schemas containing entity definitions that are specific to a general product, process or resource specialization used across several disciplines, those definitions are typically utilized for inter-domain exchange and sharing of construction information.
4. **Domain layer**: The highest layer includes schemas containing entity definitions that are specializations of products, processes or resources specific to a certain discipline, those definitions are typically utilized for intra-domain exchange and sharing of information.

Every single physical object, process objects, actors, and other basic constructs are abstractly represented similarly, for instance, a wall element has a trace down the tree shown in Figure 3.5.

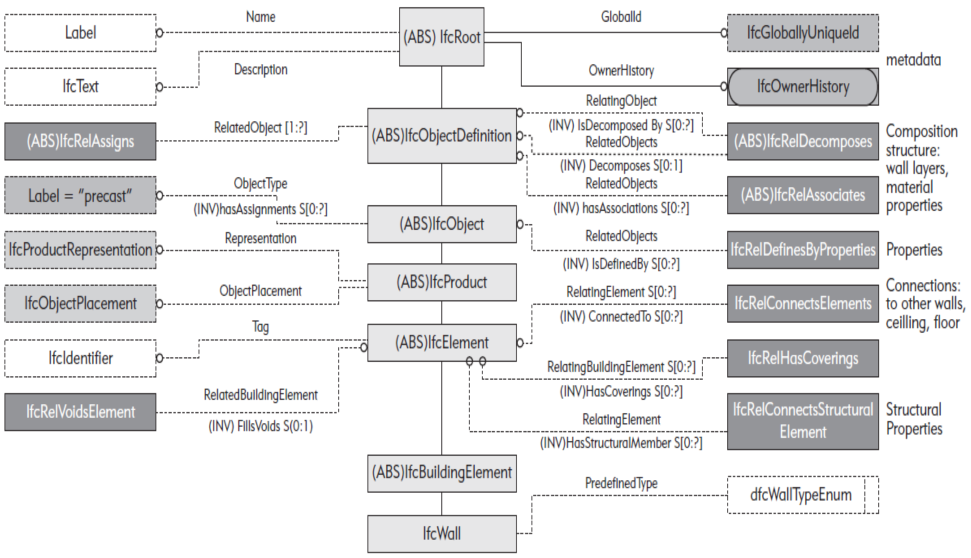


*Figure 3.5: The IFC structure for defining a wall* (Eastman *et al.*, 2011).

Each level of the tree in Figure 3.5, represents different attributes and relations to the wall entity (Eastman *et al.*, 2011). Basically, from this wall illustration, one gets a sense for how all building elements in IFC are defined (Eastman *et al.*, 2011).

## 3.6 Other BIM-related standards overview

IFC is representing only one piece of a huge puzzle related to conventions and standards in the construction industry. Interoperability is a wider issue than addressed by IFC or any current XML schema (Eastman *et al.*, 2011).

According to (Eastman *et al.*, 2011) and (buildingSMART, 2016), a quick reference and overview of other BIM-related standards efforts is given in the following subsections.

### 3.6.1 Information Delivery Manual [IDM]

The ISO 29481-1:2010 “Building information modeling - Information delivery manual - Part 1: Methodology and format” standard has been developed by buildingSMART in order to have a methodology to capture and specify processes and information flow during the lifecycle of a facility (buildingSMART, 2016).

IDM is intended to document existing or new processes and describe the associated information that have to be exchanged between parties. The result can also be used to define a more detailed specification that, if necessary, can form the basis for a software development process.

In the event of willing to make an information delivery manual operational it has to be supported by software. The main purpose of an information delivery manual is to make sure that the relevant data are communicated in a way that can be interpreted by the software at the receiving side (buildingSMART, 2016).

The concept is today explored and collaborative efforts are being made in order to make IDMs that can be used. Despite the progress it is conclusive that it is a challenge to make IDMs in some areas because there is a lack of structured and well-documented processes (buildingSMART, 2016).

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### 3.6.2 International Framework for Dictionaries [IFD]

The European Community early observed an issue in the naming of properties and object classes since objects determined in IFC may have names and attributes in different languages and their meanings need to be properly interpreted. Fortunately, IFC deals well with measures in different units (SI and Imperial) (Eastman *et al.*, 2011).

The International Framework for Dictionaries was formed to address these issues. It is developing mappings of terms between various languages, for eventual wide use in building models and interfaces. Another vital effort being attempted by IFD is the advancement of standards for building product specifications, particularly specification data (Eastman *et al.*, 2011).

### 3.6.3 OmniClass

Construction Classification System (OmniClass or OCCS) is a classification system for the construction industry. It is useful for organizing library materials, product literature, project information, or a classification structure for database systems. OmniClass has been developed by the International Organization for Standardization (ISO) and the International Construction Information Society (ICIS) subcommittees and work-groups from the early-1990s to the present (Eastman *et al.*, 2011). Currently, it consists of 15 tables, as shown in Figure 3.6.

| | | | |
|---|---|---|---|
| Table 11 | Construction Entities by Function | Table 32 | Services |
| Table 12 | Construction Entities by Form | Table 33 | Disciplines |
| Table 13 | Spaces by Function | Table 34 | Organizational Roles |
| Table 14 | Space by Form | Table 35 | Tools |
| Table 21 | Elements | Table 36 | Information |
| Table 22 | Work Results | Table 41 | Materials |
| Table 23 | Products | Table 49 | Properties |
| Table 31 | Project Phases | | |

*Figure 3.6: OmniClass tables of classification terms* (Eastman *et al.*, 2011).

### 3.6.4 COBie

Construction Operations Building information exchange (COBie) addresses the handover of data between the construction group and the owner. It deals with operations and maintenance (O&M), and also more general facility management information. COBie outlines a standard strategy for collecting the required data throughout the design and construction process, as part of the deliverable package to the owner during commissioning and handover. It collects data from designers, as they define the design, and by contractors as the building is built. It also classifies and structures the data in a practical and easy-to-implement manner. COBie was updated at the beginning of 2010 and is now called COBie2. COBie2 has been executed for the exchange of facility management data using the buildingSMART Industry Foundation Class (IFC) open standard (or its ifcXML proportionate). COBie2 has been developed to support the initial data entry into a Computerized Maintenance and Management System (CMMS); MAXIMO, TOCMO, Onuma, and Archibus support COBie2 as well as several European FM and design applications (Eastman *et al.*, 2011).

### 3.6.5 XML-Based Schemas

Extensible Markup Language (XML) gives alternate schema languages and transport mechanisms, especially suited for Web use. XML is an extension to HTML, the language used to send data over the Web. XML expands upon HTML by giving user-defined tags (a tag tells what kind of data follows and is a primitive schema) to determine an intended meaning for data transmitted. XML has turned out to be exceptionally well known for the exchange of data between Web applications, for instance, to support e-commerce transactions or collect data (Eastman *et al.*, 2011).

There are different techniques for defining custom tags, including Document Type Declarations (DTDs) that are developed for mathematical formulas, vector graphics, and business processes, among numerous others. There are multiple approaches to define XML schemas, including XML Schema Definition (XSD), RDF (Resource Description Framework), and OWL Web Ontology Language (Eastman *et al.*, 2011). These are shown in Figure 3.2.

Using current readily available schema definition languages, some effective XML schemas and processing methods have been developed in AEC areas.

According to (Eastman *et al.*, 2011), some of the most important XML schemas in AEC areas are: **OpenGIS**, **gbXML (Green Building XML)**, **ifcXML**, **aecXML**, **agcXML**,

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**BIM Collaboration Format (BCF)**, and **CityGML**[5]. Each of these different XML schemas characterizes its own entities, attributes and relations, and principles. In any case, each of the XML schemas is different and incompatible.

ifcXML provides a global mapping to the IFC building-data model for cross-referencing. On the other hand, efforts are in progress to harmonize the OpenGIS schema with IFC. The longer-term issue is to harmonize the other XML schemas with equivalence mappings amongst them and with data model representations (Eastman *et al.*, 2011).

Two important XML formats for publishing building model data are DWF and 3D PDF. These give lightweight mappings of building models for limited uses (Eastman *et al.*, 2011).

### 3.7 Functionality of BIM Servers

A BIM server is a database system whose schema is based on an object-based format, related to building models. BIM servers allow query, transfer, updating and management of individual project objects from a potentially heterogeneous set of applications. Thus, every BIM server needs to support access control and information ownership. They need to support the range of data required for its field of application (Eastman *et al.*, 2011).

The general framework architecture and exchange flows of an idealized BIM server are presented in Figure 3.7. BIM server services are complicated by the difficulties of storing the required data in the appropriate format to archive and reproduce the native project files required by the different BIM authoring and user tools (Eastman *et al.*, 2011).

Neutral formats are insufficient to reproduce the native data formats used by applications, except in a few limited cases. Therefore any neutral format exchange information, for example, IFC model data, must be augmented by or associated with the native project files produced by the BIM authoring tools. The requirements and exchanges shown in Figure 3.7 reflect the mixed formats that have to be managed (Eastman *et al.*, 2011).

[5] CityGML is an open standardised data model and exchange format to store digital 3D models of cities and landscapes (CityGML, 2017).

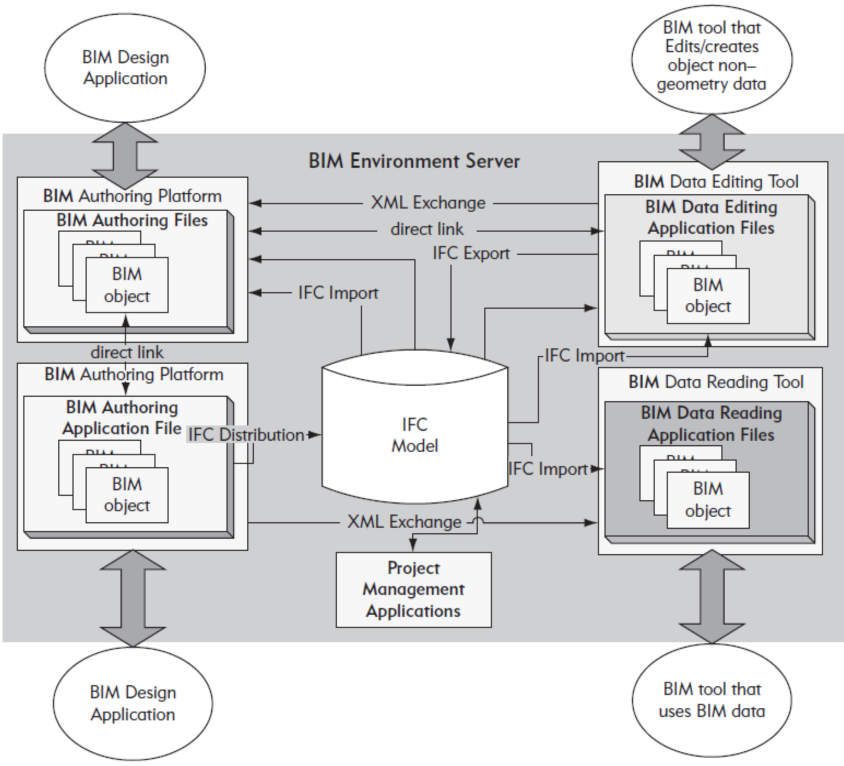


*Figure 3.7: Example internal structure of exchanges supported by a BIM server* (Eastman *et al.*, 2011).

### 3.8 BIM and Structural Analysis Software in the context of Data Exchange process

For construction software, the digital models trigger an important question about data exchange and how these models can be used efficiently for various engineering software. Pure physical geometry models are important, but a number of other models, which contain additional structural components, should be taken into consideration. Thus, such models consist of structural or analytical models which include mechanical material properties, boundary conditions, or loads which cannot be easily recognized with a pure physical model. So, these differences may affect the process when using BIM data exchange in structural engineering. Furthermore, these hurdles represent a big challenge for the developers of engineering software (Dlubal, 2017).

In the context of data exchange process, structural analysis, including any successive changes must be efficient and reliable. Actual 3D BIM models can provide valuable data input or means of communication and a better understanding regarding structural engineering. This process has been illustrated in Figure 3.8.

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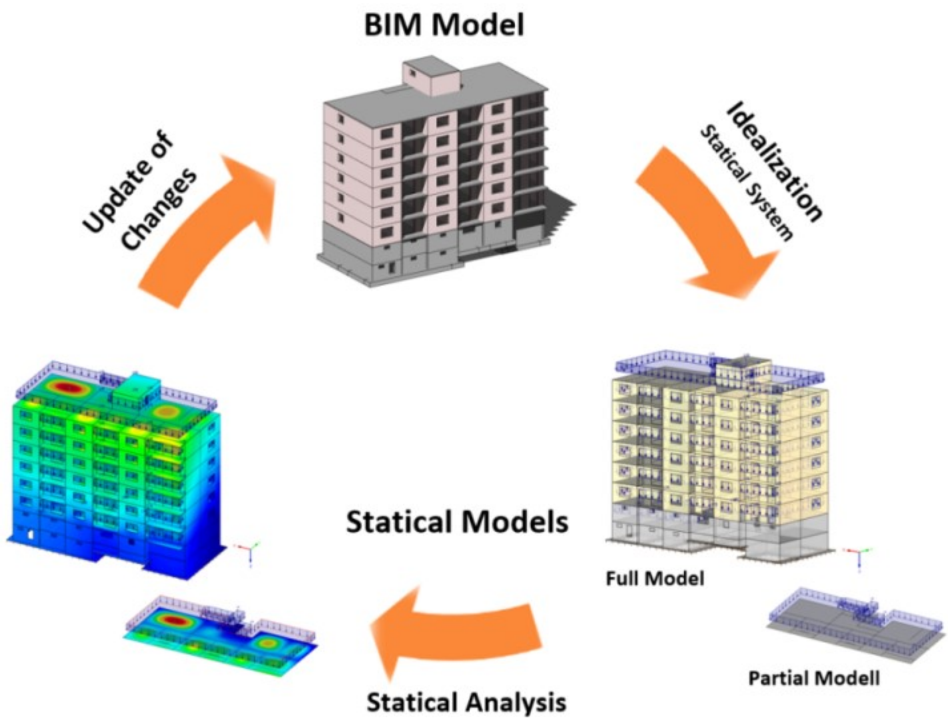


*Figure 3.8: Typical Data Exchange Scenario using BIM in Structural Engineering* (Dlubal, 2017).

In addition, BIM models explain the purpose of the building and can also provide information about the assembly time, for instance. In general, data exchange refers mainly to a parametric description of the exact building geometry (Dlubal, 2017).

On the other hand, structural components are described by boundary surface models or extraction zones that create a solid. In contrast, the focus of structural models is to show the mechanically correct projection of the support structure. Thus, the geometry of the entire structure shall be simplified and reduced to the structural elements relevant for structural analysis. Columns and beams are determined as members (1D[6] elements), while walls and ceilings are determined as slabs and plates (2D elements). Additionally, all of these member and surface elements can also be combined with one another in the 3D structural model. In order to determine these idealized models numerically, it is necessary to connect all structural components together and to check and verify the transition conditions (Dlubal, 2017).

[6] 1D elements also referred to as line elements.

Anyway, because of the component simplification from solids to center lines (for members) and middle planes (for surfaces), automated intersection is not always available. Geometrically identical modeling would also require the representation as a solid model in structural engineering. However, even with the currently available computing capacity, it is unthinkable to calculate a building as a solid model (Dlubal, 2017).

In the case when data is to be exchanged between architectural and structural BIM software, the focus is on a different view of data. Only supporting elements such as columns, walls, plates, etc., would be considered (Dlubal, 2017).

In case of additional information that would be required, such as the location of the structural lines of action, elasticity of the element connections, or characterized mechanical details of materials and cross-sections, will still be missing. This process is also known as vertical data exchange (Figure 3.9).

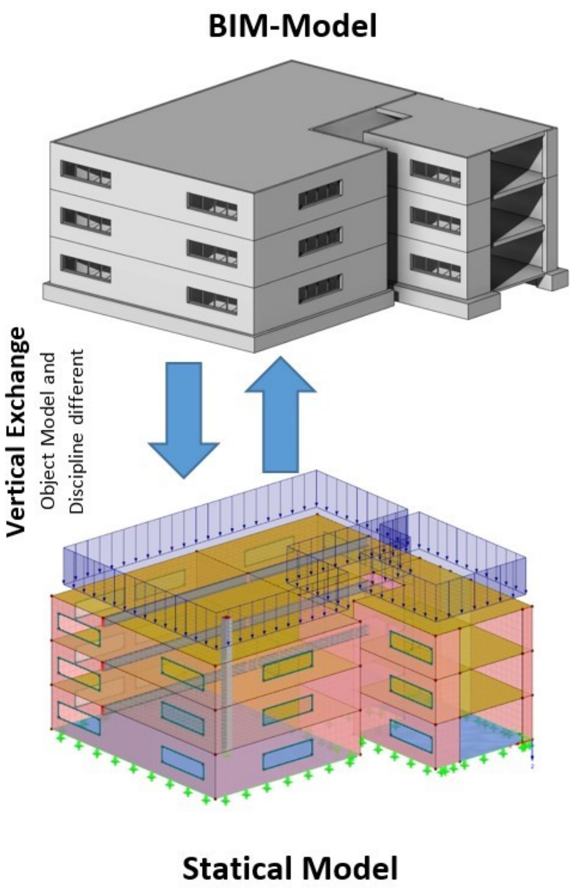


*Figure 3.9: An example of vertical data exchange* (Dlubal, 2017).

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According to (Dlubal, 2017), some of the key factors for successful and efficient data exchange include:

- Early involvement of the structural engineer and consultation of the handover time and content,
- Setting standards for materials and cross-section descriptions (mapping tables),
- Functional and consistent creating of structural elements (columns, beams as member objects, walls, plates as surface objects),
- Modeling of walls, plates, and columns in sections and levels,
- The decision whether only geometric dimensions and structural lines of action shall be transferred, or other structural properties as well (supports or hinges),
- Avoiding editing the same components simultaneously,
- Ensure that the supported BIM and FEM software are compatible,
- Performing tests on manageable models using defined exchange objects, preferably in several formats (IFC, proprietary file format of the software, DWG/DXF, SDNF, STEP, or other formats),
- Extending alternatives for data exchange and allowing verification and comparison of models.

# 4 INTRODUCTION TO BIM & STRUCTURAL ANALYSIS SOFTWARE

## 4.1 Tekla BIM Software

Moving back in the past, by the mid-1960s, computers and automatic data processing were well established in Finland. Because of the ever-increasing amount of computing work and lack of resources, a group of engineering offices established a joint software company named Teknillinen Iaskenta Oy ("technical computing") located in Helsinki. In the spring of 1966, the company trading name was abbreviated to Tekla.

In 2011 Tekla was acquired by Trimble[7], an international technology company with headquarters in Silicon Valley and offices worldwide. In 2016 Tekla Corporation rebranded as Trimble (Tekla, 2017).

Tekla offers multiple divisions: Building and Construction, Infrastructure, and Energy. It can be utilized as multi-user software, supporting multiple users working on the same project model on a server. In the early 2000s, Tekla added precast concrete design and fabrication-level detailing for structural and architectural precast (Eastman *et al.*, 2011).

Tekla software offers a wide range of model-based software products for the architectural, engineering, and construction (AEC) market: Tekla Structures, Tekla Structural Designer, Tekla BIMsight, Tekla Tedds, Tekla Field3D and Tekla Civil. These products provide users with state-of-the-art features and functionality for creating, analyzing, and changing model-based information (Tekla, 2017).

[7]Trimble - Transforming the way the world works. Trimble is a company that enables enhancing safety, boosting compliance, and reducing environmental impact (Trimble, 2017).

### 4.1.1 Tekla Structures

In 2004, Tekla Structures, structural engineering software was launched (Tekla, 2017). Tekla Structures was formerly known as Xsteel (X as in X Window System[8], the foundation of the Unix[9] GUI) (Wikipedia, 2017).

Tekla Structures is a 3D construction modeling software, with its basic functions similar to other BIM applications for structural modeling and design. Models created with Tekla Structures as BIM software contain accurate, reliable and detailed information required for successful BIM and construction execution. In addition, Tekla Structures provides an automated way to produce all structural documentation, including construction drawings, steel and reinforcement detailed drawings, reports and material schedules (Tekla, 2017).

Tekla Structures works with a central database, aiming to show that all drawings and reports are created from and stay linked to the model, get updated automatically, and stay up to date despite the changes made in the model. Tekla Structures offers an extensive component library, which enables users to create details in an efficient way. Furthermore, using Tekla Structures software, it is possible to perform each stage of a design project from conceptual design to construction planning and erection phase.

Tekla Structures is a comprehensive Building Information Modeling (BIM) solution developed specifically for Structural Engineers. Tekla Structures provide solutions to develop constructible, intelligent Building Information Models, which can contain a high level of detail for increased accuracy and confidence. From the Level of Detail / Development (LOD) point of view, using Tekla Structures, it is possible to create 3D constructible models quickly, then visualize and explore how the structure will fit together when built, before the project gets to site (Tekla, 2017).

Tekla Structures is available in different configurations that provide specialized sets of functionalities to meet the construction industry requirements (Tekla, 2017). Referring to interoperability as the main part of this thesis, its features included in different configurations are shown in Table 4.1.

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[8] X Window System (X11, or shortened to simply X) is a windowing system for bitmap displays, common on UNIX-like computer operating systems (Scheifler *et al.*, 1997).

[9] Unix (trademarked as UNIX) is a family of multitasking, multiuser computer operating systems that derive from the original AT&T Unix, development starting in the 1970s at the Bell Labs research center by Ken Thompson, Dennis Ritchie, and others (Ritchie and Thompson, 1978).

*Table 4.1: Interoperability features included in different configurations* (Tekla, 2017).

| Configuration / Feature | Full | Steel Detailing | Precast Concrete Detailing | Rebar Detailing | Engineering | Construction Modeling | Primary | Production Planner - Concrete | Project Viewer | Drafter |
|---|---|---|---|---|---|---|---|---|---|---|
| **Interoperability** | | | | | | | | | | |
| Export CNC, DSTV | ✓ | ✓ | | | | | ✓ | | ✓ | |
| Steel MIS links | ✓ | ✓ | | | | ✓ | ✓ | | ✓ | |
| Import 2D and 3D DWG, DXF | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | |
| Export 3D DWG, DXF, DGN | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Export drawings (DXF, DWG) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Import and export CAD and FEM packages | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| IFC 2x3 export | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| CIS/2 import and export | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| EliPlan import and export | ✓ | | ✓ | | | | ✓ | ✓ | | |
| BVBS export | ✓ | | ✓ | ✓ | | | ✓ | ✓ | | |
| HMS export | ✓ | | ✓ | | | | ✓ | ✓ | | |
| Unitechnik export | ✓ | | ✓ | | | | ✓ | ✓ | | |
| View reference models | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Attach reference models (DXF, DWG, DGN, 3DD, IFC, XML, PDF) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |

In a summary, Tekla Structures gives engineers the opportunity to create a single building model in order to collaborate efficiently with architects, mechanical & electrical engineers, contractors and fabricators (Tekla, 2017).

### 4.1.2 Tekla Collaboration

Tekla solutions help structural engineers and drafters to coordinate seamlessly with architects, service engineers, detailers and contractors at any stage of the project, using industry standard file formats and custom integration links. This means that Tekla provides an open approach to Building Information Modeling. Open BIM means interoperability based on open standards and workflows, not only compatibility between two software programs (Tekla, 2017).

According to (buildingSMART, 2016), open BIM supports a transparent, open workflow, allowing project members to participate regardless of the software tools they use.

Actually, using IFC (Industry Foundation Classes) data model offers the most applicable option for everyday open BIM. Thus, through IFC, Tekla is connected with AEC, MEP and mostly with plant design software. Using collaborative workflows in an appropriate way, we can reduce or minimize errors and maximize efficiency in the building and construction industry. This process has been illustrated in Figure 4.1.


*Figure 4.1: Open BIM information flow* (Tekla, 2017).

Additionally, Tekla can be successfully integrated with other AEC industry software solutions using Tekla Open API (Application Programming Interface), while maintaining the highest levels of data integrity and accuracy. Tekla Open API works through Microsoft.NET[10] connection software and provides a state-of-the-art interface for collaboration between software systems. Furthermore, Tekla Open API, also known as the .NET API, enables an interface for third-party applications to interact with the model and its objects in Tekla Structures (Tekla, 2017).

[10] .NET Framework is a software framework developed by Microsoft that runs primarily on Microsoft Windows. It provides language interoperability (each language can use code written in other languages) across several programming languages (Wikipedia, 2015).

While Tekla has an open API, it also supports a wide range of file exchange formats, some native to other applications, as shown in Table 4.2.

*Table 4.2: Exchange formats supported by Tekla* (Eastman *et al.*, 2011).

| Format | Import | Export |
|---|---|---|
| AUTOCAD (.dwg) | X | X |
| AUTOCAD (.dxf) | X | X |
| BVBs (.abs) | | X |
| Cadmatic models (.3dd) | X | |
| Calma plant design system (.calma) | X | X |
| CIS/2 lpM5/lpM6 analytical, design, manufacturing (.stp,.p21, .step) | X | X |
| DsTV (.nc, .stp, .mis) | X | X |
| Elematic Eliplan, Elipos (.eli) | X | X |
| EpC | | X |
| Fabtrol Kiss file (.kss) | | X |
| Fabtrol Mis Xml (.xml) | X | X |
| GTsdata priamos | | X |
| High level interface file (.hli) | X | X |
| HMs (.sot) | | X |
| IFC2x/IFC2x2/IFC2x3 (.IFC) | X | X |
| IFCXMl2X3 (.xml) | X | X |
| IGES (.iges, .igs) | X | X |
| Intergraph parametric modeling language (.pml) | | X |
| Microsoft project (.xml) | X | X |
| Microstation (.dgn) | X | X |
| Oracle Primavera p6 (.xml) | X | X |
| Plant Design Management system (.pdms) | | X |
| SAP, Oracle, oDBC, etc. | X | X |
| STAAD ASCii file (.std) in out | X | X |
| Steel Detailing Neutral Format (.sdf, .sdnf) | X | X |
| Steel12000 | | X |
| STEP ap203 (.stp, .step) | X | |
| STEP ap214 (.stp, .step) | X | X |
| Trimble IM80 (.txt, .cnx) | | X |
| Unitechnik (.uni) | X | X |

In a summary, according to (Tekla, 2017), the benefits of collaboration between all construction parties, linking with analysis and design (A&D) packages include:

- Coordination and visualization of the model, drawings and reports,
- Both engineers and modelers can work on the same project model,
- Efficient change management keeps project info up-to-date.

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### 4.1.3 Tekla BIMsight

In addition, Tekla offers a free tool known as Tekla BIMsight, which is a software application for BIM model-based construction project collaboration. The entire structure workflow can combine models, check for clashes, and share information using the same easy-to-use BIM environment. Tekla BIMsight enables project participants to identify and solve issues already in the design phase before construction (Tekla BIMsight, 2017).

During the process of modeling the Mall Project in Tekla Structures, an efficient way of sharing information and project collaboration was able by using Tekla BIMsight. Thus, in order to share relevant information regarding this project, two options are presented in this section.

The first option is related to the IFC data model exchange method which is further elaborated in Section 6.2.3.

Tekla BIMsight “Add-on module” in TSL is considered as the second option in this process. Thus, to implement this process, the path: Export>Tekla BIMsight>Publish to Tekla BIMsight is followed (Figure 4.2).

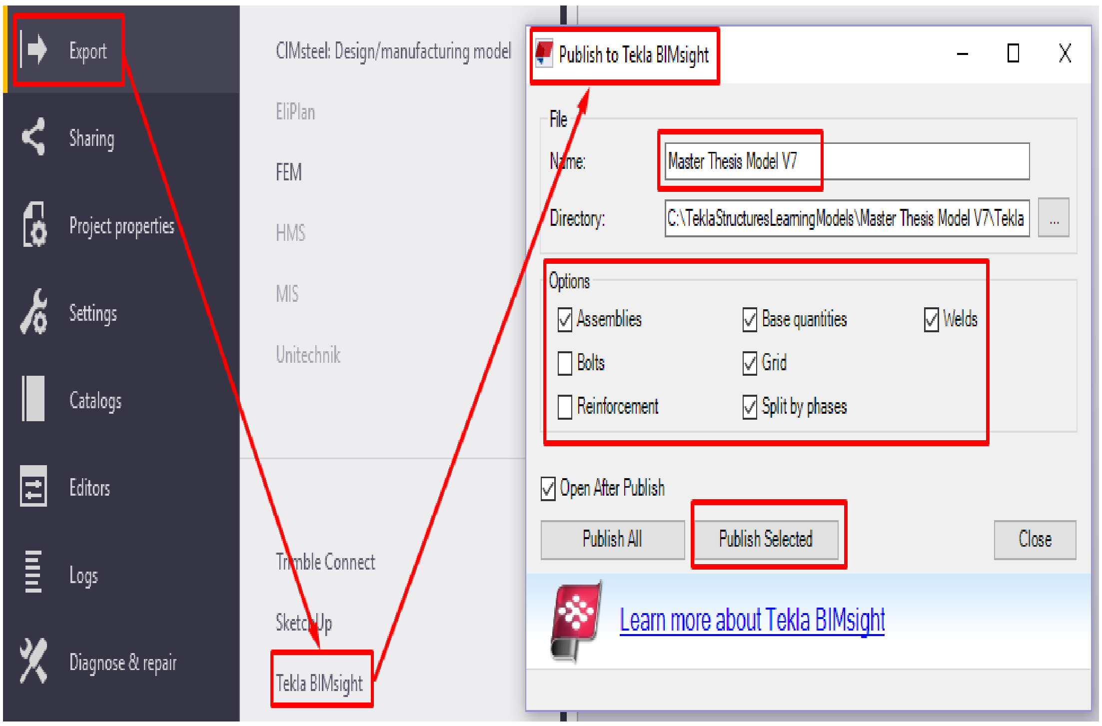


*Figure 4.2: Publishing BIM model of the Mall project to Tekla BIMsight.*

In order to view the entire BIM model of the Mall project in Tekla BIMsight application, the path: Published Project>View is followed as shown in Figure 4.3.

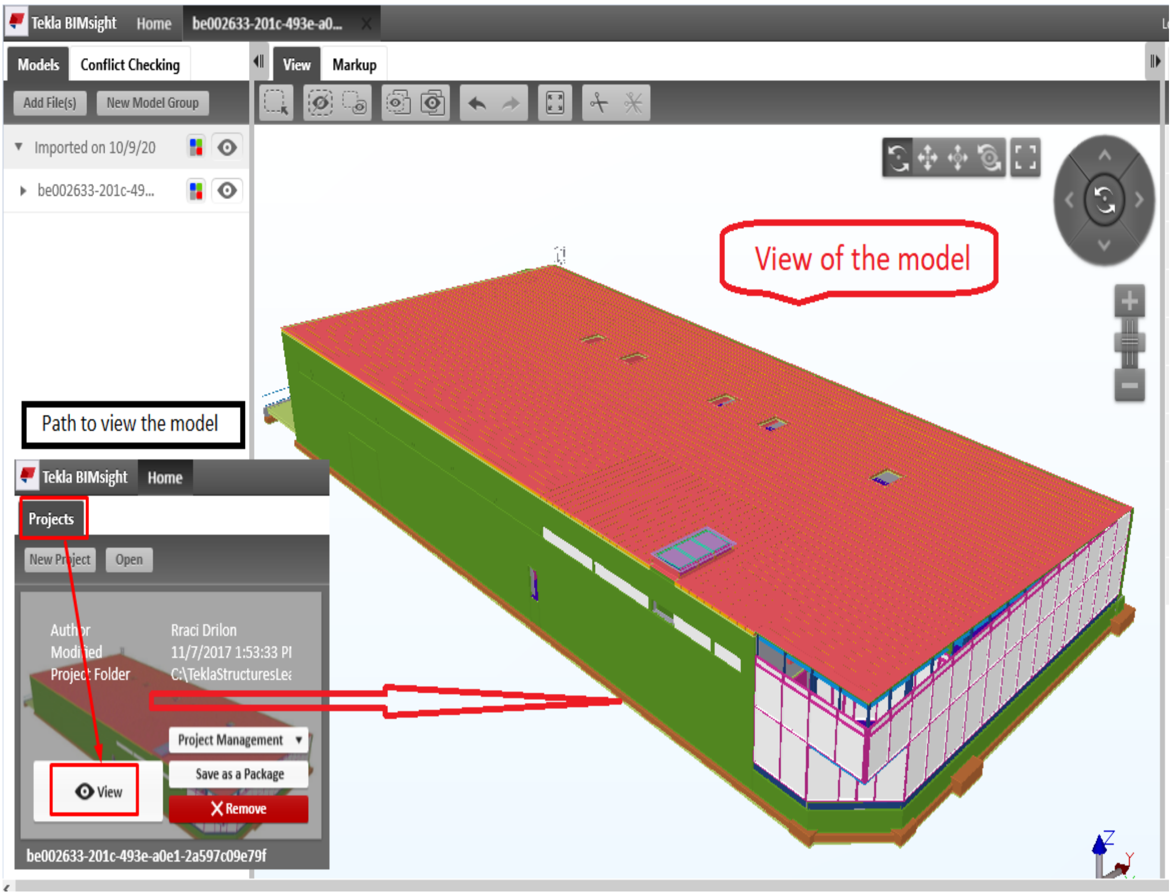


*Figure 4.3: Viewing the BIM model of the Mall Project in Tekla BIMsight.*

## 4.2 Dlubal - Structural Engineering Software for Analysis and Design

Since 1987, Dlubal Software company has been involved in the development of user-friendly and powerful programs for structural and dynamic calculations and analyses as well as for design of framework structures, such as RFEM and RSTAB (Dlubal, 2017).

In this thesis, RFEM is chosen to be used as a FEA program in order to perform structural analysis of the partial model in the case of a Mall project, and is briefly described further in this section.

In addition, Dlubal is considered as an advanced Structural Engineering Software for Analysis and Design, which offers a wide range of solutions in the construction industry, as shown in Figure 4.4.

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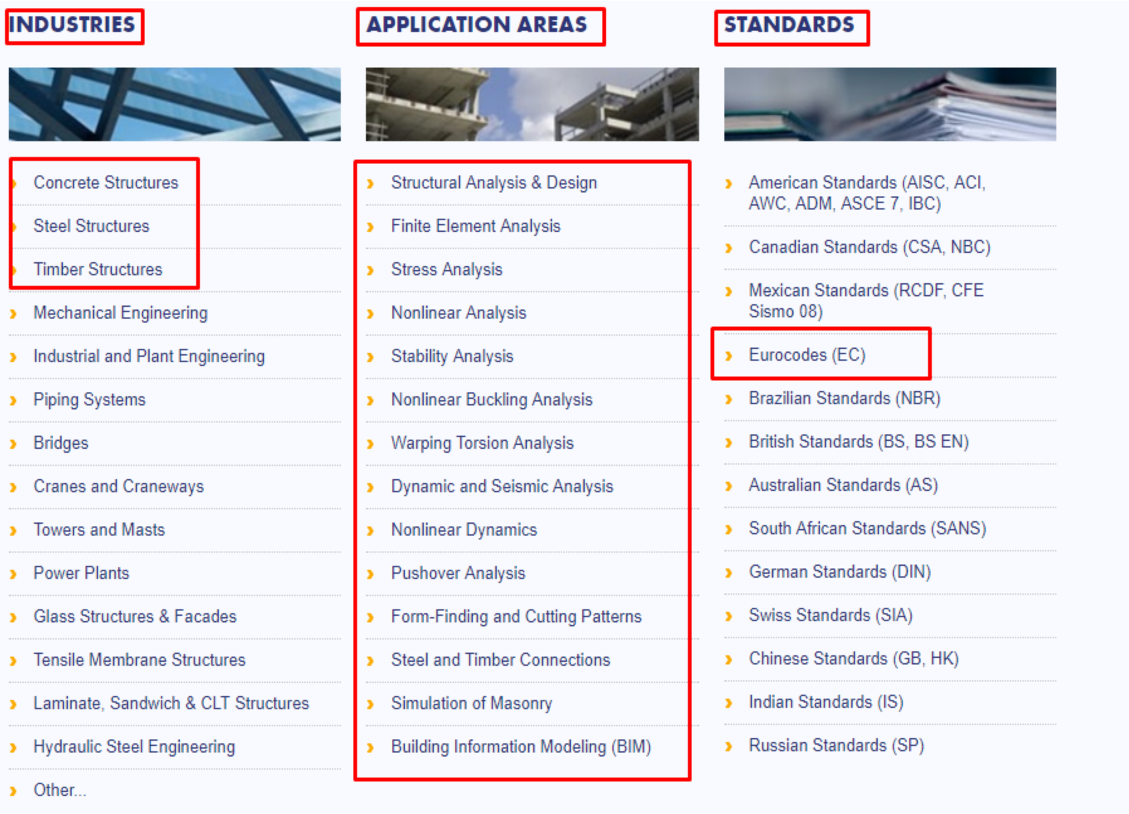


*Figure 4.4: Dlubal Software company solutions* (Dlubal, 2017). *Underlined sections refer to the main requirements of this thesis, regardless of the partial performing of structural analysis and design.*

### 4.2.1 RFEM-Finite Element Analysis program

RFEM as a finite element analysis program is a powerful software for quick and easy modeling, structural analysis and design of 2D and 3D models consisting of member, plate, wall, folded plate, shell, solid, and contact elements. The structural analysis program RFEM is the basis of a modular software system. It is used to define structures, materials, and loads for planar and spatial structural systems. Using RFEM program it is also possible to create combined structures as well as model solid and contact elements (Dlubal, 2017).

With RFEM Software it is possible to provide deformations, internal forces, stresses, support forces, and soil contact stresses of the structure. In addition, for the subsequent design, we could use various add-on modules taking into account material and standard-specific conditions. In RFEM program, a model can be created in the GUI characteristic for CAD programs, using tables, or in combination of both ways. Using RFEM to determine internal forces, results can be superimposed in combinations (Dlubal, 2017).

# 5 MODELING OF THE MALL PROJECT USING TEKLA BIM SOFTWARE

To create a BIM model in the case of a Mall project we have decided to use Tekla BIM Software. Tekla BIM Software offers also a BIM Software for students, called Tekla Structures Learning (TSL).

Tekla Structures Learning is an educational student configuration of Tekla Structures BIM software. It includes the functionality of Tekla Structures full configuration, excluding the steel and precast fabrication functionality (Tekla, 2017).

## 5.1 Description of the Mall project

The entire structure includes architectural and structural elements which represent a center Mall, located in Murska Sobota, Slovenia (Figure 5.1).

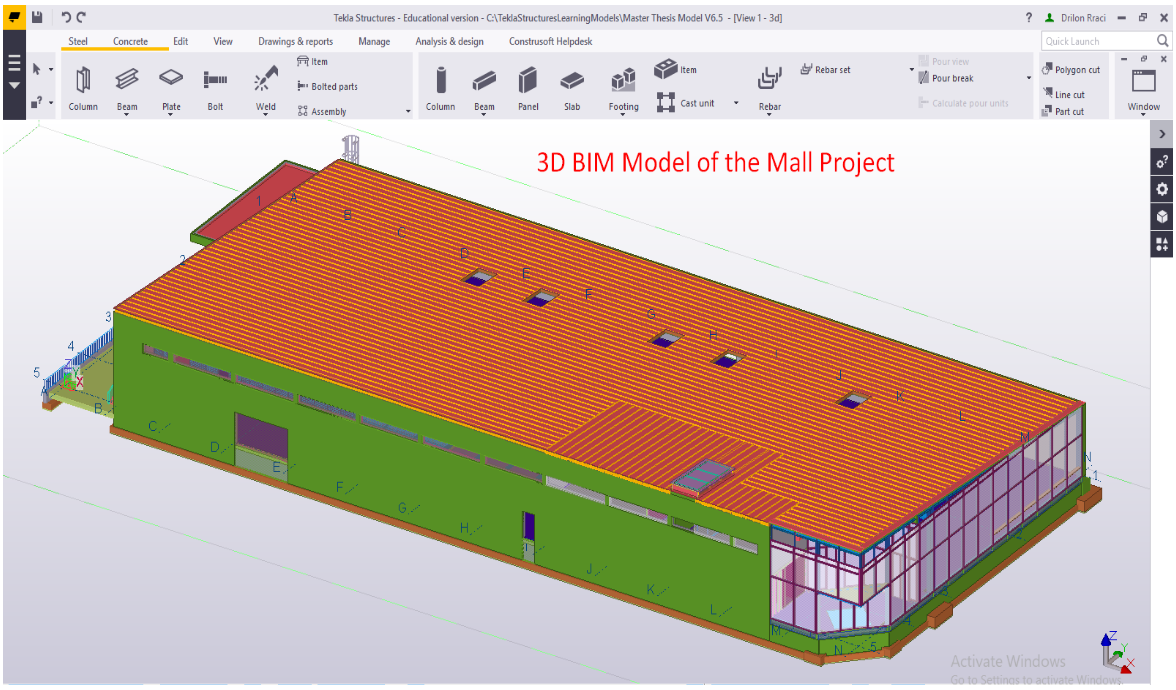


*Figure 5.1: 3D Model of the Mall Project modeled using Tekla Structures Learning.*

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Aiming to describe and represent each element modeled in the case of a Mall project, we broke up the entire BIM model of the Mall project, into smaller sections. This has been set out using 'Phase Manager' tool, as shown in Figure 5.2.

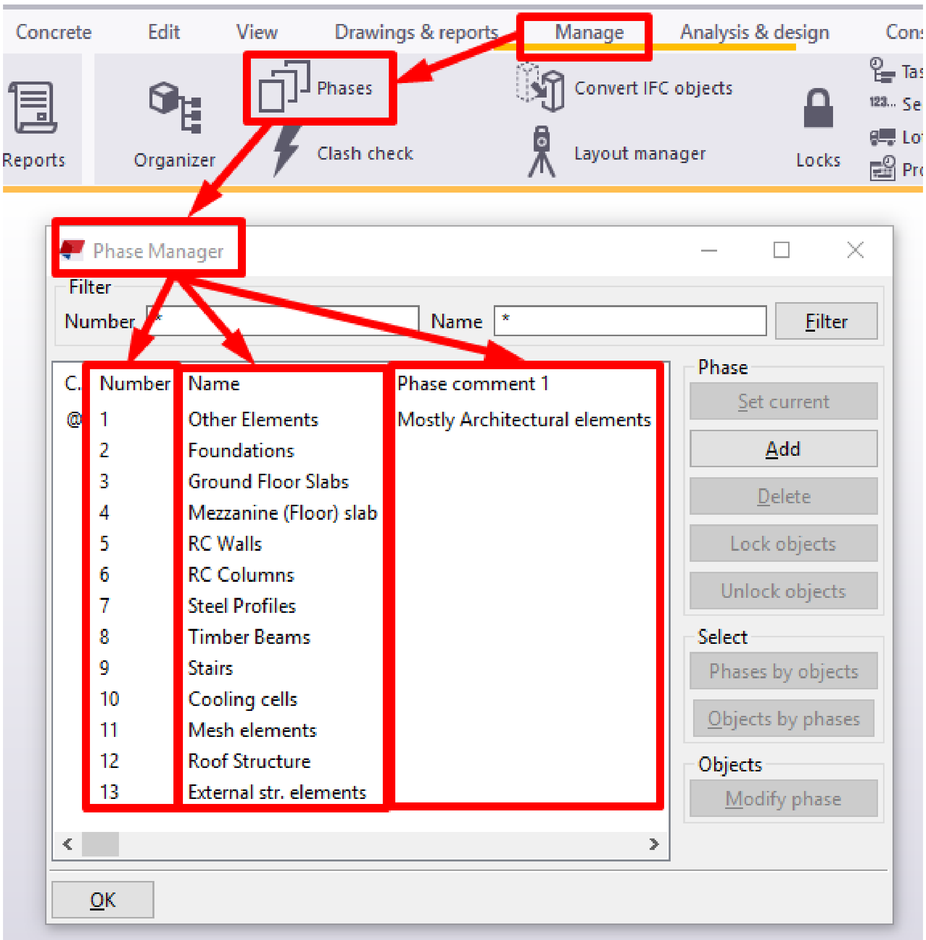


*Figure 5.2: Phase Manager Filter in TSL.*

In this section, each phase of the Mall project as underlined in Figure 5.2 has been described and discussed. Most of the elements included in phases 2-13 are considered as structural elements. These elements are represented as load-bearing elements necessary for proper structural design and include geometry, member nodes, material properties, element cross-sections, external supports, nodal restraints, and type of analysis.

Overall floor size of the building is (74,83 x 32,35) m. The total gross area of the building is approximately 2500 $m^2$. The building consists of the ground floor and a mezzanine (intermediate floor). Mezzanine is placed in the area between axes 3-5/I-M, which has the floor size of approximately 190 $m^2$ (Figure 5.3).

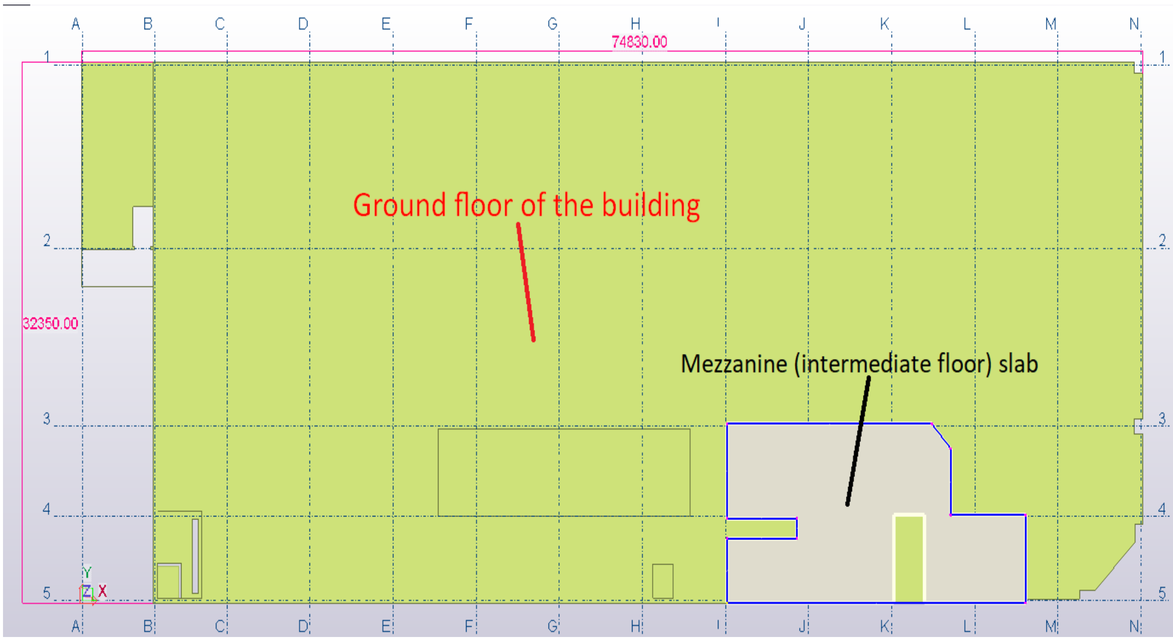


*Figure 5.3: Ground floor and mezzanine of Mall project.*

The main floor height of the Mall area varies from 5,25 m to 6,45 m, while the maximum height of storage and service area is about 7,05 m. The height of the intermediate floor is approximately 3,10 m. The roof of the structure is considered as a single-leaf roof with an inclination of 3.3° (Figure 5.4).

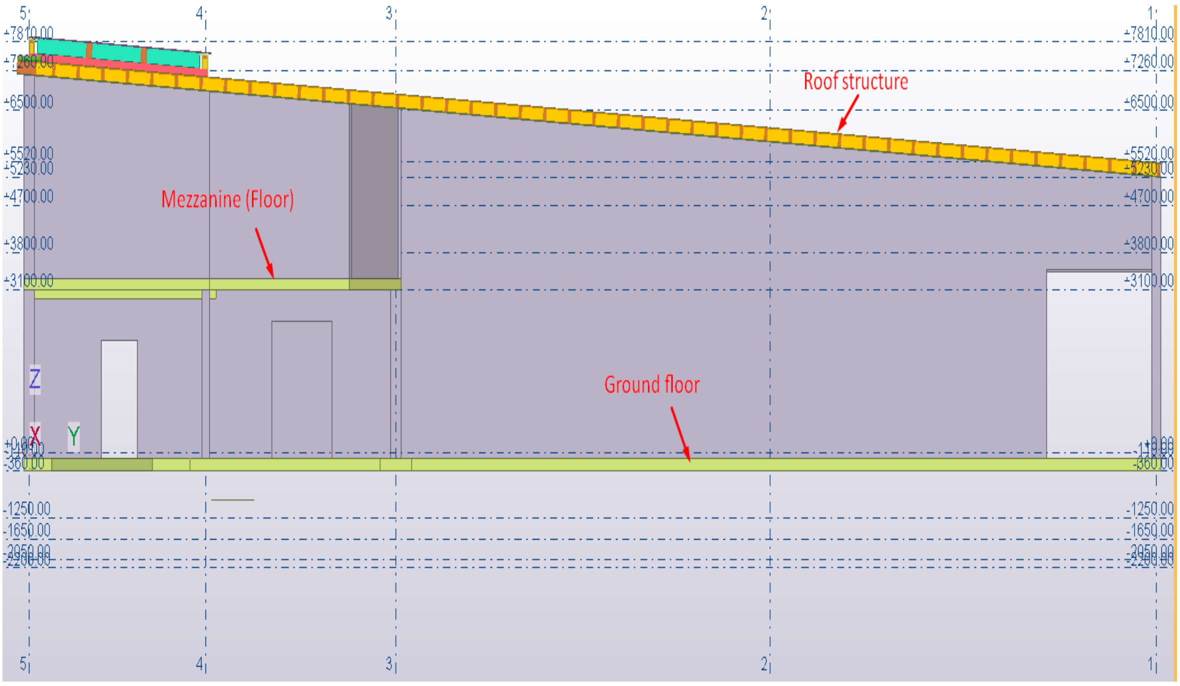


*Figure 5.4: Height differences of the Mall project.*

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A substructure of the building as an underlying or supporting structure, represents a system of strip foundations, mainly consisting of foot 100 cm wide and 40 cm thick. In addition, considering the critical (max.) loads in the axes 3/C-N, the foundation width is supposed to be 150 cm, while in the case of critical (min.) loads in the axes A/1-2, 1/A-B, 2/A-B, I/3-5 and 4/I-N, their width is supposed to be 80 cm. In the area where concentrated loads (where the main steel columns are placed) appear, the foundations have been locally expanded, being considered as pad footings. Thus, in the axes N/1 and N/3 a pad footing (2,50 x 2,50 x 0,80) m is considered, while in the axes N/4 and M/5 a pad footing (1,60 x 1,60 x 0,60) m is used (Figure 5.5).

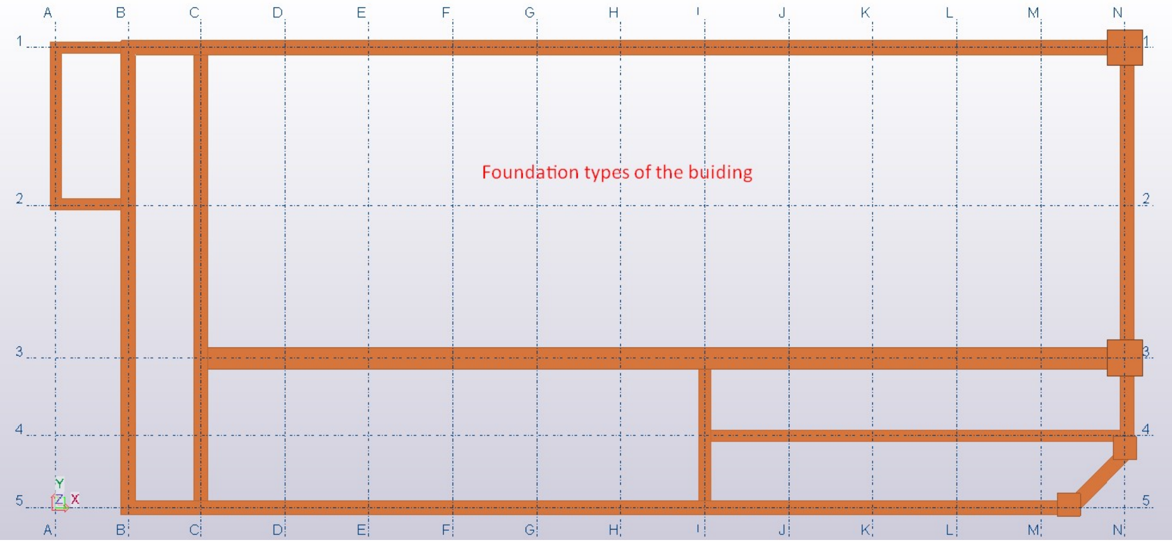


*Figure 5.5: Foundation types of the Mall project.*

The bottom level of the foundation is supposed to be placed at the height-level of -2,05 m depending on the ground floor level of the structure (Figure 5.6).

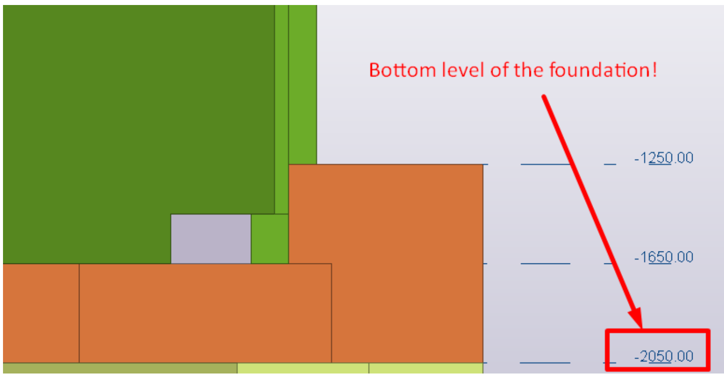


*Figure 5.6: Bottom level of the foundation.*

In addition, above the foundation footings, RC walls with the thickness of 30 cm and the height of 129 cm are considered (Figure 5.7). Through these walls is carried out the ground floor slab with the thickness of 25 cm.

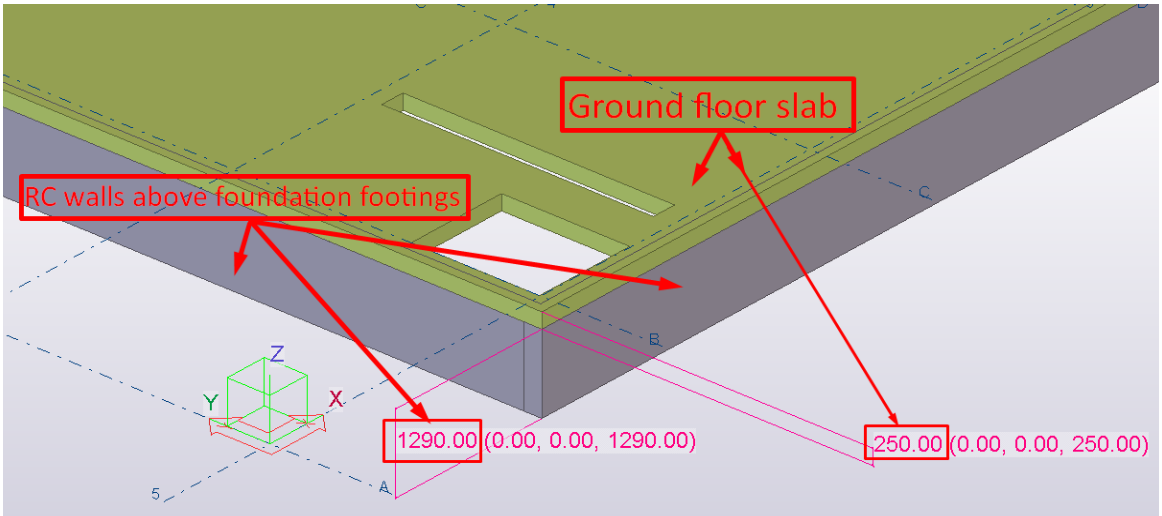


*Figure 5.7: RC walls above footing of the strip foundations.*

A superstructure is considered as an upward part of the building above the ground level. The height of the RC walls above the ground level varies from 5,40 m to 7,20 m (see Figure 5.4), with the thickness of 26 cm and 30 cm, while in the case of interior parts, respectively in the area of mezzanine (intermediate floor) of the structure, the thickness of the RC walls is taken as 20 cm into consideration (Figure 5.8).

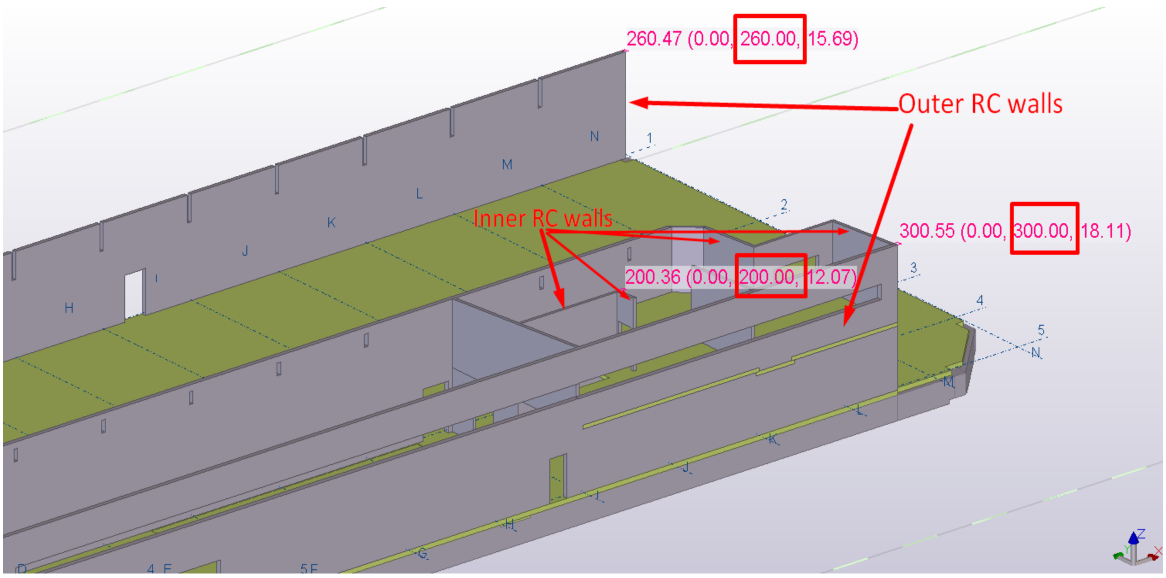


*Figure 5.8: RC walls of the Mall project.*

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The walls which are placed in the technical area of the structure are considered as masonry (brick) walls, with the thickness of 20 cm, being connected with reinforced concrete slabs. Ceiling slabs which are placed above the technical area, as well as above the delivery area were considered as RC slabs, consisting of the thickness of 20 cm (Figure 5.9).

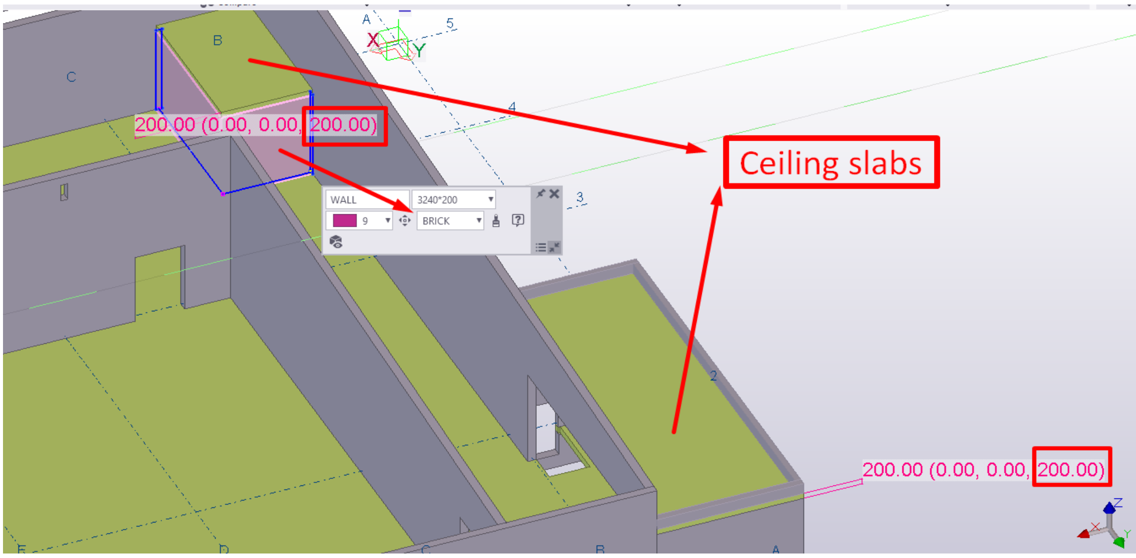



*Figure 5.9: Brick walls and ceiling slabs of the Mall project.*

The roofing system of the structure has been carried out by glued timber beams. These structural elements placed in the area between axes 1 and 3 consists of the width equal to 24 cm and the height of 140 cm, while those placed in the area between axes 3 and 5 consists of the same width as previous ones with the height of 64 cm (Figure 5.10).

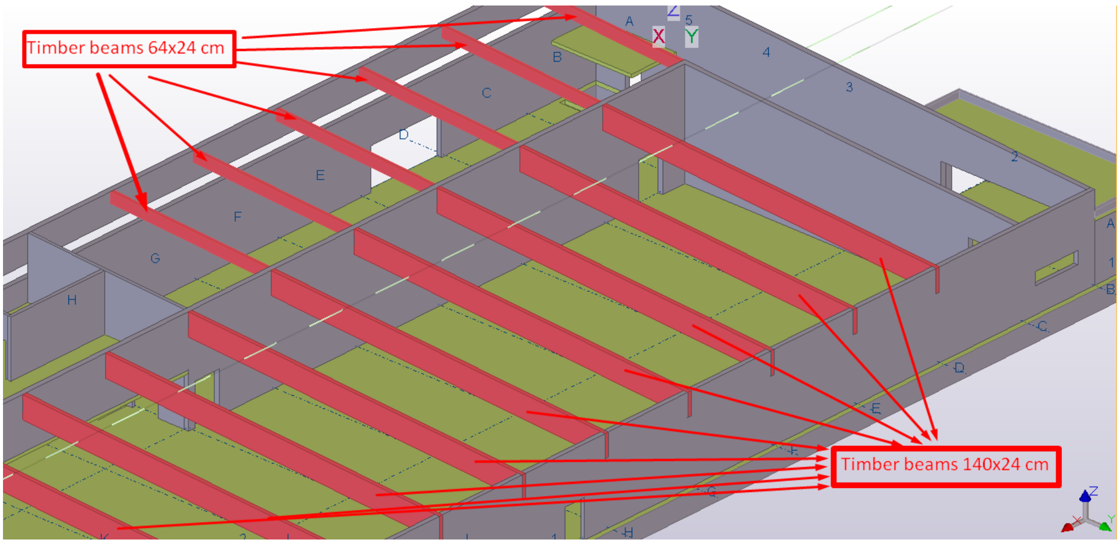



*Figure 5.10: Timber beams of the Mall project.*

In addition, timber panels as structural parts of the roof structure include the glued timber beams consisting of the cross-section of 8/24 cm placed axially with the space of 70 cm, and OSB timber plates which are placed on its upper and bottom side. In the area between the glued timber beams as supports of the roof panel is considered the thermal insulation with the thickness of 24 cm. A typical detail of this roofing system is modeled in TSL, as shown in Figure 5.11.

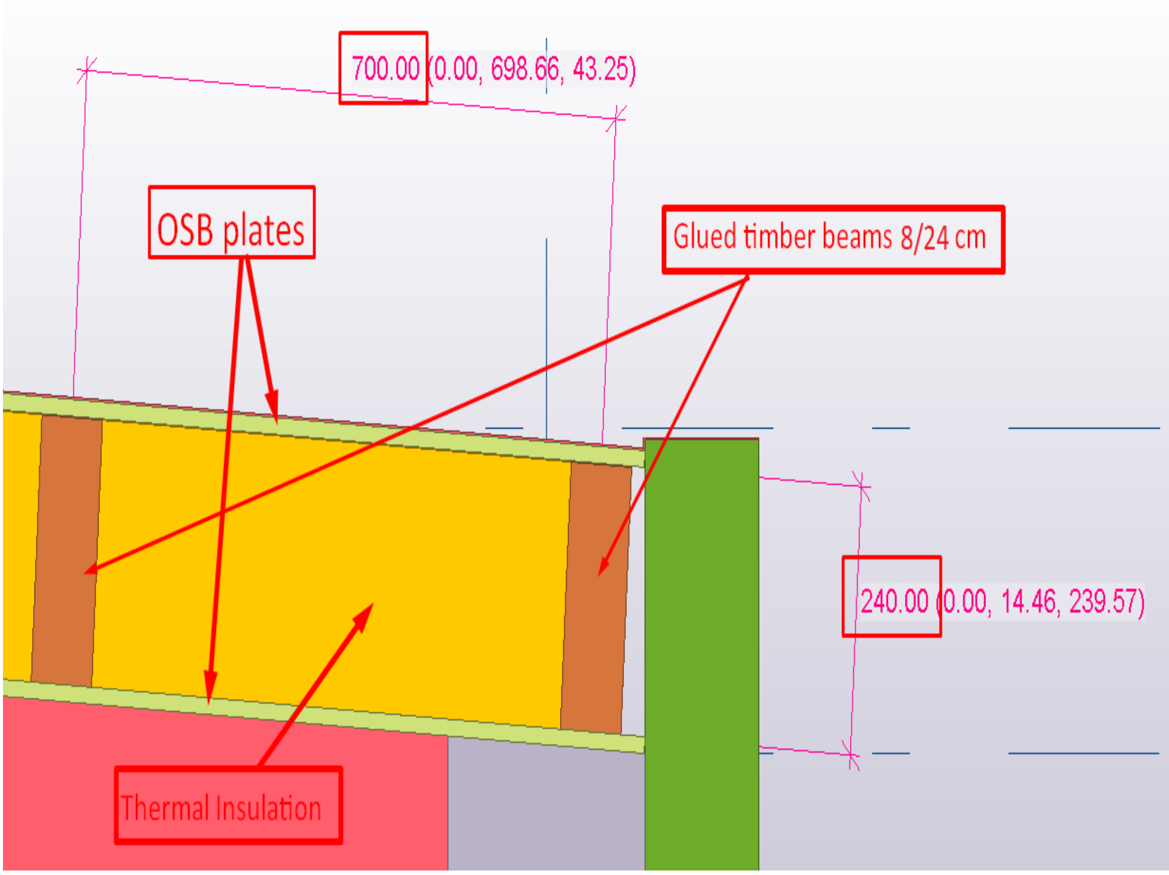



*Figure 5.11: Detail of the roof system modeled in TSL.*

Furthermore, in the area of the main entrance of the Mall center between axes 5/L-N and axis N, structural steel elements have been modeled (columns with the cross-section of 30/30 cm and HEA 500, and HEA 500 steel beam). In the axes 3/K-N a steel beam with the cross-section of HEB 1000 is considered, while in the axes 4/J-L a steel beam with the section of HEB 200 is used. Steel beam profiles RHS (18x26x0,8) cm, which must be anchored in the walls of the structures between axes 3-5/E-I are considered. Steel profiles of the Mall project have been shown in Figure 5.12.

`

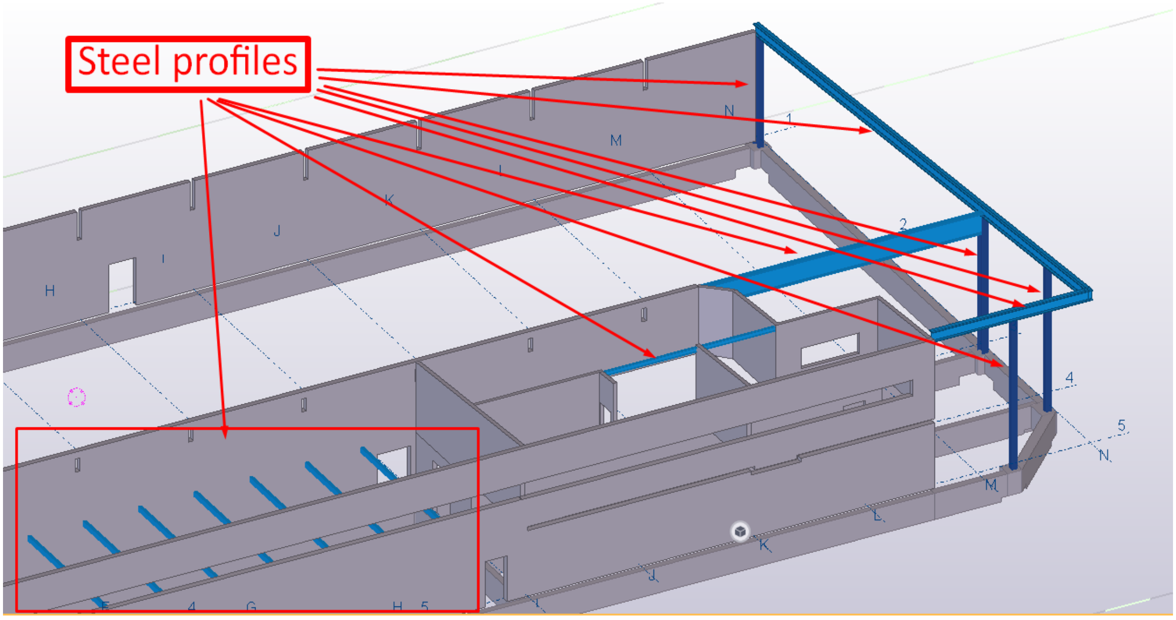



*Figure 5.12: Steel profiles of the Mall project.*

RC columns with the cross-section of 30/30 cm, have been modeled as load-bearing elements, as shown in Figure 5.13.

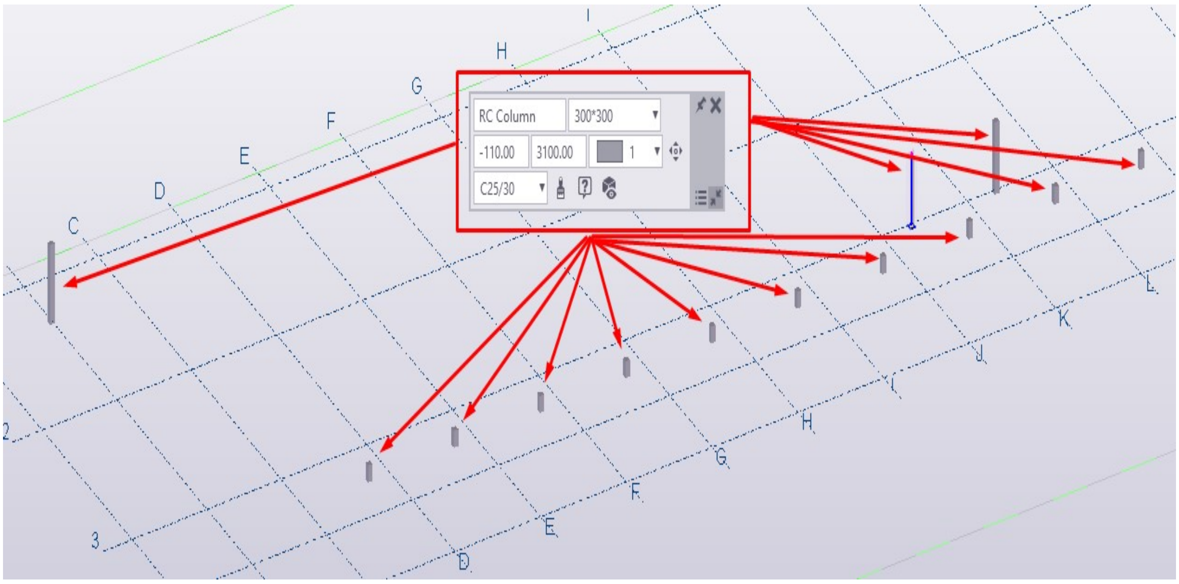



*Figure 5.13: RC columns of the building.*

In the case of modeling aluminium profiles and glass surfaces to cover the entrance of the building, Schuco profiles (see Figure 5.44) adopted from Tekla Warehouse library are taken into consideration. Modeling of these profiles is shown in Figure 5.14.

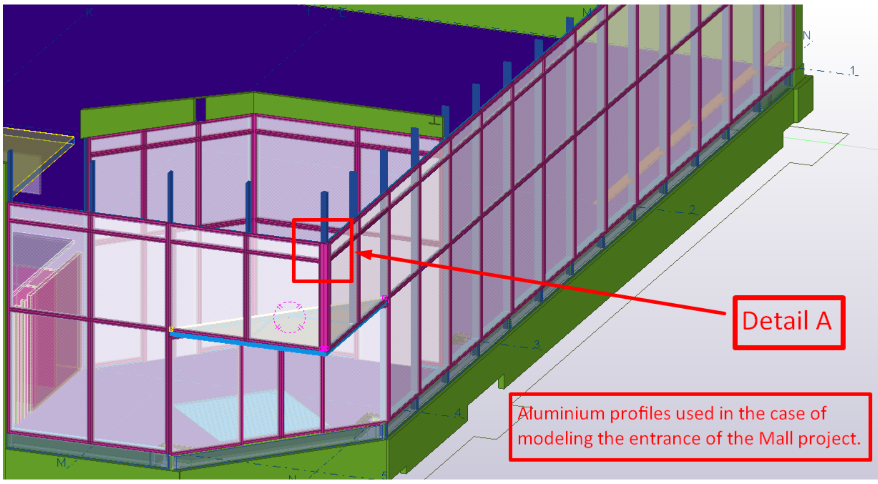



*Figure 5.14: Aluminium profiles and glass surfaces modeled in TSL.*

A detail (Detail A) of modeled Schuco profiles in TSL is shown in Figure 5.15.


*Figure 5.15: A detail of modeled Schuco profiles in TSL.*

Furthermore, three types of stairs are modeled in this project, as shown in Figure 5.16.

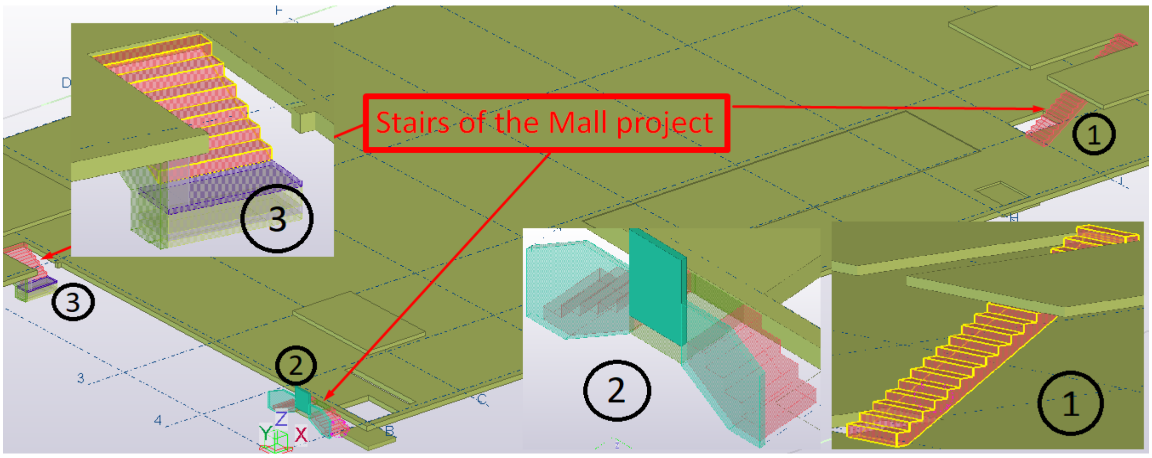



*Figure 5.16: Different types of stairs modeled in TSL.*

`

Cooling cells consisting of masonry walls and rock wool insulation layers have been modeled between axes 3-4/E-I, as shown in Figure 5.17.

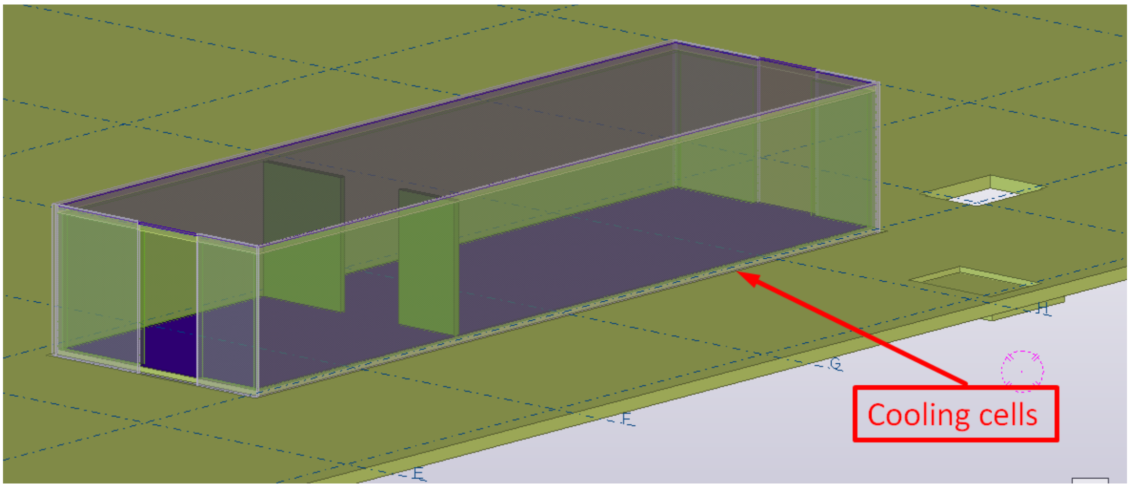



*Figure 5.17: Cooling cells of the Mall project.*

Mesh elements which are modeled inside of the building area, are made of steel profiles. These elements are shown in Figure 5.18.

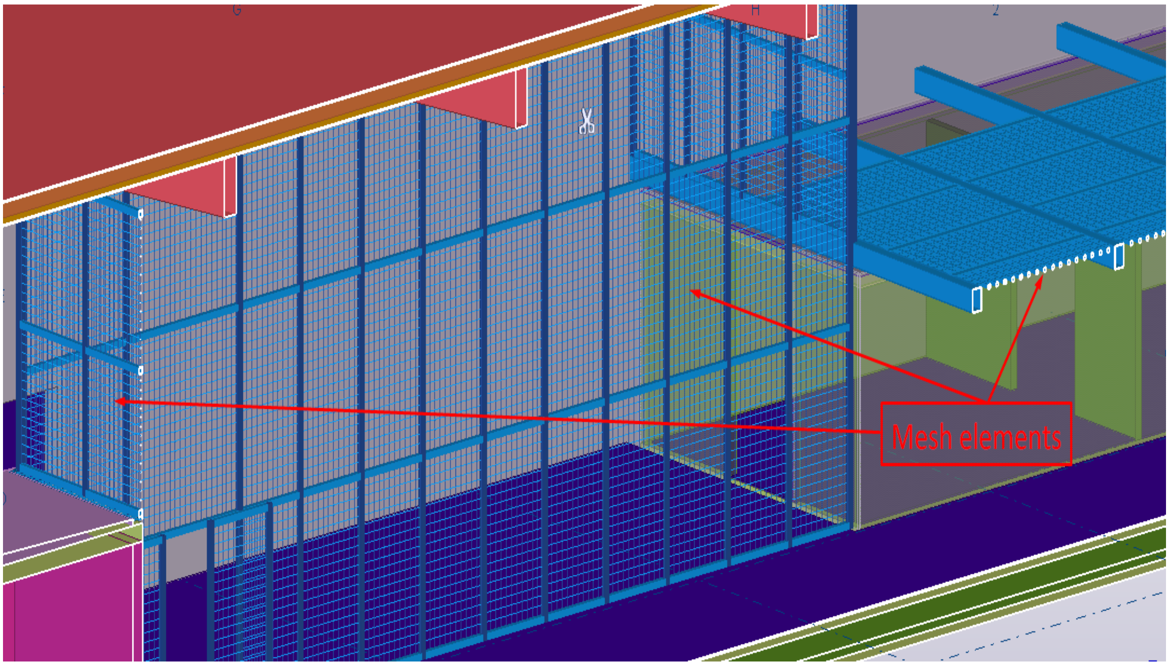



*Figure 5.18: Mesh elements made of steel profiles.*

In addition, external structural elements such as RC slab, strip foundations, and RC walls, have been modeled between axis 2-5/A-B, as shown in Figure 5.19.

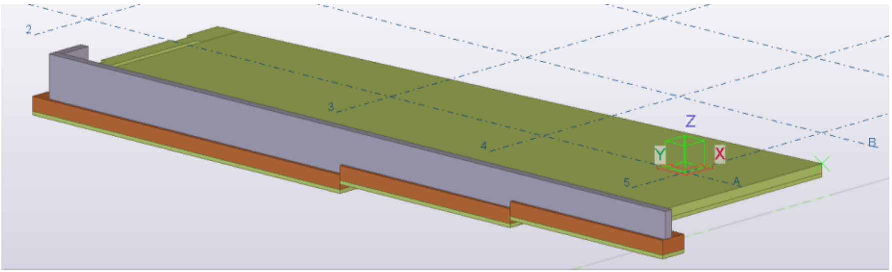


*Figure 5.19: External structural elements of the Mall project.*

Finally, elements included in the first phase of the Mall project (wood covering elements, ladder, Schüco aluminium elements, etc.), have been considered as architectural elements. These architectural elements are modeled as non-load-bearing elements in TSL, as shown in Figure 5.20.

However, these elements have also been specified with materials, element cross sections, and exterior/interior finishes that are not connected with the structural model but belongs more to the aesthetic role of the building.

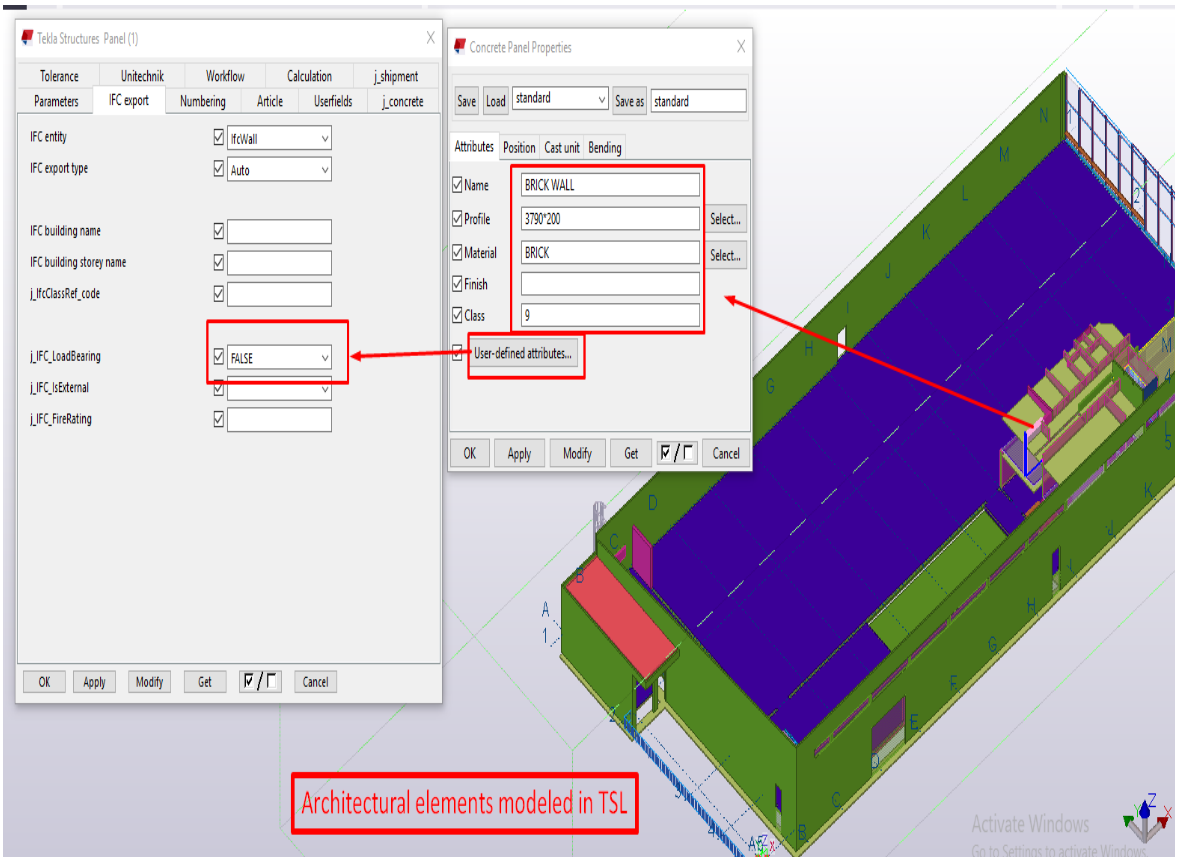



*Figure 5.20: Architectural elements of the Mall project modeled as non-load-bearing elements in TSL.*

`

## 5.2 Modeling of the Mall project

### 5.2.1 Tekla Structures Learning Environments

In this thesis, we have paid a close attention while setting out the libraries of property for different objects and materials, since those represent an integral part of a well-developed BIM environment.

BIM environment includes object and assembly libraries for reuse, interfaces to the applications the organization supports and links to collaborate management and accounting systems (Eastman *et al.*, 2011).

Currently, TSL offers a wide range of environments. Based on the country origin the environments showed in Figure 5.21, offers adequate engineering standards that are applicable in that country.

| | | | |
|---|---|---|---|
| Australasia (26 MB) | Download | Netherlands (62 MB) | Download |
| Austria (26 MB) | Download | Netherlands enu (22 MB) | Download |
| Brazil (35 MB) | Download | Norway (9 MB) | Download |
| China (10 MB) | Download | Poland (18 MB) | Download |
| Czech (21 MB) | Download | Portugal (21 MB) | Download |
| Denmark (56 MB) | Download | Russia (21 MB) | Download |
| Finland (23 MB) | Download | South Africa (27 MB) | Download |
| France (53 MB) | Download | South America (20 MB) | Download |
| Germany (21 MB) | Download | South East Asia (15 MB) | Download |
| Hungary (28 MB) | Download | Spain (23 MB) | Download |
| India (25 MB) | Download | Sweden (26 MB) | Download |
| Italy (53 MB) | Download | Switzerland (70 MB) | Download |
| Japan (68 MB) | Download | Taiwan (9 MB) | Download |
| Korea (24 MB) | Download | UK (50 MB) | Download |
| Middle East (17 MB) | Download | US imperial (60 MB) | Download |
| | | US metric (58 MB) | Download |

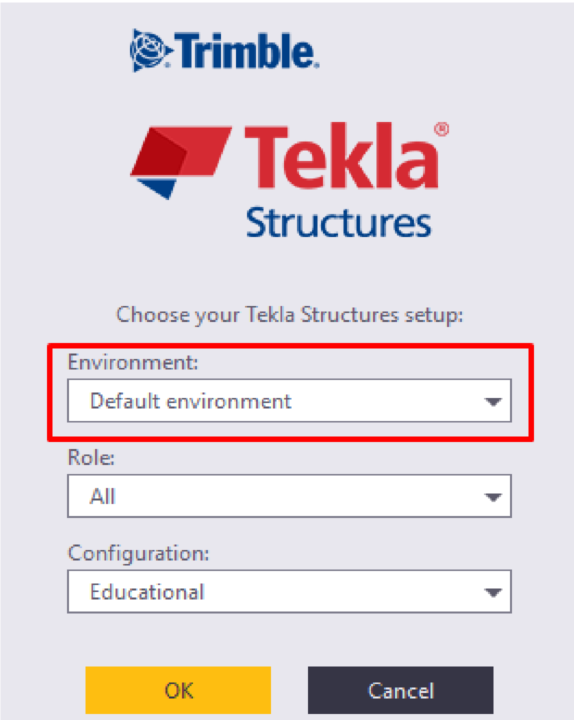
*Figure 5.21: Tekla Structures Learning available Environments* (Tekla, 2017).

For the purposes of this Thesis, we have decided to use Netherlands enu[11], as it is underlined in Figure 5.21. We installed the setup of Netherlands enu environment in TSL by downloading it from Tekla home page.

The main reason for choosing Netherlands enu environment instead of Default environment lies in the research we have done, while we noticed some crucial differences between them, regarding their overall usage in the case of libraries of property sets for different objects and materials. This was mainly related to the properties of structural elements.

On the other hand, Netherlands enu environment contains all the necessary European standards used for different engineering purposes, and all of them are given in English which satisfies basic requirements of this thesis.

Below, we have shown a brief overview of the main differences between the following environment cases: Default environment and Netherlands (English) environment. Both environment cases are presented in Figure 5.22.



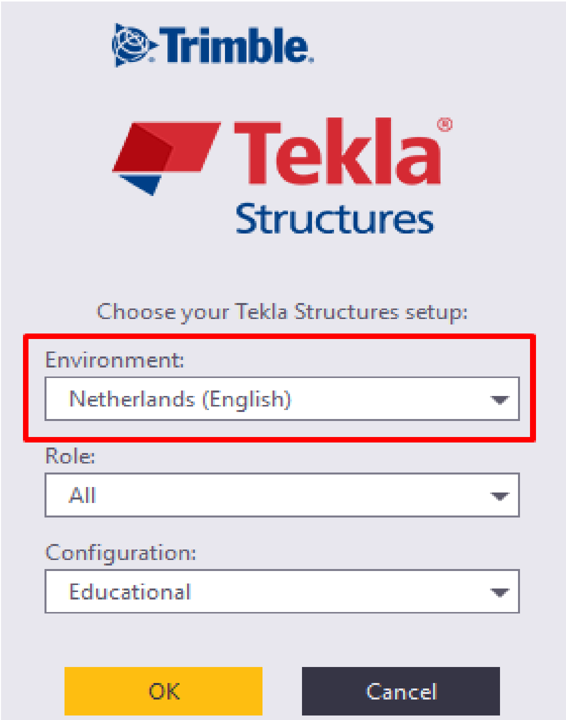




*Figure 5.22: Representing two different Tekla Structures environments.*

[11] Netherlands enu = Netherlands (English), is one of the available environments at Tekla Structures Learning, which can be downloaded and used for different modeling purposes. It is offered in the English language.

`

As it can be seen in Figure 5.22, the same Role and Configuration of the program TSL was chosen, for both environment types. The Role was selected All, in the case of being able to use all available functionalities that TSL offers. In addition, the Configuration of the software remains Educational, which means that the created BIM model of the Mall in TSL cannot be used for production purposes.

TSL options for defining the properties of different elements are offered in different properties settings due to environments differences. Some of the main differences between above-mentioned environments have been illustrated in figures below.

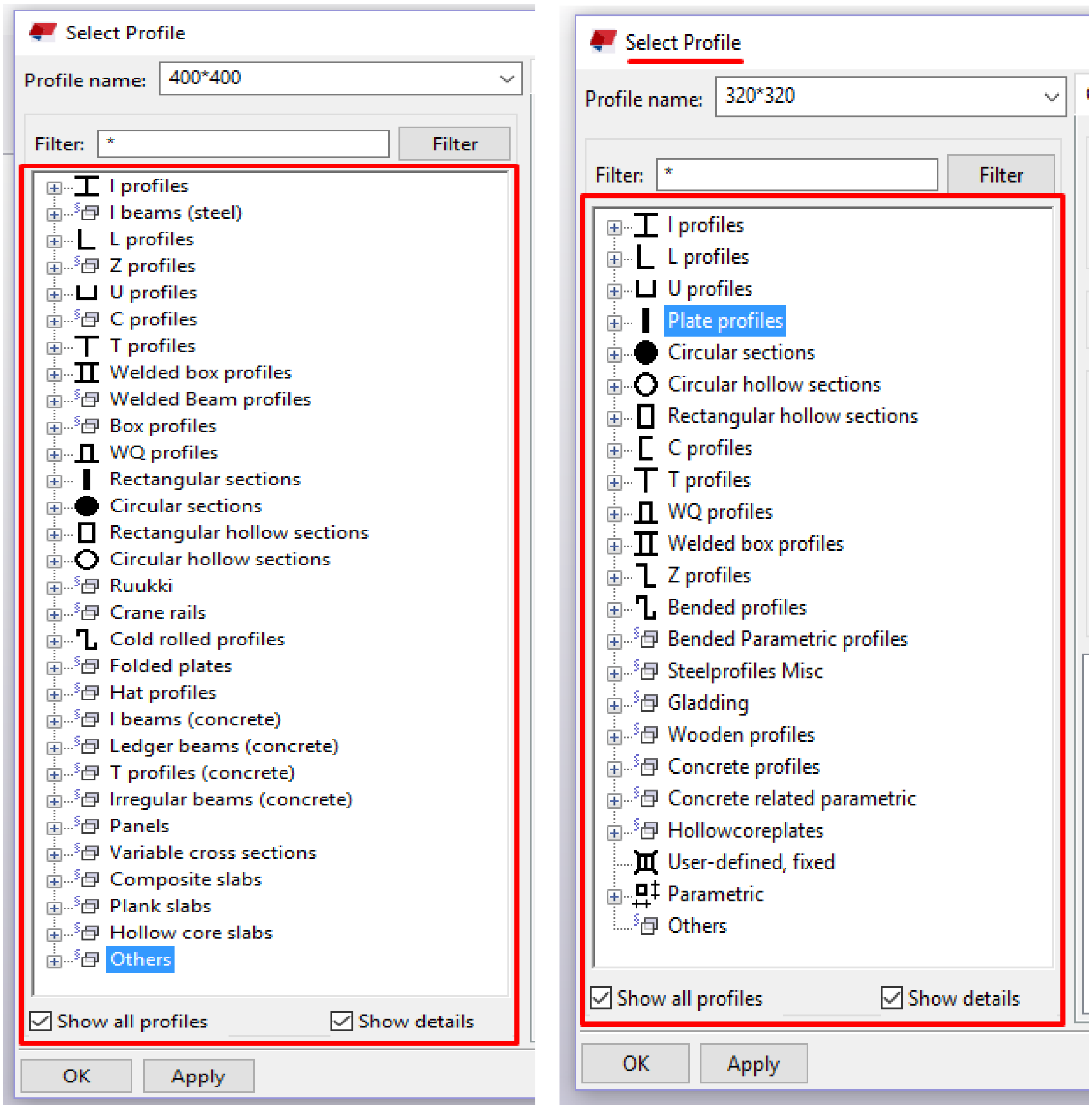



*Figure 5.23: Concrete profile selection differences. Default environment (left side) and Netherlands-English (right side).*

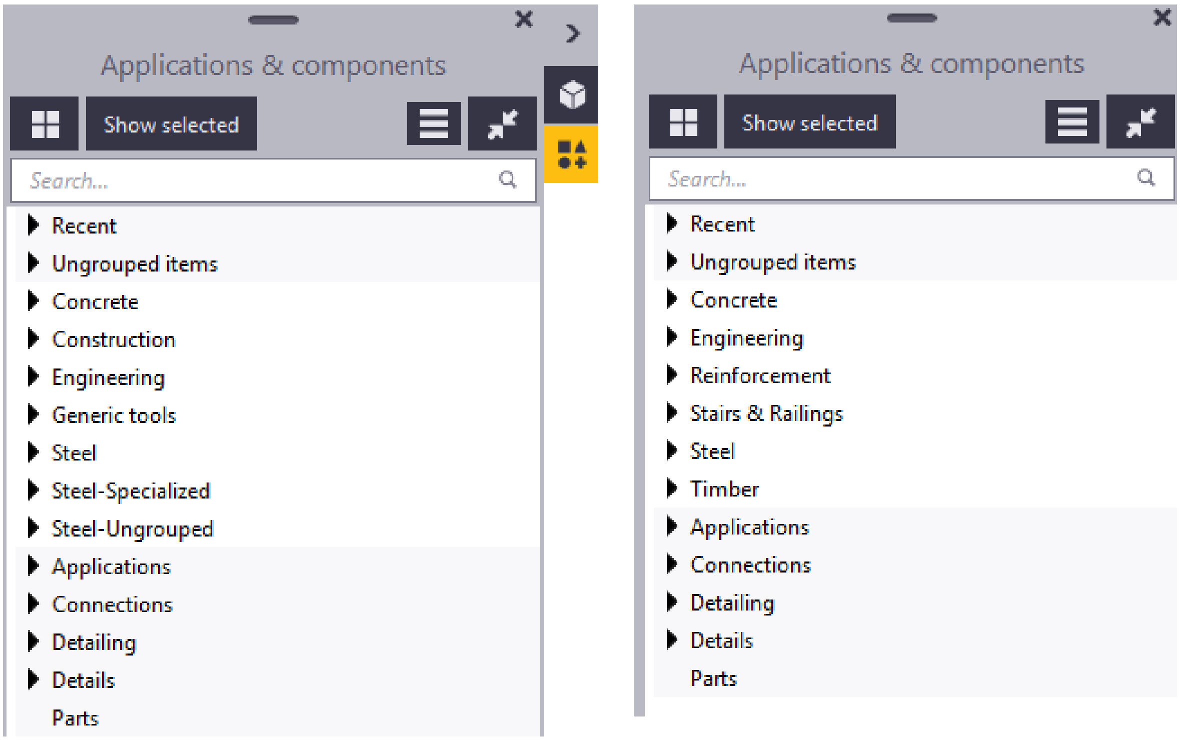
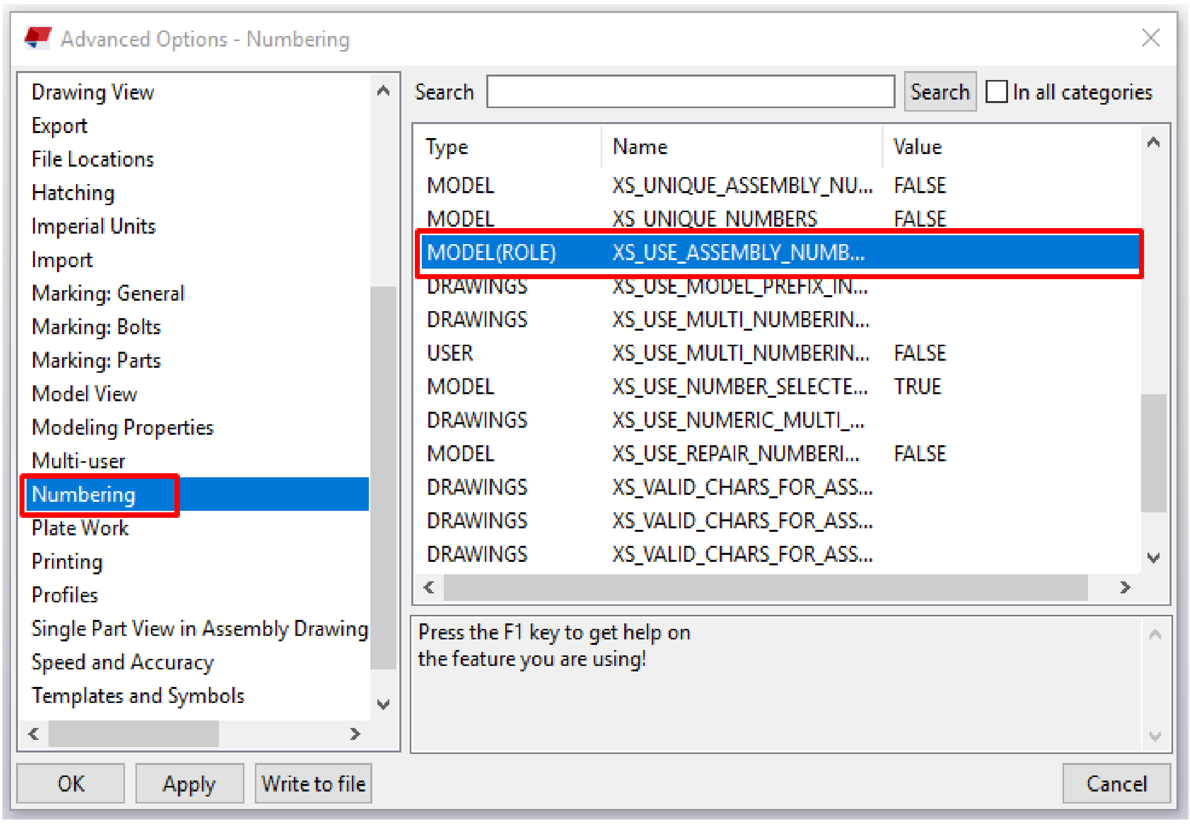



*Figure 5.24: Applications and components differences. Default environment (left side) and Netherlands-English (right side).*

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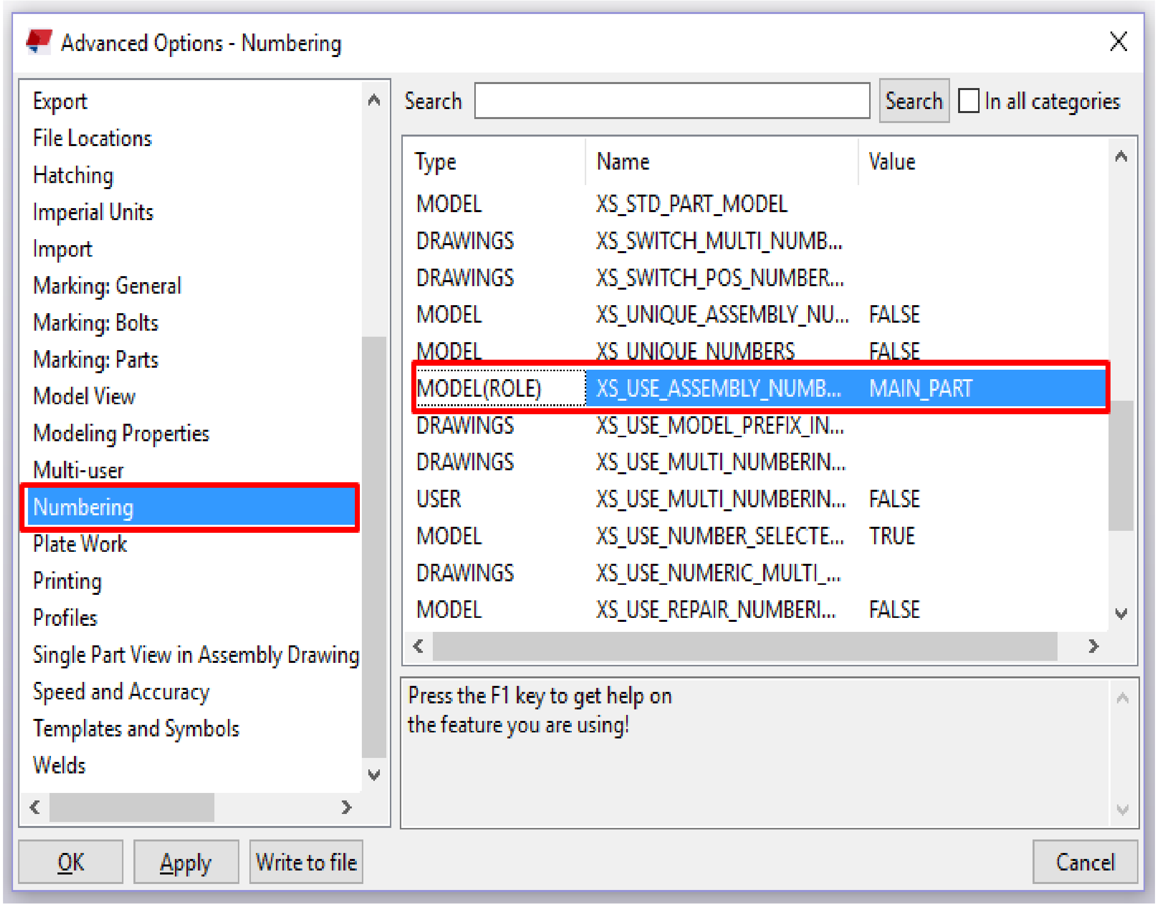


*Figure 5.25: Important advance option differences. Default environment (upward side) and Netherlands-English (downward side).*

Additionally, some differences while using the above-mentioned environments at the same project appeared also when drawing template layouts were automatically created. This cleared the basic dilemma on which type of the above-mentioned environments should be taken into consideration, in the case of this thesis.

Hence, Netherlands (English) environment appeared to be more useful and better implemented for the overall purposes of this thesis.

### 5.2.2 Tekla Structures Learning standards and settings in the case of a Mall project

First, to create a BIM model in Tekla Structures Learning (TSL), the appropriate way of setting out necessary and most important information of the project must be considered. Thus, the path: Open Software>File>Project Properties is followed. The following dialog box appears as shown in Figure 5.26.

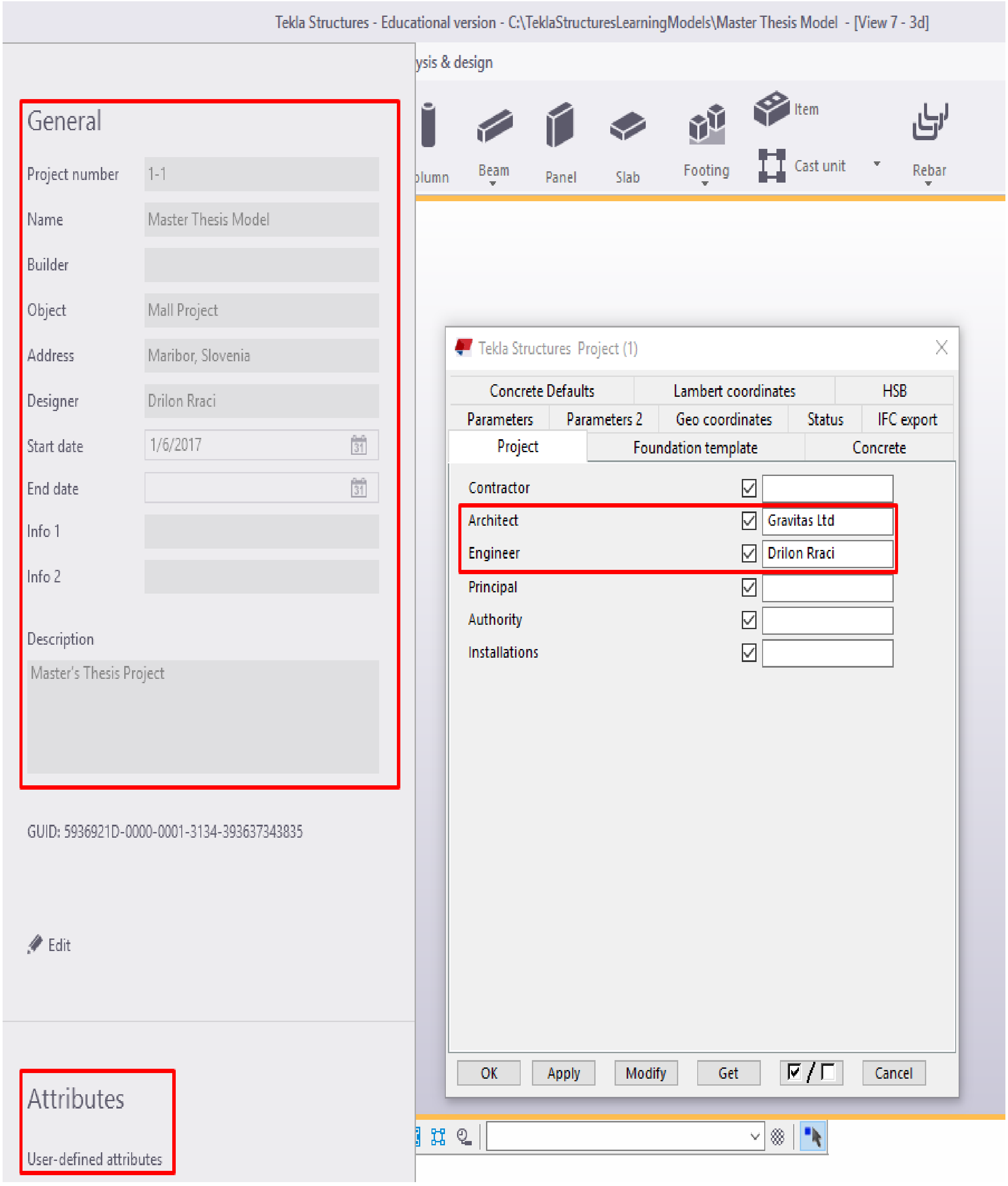


*Figure 5.26: Tekla Structures Learning properties in the case of a Mall Project.*

In addition, grid settings specified for the Mall project are set out as shown in Figure 5.27 (left side). Grids have been used to create plan and elevation views in TSL. As soon as we have defined the grid lines, we could use them to create a series of so-called named views. For instance, seven of the named views created by using a grid that was selected and then moved over to the visible views section, are shown in Figure 5.27 (right side).

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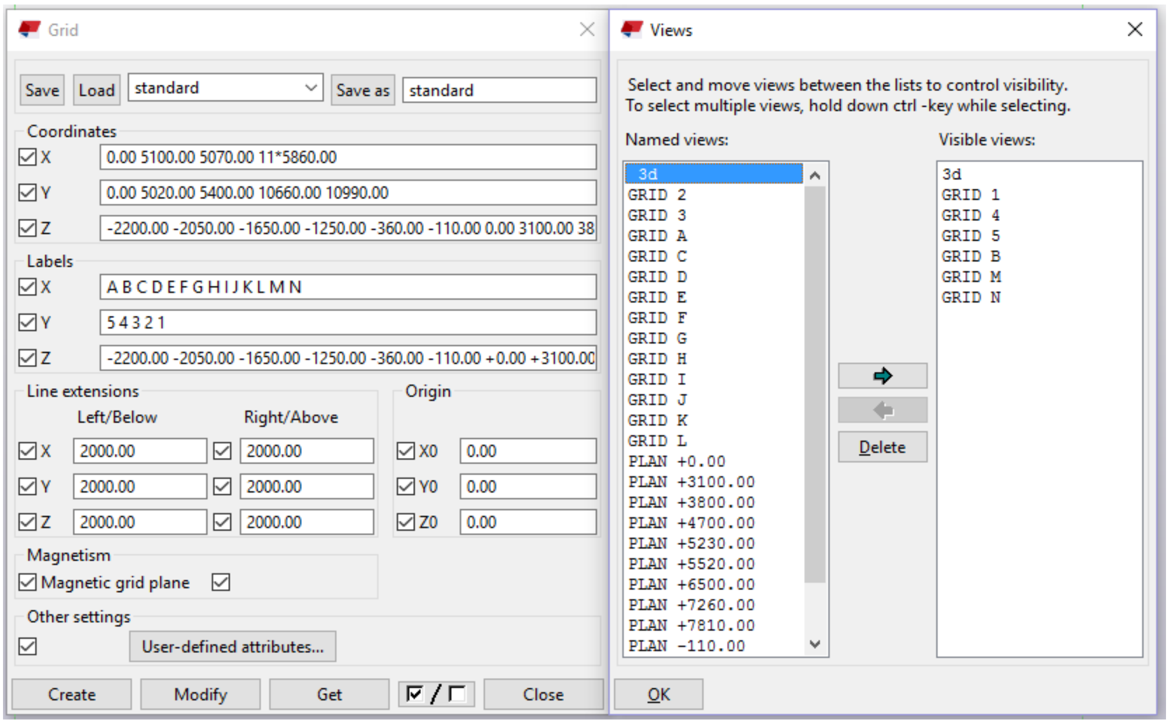


*Figure 5.27: The grid settings (left side) and views along the grid lines (right side).*

When we have already created grid and views, we continued to create the model using the various tools for typical elements such as beams, polygon beams, columns, plates, slabs, walls, etc. Basically, various tools appear to be grouped together into toolbars. For instance, steel toolbar contains tools for modeling steel elements, the concrete toolbar contains tools for creating concrete elements, then detailing toolbar contains tools for editing elements etc. Moreover, TSL offers numerous additional toolbars containing tools for creating connections, components, as well as tools for creating and managing views and work planes. These toolbars are placed on top of the modeling window of TSL application, as shown in Figure 5.28.

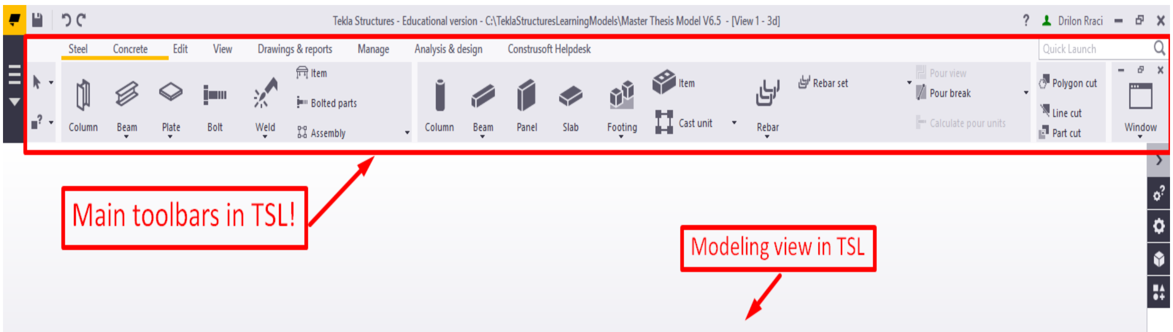


*Figure 5.28: Main toolbars in TSL.*

In the first stage of creating the BIM model of the Mall project in TSL, we had the chance to set out the execution class of the steel parts of the structure.

According to (CEN, 2008), four execution classes (EXC) are defined as follows: each class provides its own set of requirements, with complexity increasing as the number rises, while EXC2 is considered the most used specification for different kind of projects. The EXC assigned to a structure is mostly generated and defined by the engineering effort required to create and realized the project-specific design parameters.

Hence, the basic execution classes defined by (CEN, 2008), available at TSL, are described based on their purpose of uses, as shown in Figure 5.29.

| | |
|---|---|
| EXC1 | Supporting structures with steel up to strength class S275, buildings with up to 2 floors (4 floors if detached), bending beams up to 5m, projection beams up to 2m.<br>Stairs & railings in residential buildings.<br>Agricultural buildings, e.g. barns. |
| EXC2 | Supporting structures with steel up to strength class S700.<br>Buildings with 2–15 floors. |
| EXC3 | Supporting structures with steel up to strength class S700.<br>Assemblies/stadiums with large surface roof structures.<br>Buildings with more than 15 floors.<br>Pedestrian, bicycle, road and railway bridges.<br>Crane track |
| EXC4 | Bridges (road & rail) over densely populated areas or industrial plants with high hazard potential.<br>Safety tanks in nuclear power plants. |

*Figure 5.29: Examples of execution classes* (Linde Group, 2014).

Since, the Mall project is considered as a commercial structure, than EXC2 is adopted as an appropriate execution class for steel elements (Figure 5.30).

`

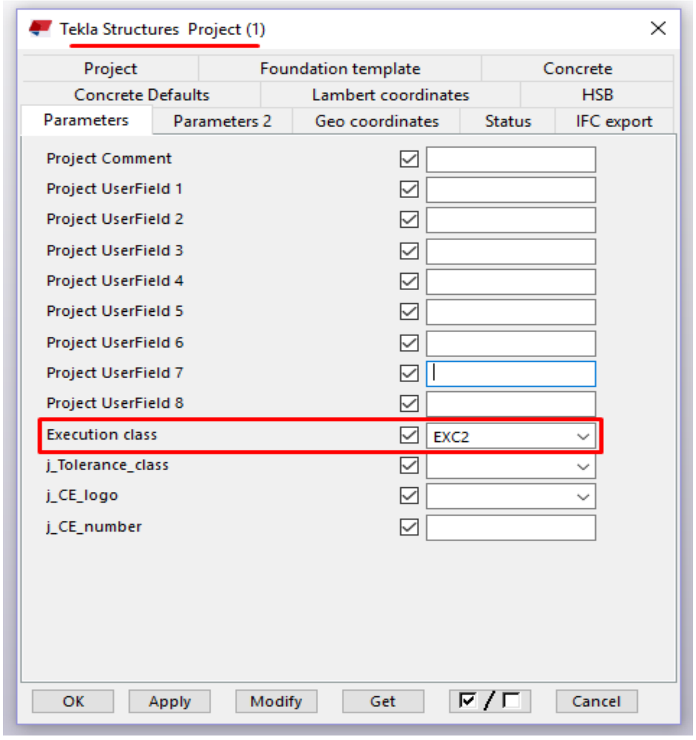


*Figure 5.30: Execution class for steel elements dialog box.*

Using TSL, we could define the properties of components before creating them, or modify the properties after creation. An example is shown in Figure 5.31, where a concrete column properties dialog box appears. Furthermore, we could choose the profile from an extensive catalog of steel and concrete sections, and then select the material from a catalog of industry standard types.

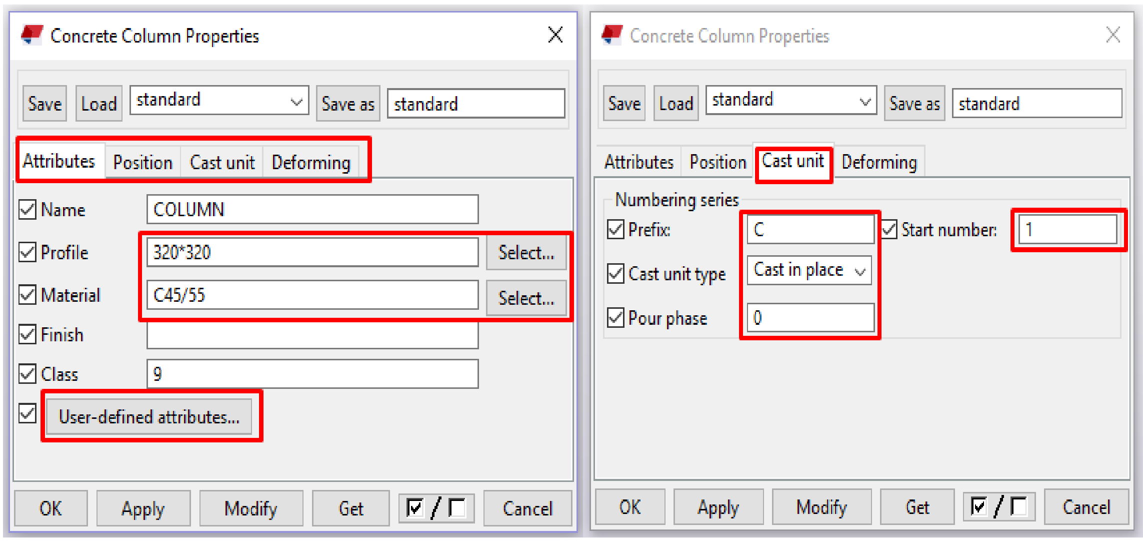


*Figure 5.31: The Concrete Column Properties dialog boxes.*

In addition to specifying various other properties, needed for modeling and especially for further structural analysis purposes, we were able to define our own attributes for any object which is part or belongs to the Mall project. Some of the most important attributes have been represented in Figure 5.32.

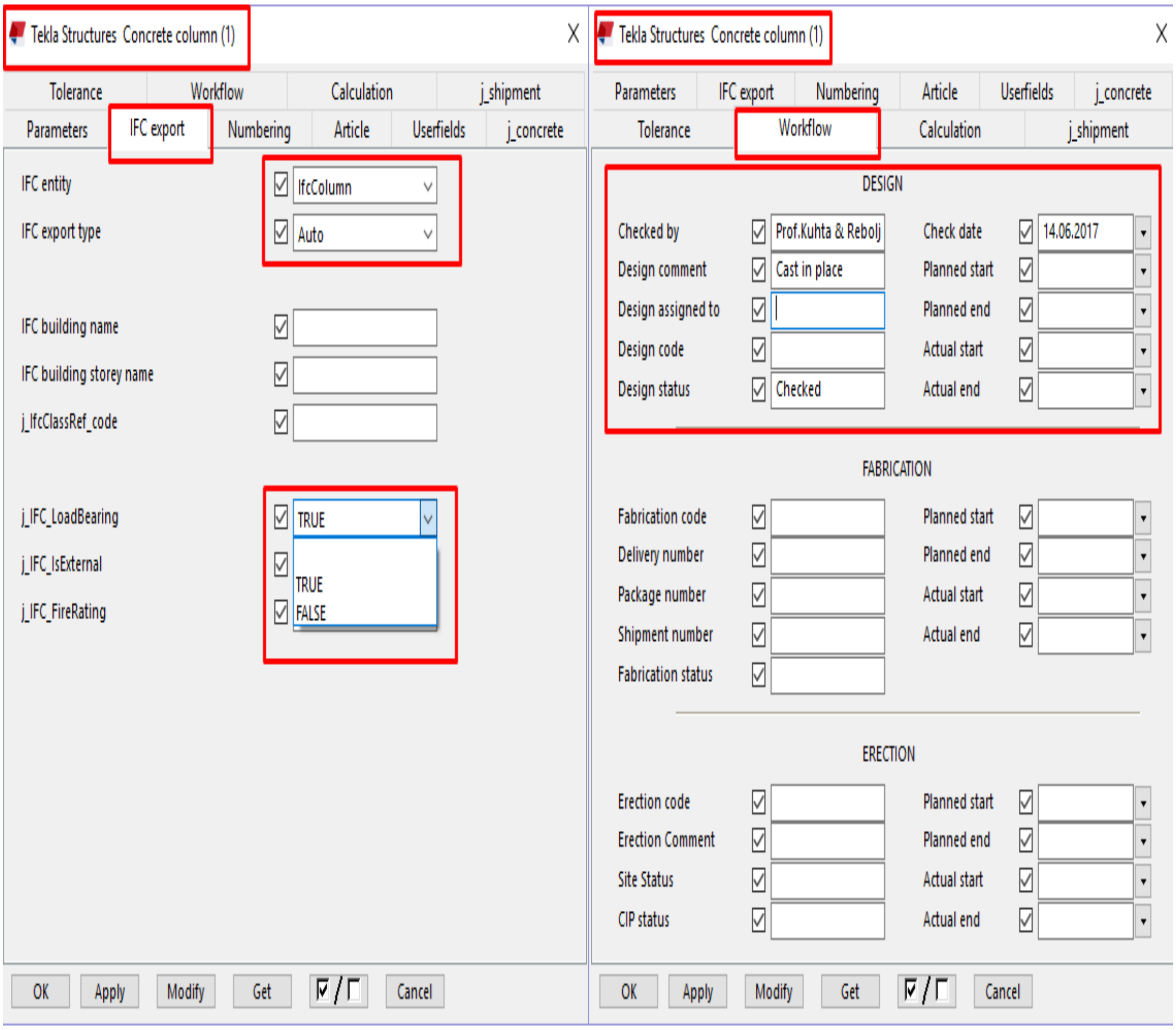


*Figure 5.32: The UDA's of Concrete Column dialog box. IFC export properties (left side) and Workflow properties (right side).*

The procedure in the case of setting up the appropriate tolerance values while modeling steel and concrete elements in TSL has been represented in the following dialog box (Figure 5.33). However, the same dialog box represents options which have been used in the case when renumbering of modified elements was needed. These options are connected in an automated way and have a direct impact on drawings. It means that changes made in "Numbering Setup" dialog box appear automatically in drawings that are already created.

`

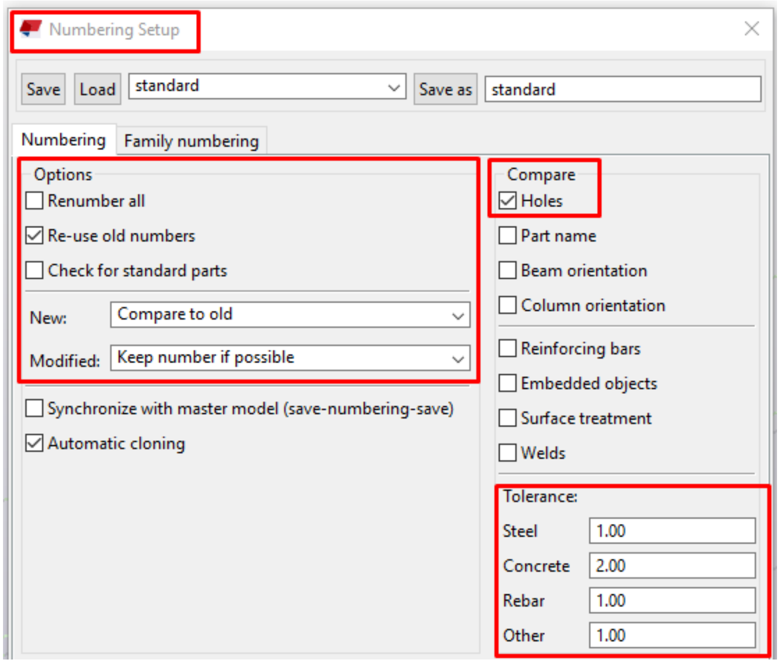


*Figure 5.33: Numbering Setup dialog box.*

.

In addition, the appropriate values of components, which were used directly in the following stages of the project, have been set out using the following path: Settings>Options>Components. These values appear in the following dialog box (Figure 5.34).

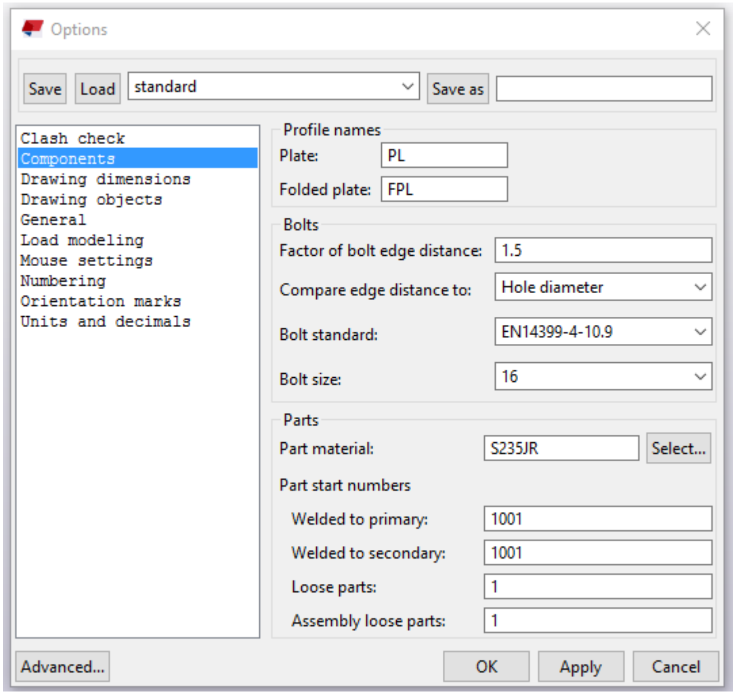


*Figure 5.34: Default settings for components in Tekla Structures.*

Similarly, the path: Settings>Options>Clash checks is followed to set out necessary default values in the case of detecting clash checks while modeling the Mall project, avoiding the possibilities of making eventual mistakes. This has been connected and set out in accordance with Eurocodes. The procedure is illustrated in Figure 5.35.

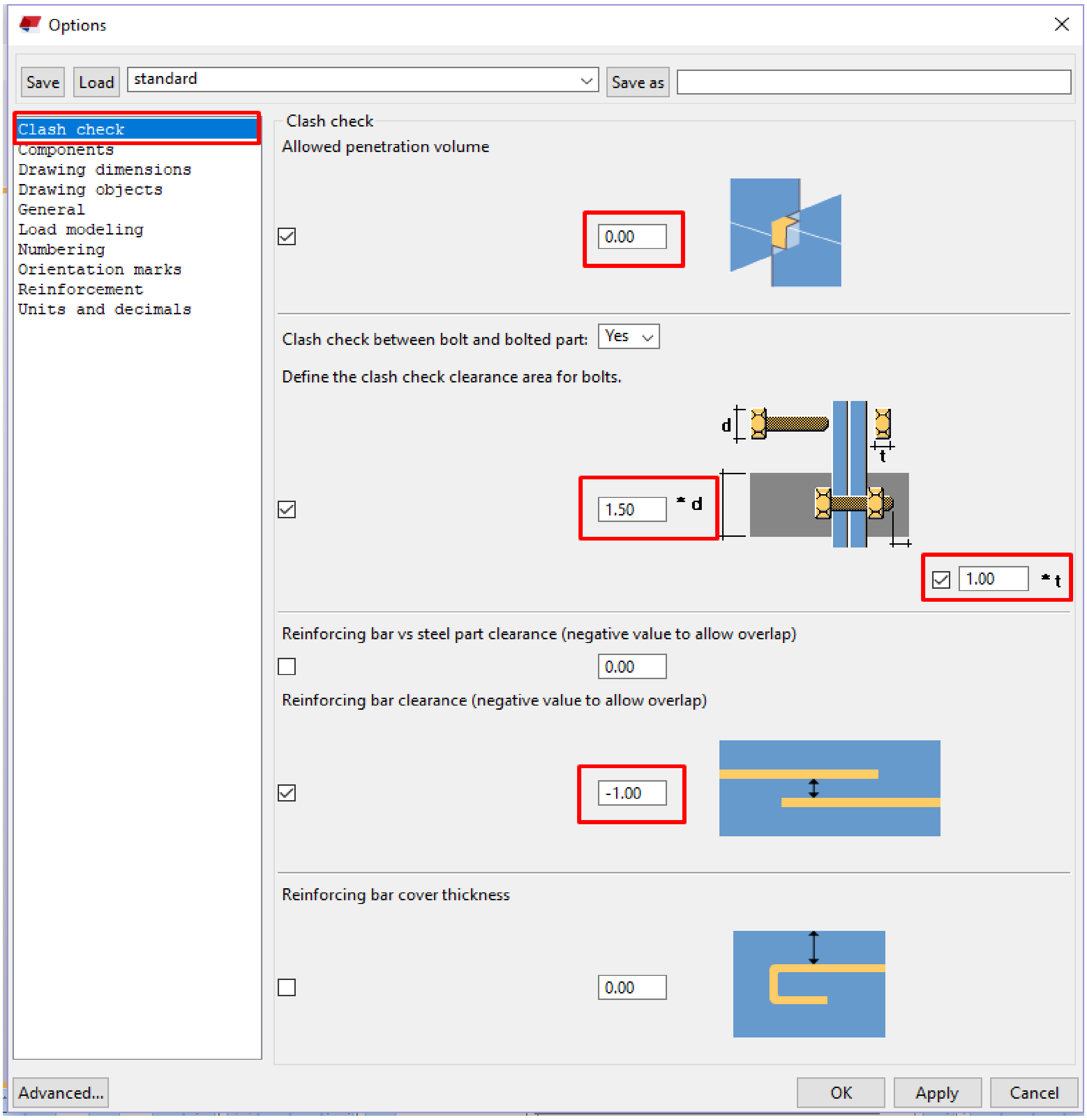


*Figure 5.35: Default settings for clash checks in TSL.*

Additionally, we used the following dialog boxes that appear in figures below, to set out necessary settings for units and decimals, which are applicable and implementable in accordance with Eurocodes. This was done using "options" for modeling and catalogs in TSL, as shown in Figure 5.36 and Figure 5.37, respectively.

`

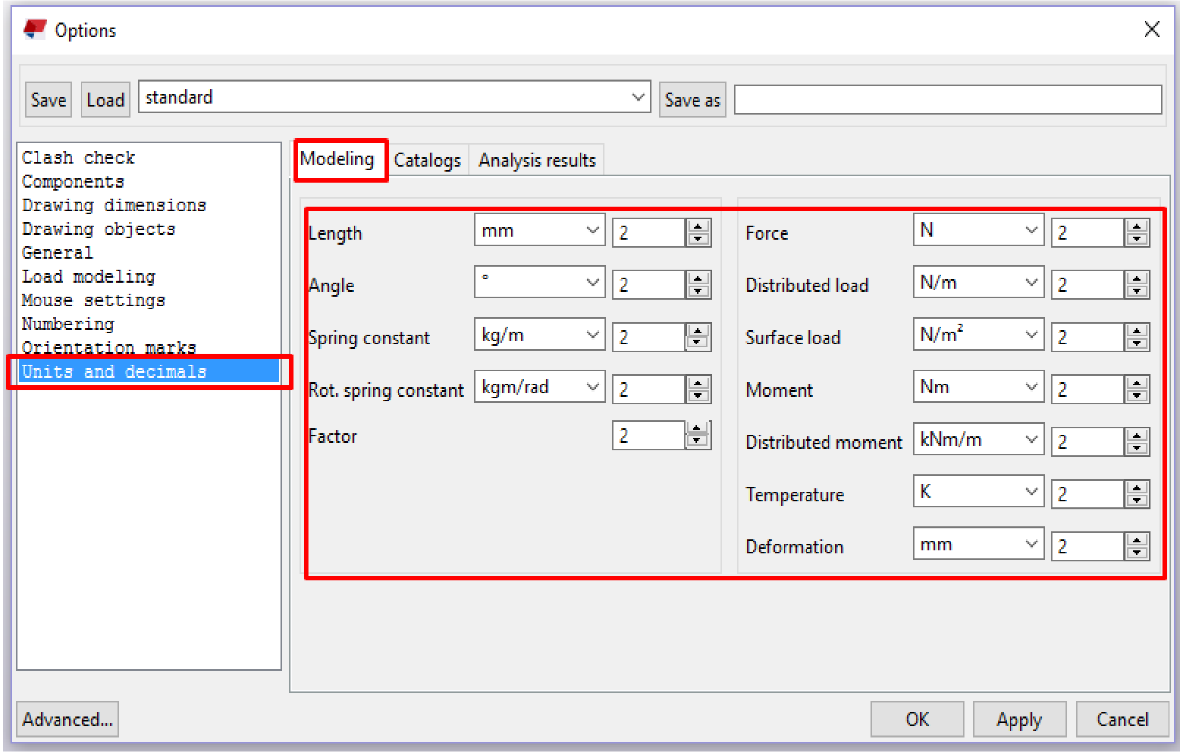


*Figure 5.36: Units and decimals settings for modeling purposes.*

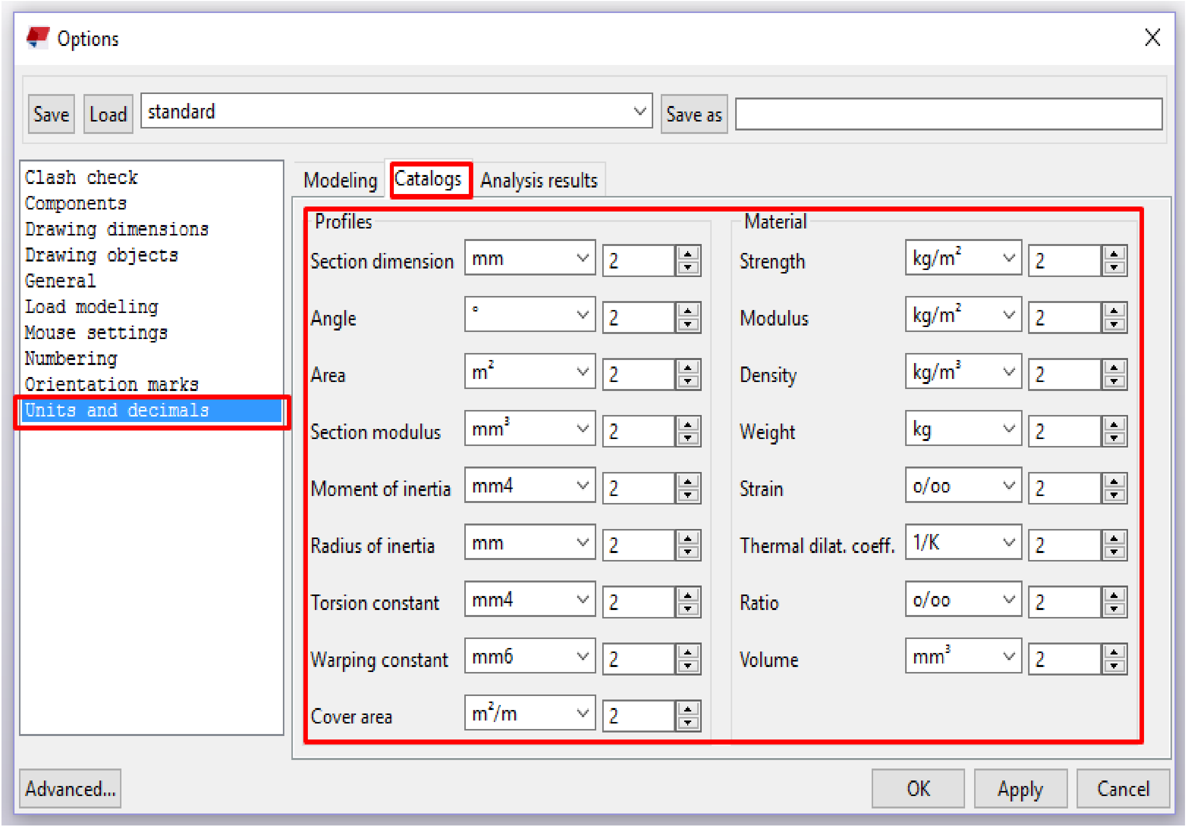


*Figure 5.37: Units and decimals settings for catalogs.*

Finally, the most important settings regarding dimensioning in the case of preparing drawing types of this project have been underlined and shown in the following Figure 5.38. Since such settings have been required through different phases of this project, the procedure for creating and saving them as a new settings version such as ”Drilon settings”, for instance, has also been shown in Figure 5.38. Other dimension properties included in Figure 5.38 are left as default properties in TSL.

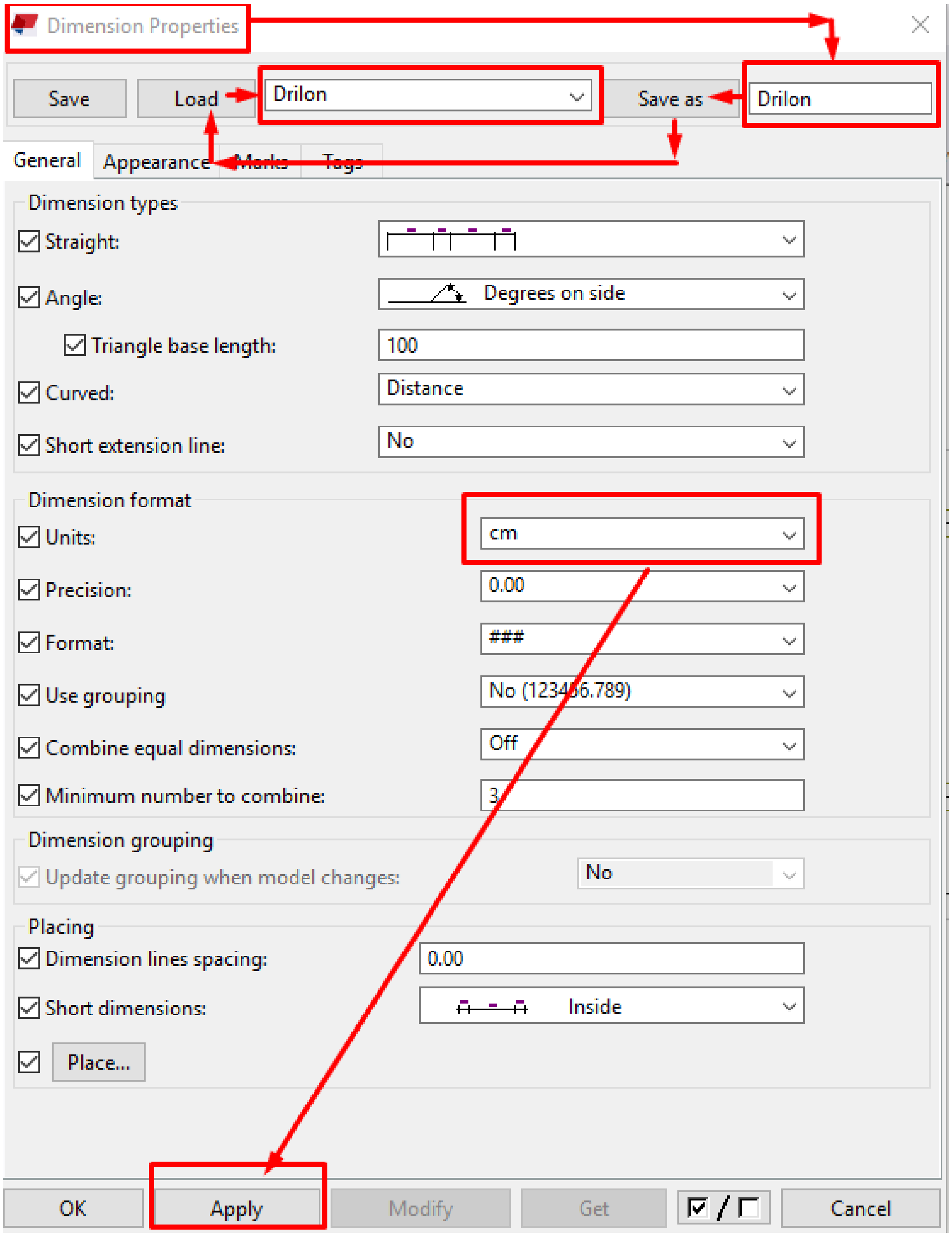


*Figure 5.38: Dimension properties settings in the case of creating drawings for this project.*

`

### *5.2.3* Importing CAD files as reference models

Tekla Structures Learning offers tools that we were able to use in case of importing reference models including the information they contained. In this case, we could import 2-D CAD architectural drawings of Mall project, prepared by (Gravitas d.o.o, 2017). Thus, we could use those reference models as a layout to directly build the model on.

In general, according to (Tekla, 2017), the following file types are supported in TSL as reference models:

- AutoCAD files.dxf,
- AutoCAD files.dwg (supported version ACAD2014 and earlier),
- Cadmatic files.3dd,
- IFC files.ifc, .ifczip, .ifcxml,
- IGES files.igs, .iges,
- LandXML files.xml,
- MicroStation files.dgn, .prp,
- PDF files.pdf,
- Tekla Collaboration files.tczip,
- SketchUp files.skp (supported version SketchUp 2016 and earlier),
- STEP files.stp, .STEP.

Basically, this section involves importing of existing CAD data, respectively 2-D CAD architectural drawings. To do this, we have imported CAD file first using the Insert tab Reference Model command in TSL. This brought up the Import CAD Formats (Reference Models) dialog box, which allowed us to browse a saved CAD file and then we used it as a reference model in TSL (Figure 5.39).

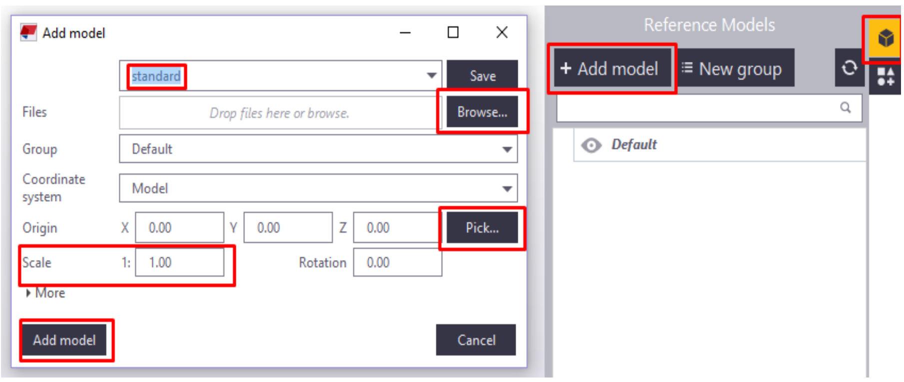


*Figure 5.39: Importing CAD files to Tekla Structures dialog box.*

In addition, imported 2-D CAD architectural drawings as reference models, have been shown in Figure 5.40 and Figure 5.41, respectively. These figures include planar and section view drawings.

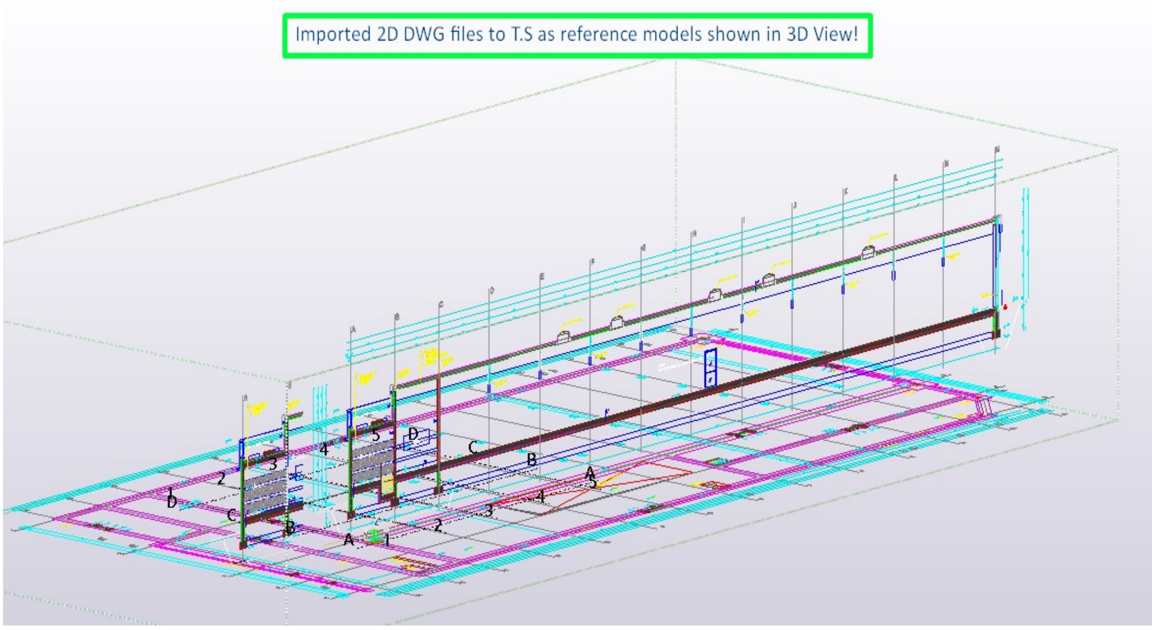


*Figure 5.40: Imported 2-D DWG Mall project files to TSL as Reference Model (3D View).*

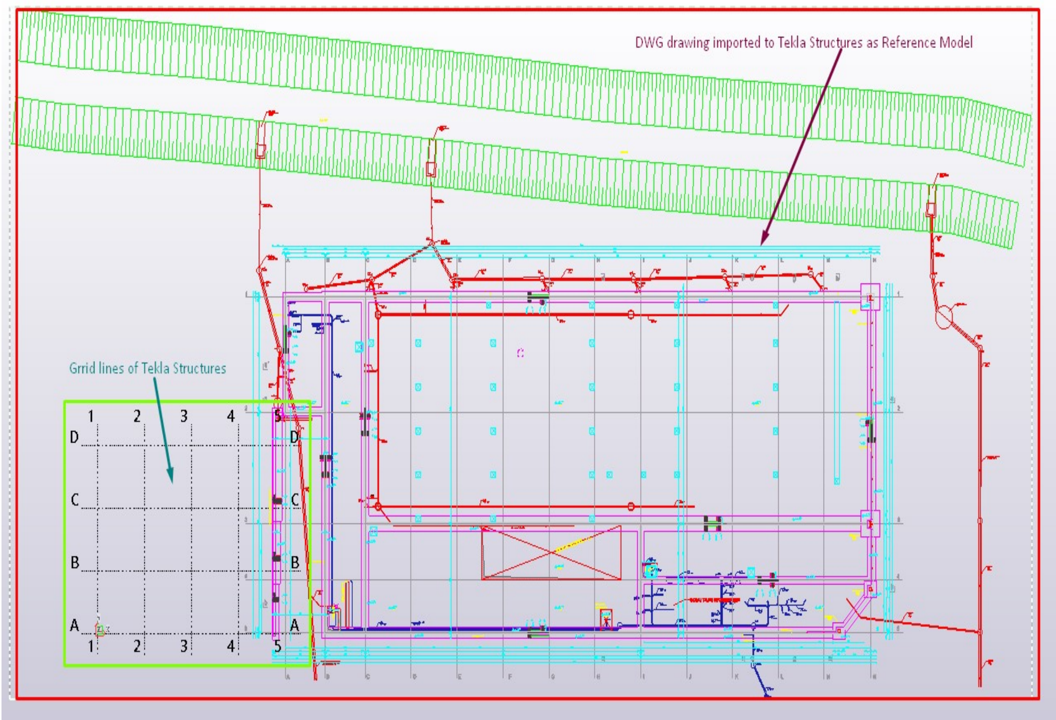


*Figure 5.41: DWG foundation drawing imported to Tekla Structures as Reference Model (Basic View).*

`

The entire BIM model of the Mall project modeled with the help of 2D CAD architectural drawings has been shown in Figure 5.42.

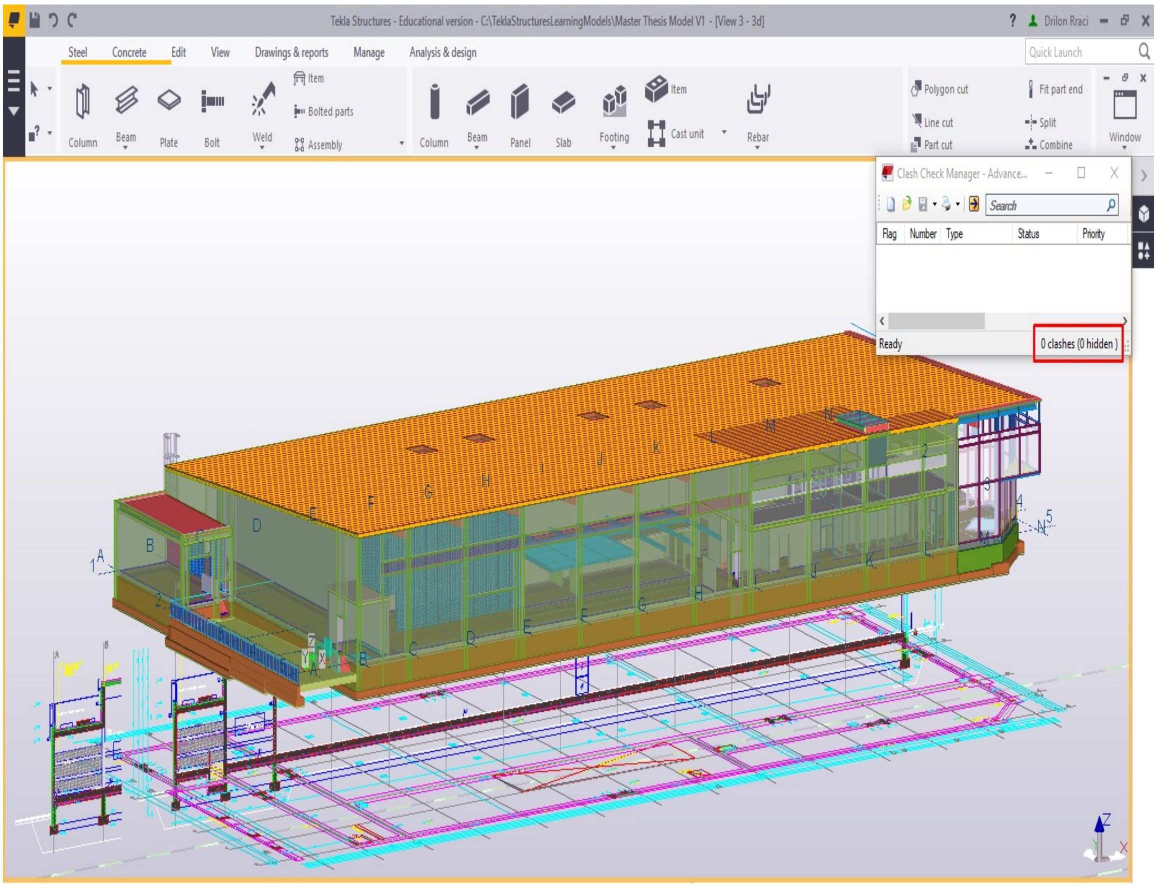

*Figure 5.42: Overlaying DWG Mall project modeled in TSL.*

In addition, according to (Tekla, 2017), limitations while importing DWG profiles to TSL, are listed below:

- The profile must be the only object in the DWG file. The file must not contain any titles, blocks or any other graphics,
- It is preferable for the profile to be a closed polyline,
- The profile needs to be scaled up,
- The DWG files imported with the DWG tool do not show the surfaces of the imported objects, only the construction lines or lines converted to part profiles that can be used to create a model. For instance, while we wanted to show the surfaces of the objects, we had to import DWG files as reference models.

### 5.2.4 Tekla Warehouse

Tekla Warehouse represents a free Tekla Structures BIM storage. It is very useful for the following purposes: find, import, install, and share products and applications internally and globally. Basically, it is an efficient store that produces high-quality models. In the case of libraries of BIM elements, each BIM platform has various libraries of predefined objects that can be imported for use (Tekla, 2017).

Tekla Warehouse offers applications, custom components, parts, profiles, materials like steel and concrete grades, bolts, rebars, mesh, shapes, and templates which can be used in Tekla Structures. Tekla Warehouse shows a centralized access to this content that can now be taken into use in a streamlined way. The content in Tekla Warehouse is time by time increasing (Tekla, 2017).

According to (Tekla, 2017), manufacturers can create their products and applications available for being utilized. Thus, we could take the exact 3D product models straight into our TSL model. Figure 5.43 shows the general opportunities that this tool offers for worldwide costumers and Tekla BIM software users.

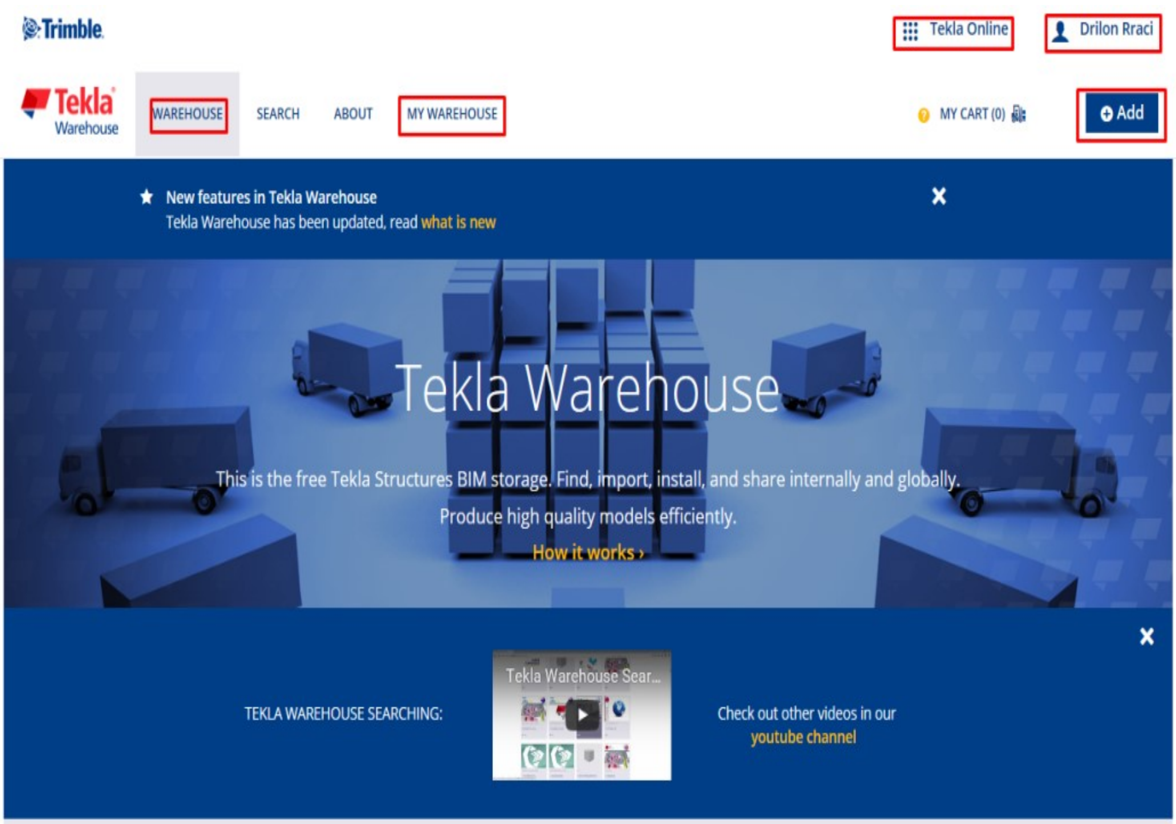


*Figure 5.43: Tekla online service - Tekla Warehouse.*

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Using Tekla Warehouse made us finding approximately what we needed easy regardless the content type we had to input in BIM model of the Mall project. This has been illustrated in Figure 5.44. Profiles shown in Figure 5.44, were used in the case of modeling aluminium and glass elements of the project.

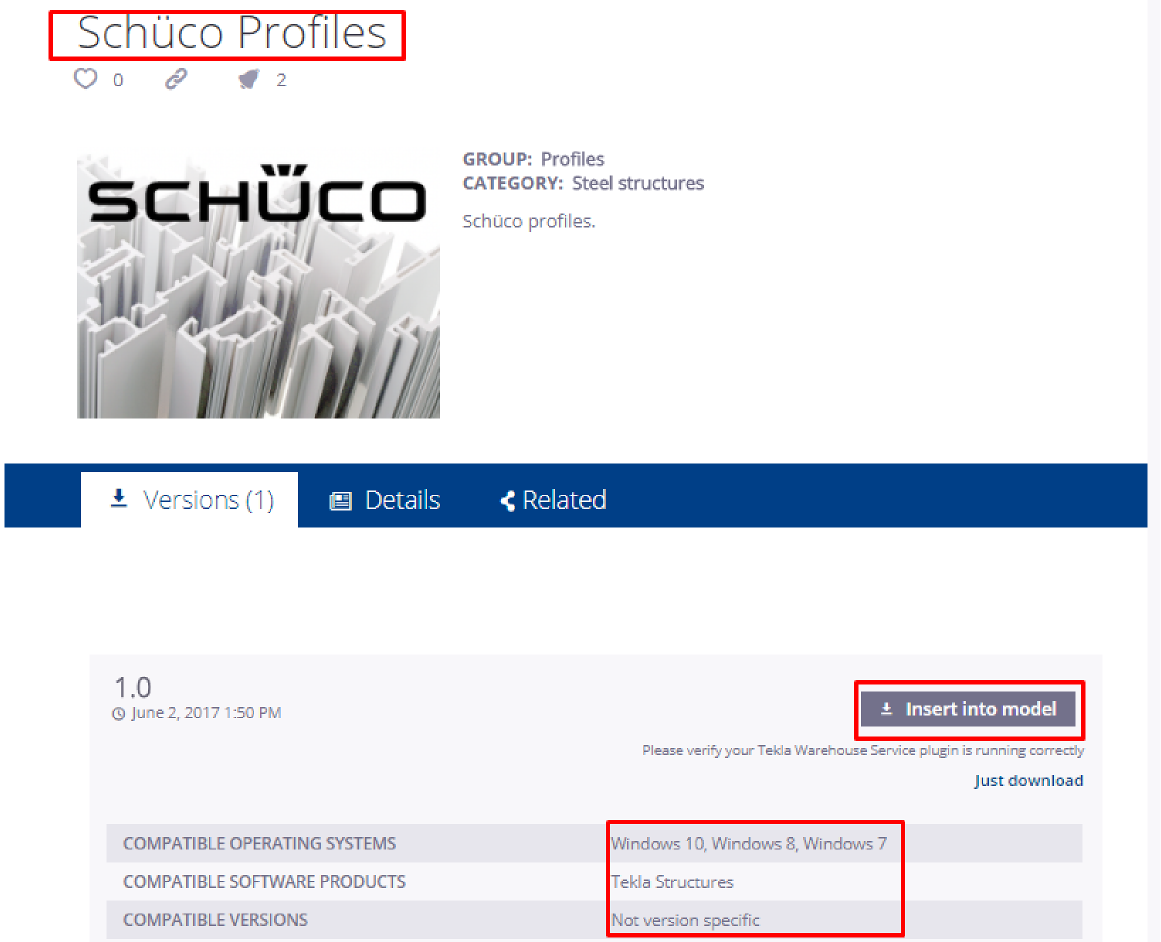


*Figure 5.44: Schüco Profiles used in the case of modeling steel/aluminum profiles in Tekla Structures.*

However, it is interesting to mention that Tekla Warehouse has some limitations in the case of using some applications available online, since those require a valid license as a customer user, to be able to download them. Examples of such cases are shown in Figure 5.45 and Figure 5.46, while we tried to download the following applications which could have allowed us to model glass unit surfaces directly in Tekla Structures, respectively to publish the thesis project to 3D PDF.

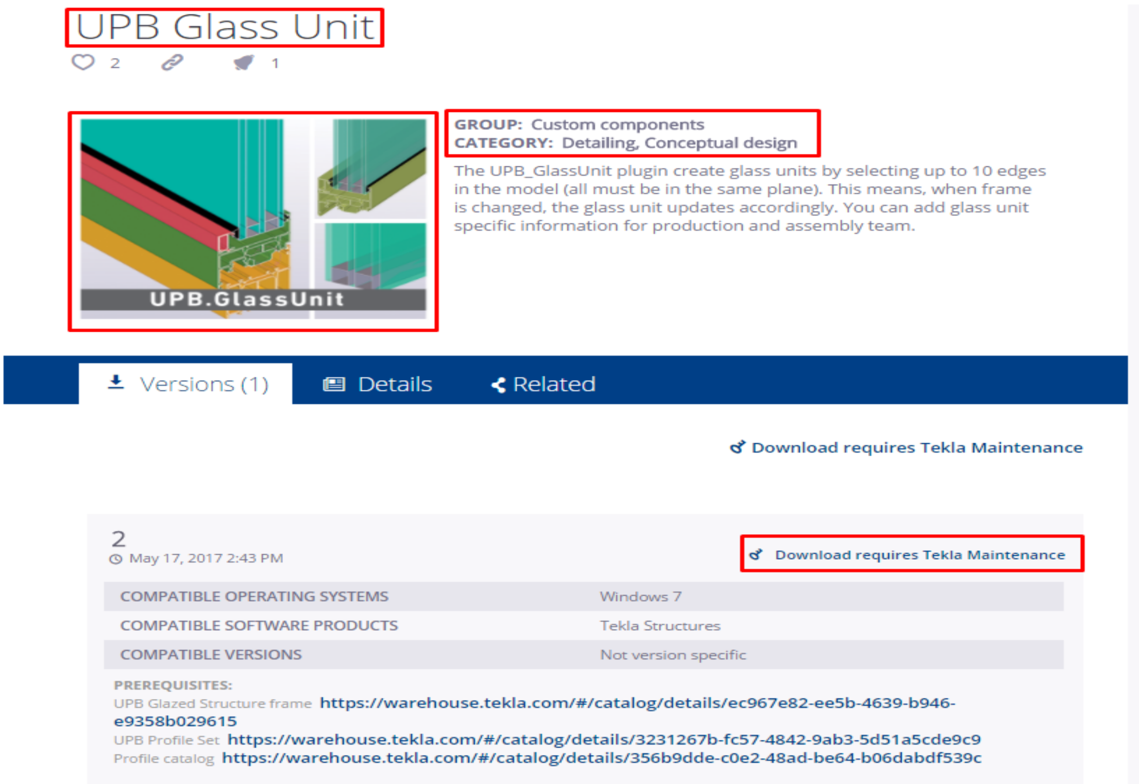


*Figure 5.45: UPB Glass Unit application for modeling aluminum and glass profiles in TSL.*

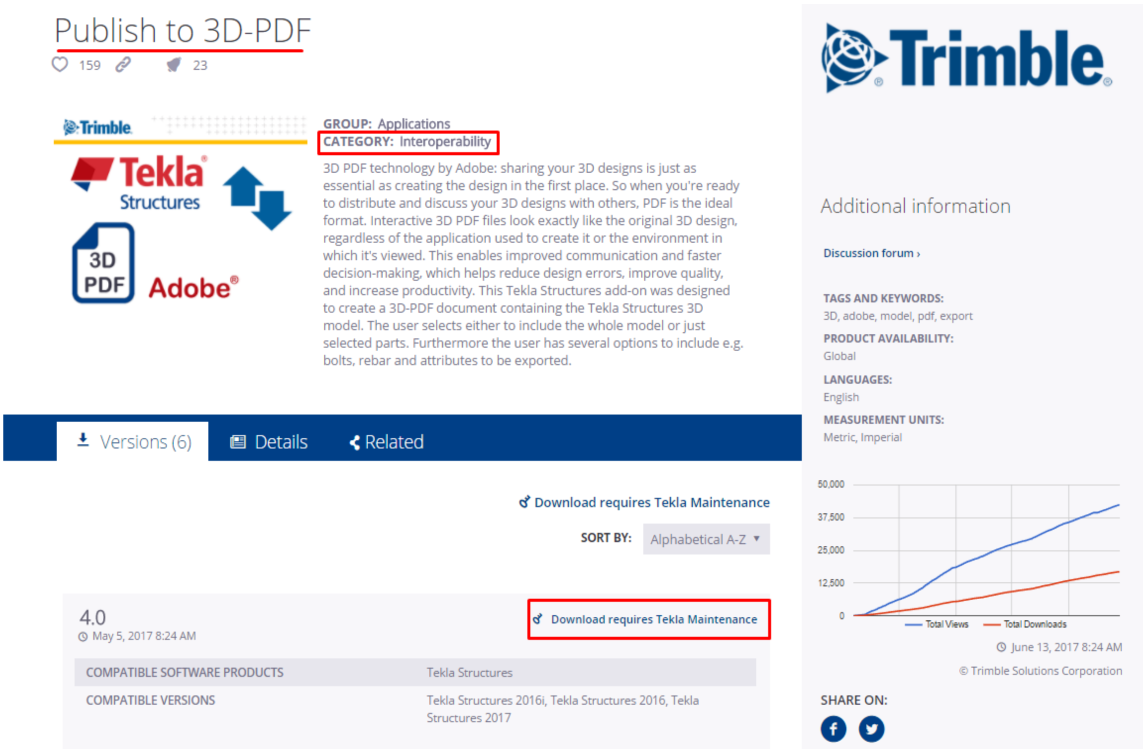


*Figure 5.46: Tekla Warehouse Application for publishing BIM model to 3D PDF.*

## 5.3 Creating Drawings

Since documents are still required in a construction site and manufacturing processes, drawings play a very important role in the construction industry. Thus, it is always necessary to create drawings that contain detailed information. Using TSL, it is possible to create drawings one by one, in groups, or generate all drawings automatically.

### 5.3.1 Drawing types

First, to create a drawing in TSL, the path: Drawing and Reports >Create Drawings >Any Drawing Type is followed (Figure 5.47).

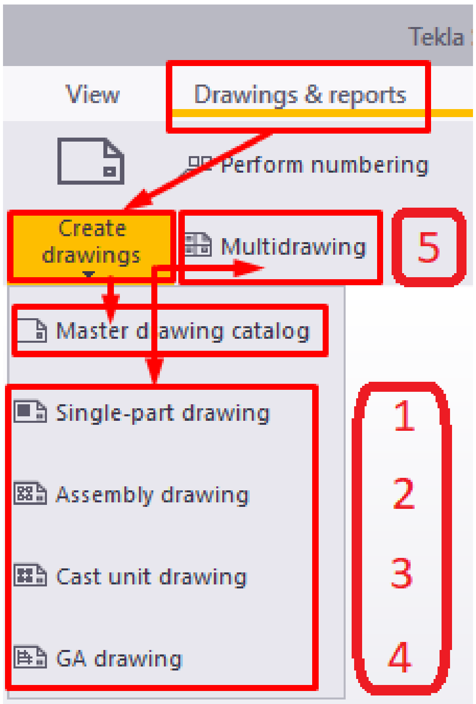


*Figure 5.47: The procedure for creating a drawing in TSL.*

Referring to Figure 5.47, many types of drawings could be created in TSL, which are listed and described below:

1. **Single-part drawings:** These drawing types are known as workshop drawings that represent the fabrication information for one part (usually without welds). Single-part drawings are usually prepared in small paper sizes, for example, A4. An example of a single-part drawing is shown in Appendices, Section 10.3.2.

2. **Assembly drawings:** Similarly to single-part drawings, assembly drawings also represent workshop drawings that show the fabrication information for one assembly. Usually, an assembly consists of the main part and secondary parts. Thus, the secondary parts are connected to the main part by either welded or bolted. These types of drawings are usually prepared in larger sheet sizes than previous drawing types, for instance, A3. An assembly drawing example is shown in Appendices, Section 10.3.3.
3. **Cast unit drawings:** Cast unit drawings are considered as dimensional, formwork, or reinforcement drawings. In most cases, these drawing types are used in concrete design and construction. They usually show the edge chamfers and hard or soft insulation information.

   Cast unit drawings that are created to represent cast-in-place concrete structures are usually prepared in large sheet sizes, such as A1, while those created to show precast structures are usually prepared to A3 paper size. An example of a cast unit drawing is shown in Appendices, Section 10.3.4.
4. **General arrangement drawings:** Usually a GA drawing represents a contract document, which contains information that is necessary to understand the general arrangement structural elements of a project. According to (Tekla, 2017), a GA drawing is created in BIM workflows from one or more model views, with associated schedules, and on a project title sheet.

   Often, GA drawings contain enlarged views of complex areas or details, and additional information that can be useful in the approval process and during the installation phase. GA drawings are usually prepared in large sheet sizes, such as A1 or A0. An example of a GA drawing is shown in Appendices, Section 10.3.1.
5. **Multidrawings:** Like single-part and assembly drawings, these drawing types are also considered as workshop drawings. Multidrawings are usually used to combine several single-part or assembly drawings on one sheet. Thus, they usually require large sheet sizes, for example, A1 or A0.

   It is recommended to create multidrawings when one or more assembly drawings appear on a sheet, and when a collection of multiple single-part drawings on a large sheet is needed. A multidrawing example is shown in Appendices, Section 10.3.5.

`

## 5.4 Visualization of the Mall Project

One of the most obvious uses of a BIM model (Mall project model), is the use of the project as a visualization tool. Comparing to traditional drawings, 3D visualization of the project helped us to better understand the details of the design and its general concept. 3D visualization is still being considered one of the most important parts of the project, making design processes and construction tasks easier to understand especially for people who have less knowledge or are not familiar with this field. Planning how to construct complex details of the Mall Project is considered much easier using a 3D view, which could be manipulated and cross-sectioned in multiple directions. Examples of 3D visualization details created in the case of a Mall project in TSL are shown in Figure 5.48 and Figure 5.49, respectively.

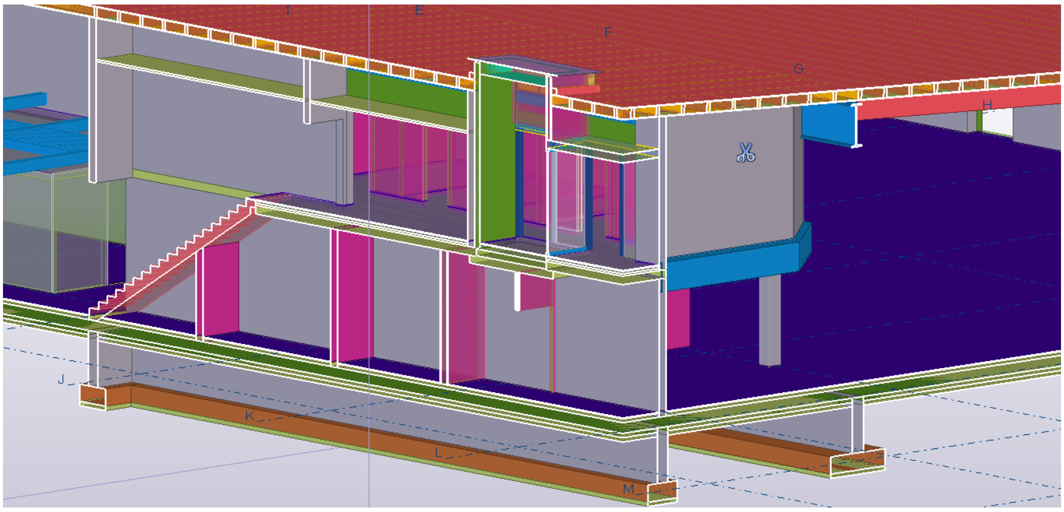

*Figure 5.48: Render of section view details of the Mall project.*

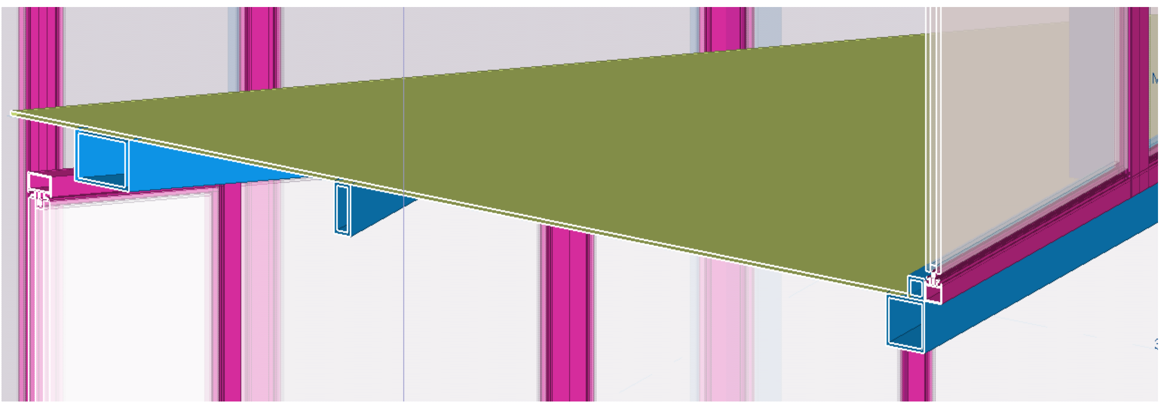

*Figure 5.49: 3D visualization details of the entrance elements of the Mall project.*

# 6 INTEROPERABILITY BETWEEN TEKLA STRUCTURES LEARNING AND RFEM

This section describes the general process of data exchange between BIM and FEM software. The following softwares that were chosen for this project: Tekla Structures Learning as BIM modeling software and RFEM as FEM analysis software, represent the interoperability features and findings between BIM and FEM softwares. In addition, the data exchange methods included in Figure 6.4 that are used for various cases of this project, are described and discussed in detail in this section.

## 6.1 Physical and analytical models

The analytical model of the structure is a simplified three-dimensional (3D) representation of the full physical description of a structural model; all structural elements are connected to each other continuously. An analytical model is known also as the ”stick model”. The analytical model consists of those structural elements, geometry, material properties, nodal restraints, external supports, and loads that together create a model for structural design. Analytical models use the simplified assumptions, such as for connecting members (hinged or rigid). It is important to emphasize that only analytical models of the structure can be analyzed and not the real structure (Nawari and Kuenstle, 2015).

In the physical model, every structural element such as beam, column, slab, wall, etc., must be supported with a point support. In other words, a supporting member must have a point intersection with a supported member (Nawari and Kuenstle, 2015).

### 6.1.1 Creating analytical models in Tekla Structures Learning

Once we have created a physical model that can be used to analysis and design tools, we could automatically use it to create various types of analytical models in TSL.

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However, before creating a new analytical model, it is always recommended to check out the analysis properties of each structural element, because sometimes some of the properties are required to be manually set up. This process could be done by clicking “Part and analysis properties” icon on the main toolbar in TSL (Figure 6.1). In other words, this is considered a very important step before creating analytical models, since not every process of the project could be implemented in an automated way in TSL.

Secondly, to create an analytical model, the path: Analysis & design>A&D models>Create new models is followed. This procedure has been shown in Figure 6.1.

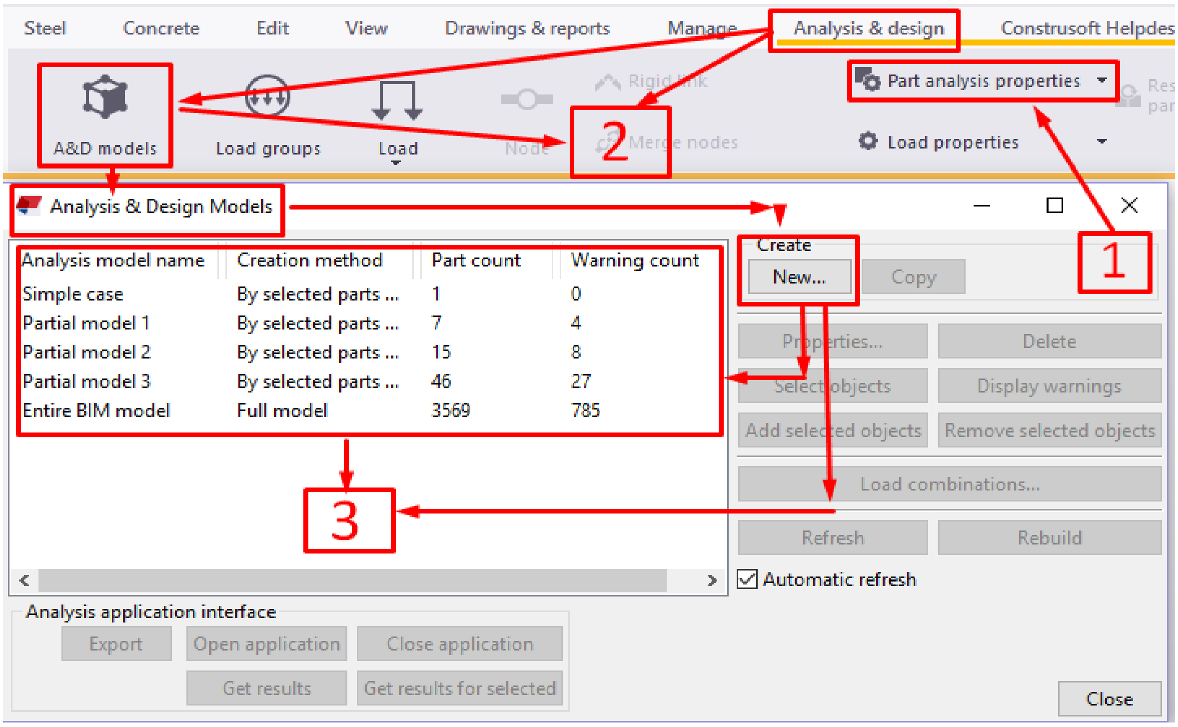


*Figure 6.1: Procedure for creating an analytical model in TSL.*

While creating a new analytical model, numerous of analysis properties appeared in the dialog box as shown in Figure 6.2. It was not necessary to take all of them into account. Therefore, the most important properties that are considered in the case of this project are underlined and shown in Figure 6.2. Other properties included in this dialog box, are mostly related to structural analysis and design of relevant model cases. Since Tekla BIM software is not considered in the case of performing structural analysis of this project, these properties were better left to be specified in Dlubal-Structural Engineering Software for Analysis and Design.

Three creation methods exist in the case of preparing an analytical model including: Full model, by selected parts and loads, floor model by selected parts and loads (Figure 6.2). The first two methods are considered the most common methods to create various analytical models. Thus, these two creation methods have also been considered in the case of this project, which are included in the third stage of creating analytical models and can be seen in Figure 6.2.

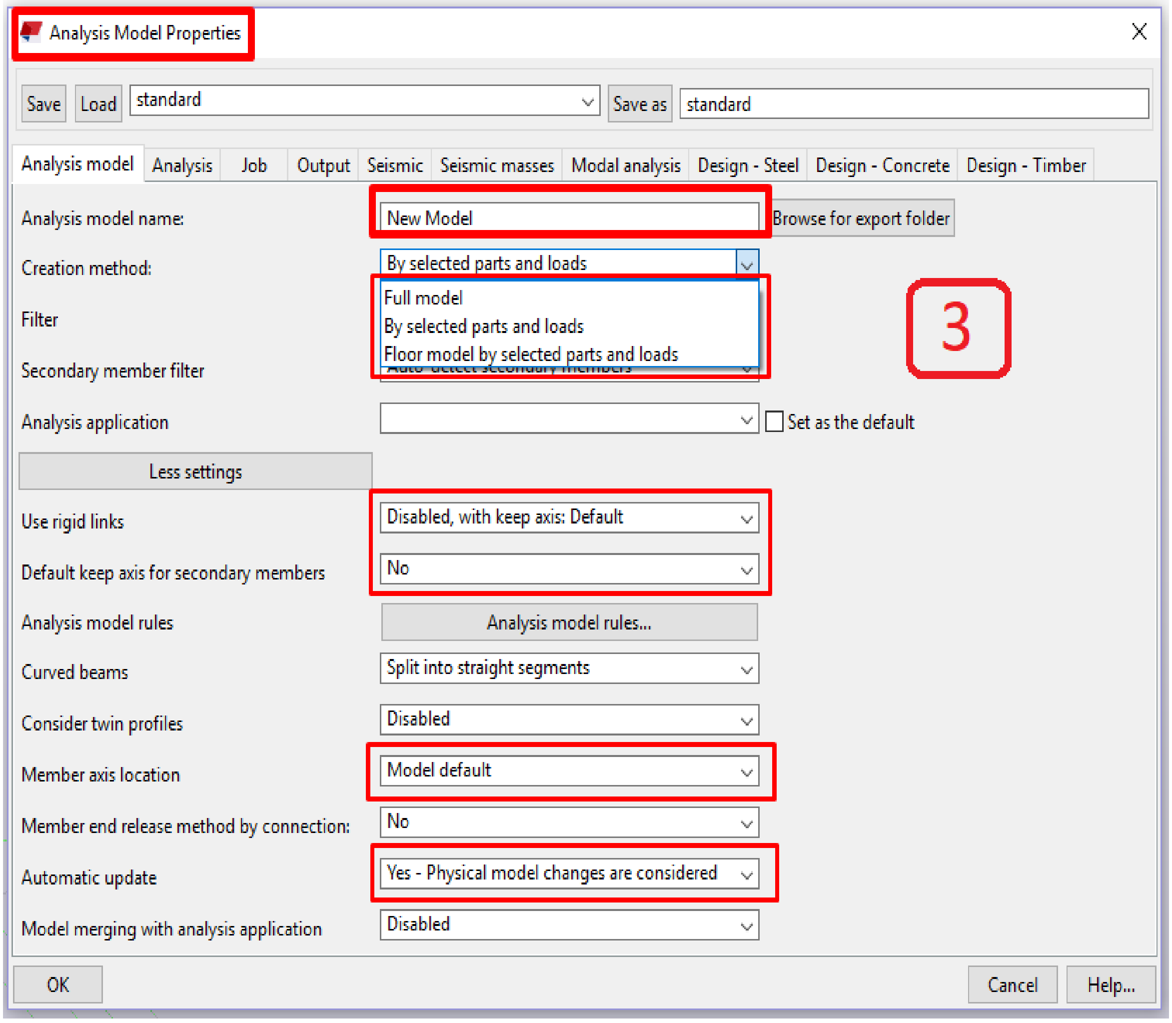


*Figure 6.2: Analysis Model Properties in the case of a Mall project.*

The relationship between a physical and corresponding analytical partial model in the case of a Mall project has been shown in Figure 6.3. Thus, Figure 6.3 (left side) shows the physical partial model, while Figure 6.3 (right side) represents the corresponding analytical partial model of this project. More detailed information for this partial model of the Mall project has been further presented in Section 6.4.3.

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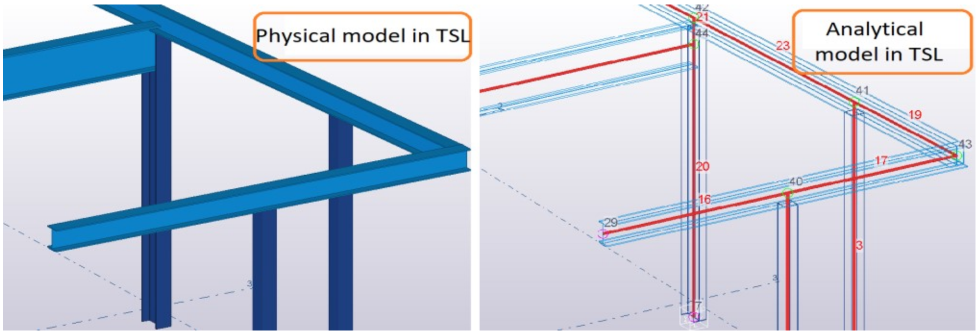


*Figure 6.3: Relationship between physical (left side) and analytical (right side) partial model of the Mall project.*

## 6.2 Data exchange methods

Since all adequate building data is included in a 3D model, it is not necessary to use different models created in various BIM and structural analysis software, but the same model, which can be directly exchanged and or transferred between the programs. While planning a building or a construction, there are usually not the same individual models used for BIM and structural analysis. These models sometimes may cause planning and transfer errors. Therefore, they require more effort. Thus, integrated interfaces between RFEM and Tekla Structures Learning, while both use the 64bit operating system, prevent such problems. This collaboration between BIM and structural analysis provides efficient and reliable planning. Based on this, the bidirectional data exchange between RFEM and the Tekla BIM software is possible (Dlubal, 2017).

According to (Dlubal, 2017), three main options for data exchange between Dlubal-RFEM and Tekla Structures software exist, which are described as follows:

- The STP (see Table 3.1) interface allows for a file-based transfer of framework models in both directions,
- The analytical model which is generated and contained in Tekla Structures can be transferred to RFEM using another direct interface,
- Finally, a further direct interface is provided to exchange and adjust physical models in both directions.

The main options considered as general exchanging methods for transferring a model from BIM to FEM software, relevant to this project are presented in Figure 6.4.

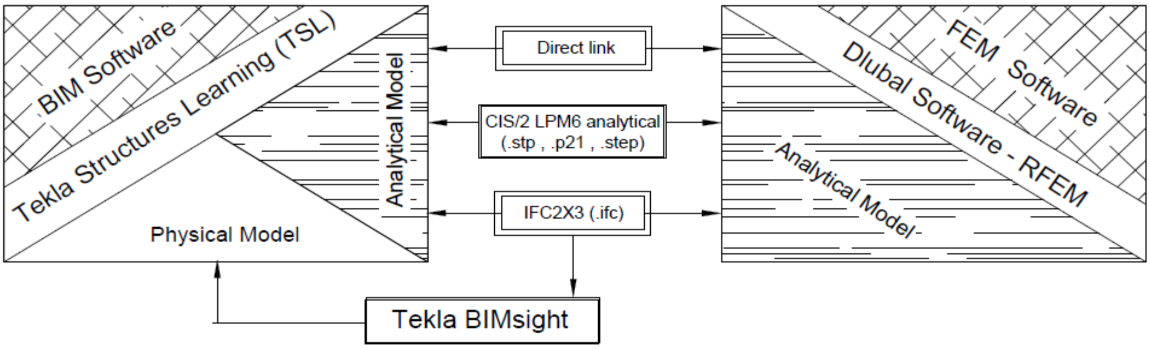


*Figure 6.4: Data exchange methods between BIM and FEM software.*

In addition, the IFC format could be opened with the Tekla BIMsight to view the model and detect eventual errors, which is elaborated previously in Section 4.1.3.

### 6.2.1 Tekla Structures Learning– RFEM direct link

The process of data exchange based on the »direct link« exchange method has been presented in Figure 6.5.

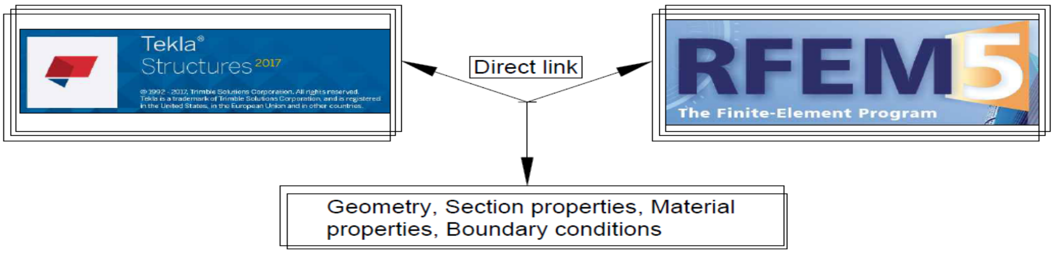


*Figure 6.5: Data exchange between Tekla Structures Learning and RFEM using the direct link.*

The direct link between Tekla Structures Learning and RFEM represent a practical method to exchange data and very easy to use. In the case of this project, the data exchange process has been initiated in Tekla Structures Learning.

To implement this process both software applications have been installed on the same computer and running simultaneously. However, to import a model created in TSL to RFEM, the path: File>Import>Tekla Structures or the process by clicking the "Direct import from Tekla Structures" icon in the main Toolbar of RFEM program could be followed. This procedure is shown in Figure 6.6.

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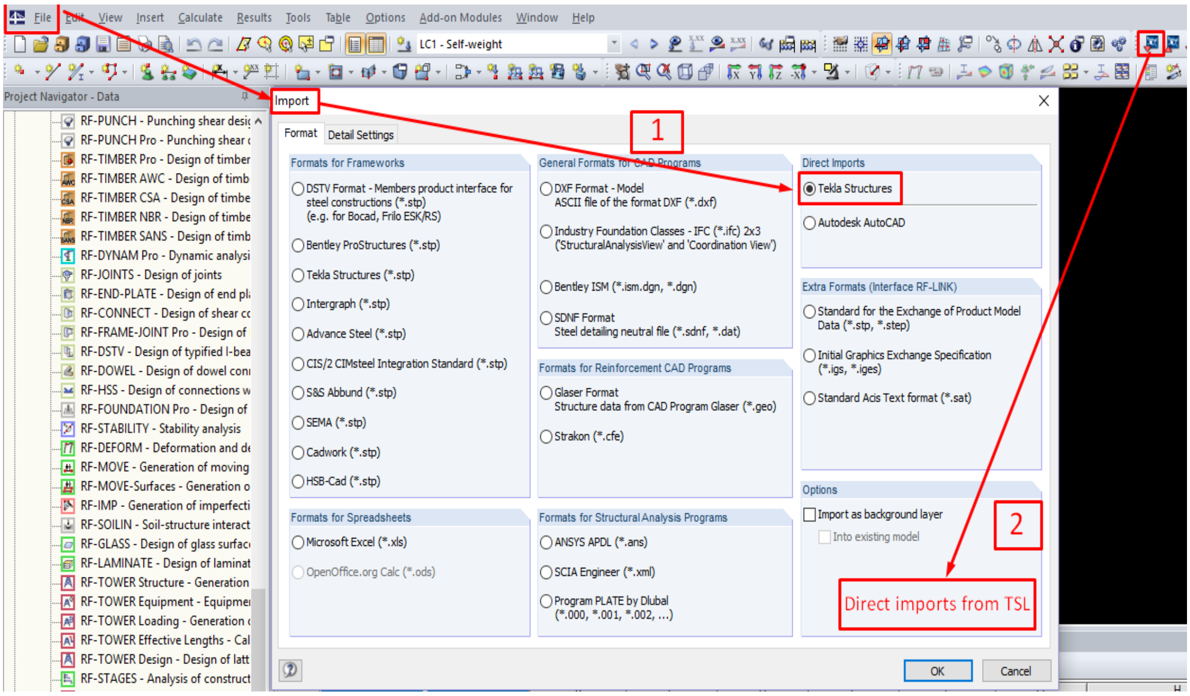


*Figure 6.6: Importing models from TSL to RFEM.*

The following dialog box appeared as shown in Figure 6.7.

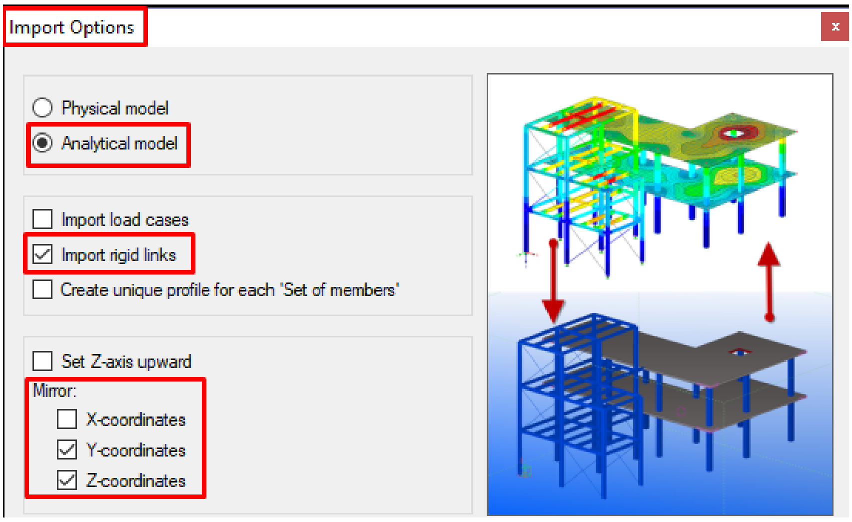


*Figure 6.7: Import options dialog box in RFEM program.*

Both structural data and load data can be transferred while taking this exchange method into account. Referring to Figure 6.7, only the structural data have been exchanged in this project which includes members, member types, lines, nodes, cross-sections, materials, nodal supports, eccentricities, rigid connection, etc.

### 6.2.2 DSTV data exchange file format

First, to import a DSTV[12] file (.stp) from TSL to RFEM, the path in TSL: Export>FEM>Tekla Structures Export FEM (S4) has been followed. A dialog box appears where the necessary parameters in the case of this project could be set out as shown in Figure 6.8. The DSTV file (*.stp) is automatically created as an output file in the main TSL folder where the relevant model has already been saved.

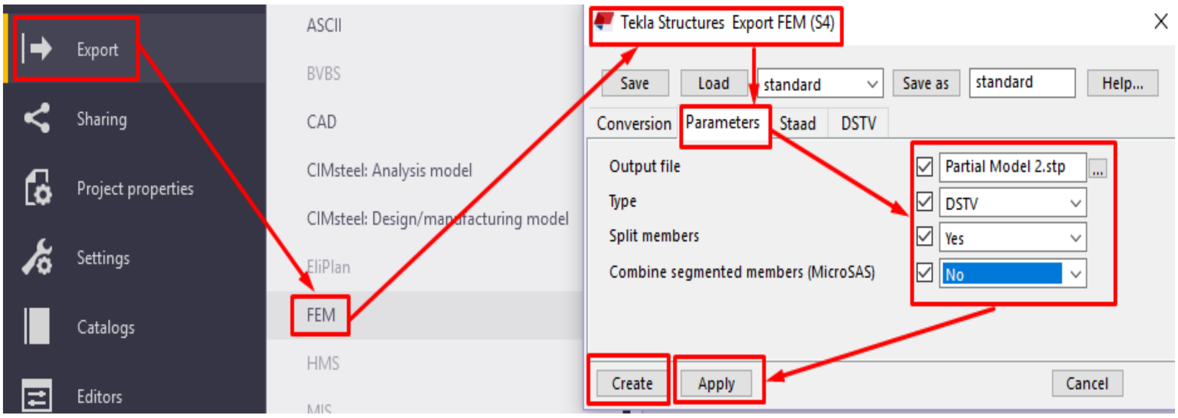


*Figure 6.8: Creation of a DSTV (*.stp) exchange file format in TSL.*

In addition, to import a (.stp) file in RFEM, the path: File>Import>Tekla Structures (*.stp) is followed (Figure 6.9).

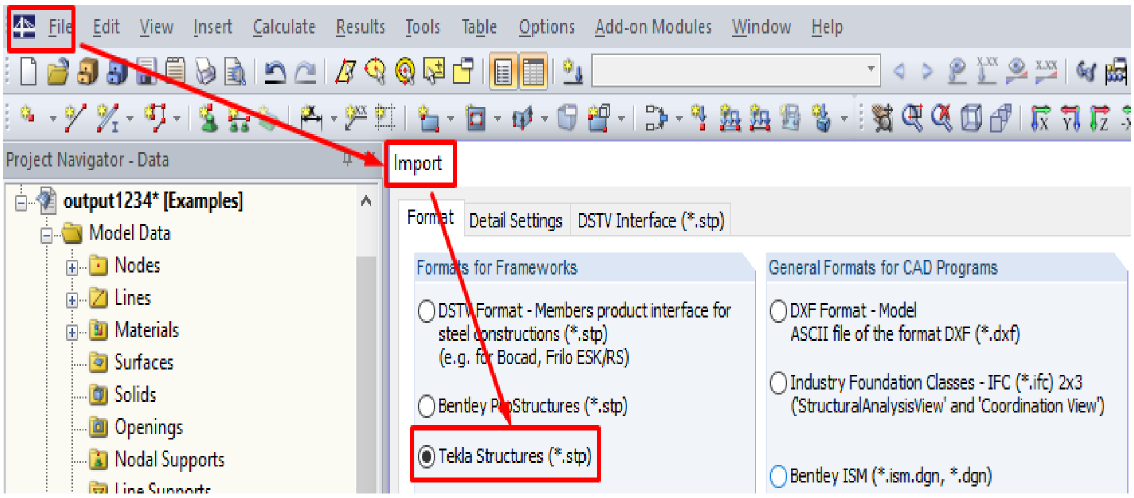


*Figure 6.9: Importing a DSTV file (*.stp) from TSL to RFEM.*

[12] DSTV (Deutscher STahlbau-Verband) manufacturing format is the standard format used for manufacturing steel components on numerically controlled (NC) machines. It also has an Analysis & Design format that is used for transferring Analysis & Design models to the physical 3D model (Tekla, 2017).

`

DSTV file (*.stp) is a data exchange file format mostly applicable for structural steel projects. It saves the data elements such as end points, material, cross sections, references, etc., as a standard DSTV file which could be used for importing and exporting models.

### 6.2.3 IFC data model exchange

Similarly as explained in the previous data exchange method, as a first step to import an IFC file from TSL to RFEM, the path in TSL: Export>IFC>Export to IFC is considered. The following dialog box appears as shown in Figure 6.10.

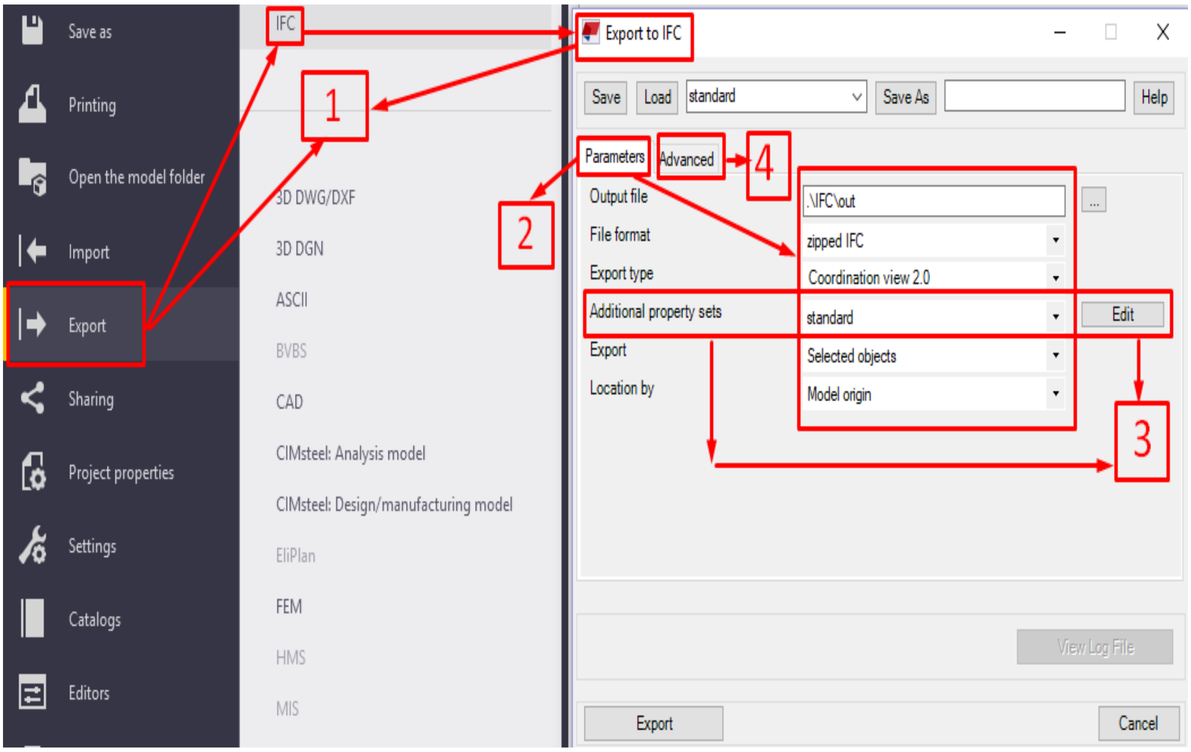


*Figure 6.10: Creating an output IFC file in TSL.*

Secondly, the necessary parameters could be set out in accordance with the requirements of this project. Four export types could be chosen which are presented in Figure 6.11.

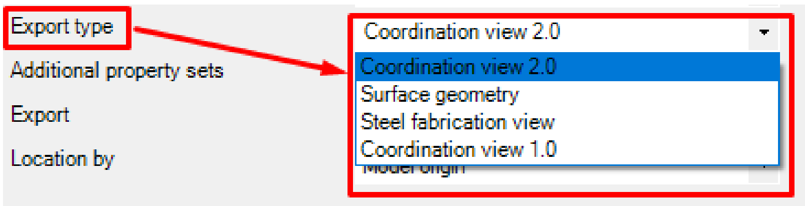


*Figure 6.11: Types of export using IFC data model exchange in TSL.*

The Coordination view (Coordination view 2.0) targets the coordination between the architectural, mechanical and structural engineering tasks during the design phase. It has been the first view definition developed by buildingSMART International and is currently the most implemented view of the IFC schema (buildingSMART, 2016).

Moreover, Coordination view 2.0 is considered as a compatible exchange format in TSL. Examples of exchanging data between BIM and FEM software using IFC "Coordination view 2.0" export type, are included in the following case studies which are elaborated further in Section 6.4.

In addition, surface geometry export type represent the format for viewing and clash checking, while the last two types of export could only be used for Tekla BIMsight and Tekla Structures.

Export of the existing model in TSL using IFC data model exchange could be either done by choosing "selected" or "all objects" of the model as shown in Figure 6.12.

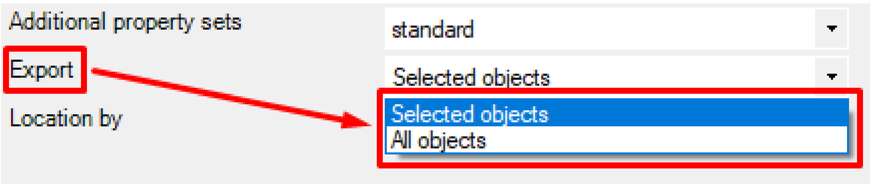


*Figure 6.12: Different ways of exporting files using IFC exchange format.*

In the third step of this process, "Additional property sets" parameter based on a standard XML data schema could be either left as default or modified using the following dialog box shown in Figure 6.13.

Furthermore, creation and or modification of properties in this dialog box are directly connected to UDA's of the relevant element of this project. Hence, additional information inserted to the "User fields" in the UDA's dialog box, followed by the creation of "new property sets" as shown in Figure 6.13, could be automatically seen in the model that is already published to Tekla BIMsight.

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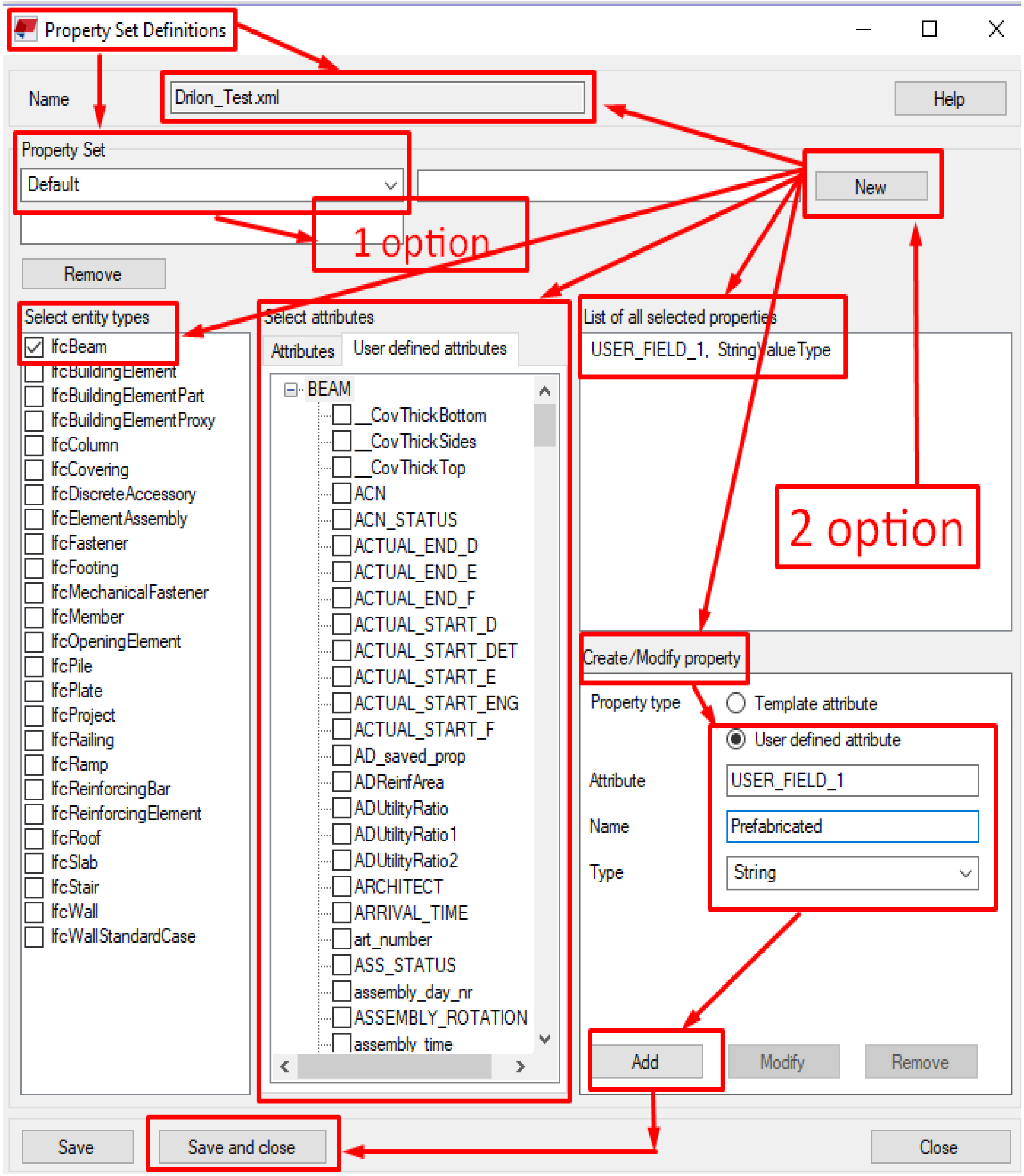


*Figure 6.13: Additional property sets dialog box in TSL.*

Finally, before exporting the model using an IFC file format, it is recommended to specify which object types of the model need to be exchanged between BIM and FEM software. These object types appear in the advanced settings dialog box and could be set up in accordance with the purposes of this project as shown in Figure 6.14.

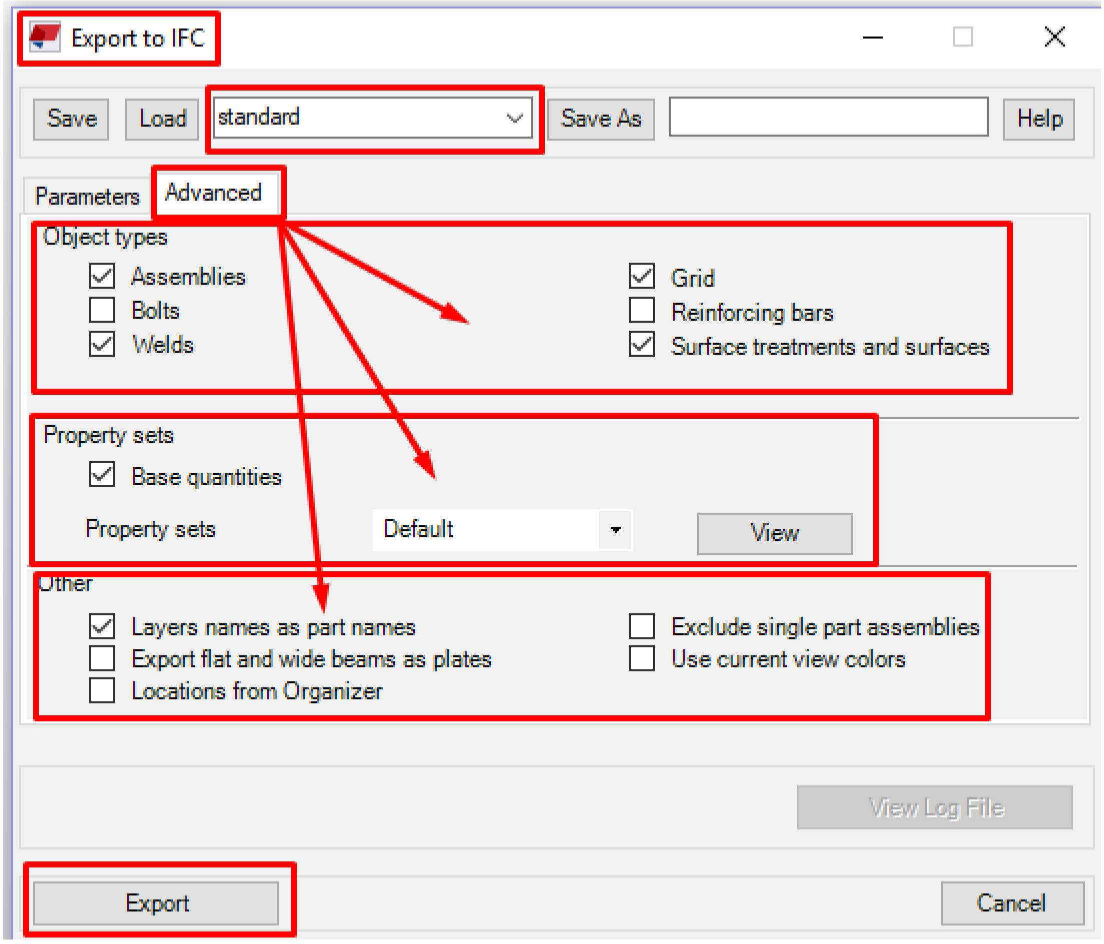


*Figure 6.14: Export to IFC-Advanced settings dialog box.*

## 6.3 Updating Tekla BIM model using direct interface from RFEM

When changes in structural planning are necessary, it is possible to use the direct interface to promptly update the Tekla model by adjusting the modified materials, coordinates, and cross-sections (Dlubal, 2017).

Hence, to reimport the model from RFEM to Tekla Structures Learning, two options could be used. The path in RFEM: File>Export>Tekla Structures or the process by clicking the “Direct export from Tekla Structures” tool in the main Toolbar of RFEM program could be followed. Both options are shown in Figure 6.6.

Moreover, the necessary requirement to implement this process is that both software applications must be running simultaneously.

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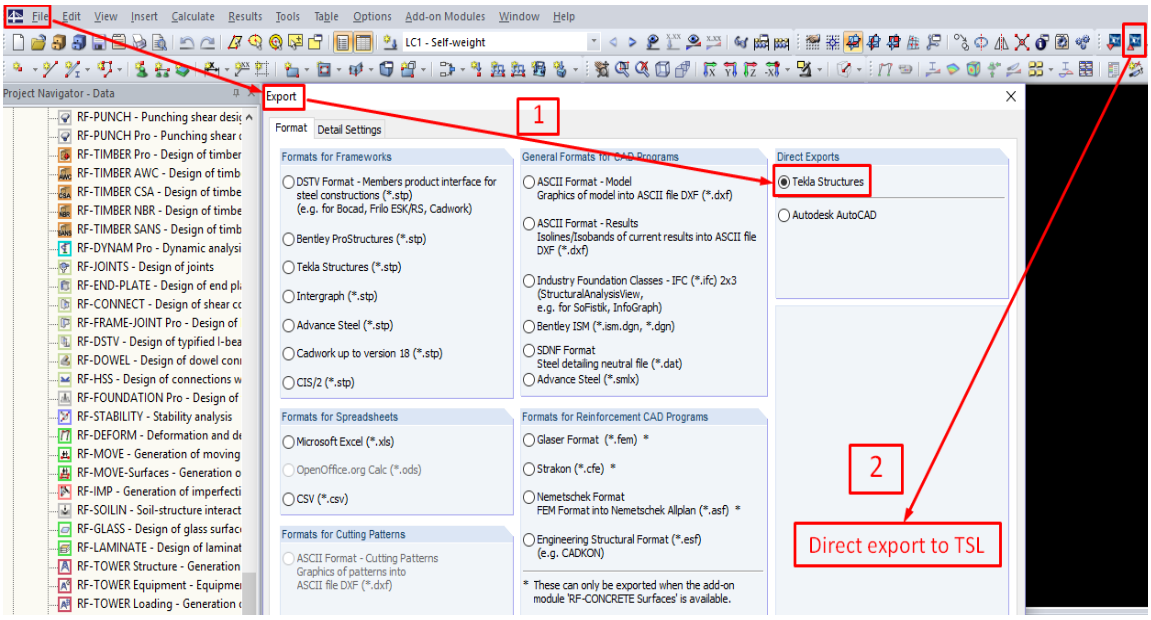


*Figure 6.15: Exporting models from RFEM to TSL.*

After following the path described before, the dialog box appears as shown in Figure 6.7. In addition, referring to Figure 6.16, different options to update an existing model in TSL are presented, including the option to export internal forces if those could be required to create further structural details of relevant structural elements in TSL.

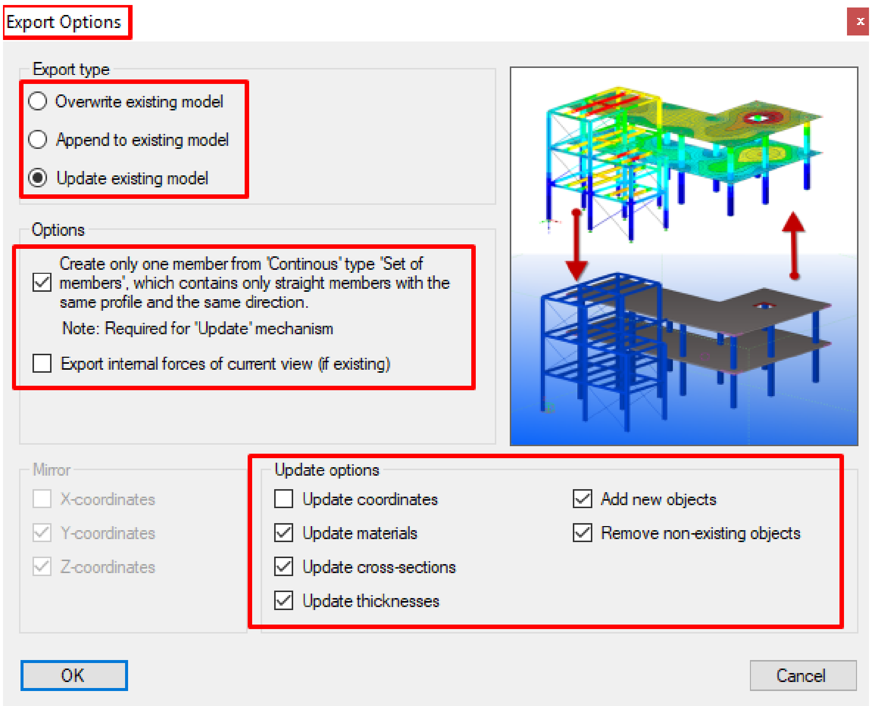


*Figure 6.16: Import options dialog box in RFEM program.*

## 6.4 Case studies based on the Mall project

Various case studies which provide data exchanges between TSL and RFEM in the case of a Mall project are presented in this section. The entire and partial models of the Mall project were examined to explore the basics of the data exchange and identify the methods that have the most potential.

### 6.4.1 Simple case – Concrete column

To provide interoperability and data exchange methods between TSL and RFEM, which are previously described, the first model was chosen to be a simple concrete column with the cross-section of (b/h=30/26cm) and the height of 3,55 m. The BIM model of this structural element, which includes information about the structural type, material and section properties, ifc entity, etc., is shown in Figure 6.17.

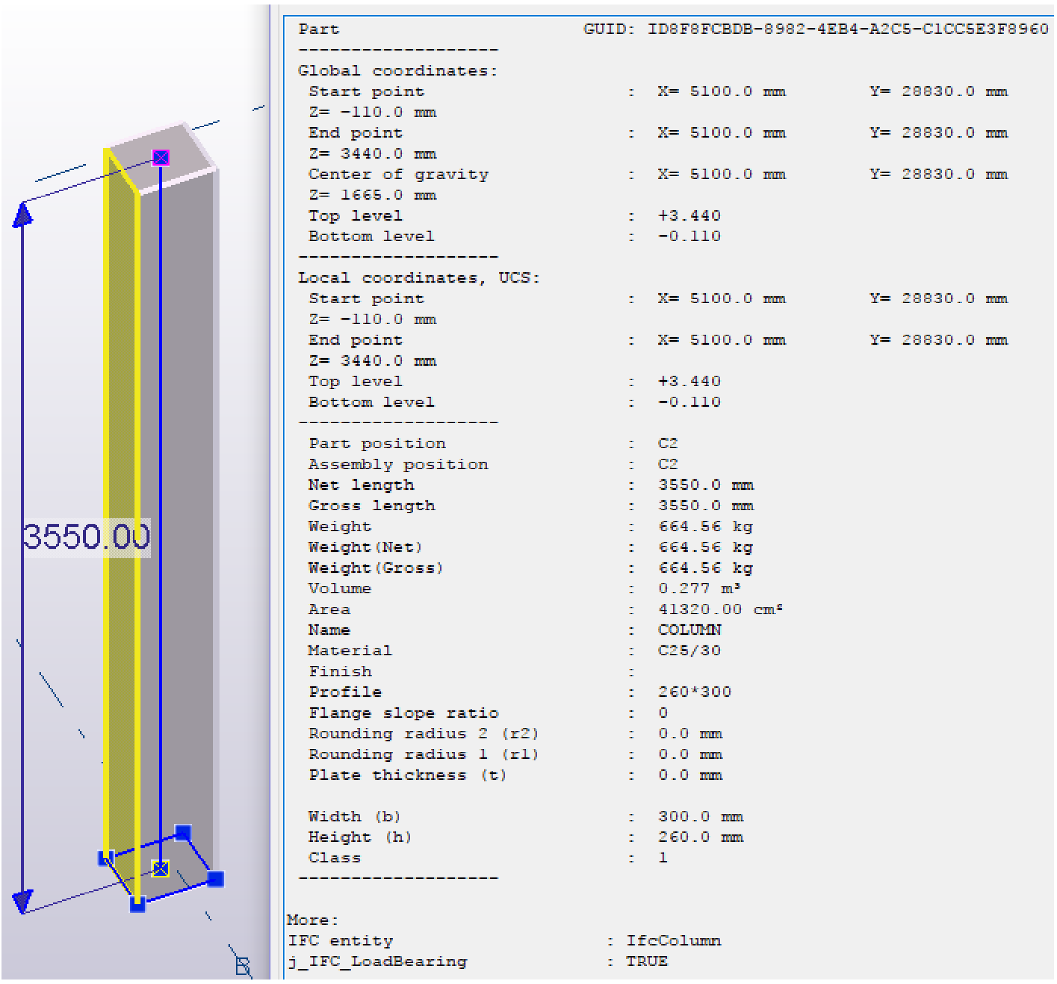


*Figure 6.17: BIM model and structural data of a concrete column.*

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The physical model of the concrete column modeled in TSL, which is afterward converted to an analytical model using the creation method described in Section 6.1.1, is shown in Figure 6.18.

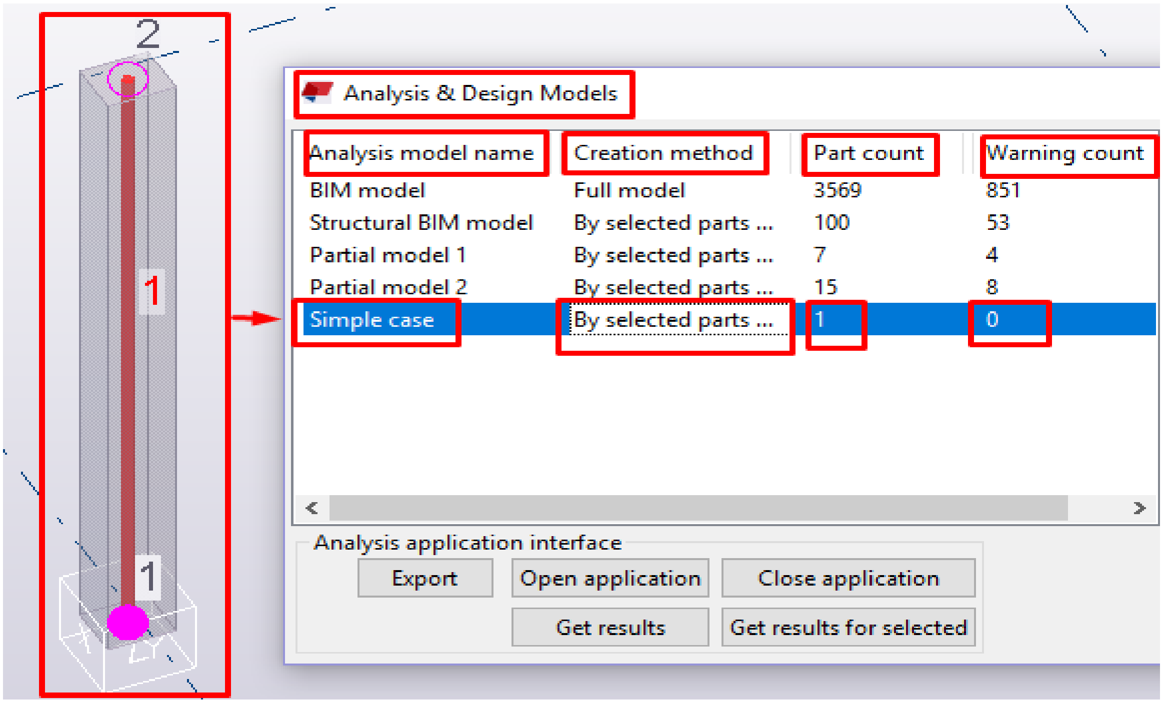


*Figure 6.18: Representation of the physical model of the concrete column converted to an analytical model.*

As it can be noticed in Figure 6.18, no warnings/errors appeared for this simple case, which means that the analytical model of this element has been well created automatically and the element is fully supported (Node 1 = fully supported, Node 2 = connected).

However, analysis properties in the case of this simple model could be manually modified if needed (Figure 6.19).

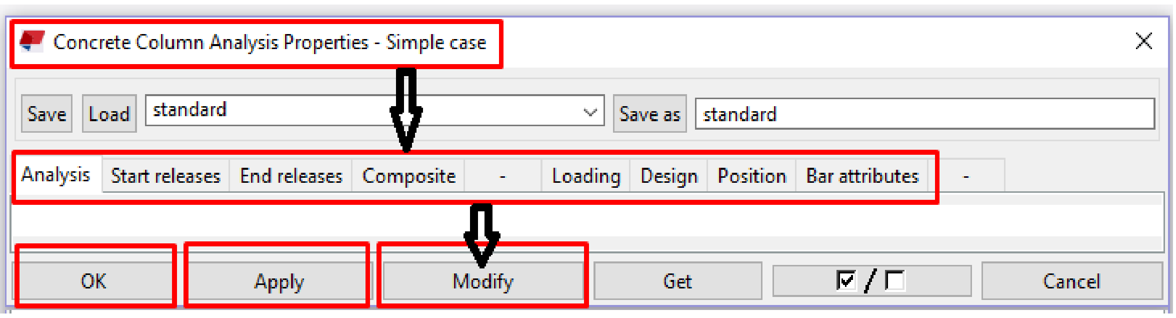


*Figure 6.19: Concrete Column Analysis Properties dialog box.*

Afterwards, the model of the concrete column was exported using the data exchange methods described in Section 6.2. The imported analytical models to RFEM using are presented in Figure 6.20.

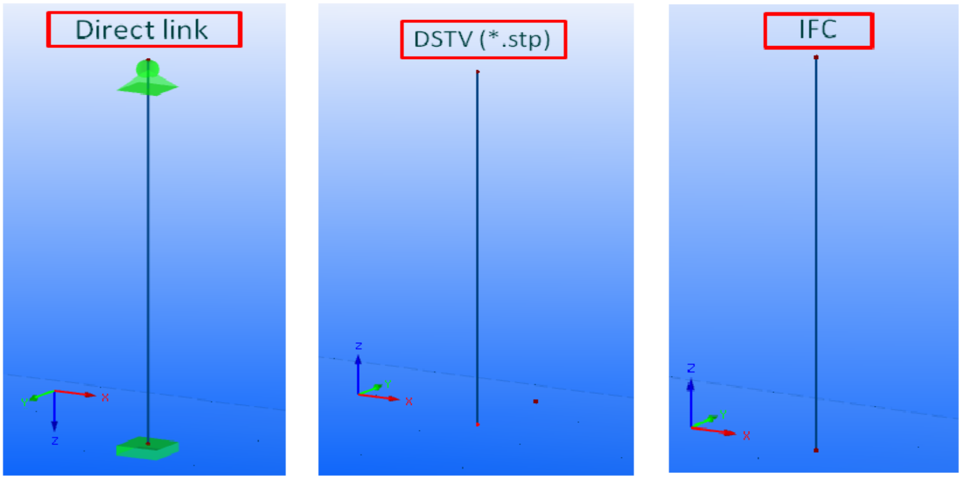


*Figure 6.20: Data exchange scenarios used in the case of a simple concrete column.*

Referring to Figure 6.20, different results were obtained when each data exchange scenario was performed in the case of this simple model. Thus, some of the most important results of the data exchange are presented in Table 6.1.

*Table 6.1: Data exchange results obtained for the simple case study of the Mall project.*

| | **Direct link** | **DSTV (*.stp)** | **IFC** |
|---|---|---|---|
| **Geometry** | | | |
| Nodes | ✔ | ✘ | ✘ |
| Line | ✔ | ✔ | ✔ |
| **Material main properties** | | | |
| Material description | ✔$^{o}$ | ✔$^{o}$ | ✔$^{\square}$ |
| Modulus of Elasticity | ✘ | ✘ | ✘$^{*}$ |
| Shear Modulus | ✘ | ✘ | ✘$^{*}$ |
| Poisson's Ratio | ✔ | ✔ | ✘$^{*}$ |

`

| | | | |
|---|---|---|---|
| Specific Weight | ✔ | ✔ | ✘* |
| Coeff. of Th. Exp. | ✔ | ✔ | ✘* |
| Partial Factor | ✔ | ✔ | ✘* |
| **Boundary conditions** | | | |
| Nodal supports | ✔ | ✘ | ✘ |
| Line supports | ✔ | ✔ | ✔ |
| Structural member type | ✔** | ✔** | ✔** |
| **Section properties** | | | |
| Cross-Section type | ✔ | ✘ | ✘ |
| Moments of inertia | ✔ | ✘+ | ✘+ |
| Cross-Sectional Areas | ✔ | ✔ | ✔ |
| Width b | ✔ | ✘ | ✘ |
| Height h | ✔ | ✘ | ✘ |

- ✔ - The property has been imported correctly.
- ✔° - The material has been imported, but not according to EN standards. It was interpreted according to DIN standards.
- ✔□ - The material has been imported, but it was not described according to which standard it has been imported.
- ✘ - The property has not been imported correctly.
- ✔** - Representation of the member type has not been correctly imported, but it has been well described in comments.
- ✘* - Property value was shown as zero.
- ✘+ - The property has been partially imported correctly.

It is already known that different software vendors use different material and cross-sections types of elements, defined by various producers around the world. Thus, a software vendor cannot always recognize a material and cross-section type in the same way that the other one does. Such situations arose in the case of this project as well, while the data of material and cross section type of an element was transferring between TSL and RFEM, which are shown in Table 6.1.

Hence, it was possible to use a conversion file to name each material and cross-section type exactly as they are already defined in the relevant software vendors, before trying to transfer the data from one to another software vendor. To implement this process in RFEM, the path: File>Import>Detail Settings has been followed.

Furthermore, the necessary steps to create a conversion file, which could be followed and implemented in the case of both software vendors, are shown in Figure 6.21.

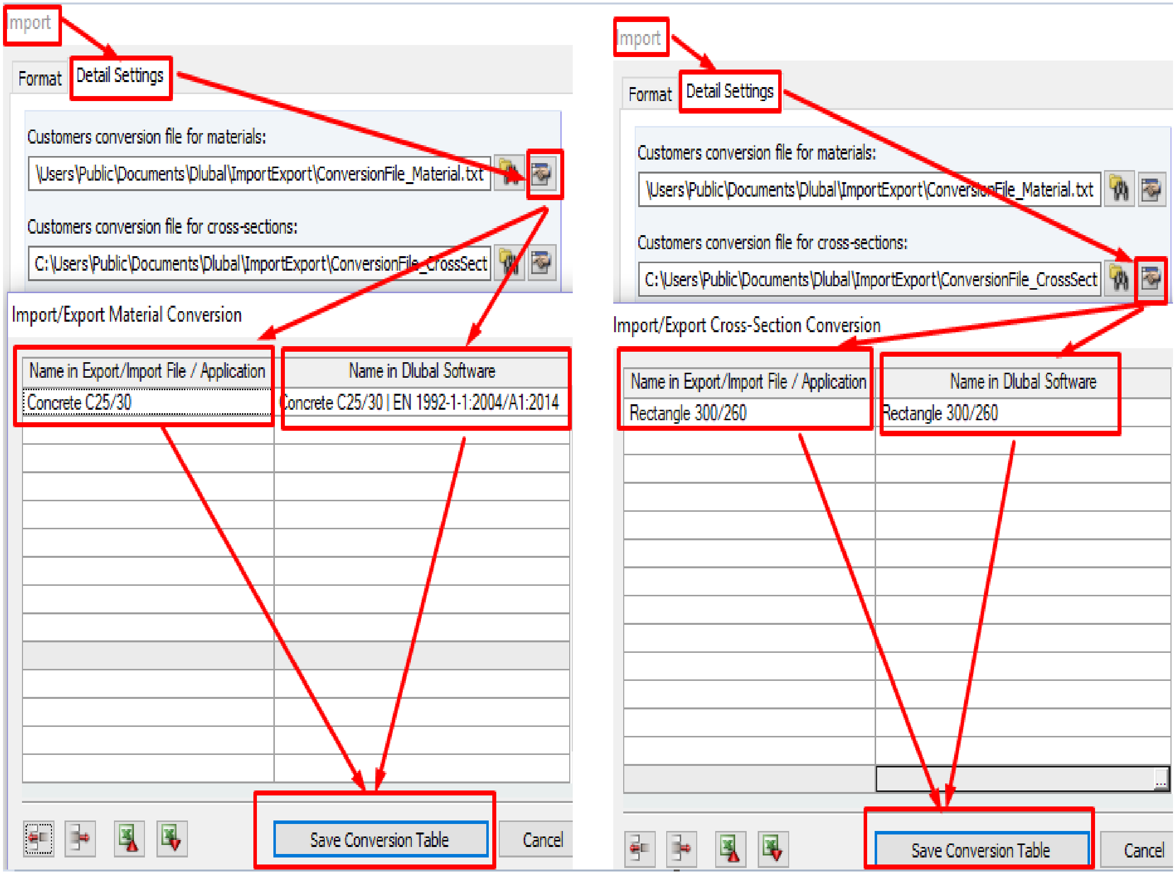


*Figure 6.21: Conversion files for materials (left side) and cross-sections (right side).*

In addition, to describe and discuss the capabilities of updating a BIM model created in TSL, using the direct interface from RFEM, this simple concrete column has been considered. This example shows the possibilities of editing the cross-section of this simple element in RFEM, and chances to automatically update the existing model in TSL.

`

First, to elaborate this process, the path in RFEM: Double click on the element>Edit cross-section is followed. Afterwards, the relevant changes in the cross-section and material of the element could be made in the following dialog box as shown in Figure 6.22.

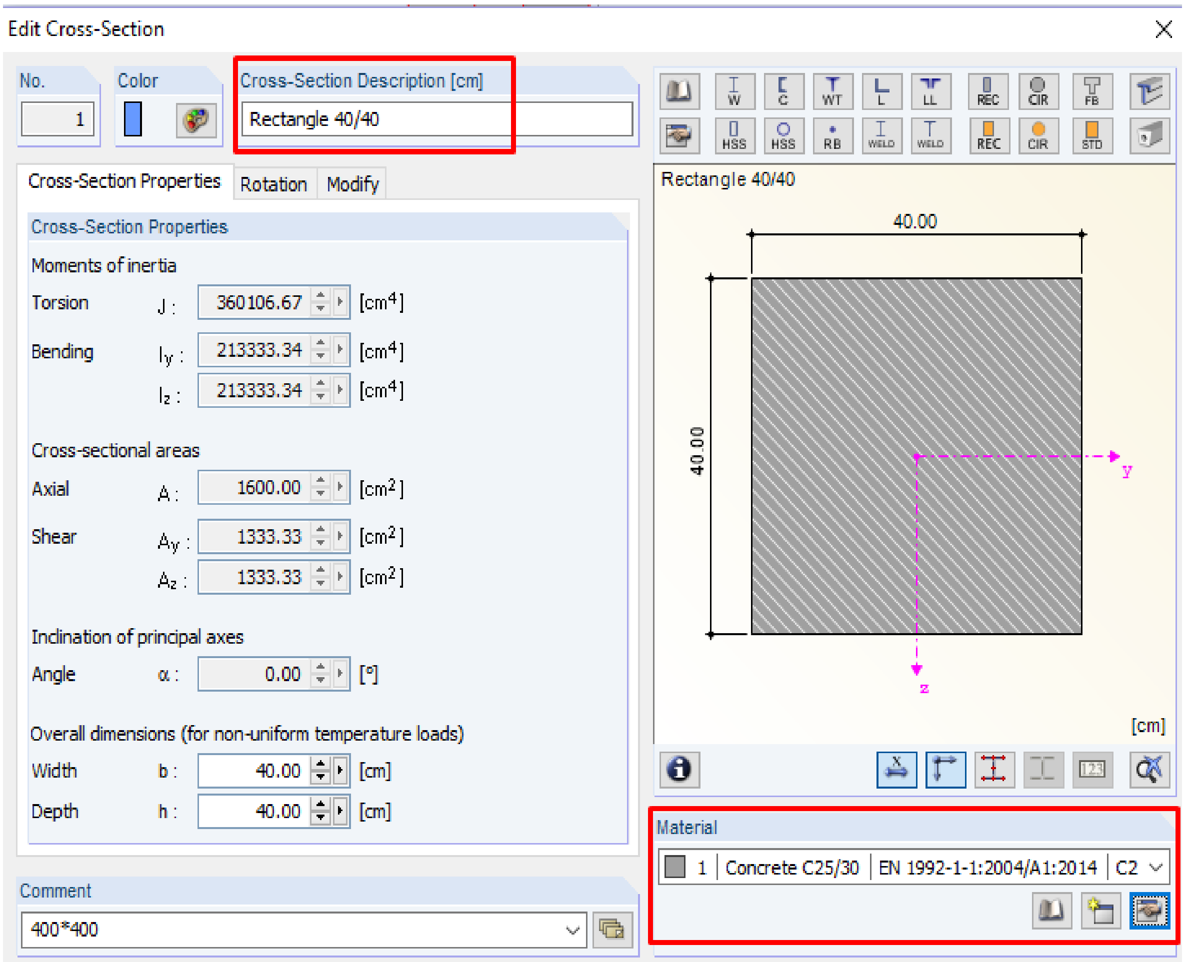


*Figure 6.22: Editing the cross-section properties of the concrete column in RFEM.*

Additionally, in the case of updating the cross-section and material properties of the existing element in TSL, using the direct interface from RFEM, the procedure elaborated in Section 6.3, has been followed.

While editing this structural member type, additional comments such as "Changed Column" could be added in RFEM, to represent the updated existing member type in TSL. Thus, the updated existing structural element and the relevant comment added previously in RFEM could be automatically seen afterward in TSL, as shown in Figure 6.23.

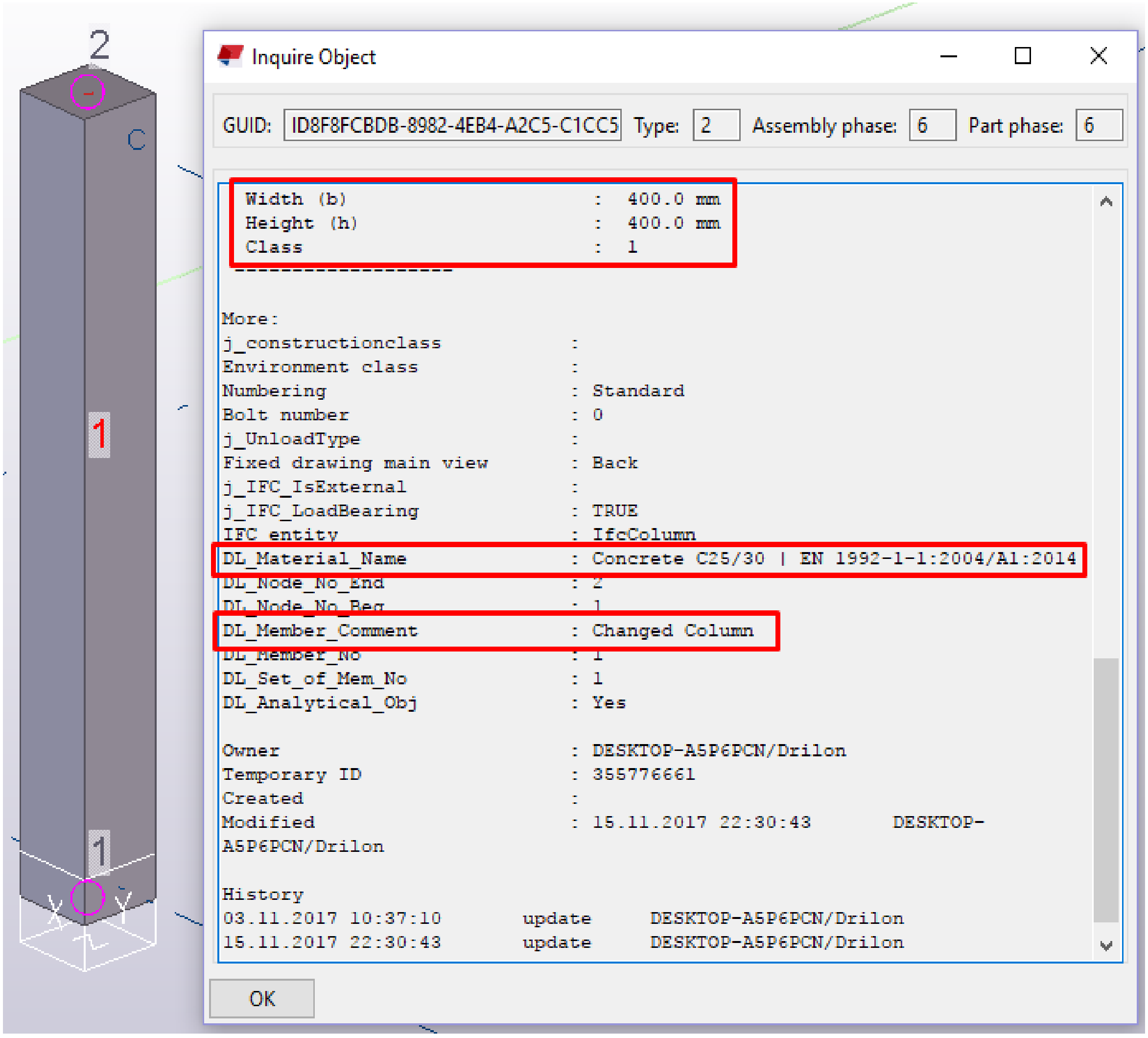


*Figure 6.23: A simple example of an updated existing model in TSL, using direct interface from RFEM.*

### 6.4.2 Partial model 1 – Ground and intermediate floor slabs

To further analyze and verify the capabilities of the data exchange methods a partial structural model representing ground and intermediate floor slabs of the Mall project has been examined. Two types of slab have been introduced in order to be dealt with the data transfer issues which are already mentioned in Section 6.2.

A detailed physical model of both slab types (ground and intermediate floor slabs) created in TSL, has been shown in Figure 6.24.

In addition, Figure 6.24 (enlarged views) shows that both, ground and intermediate slabs have been modeled as depressed slabs.

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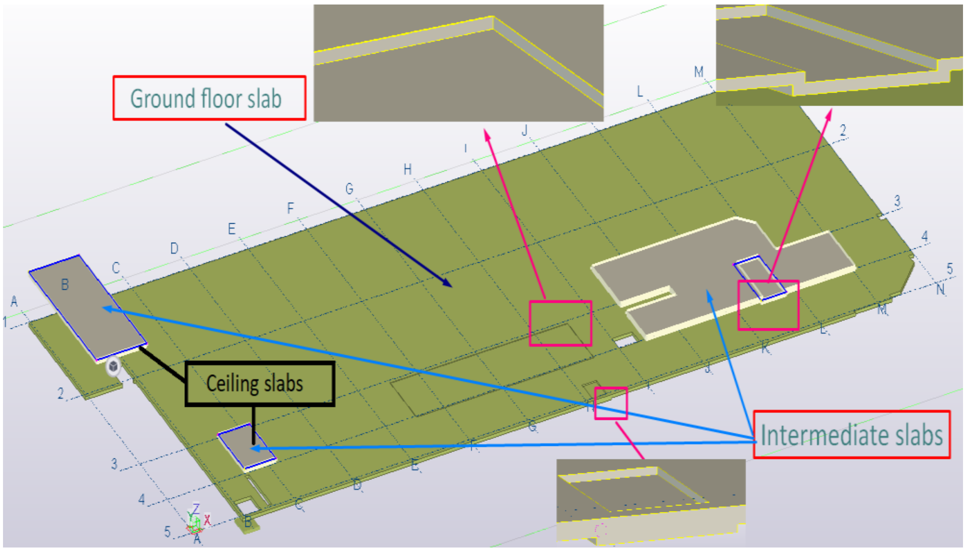


*Figure 6.24: Physical model of ground and intermediate floor slabs created in TSL.*

There were no issues encountered during the process of creating the physical model of both structural elements. However, when the analytical model was generated for the same parts, some problems arose, which are further presented in Figure 6.25.

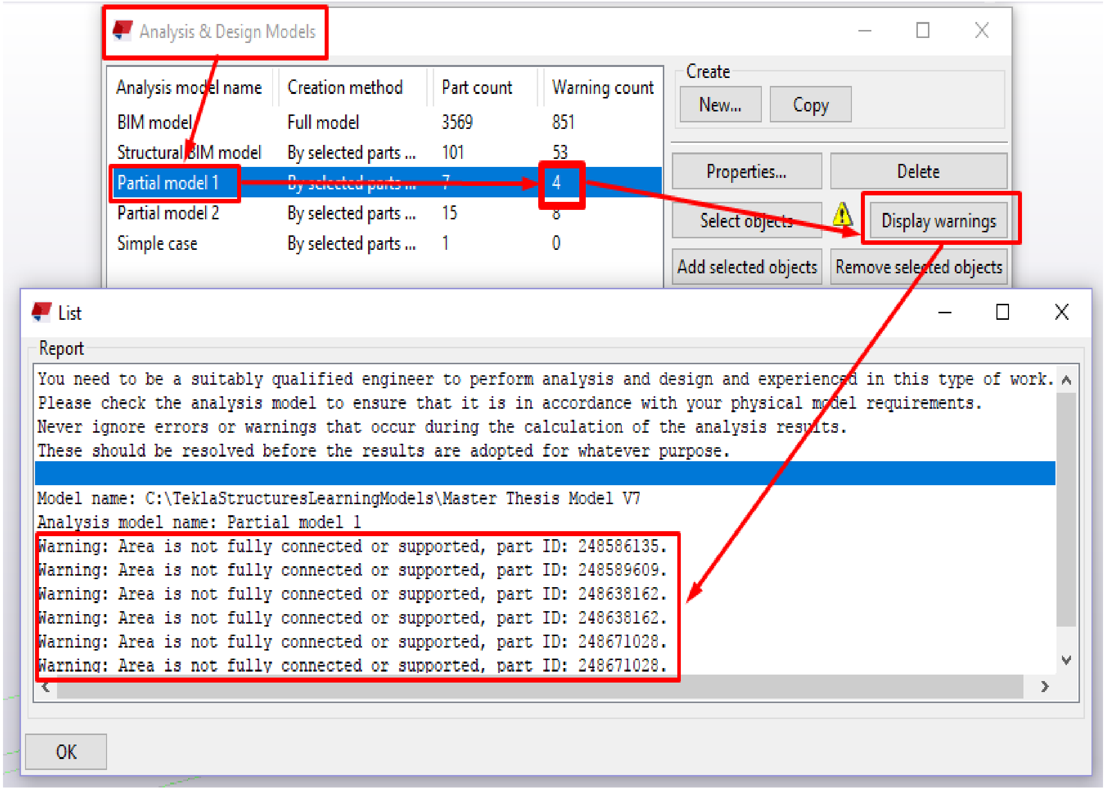


*Figure 6.25: Display of problems encountered after creating the analytical model of this case study.*

As it can be seen in Figure 6.25, almost every problem (warning/error) that arose during this process was related to the boundary conditions of each analytical model created for this study case.

However, the most important issue was related to the creation of depressed slabs. Different ways to create a depressed slab in TSL could be used. Thus, a combination of two parts or cutting the unwanted parts of a simple slab could be considered. Hence, the program TSL could not well recognize separately each part used in the case of creating a depressed slab. Therefore, the analytical model could not be correctly created in this case. The analytical model of a depressed slab in the case of a ground and mezzanine floor is shown in Figure 6.26.

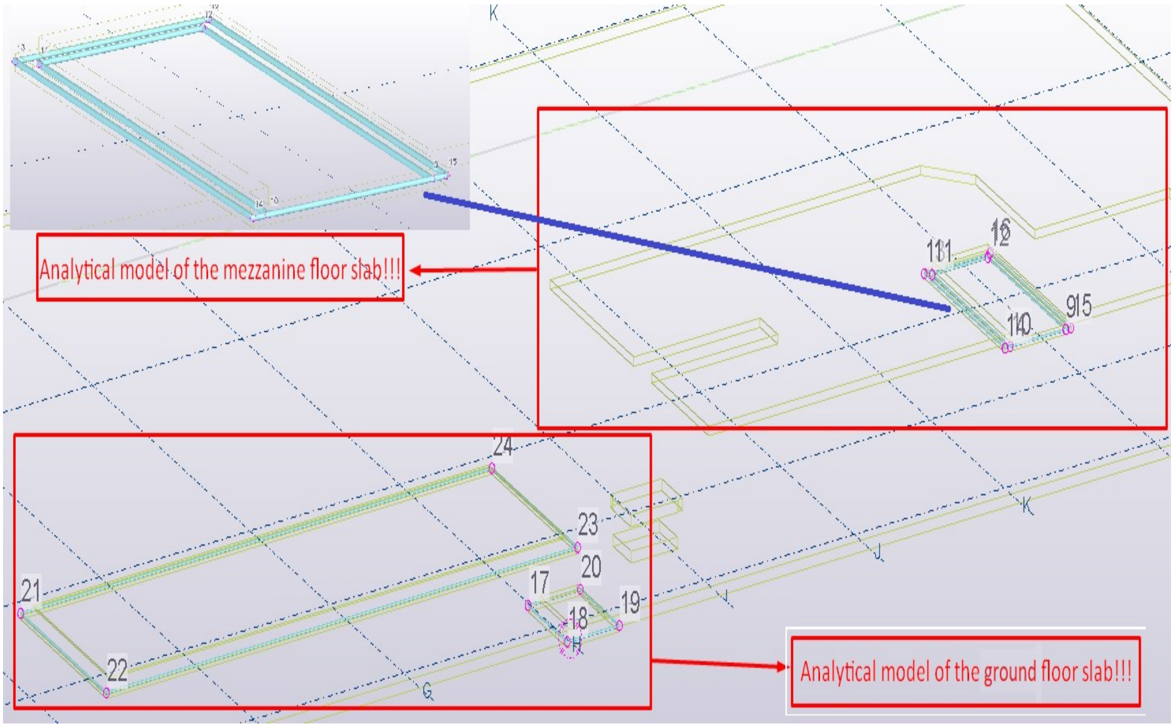


*Figure 6.26: Analytical model in the case of a ground and mezzanine floor depressed slab.*

Furthermore, the problem that arose during the creation of the analytical model in the case of ceiling (intermediate) slabs was not very complicated in comparison with the problems of depressed slabs. The problem was only related to the boundary conditions of these structural elements. Thus, such problems could be manually fixed using the analysis properties dialog box as it is shown in Figure 6.27. Two options could be used to make the relevant elements as simply translated or fully supported elements.

`

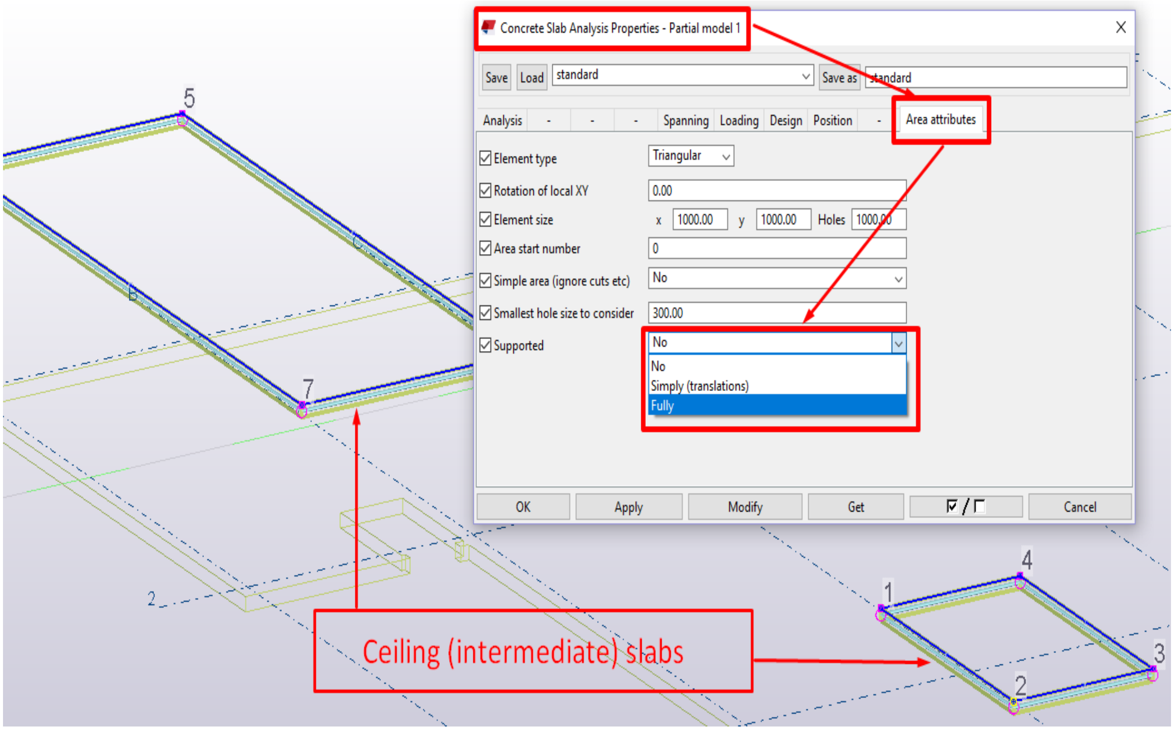


*Figure 6.27: Analytical model & Analysis properties of the ceiling (intermediate) slabs.*

After following the necessary instructions shown in Figure 6.27, the number of problems (warnings/errors) was reduced from 4 to 2 (Figure 6.28).

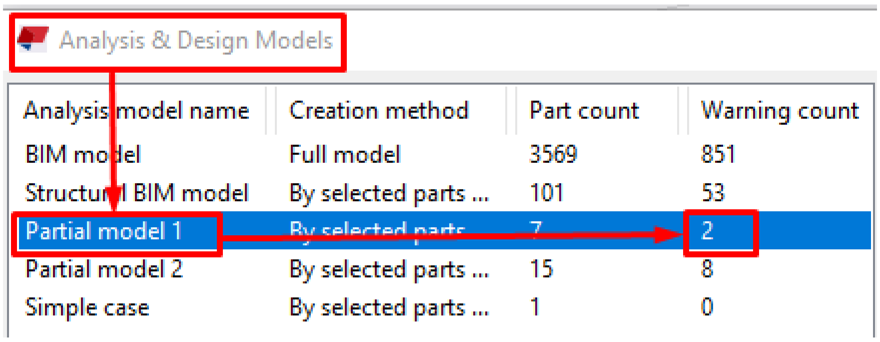


*Figure 6.28: Improving the quality of the created analytical model by reducing the number of displayed warnings/errors.*

In addition, based on the above-mentioned problems that arose when the analytical model of this partial model of the Mall project was created, it was obvious that the data could not be correctly transferred between TSL and RFEM. In other words, results of data exchange methods are strongly connected with the creation of an analytical model.

Hence, from the three available data exchange methods, only “direct link” and “IFC data model exchange” could be performed for this study case. The “DSTV (*.stp)” data exchange method could not be implemented at all. The imported partial model from TSL to RFEM using the “direct link” has been shown in Figure 6.29.

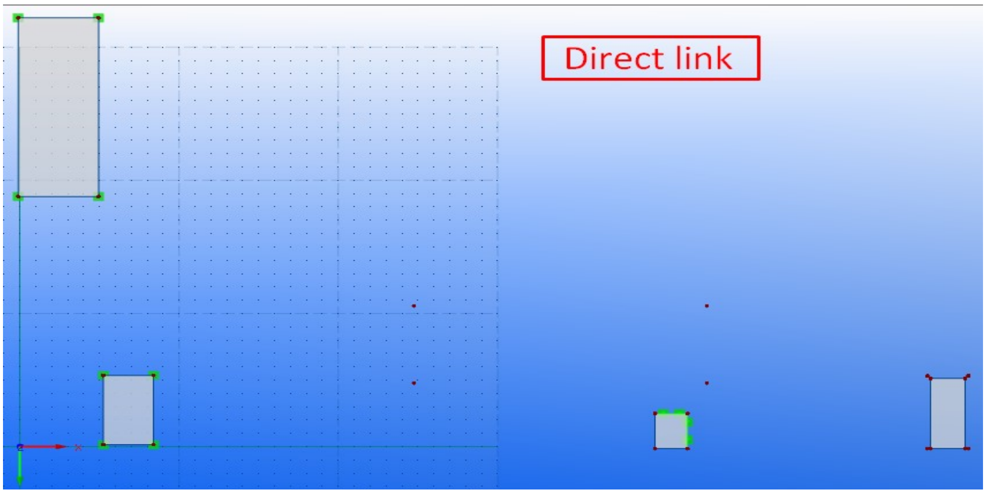


*Figure 6.29: Importing the analytical model from TSL to RFEM using the direct link.*

In addition, we could create an output IFC file of the analytical model for this study case in TSL, after making some relevant modifications regarding additional property sets of each element. Anyway, some element types of this file could not be imported in RFEM. The imported parts and the reason why the other element types could not be imported and stored are shown in Figure 6.30.

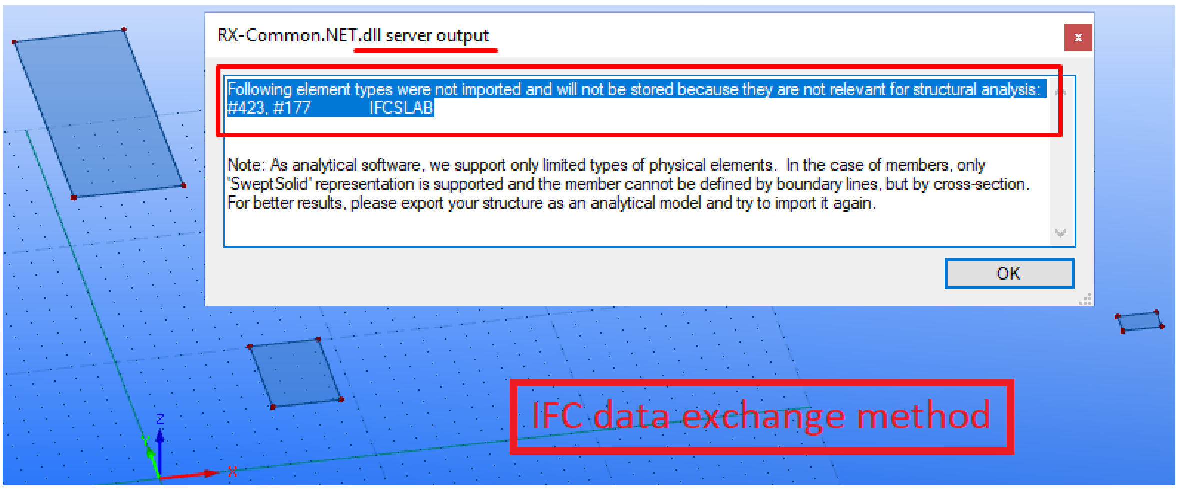


*Figure 6.30: Importing the analytical model of this study case using IFC data model exchange method.*

`

As it can be noticed in Figure 6.30, in the case of performing further structural analysis of such element types, it is advisable to avoid the export of physical model, since RFEM supports only limited types of physical models.

A summarized overview of the results obtained when this partial model of the project was transferred from TSL to RFEM, using already mentioned data exchange methods (direct link as the most useful method in this case), has been presented in the following Table 6.2.

*Table 6.2: Data exchange results obtained after transferring the partial model of this study case from TSL to RFEM.*

| | **Direct link** | **DSTV (*.stp)** | **IFC** |
|---|---|---|---|
| **Structural elements of the "Partial model 1"** | ☑* | ☒ | ☒* |

- ☑* - Not every structural element of this partial model (analytical model) of the project was correctly imported. Geometry and properties of imported elements were partially well recognized by RFEM.
- ☒ - Structural elements of this partial model (physical and analytical models) of the project could not be imported.
- ☒* - Not every structural element of this partial model (analytical model) of the project was correctly imported. The majority of the geometry and properties of the imported elements were not recognized by RFEM.

In summary, the main problem of this study case was related to the way the analytical model of depressed slabs has been created in TSL. To eliminate such problems, a simplified structural type of the slab could be used instead of a depressed slab.

Thus, regarding structural analysis and design, such modifications will be considered necessary to be made in case of being able to correctly create the analytical model in TSL. This process is further elaborated in Section 7.

### 6.4.3 Partial model 2 – Structural steel elements

The following partial model of this project deals with the structural steel elements, which are considered and discussed in this study case. The 3D BIM model of this partial model has been previously presented in Figure 5.12. The analytical model of these structural steel elements is shown in Figure 6.31.

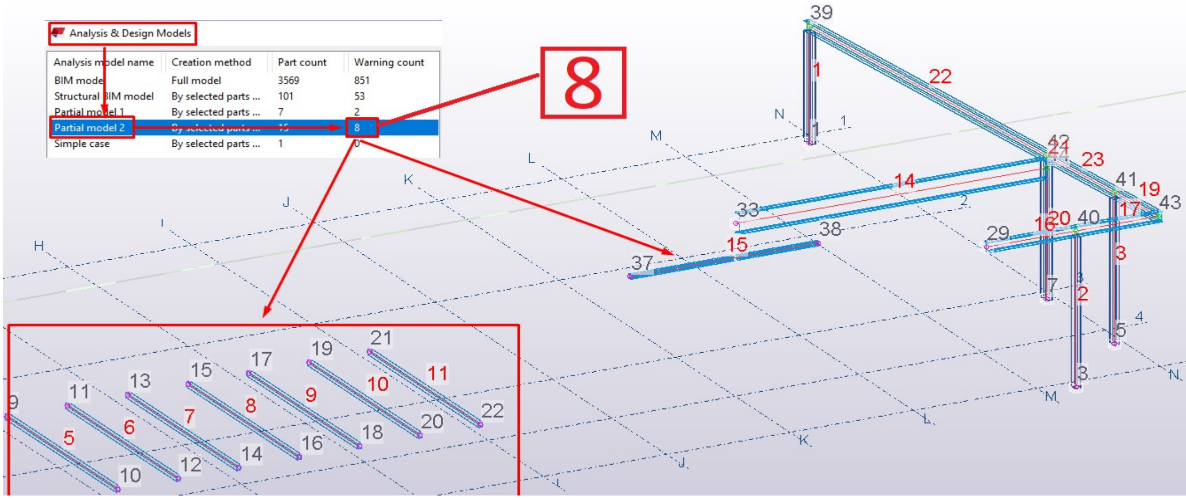


*Figure 6.31: The analytical model of structural steel elements.*

The problem (warnings/errors) with some structural elements that arose when the analytical model was created has been displayed in the following Figure 6.32.

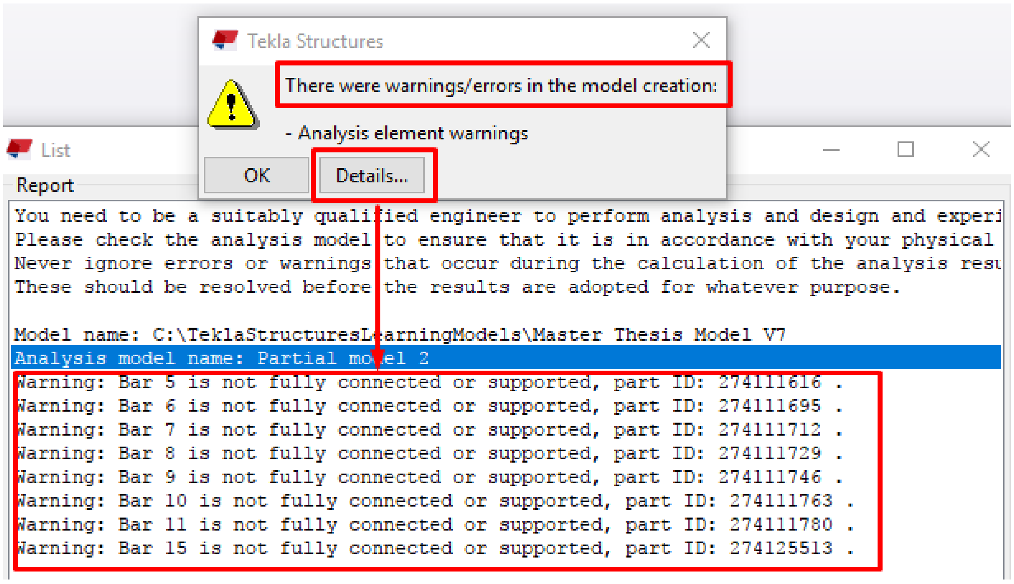


*Figure 6.32: Display of warnings/errors in the analytical model creation in the case of structural steel elements.*

`

As it can be seen in Figure 6.32, every warning/error issue in the created analytical model for these relevant structural elements was related to their boundary conditions. Thus, these structural steel elements were not fully connected or supported. Anyway, such problems could be manually fixed by modifying the relevant boundary condition of each element separately.

However, it was already supposed that these structural steel elements shall be anchored in the RC walls of the building. Hence, these elements shall be considered as supported elements. The following necessary modifications were made in this case (Figure 6.33).

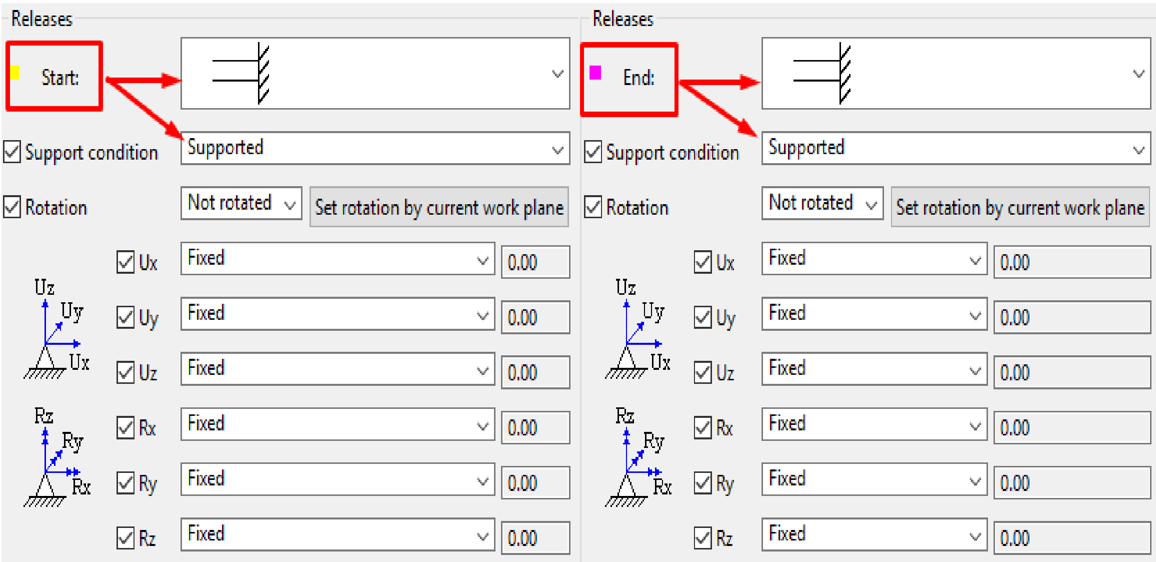


*Figure 6.33: Modification of the boundary conditions of structural elements in the analytical model.*

In addition, the effect of such modifications has been automatically seen in the "Analysis & Design Models" dialog box, which is presented in Figure 6.34.

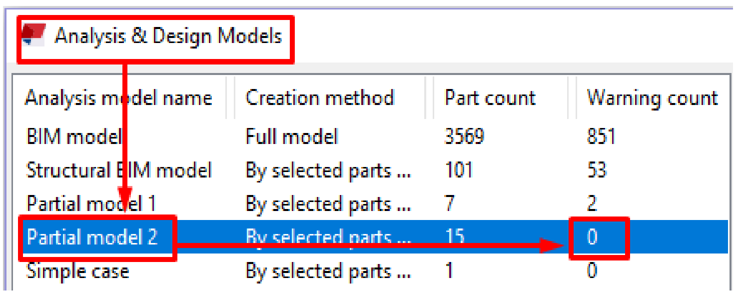


*Figure 6.34: Display of warnings/errors after the necessary modifications that were made for some relevant structural elements in the case of this analytical model.*

In addition, the exchange methods used to transfer the analytical model from TSL to RFEM are implemented in the same way as it has been described in the previous case studies. Different results were obtained when the analytical model of this study case was imported from TSL to RFEM, using the three applicable data exchange methods, which can be seen in Figure 6.35.

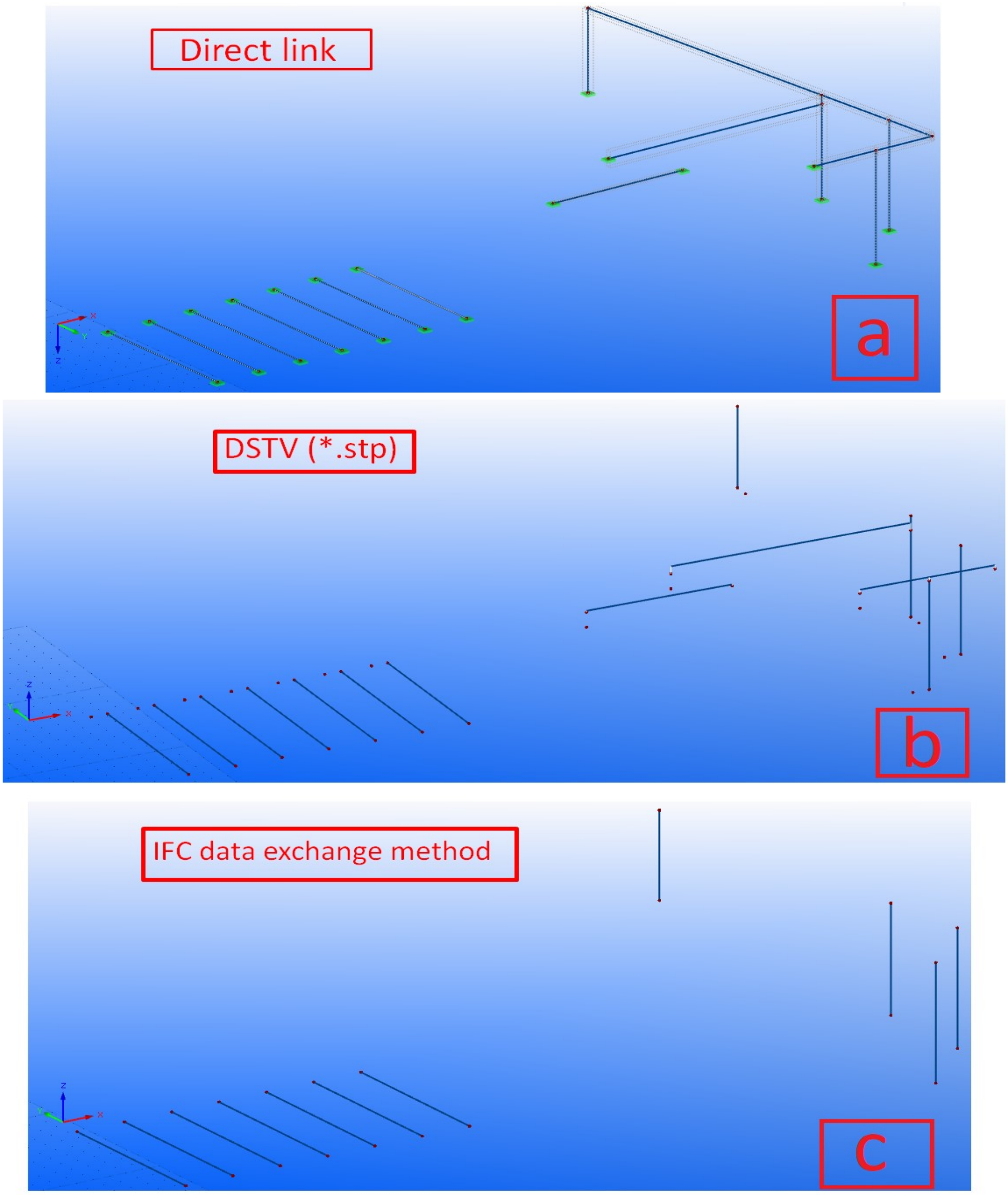


*Figure 6.35: Data exchange methods used to transfer the analytical model of structural steel elements from TSL to RFEM.*

The basic results of the data exchange methods, which are used in the case of transferring the analytical model of this study case from TSL to RFEM, are presented in Table 6.1.

*Table 6.3: Data exchange results obtained after transferring the analytical model of this study case from TSL to RFEM.*

| | Direct link | DSTV (*.stp) | IFC |
|---|---|---|---|
| **Structural steel elements** | ☑ | ☑* | ☑* |
| **Geometry** | | | |
| Nodes | ✔ | ✘ | ✔* |
| Lines | ✔ | ✔* | ✔* |
| **Material properties** | | | |
| Material description | ✔° | ✔° | ✔□ |
| Modulus of Elasticity | ✔ | ✔ | ✘* |
| Shear Modulus | ✔ | ✔ | ✘* |
| Poisson's Ratio | ✔ | ✔ | ✘* |
| Specific Weight | ✔ | ✔ | ✘* |
| Coeff. of Th. Exp. | ✔ | ✔ | ✘* |
| Partial Factor | ✔ | ✔ | ✘* |
| **Boundary conditions** | | | |
| Nodal supports | ✔ | ✘ | ✘ |
| Line supports | ✔ | ✘ | ✘ |
| Structural member type | ✔** | ✘** | ✘** |
| **Section properties** | | | |
| Cross-Section type | ✔+ | ✔+ | ✘ |
| Moments of inertia | ✔+ | ✔+ | ✘ |
| Cross-Sectional Areas | ✔+ | ✔+ | ✘ |
| Width b | ✔+ | ✔+ | ✘ |

| | | | |
|---|---|---|---|
| Height h | ✔+ | ✔+ | ✘ |

- ☑ - All structural steel elements were correctly imported.
- ☑* - Not every structural steel element was correctly imported.
- ✔ - The property has been imported correctly.
- ✔* - The property has been partially imported correctly.
- ✔° - The material has been imported, but not according to EN standards. It was interpreted according to DIN standards.
- ✔□ - The material has been imported, but it was not described according to which standard it has been imported.
- ✔+ - The property was not totally imported correctly. Property in the case of HEA steel profiles was imported correctly, but in the case of RHS steel profiles, RFEM did not recognize them in the same way that TSL does. Thus, the RHS profiles were named differently in RFEM and the majority of their section properties could not be imported at all.
- ✔**- Representation of some member types has not been imported correctly during the transferring process, but they were well described separately in comments.
- ✘ - The property has not been imported correctly.
- ✘* - The property value was shown as zero.
- ✘**- Representation of some member types has not been imported correctly during the transferring process, but they were well described separately in comments. Some member types have not been imported at all.

### 6.4.4 Partial model 3 – Structural concrete walls and columns

In this study case, phases 5 and 6 of this project (see Figure 5.2) have been examined in the case of providing a further investigation of the capabilities of using data exchange methods to transfer the model from TSL to RFEM.

The physical model of structural concrete walls and columns is shown in Figure 6.36.

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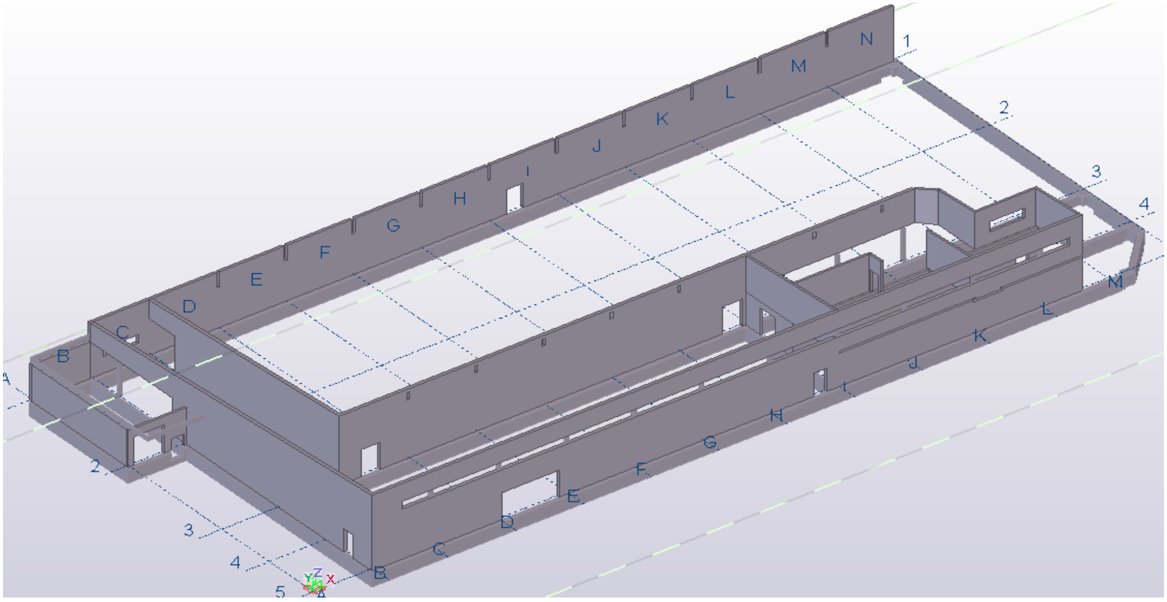


*Figure 6.36: Physical model of structural concrete walls and columns.*

On the other hand, the analytical model of the same structural elements of this project has been shown in Figure 6.37.

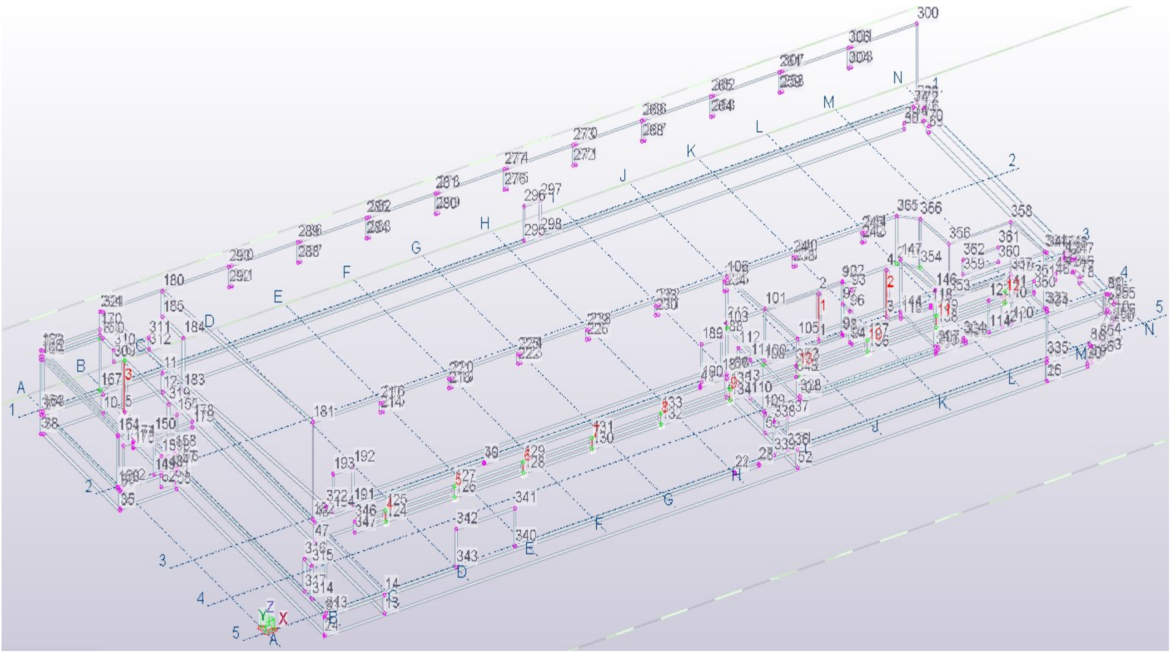

*Figure 6.37: Analytical model of structural concrete walls and columns.*

Numerous problems (warnings/errors) occurred after the analytical model was created for this study case. Such problems are presented in Figure 6.38.

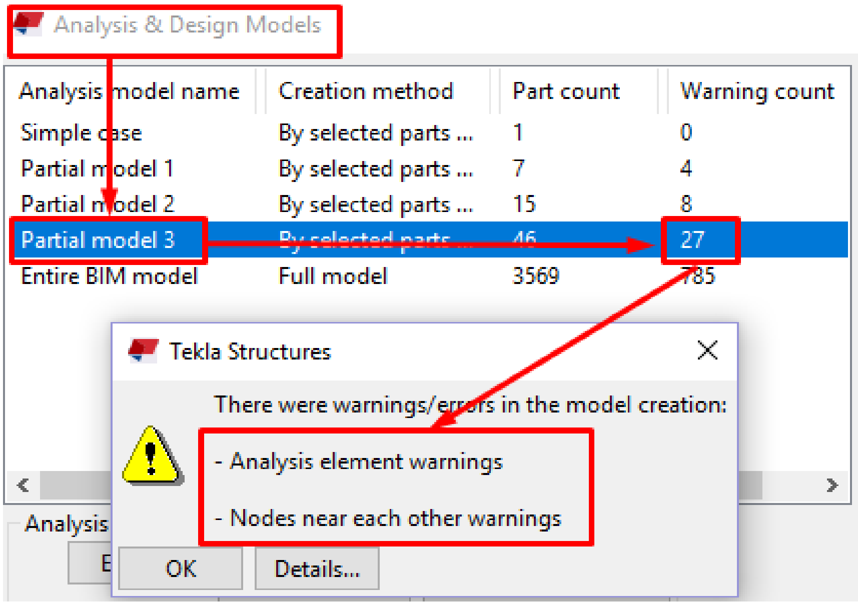


*Figure 6.38: Warnings/errors of the analytical model created in the case of structural concrete walls and columns.*

Most of the problems underlined in Figure 6.38 were related to the boundary conditions of each structural element of this study case. Only two of them had to do with the opposite nodes of wall elements, which are placed close to each other. A detailed representation of such problems has been shown in Figure 6.39.

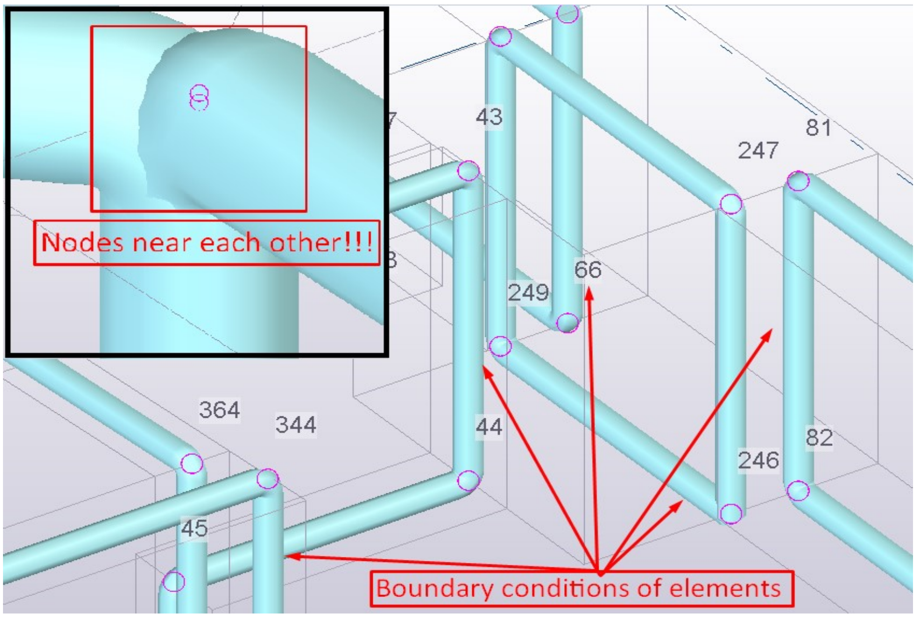


*Figure 6.39: A detailed representation of warnings/errors of the analytical model created in the case of structural concrete walls and columns of this project.*

`

To reduce or eliminate such problems, manual modifications were necessary to be made in the case of every stick element of this analytical model. These types of modifications are recommended to be made before trying to transfer the analytical model or verify the capabilities of data exchange methods between TSL and RFEM. Thus, in the case of eliminating the problem of boundary conditions of each structural element and the gaps between them, the path in TSL: Double click on the stick element>Element Analysis Properties>Position>Connectivity has been followed. Depending on the nature of the problem, the connectivity has been changed from manual to automatic, and vice versa. Connectivity between two elements (elimination of eventual gaps between them) could also be realized by using the icon “Rigid link” in the main toolbar of TSL. Furthermore, in the case of eliminating the problem of the nodes which were placed near each other, the icon “Merge nodes” in the main toolbar of TSL, has been used.

Close attention had to be paid during the implementation of this process, because sometimes manual modifications of relevant elements might cause additional unexpected warnings/errors. After following and implementing this process step by step for each element of this analytical model, the problems (warnings/errors) were eliminated and some of the modified elements are shown in Figure 6.40.

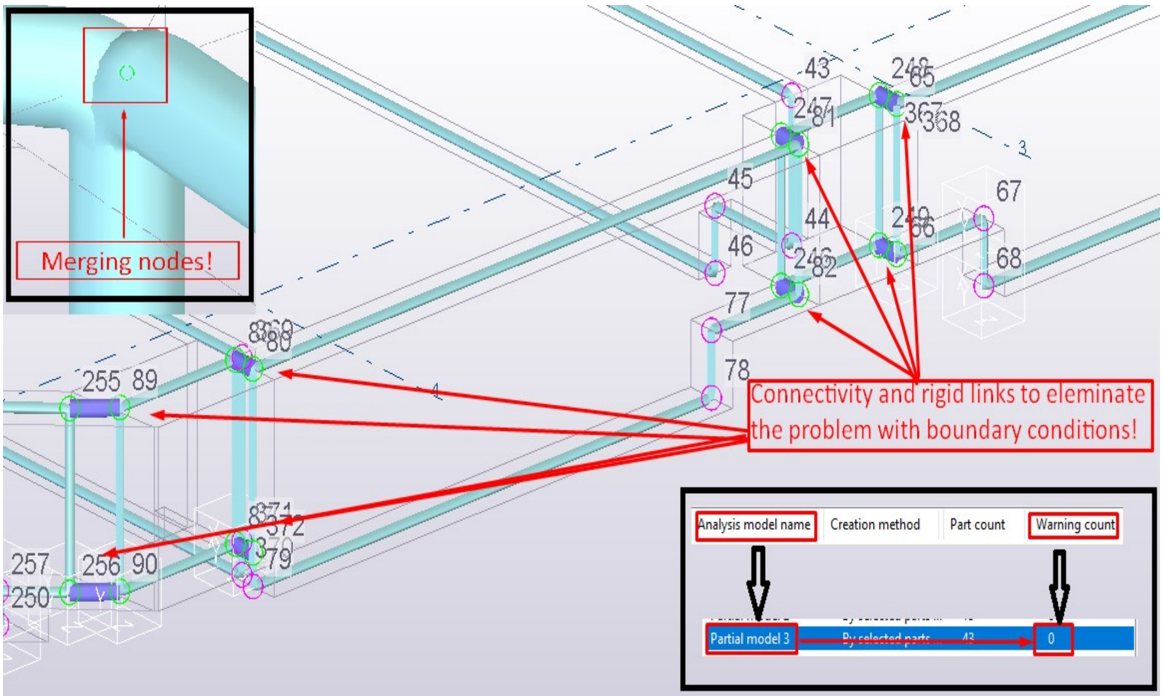


*Figure 6.40: Elimination of warnings/errors of the analytical model created in the case of structural concrete walls and columns.*

Finally, when this process was successfully finished, the analytical model of this study case has been transferred from TSL to RFEM, using relevant data exchange methods which are previously described in Section 6.2.

The analytical model for this study case could only be transferred from TSL to RFEM, by using the “direct link” and “IFC data model exchange” as applicable data exchange methods. However, after using both of these data exchange methods, some of the structural elements could not be transferred at all.

The result of using the “direct link” to transfer the structural concrete walls and columns, from TSL to RFEM has been shown in Figure 6.41.

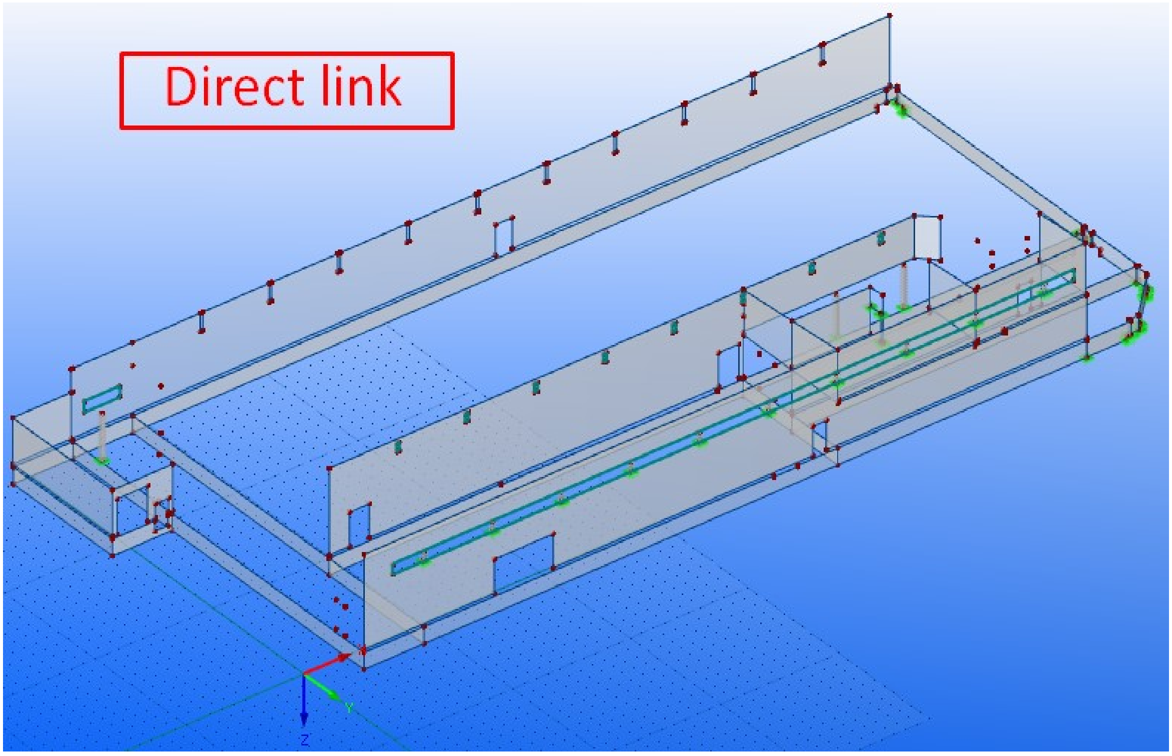


*Figure 6.41: Transferring data of structural concrete walls and columns using "direct link" exchange method.*

In addition, using the “IFC data model exchange” as data exchange method, the majority of the elements of this study case were not able to be transferred from TSL to RFEM. The transferred model based on this data exchange method has been shown in Figure 6.42.

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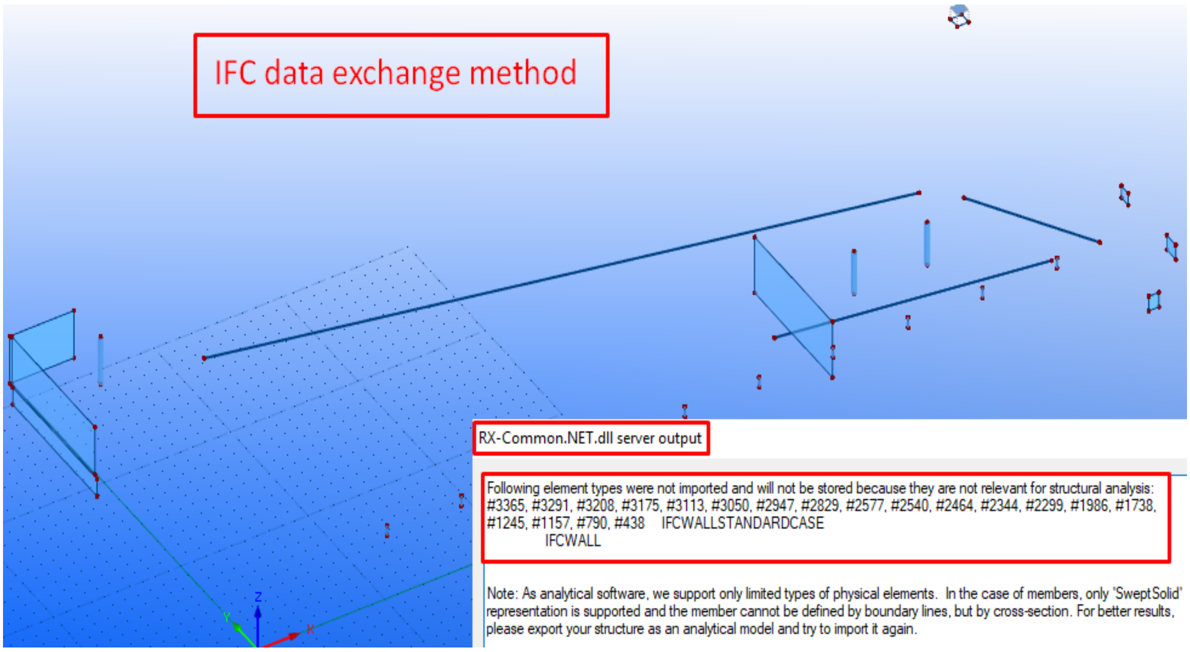


*Figure 6.42: The analytical model of the structural concrete walls and columns transferred from TSL to RFEM, using the IFC data model exchange method.*

The reason why numerous of elements of this study case, could not be imported has been noticed and underlined in Figure 6.42.

Furthermore, it must be mentioned that only the physical model of this study case, could be transferred from TSL to RFEM, using the "DSTV (*.stp)" exchange format. The transferred model in RFEM is presented in Figure 6.43.

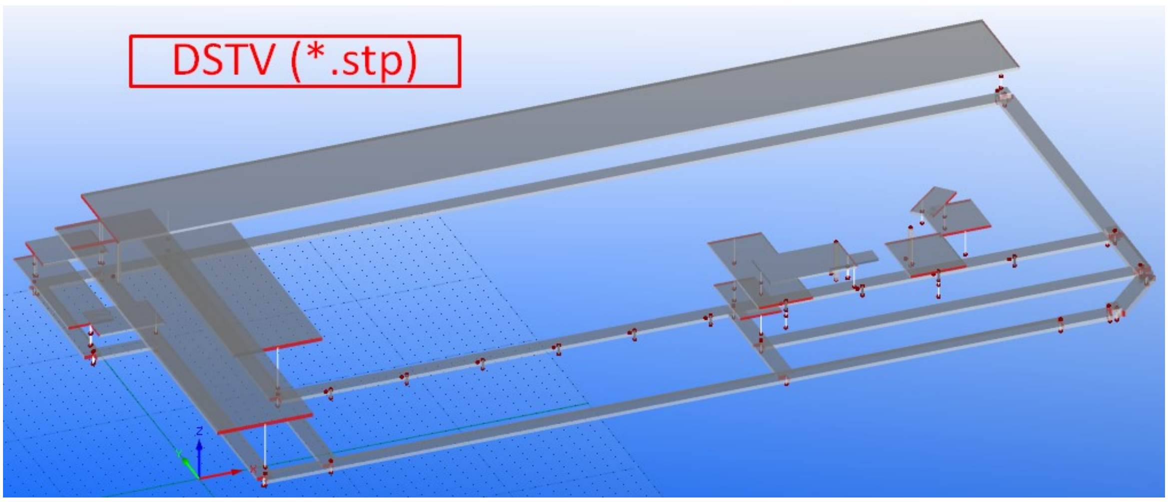


*Figure 6.43: Transferring the physical model of the structural concrete walls and columns using the "DSTV (*.stp) file format.*

As it can be seen in Figure 6.43, not every physical element of this study case has been imported. Some of the imported elements have changed their work plane from "Z" as they were previously modeled in TSL, into "Y" in RFRM.

It is already mentioned in Section 6.2.2, that this data exchange method is mostly applicable for structural steel projects. Therefore, since the structural elements of this study case have been modeled as concrete elements, such problems were predictable. Hence, we could not present results (geometry and properties of the elements) of this data exchange method in the following Table 6.4.

The basic results, which are obtained after transferring the analytical model of the structural concrete walls and columns from TSL to RFEM, using above-mentioned data exchange methods, are presented in Table 6.1.

*Table 6.4: Data exchange results obtained after transferring the analytical model of the structural concrete walls and columns from TSL to RFEM. The results are only evidenced and presented for the imported elements.*

| | **Direct link** | **DSTV (*.stp)** | **IFC** |
|---|---|---|---|
| **Structural concrete walls and columns** | ☑* | ☒** | ☒* |
| **Geometry** | | | |
| Nodes | ✔ | / | ✘+ |
| Lines | ✔* | / | ✘+ |
| Surfaces | ✔* | / | ✘+ |
| Openings | ✔* | / | ✘ |
| **Material properties** | | | |
| Material description | ✔° | / | ✔□ |
| Modulus of Elasticity | ✘ | / | ✘* |
| Shear Modulus | ✘ | / | ✘* |
| Poisson's Ratio | ✔ | / | ✘* |
| Specific Weight | ✔ | / | ✘* |

| | | | |
|---|---|---|---|
| Coeff. of Th. Exp. | ✔ | / | ✘* |
| Partial Factor | ✔ | / | ✘* |
| **Boundary conditions** | | | |
| Nodal supports | ✔ | / | ✘ |
| Line supports | ✔* | / | ✘ |
| Structural member type | ✔** | / | ✘** |
| **Section properties** | | | |
| Cross-Section type | ✔ | / | ✘+ |
| Moments of inertia | ✔ | / | ✘+ |
| Cross-Sectional Areas | ✔ | / | ✘+ |
| Width b | ✔ | / | ✘+ |
| Height h | ✔ | / | ✘+ |

- ☑* - All of the structural concrete columns were correctly imported, but not every structural concrete wall was correctly imported.
- ☒* - Only a few of structural concrete elements (counting both walls and columns) were correctly imported.
- ☒** - The analytical model of the structural concrete walls and columns could not be imported. The physical model of the same structural elements was not correctly imported.
- ✔ - The property has been imported correctly.
- ✔*- The property has been partially imported correctly.
- ✔° - The material has been imported, but not according to EN standards. It was interpreted according to DIN standards.
- ✔□ - The material has been imported, but it was not described according to which standard it has been imported.
- ✔** - Representation of some member types has not been imported correctly during the process, but some of them were well described separately in comments.
- ✘ - The property has not been imported correctly.

- ✘* - The property value was shown as zero.
- ✘+ - The property of only a few elements was correctly imported.
- ✘**- Representation of some member types has not been imported correctly during the process, but some of them were well described separately in comments. Some member types have not been imported at all.

### 6.4.5 Entire BIM model

In this study case, the entire BIM model of the Mall project has been discussed. The entire (BIM and/or physical) model of this project has been presented previously in Figure 5.1. The entire BIM model of the mall project has been modeled in TSL in the way it has to be built in real.

Comparing to the other case studies of this project, the model of this study case contains the largest number of objects and information. Therefore, creation and transferring process of the analytical model for this study case took longer time, and the number of problems (warnings/errors) was larger in comparison with the other case studies.

The process of creating the analytical model in the case of the entire BIM model and other case studies of this project has been shown in Figure 6.1. Hence, the analytical model for this study case, created by using the »Full model« creation method has been shown in Figure 6.44.

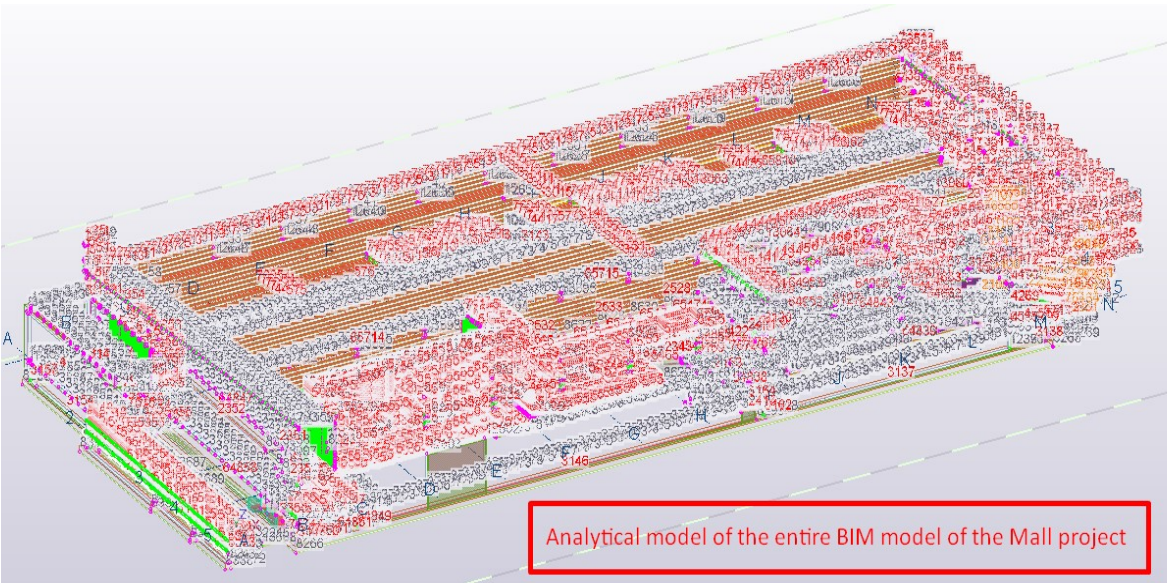


*Figure 6.44: The analytical model of the "Entire BIM model" of the Mall project.*

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Referring to Figure 6.44 shown above, it is not possible to see clearly how the analytical model of this study case has been created. Therefore, a detailed (enlarged view) representation of some parts of this analytical model has been shown in Figure 6.45.

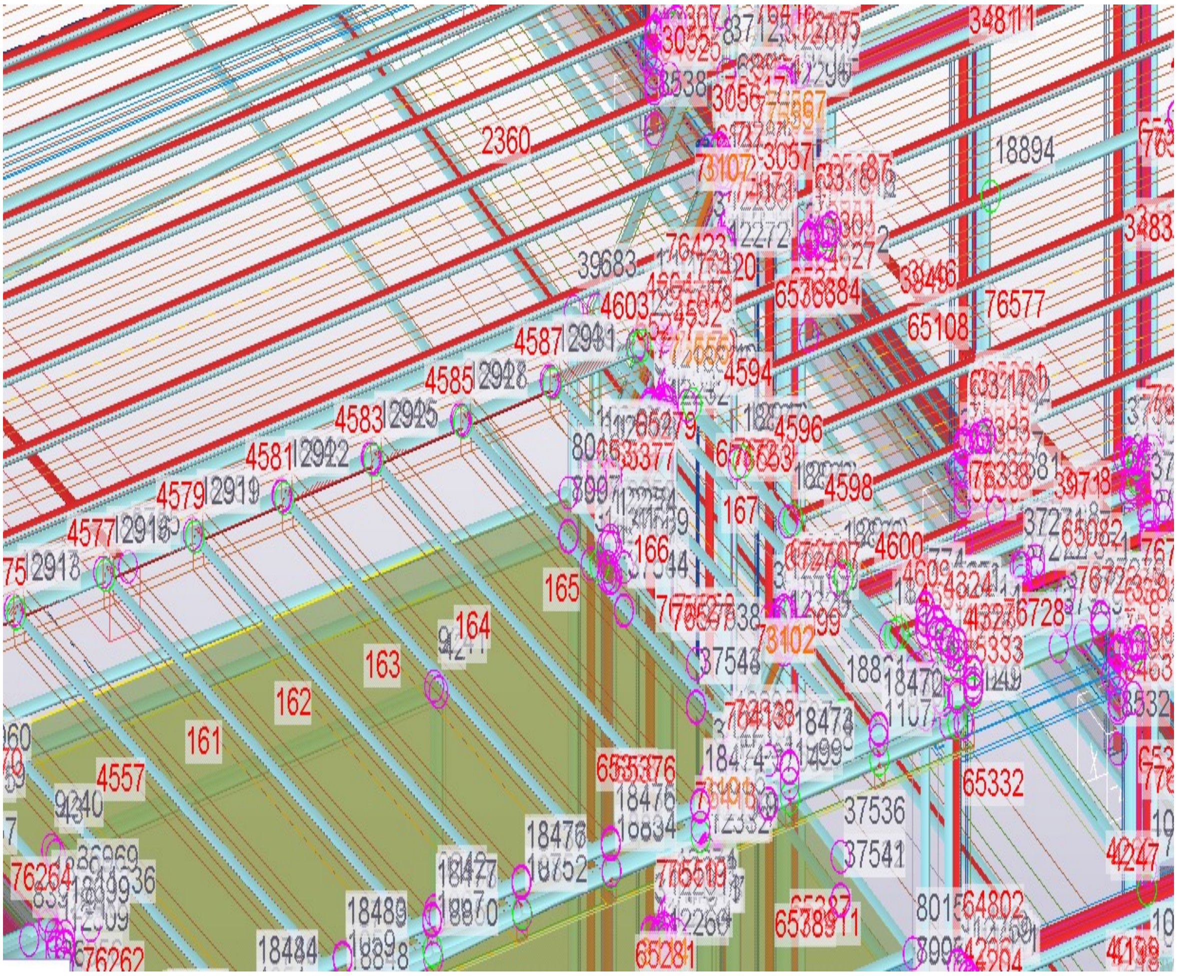


*Figure 6.45: Enlarged view of the analytical model of some parts of the entire BIM model.*

In addition to this study case, we have shown the number and the nature of problems that arose during the process of creating the analytical model in the case of the entire BIM model of this project.

First, it could be noticed that from the total number of objects (3688 objects) that were identified in the physical model of the entire BIM model, only 3566 were counted in the analytical model.

This problem and the number of warnings/errors that occurred after the analytical model was created are shown in Figure 6.46.

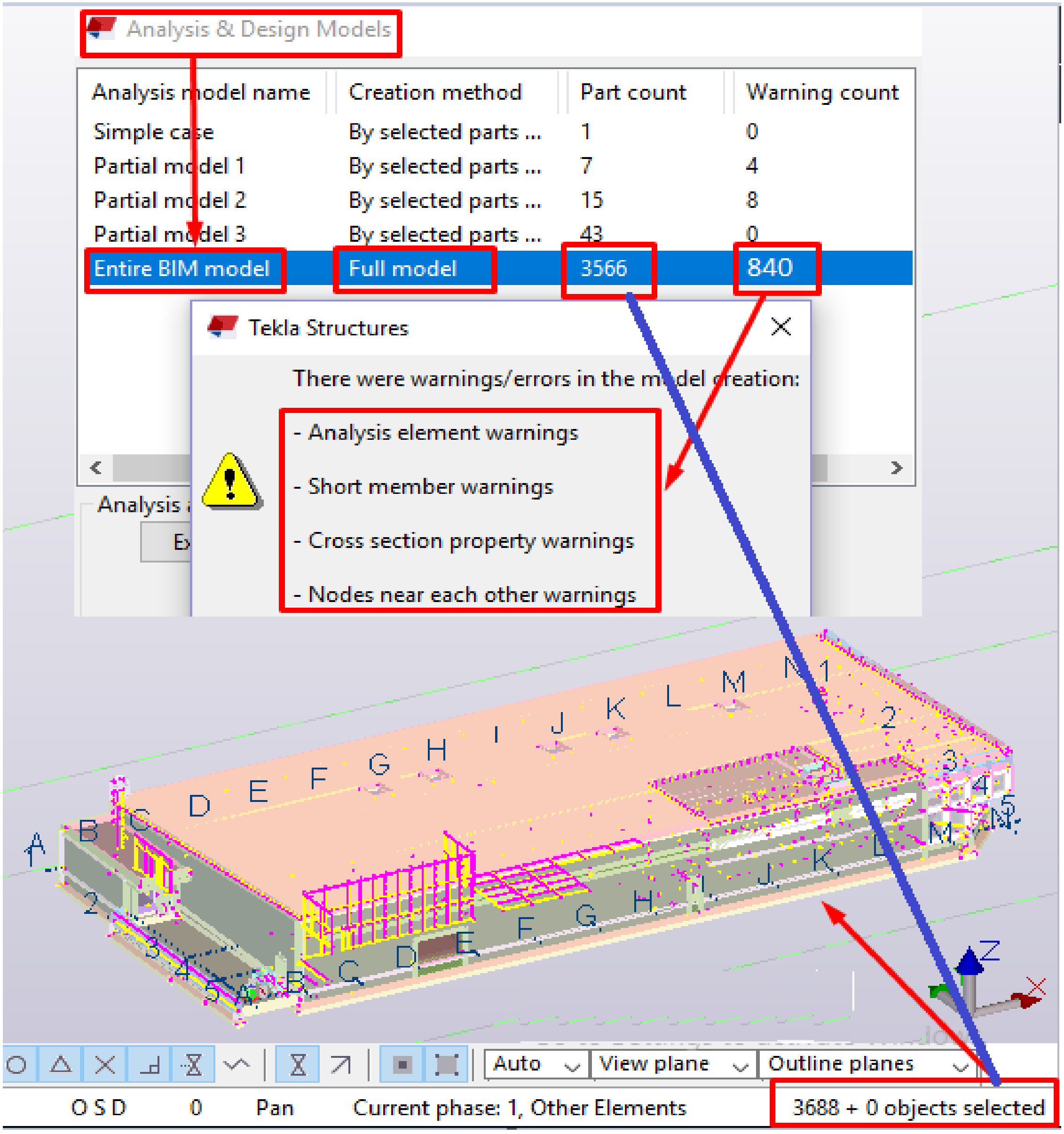


*Figure 6.46: Basic problems occurred after the creation of the analytical model of the entire BIM model of this project.*

Referring to Figure 6.46, not every object of this model has been considered in the analytical model. There was no automatic information from TSL to identify immediately which objects were not included in the entire analytical model. Thus, this process had to be manually analyzed by checking each object individually. A pad foundation of this project has been considered as a potential example to describe this process. Thus, the identified object (pad foundation) and the procedure of using manual modifications are shown in Figure 6.47.

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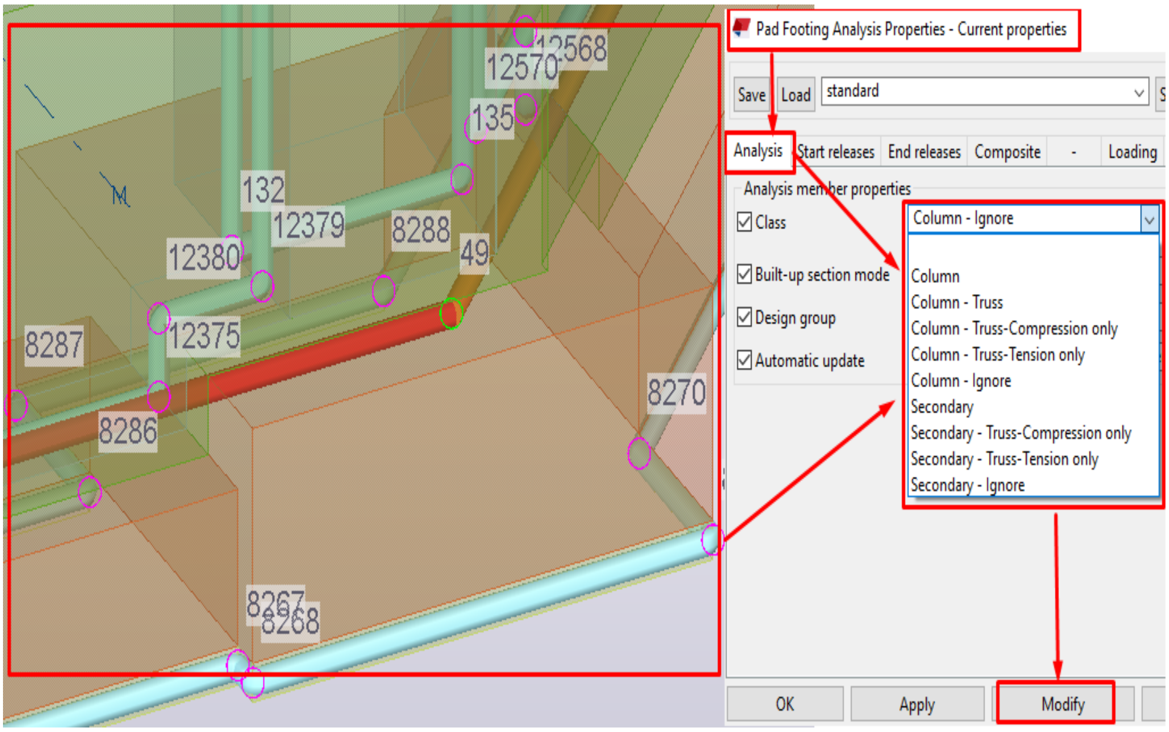
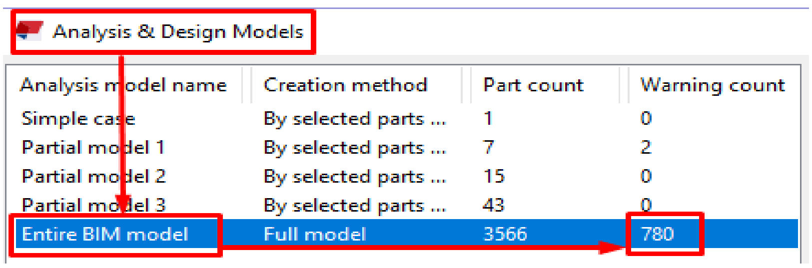



*Figure 6.47: Manual identification and modification of the object which has not been automatically recognized in the analytical model created in the case of the entire BIM model of this project.*

Related to the appearance of numerous of warnings/errors, it has already been mentioned that a possible option to reduce or eliminate such problems is; the use of different kinds of manual modifications to each element one by one. Since the number of warnings/errors is enormous and the nature of such problems was not similar for each element, manual modifications were impossible to be successfully finished. All we could do in this process is that we were able to reduce the total number of warnings/errors, by implementing some manual modifications which were applicable in this case (Figure 6.48).


Analysis & Design Models

| Analysis model name | Creation method | Part count | Warning count |
|---|---|---|---|
| Simple case | By selected parts ... | 1 | 0 |
| Partial model 1 | By selected parts ... | 7 | 2 |
| Partial model 2 | By selected parts ... | 15 | 0 |
| Partial model 3 | By selected parts ... | 43 | 0 |
| Entire BIM model | Full model | 3566 | 780 |

*Figure 6.48: Reduction of the number of warnings/errors in the case of the analytical model of the entire BIM model.*

Additionally, to test the interoperability and investigate the capabilities of using the data exchange methods for this study case, the analytical model which is shown in Figure 6.44, has been transferred from TSL to RFEM.

However, it was cleared before transferring the analytical model that it will not be correctly imported, based on the problems we described and elaborated before in this section. Also, due to the large size of data that the model contained, the program RFEM was slowed down during the transferring process. This notification from the "Help-Assistant" in the RFEM program can be seen in the following Figure 6.49.

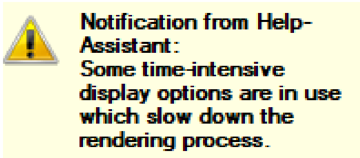



*Figure 6.49: Notification from the "Help-Assistant" in the RFEM program, while the analytical model has been on the way of transferring from TSL to RFEM.*

The analytical model created in the case of the entire BIM model of this project could only be partially transferred from TSL to RFEM, using the "direct link" and "IFC data model exchange" as applicable data exchange methods. On the other hand, the DSTV (*.stp) file format could not be used as an effective data exchange method for this study case.

Hence, the results of the two data exchange methods that could be used somehow in this study case are presented in Figure 6.50 and Figure 6.52.

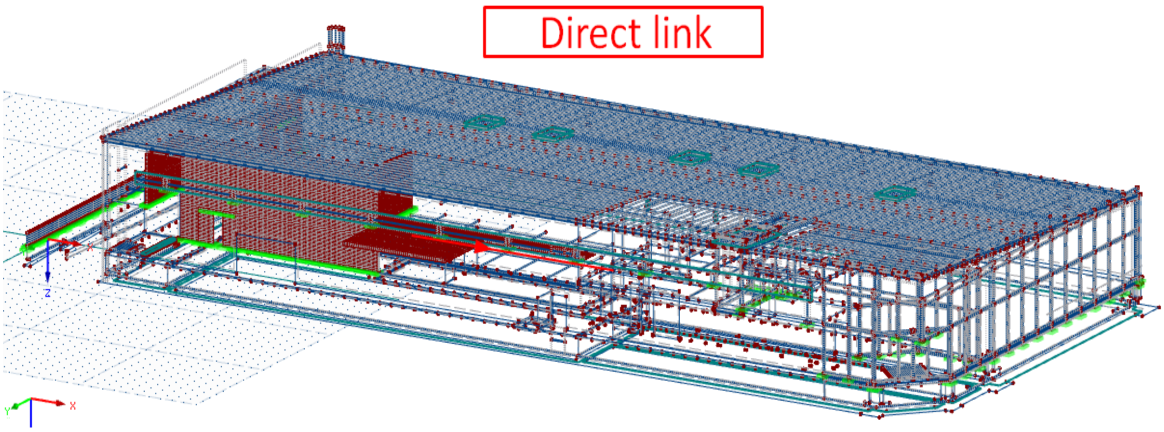



*Figure 6.50: Importing the analytical model of the entire BIM model of this project, using the "direct link" as data exchange method.*

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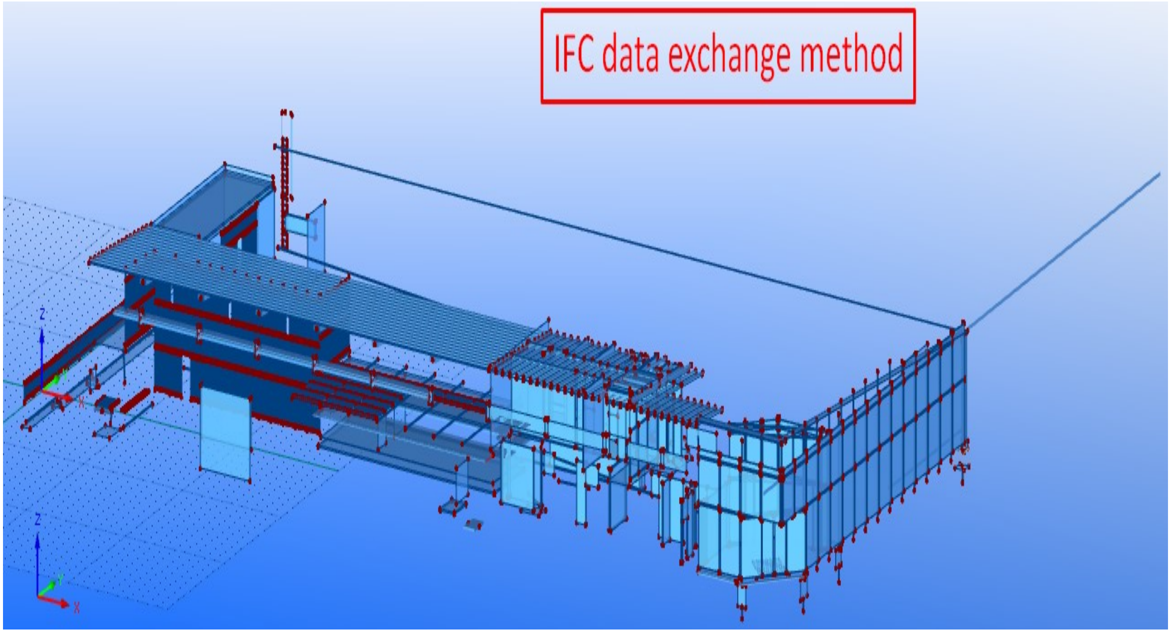


*Figure 6.51: Importing the analytical model of the entire BIM model of this project, using the "IFC data model exchange" as data exchange method.*

The reason why most of the objects could not be imported in RFEM, using the "IFC data model exchange" as data exchange method has been shown in Figure 6.52.

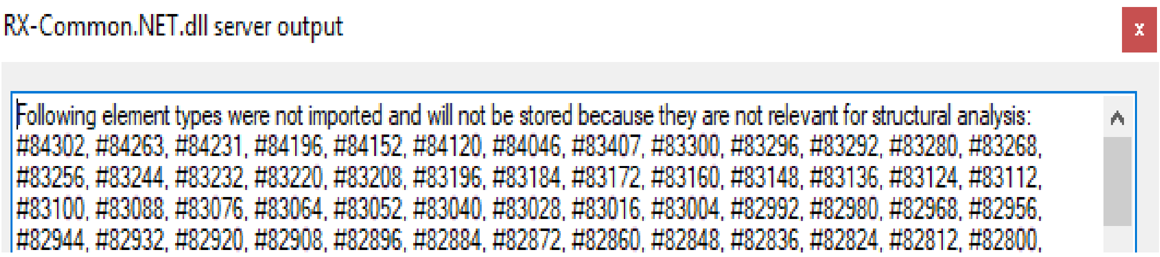


*Figure 6.52: The reason why numerous of objects from the analytical model of the entire BIM model could not be imported into RFEM.*

In addition, a summary of results, which were obtained after using the "direct link" and "IFC data model exchange" as applicable data exchange methods to transfer the analytical model of the entire BIM model of the Mall project from TSL to RFEM is given in Table 6.1.

*Table 6.5: Results of the data exchange methods used to transfer the analytical model of the entire BIM model of the Mall project from TSL to RFEM. The results are only evidenced and presented for the imported elements.*

| | **Direct link** | **IFC** |
|---|---|---|
| **BIM model elements** | ☑* | ☒* |
| **Geometry** | | |
| Nodes | ✔ | ✘+ |
| Lines | ✔* | ✘+ |
| Surfaces | ✔* | ✘+ |
| Openings | ✔* | ✘ |
| **Material properties** | | |
| Material description | ✔o | ✔□ |
| Modulus of Elasticity | ✔* | ✘* |
| Shear Modulus | ✔* | ✘* |
| Poisson's Ratio | ✔* | ✘* |
| Specific Weight | ✔* | ✘* |
| Coeff. of Th. Exp. | ✔* | ✘* |
| Partial Factor | ✔* | ✘* |
| **Boundary conditions** | | |
| Nodal supports | ✔ | ✘ |
| Line supports | ✔* | ✘ |
| Structural member type | ✔** | ✘** |
| **Section properties** | | |
| Cross-Section type | ✔* | ✘+ |
| Moments of inertia | ✔* | ✘+ |
| Cross-Sectional Areas | ✔* | ✘+ |
| Width b | ✔* | ✘+ |

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| | | |
|---|---|---|
| Height h | ✔* | ✘+ |

- ☑* - BIM model elements were partially imported correctly.
- ☒* - Only a few elements of the BIM model were correctly imported.
- ✔ - The property has been imported correctly.
- ✔° - The material of some elements has been partially imported correctly. In the case of concrete elements, it was not imported according to EN standards, but it was interpreted according to DIN standards.
- ✔□ - The material has been imported, but it was not described according to which standard it has been imported.
- ✔* - The property has been partially imported correctly.
- ✔** - Some of the member types were correctly imported and represented. Representation of other member types has not been imported correctly during the process, but some of them were well described separately in comments.
- ✘ - The property has not been imported correctly.
- ✘* - The property value was shown as zero.
- ✘+ - Properties of only a few elements were correctly imported.
- ✘**- Representation of only a few of member types has been imported correctly during the process.

# 7 STRUCTURAL ANALYSIS AND DESIGN USING DLUBAL SOFTWARE

In this section, Structural Analysis and Design (A&D) are performed in the case of two different partial models of the Mall project. Based on the research regarding interoperability between BIM and FEM software and results presented before in Section 6, partial models such as "the simplified mezzanine slab" and "structural steel elements" of the Mall project have been chosen as adequate models to be analyzed in this section.

The purpose of this section is not intended to present a detailed discussion of FEM analysis or structural analysis methods, but to provide a brief presentation of results obtained after performing such analysis in the transferred partial models from TSL to RFEM. Hence, this section presents a preliminary structural analysis and design performed in the case of the partial models of the Mall project. The structural analysis and design (A&D) and results were analyzed and checked with the help of Dlubal-Structural Engineering Software for Analysis and Design. Using RFEM the structural design has been implemented according to European Standards (EN), and SIST EN (National Annex) relevant to Slovenia territory.

## 7.1 A&D in the case of the partial models (simplified mezzanine slab and structural steel elements) of the Mall project

### 7.1.1 General description of the problem

Preliminary structural analysis and design (A&D) were performed in the case of two different types of partial models of the Mall project, based on the interoperability capabilities between BIM and FEM software shown before.

The first case deals with the structural mezzanine slab of the Mall project. Analytical and physical model of this structural element has been previously discussed in details in Section 6.4.2.

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The main problem that encountered after the creation of the analytical model of this element has been related to the form of the depressed slab. Therefore, in the case of performing preliminary A&D of this structural element, we have decided to simplify the form of the mezzanine slab from a depressed slab to a simple form of a slab, to avoid (eliminate) the above-mentioned problems in Section 6.4.2. Hence, the simplified physical model of the mezzanine slab has been shown in Figure 7.1.

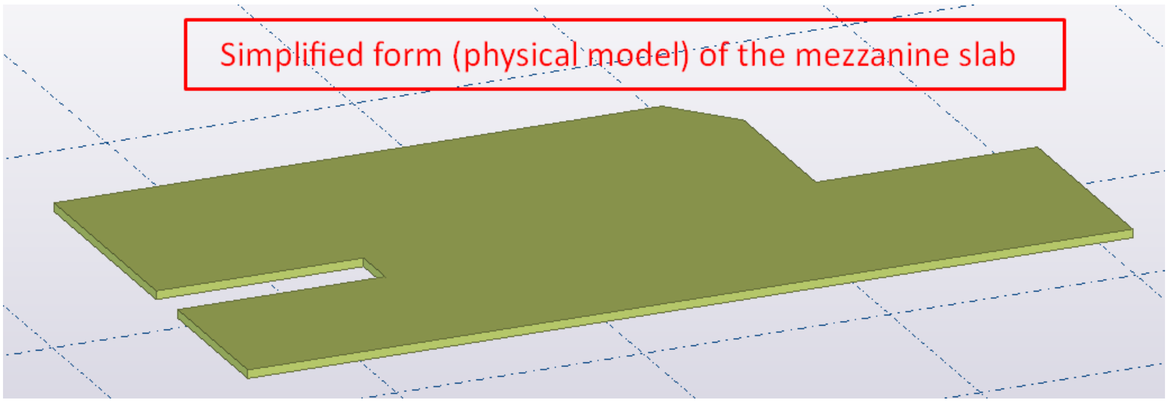


*Figure 7.1: The simplified physical model of the mezzanine slab in TSL.*

Additionally, the analytical model of the simplified form of the mezzanine slab has been presented in Figure 7.2.

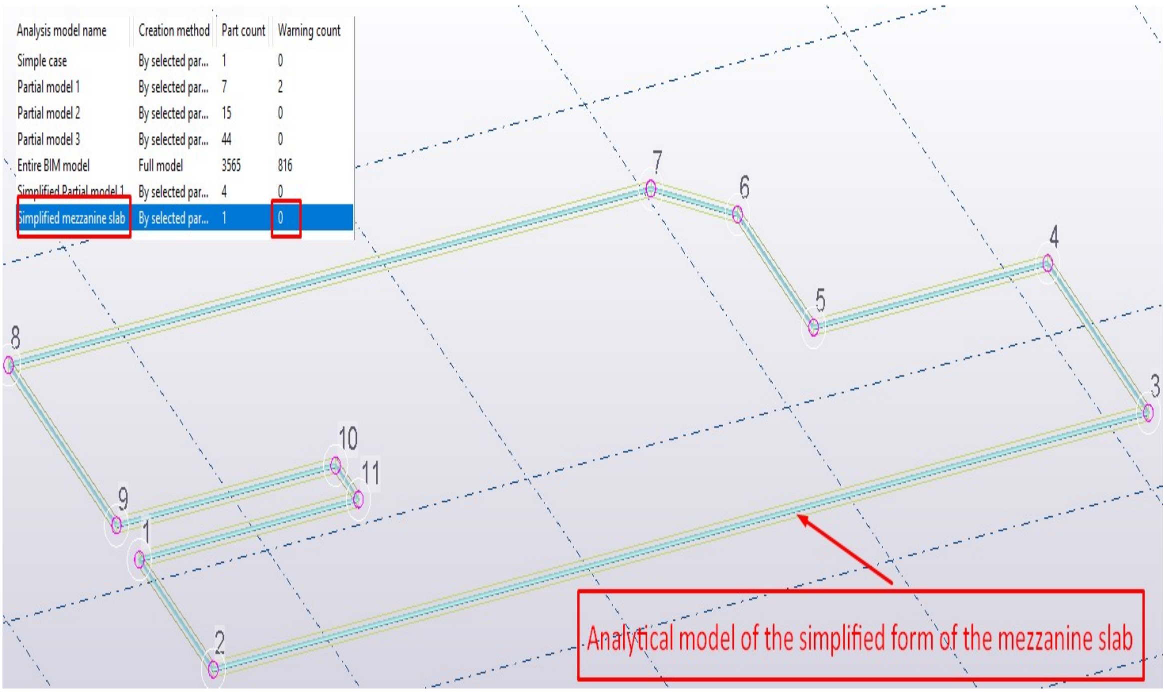


*Figure 7.2: Analytical model of the simplified form of the mezzanine slab in TSL.*

Referring to Figure 7.2, the previous problem due to the form (depressed slab) of this structural element has been eliminated, and no warnings/errors appeared anymore. This simplified model has been transferred from TSL to RFEM, using the data exchange methods, which are previously mentioned and explained in details in Section 6.2. The analytical model of this structural element, which is imported in RFEM using the "direct link" exchange method as the most useful and practical method so far, has been shown in Figure 7.3.

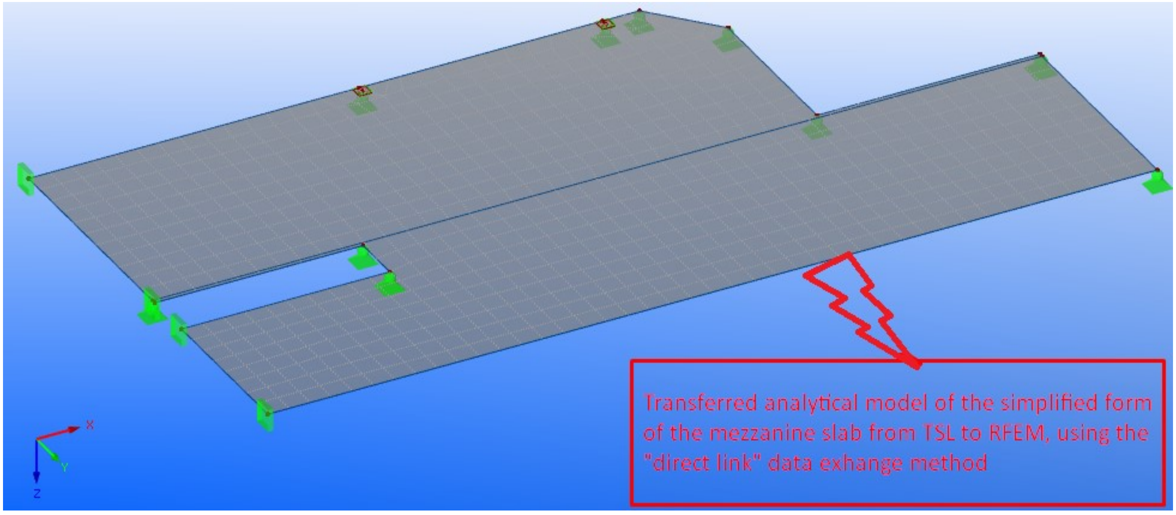


*Figure 7.3: The analytical model of the simplified form of the mezzanine slab, transferred from TSL to RFEM.*

Before performing structural analysis and design in the case of this simplified analytical model in RFEM, it was necessary to verify if the material and boundary conditions of this structural element have been correctly transferred and well recognized in RFEM. Such verification processes have been discussed in details in Section 6.4.2 and Table 6.2, respectively. Thereby, manual modifications were necessary to carry out in this case. A not well-recognized material had to be modified and edited in accordance with the European Standards (EN).

In addition, since only nodal supports of this structural element could be created in TSL and transferred afterward to RFEM, the line supports had to be manually set up in RFEM (see Figure 7.4). Two types of slab supports could be defined in RFEM: supports created when the slab was being supported by other elements in a structure model (walls, columns, beams, etc.), and support types that could be defined directly in RFEM.

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The second case that was chosen to be analyzed and discussed in this section is related to the third case study of this project, which has been previously elaborated in details in Section 6.4.3. This study case deals with the structural steel elements of the Mall project. Referring to Figure 6.31, the most proper form of the analytical model of this partial model was obtained, after it has been transferred from TSL to RFEM using the "direct link" exchange method. Hence, no additional modifications in the analytical model (except changes of unrecognized material and cross-section properties of the relevant elements) were necessary to be set up.

### 7.1.2 Preliminary Analysis and Design (A&D)

Before running the finite element computation, the analytical model of the simplified form of the mezzanine slab was modified in RFEM, and it is shown in Figure 7.4.

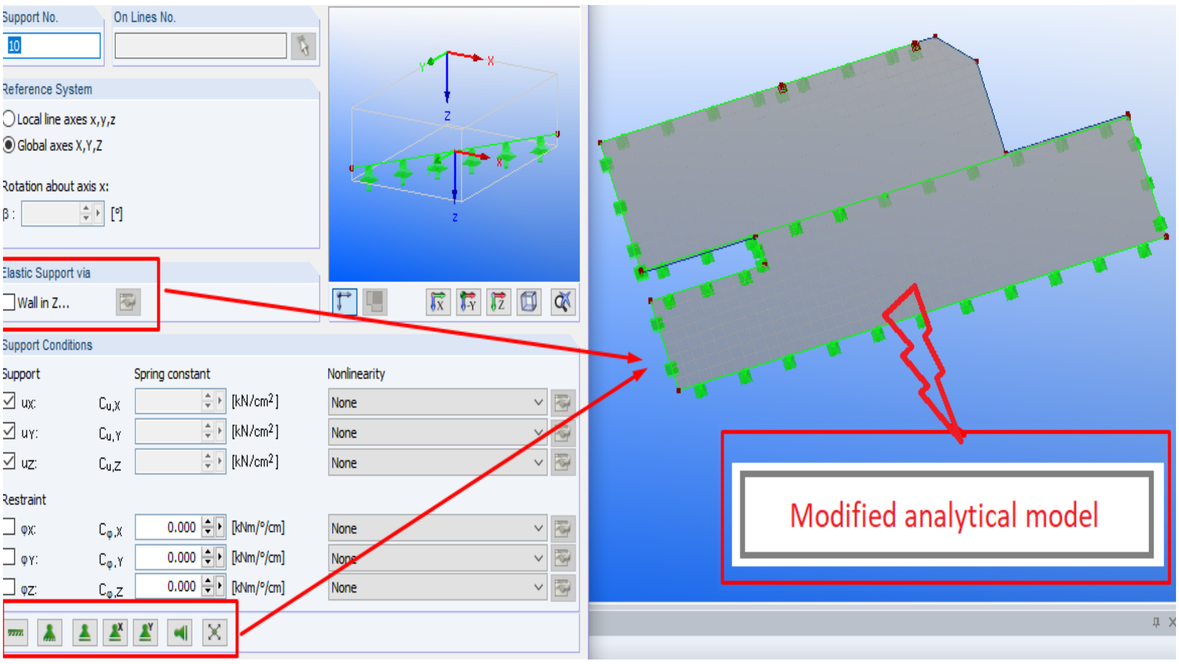


*Figure 7.4: The modified analytical model of the simplified mezzanine slab, using relevant slab supports defined in RFEM.*

Referring to Figure 7.4, two basic types of supports (two nodal supports result from the slab being supported by columns, and edge supports result from the slab being supported by walls) have been considered in the case of this partial analytical model of the Mall project.

Another important step in the case of the simplified form of the mezzanine slab was to set up the meshing parameters before performing the FEA (Finite Element Analysis). This could be achieved by selecting the “Display FE Mesh” tab of the “Static Calculation” of slabs tool in RFEM. Additionally, the characteristics of materials and cross-sections, which are used in the case of these analytical models in RFEM, can be found in the Appendices of this thesis. The load cases and load combinations which are considered in the case of such models have been generated automatically in RFEM. They were set out in accordance with Eurocode 0 (EN 1990) and relevant National annex (SIST EN) in compliance with the corresponding combination expressions.

When all the necessary modifications were done, the structural analysis and design were performed for both cases.

### 7.1.3 Interpretation of basic results from RFEM

After the FEA was performed in RFEM software the results obtained include global and local displacements, support reactions, basic internal forces, etc. To represent the basic results obtained in the case of the simplified model of the mezzanine slab, the local displacement results (extreme values) and the required reinforcement (top) in the X direction of the element, were chosen to be presented in this section. These results can be seen in Figure 7.5 and Figure 7.6, respectively.

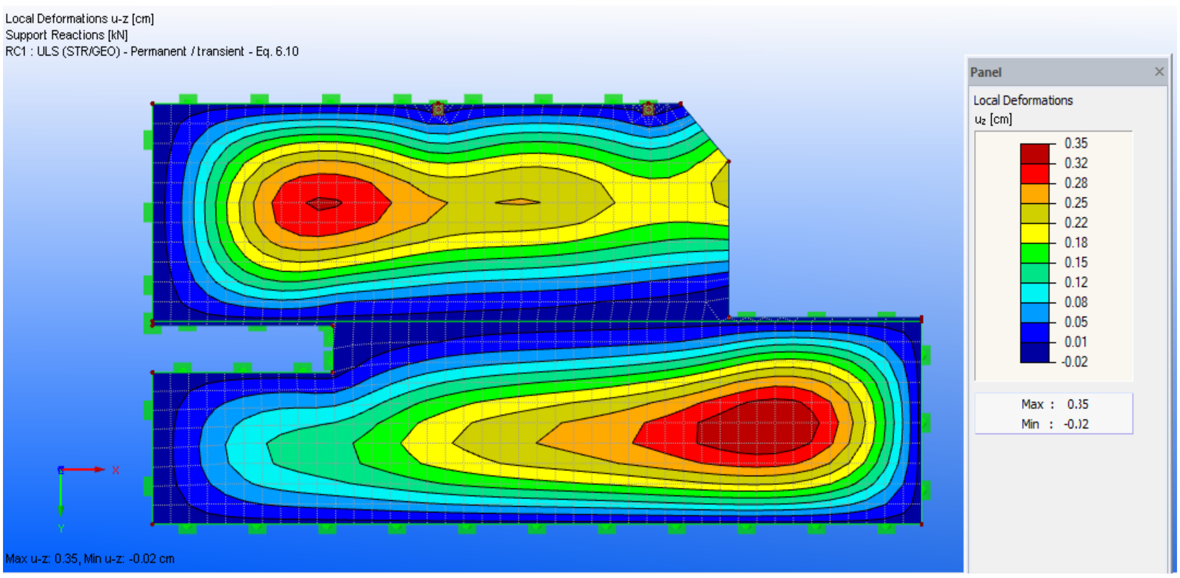


*Figure 7.5: Local displacement results obtained in the case of the simplified model of the mezzanine slab, using preliminary A&D in RFEM.*

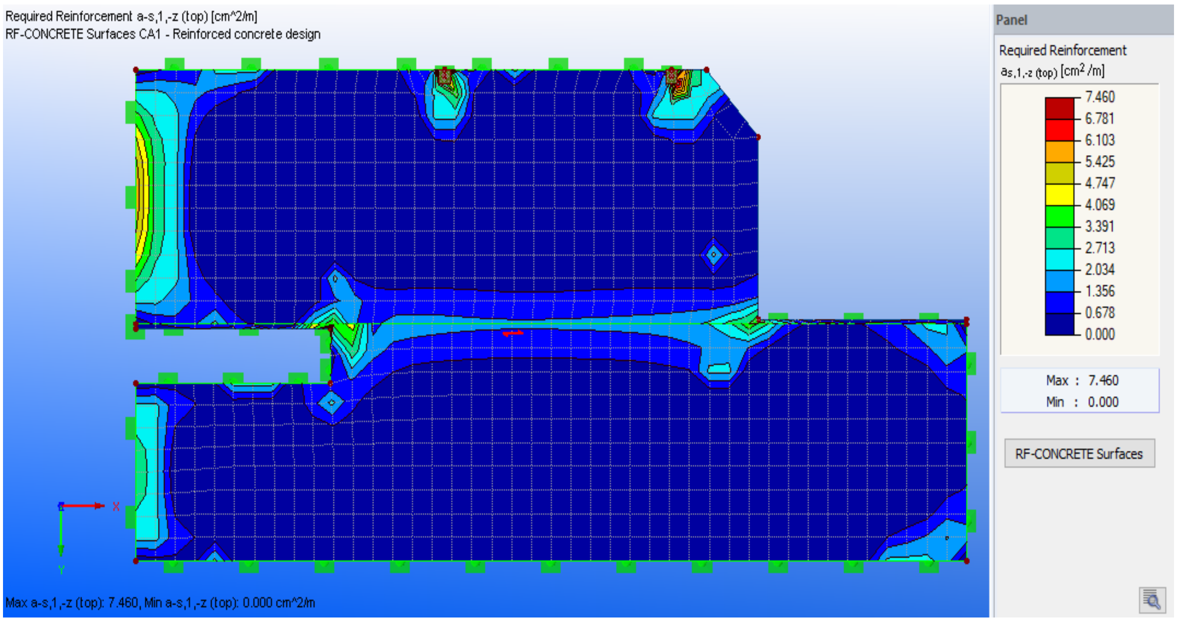


*Figure 7.6: Required reinforcement (top) in the X direction of the simplified model of the mezzanine slab.*

Additionally, in the case of structural steel elements of the Mall project, global displacements results (extreme values) and maximum design ration (utilization) of steel profiles are shown in Figure 7.7 and Figure 7.8, respectively.

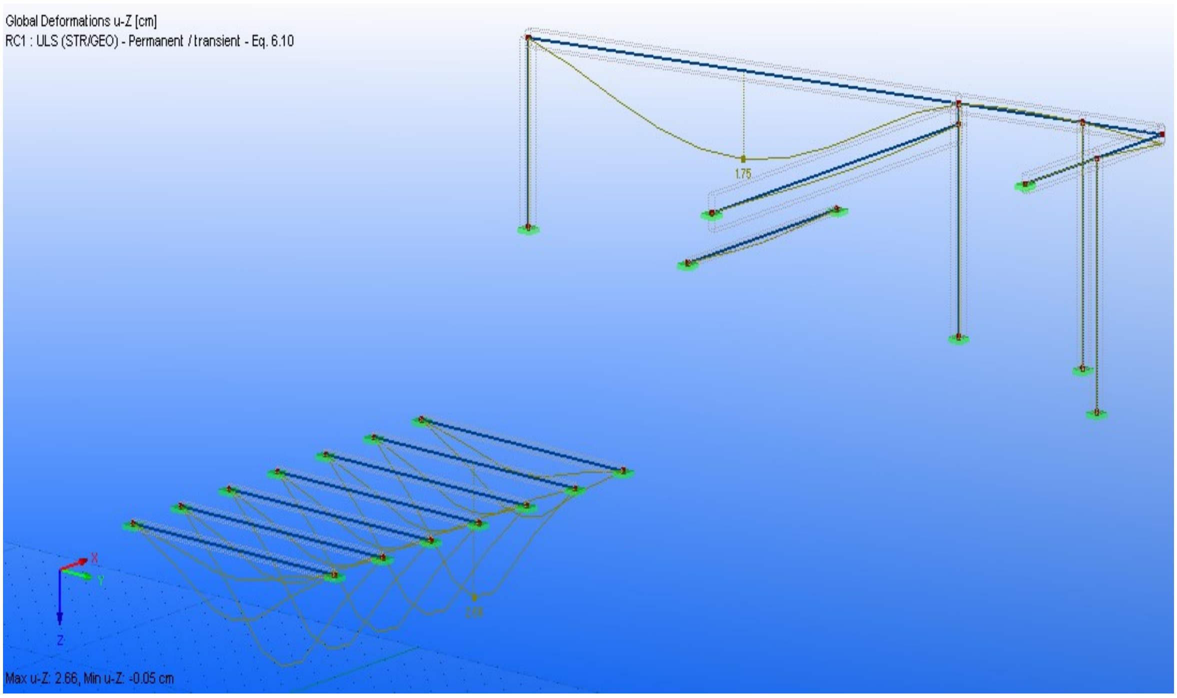


*Figure 7.7: Global displacement results obtained in the case of steel elements in RFEM.*

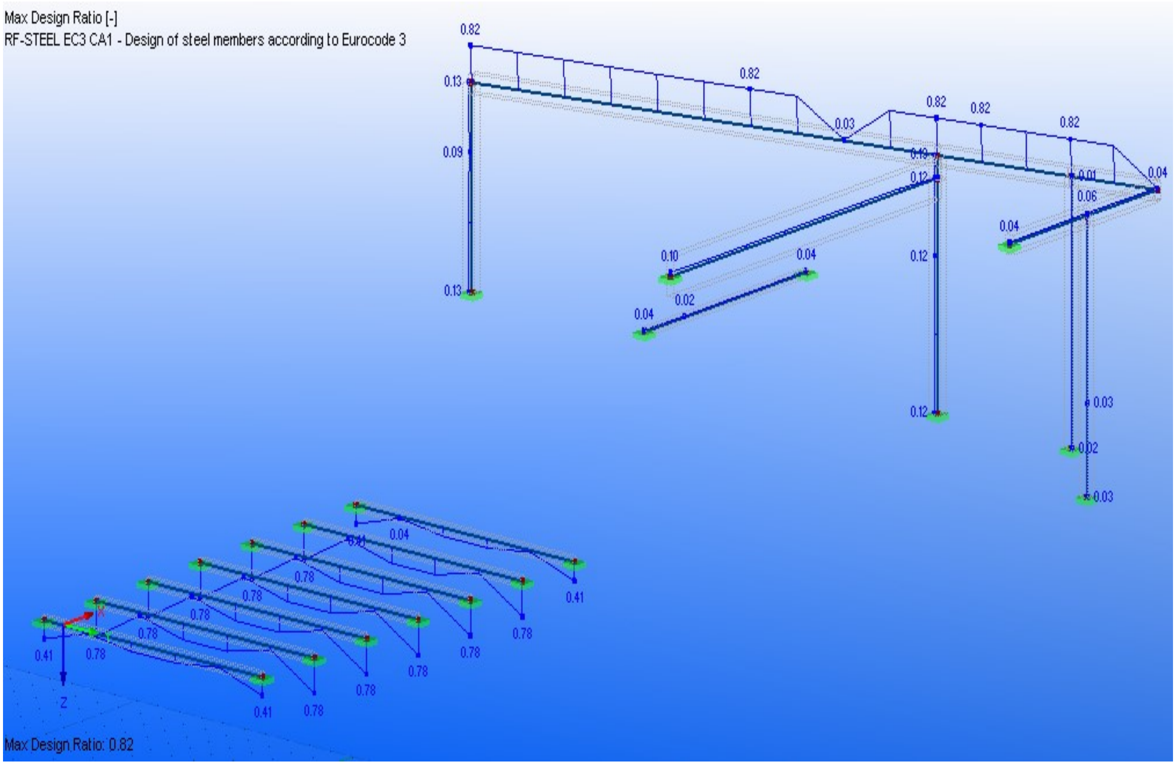


*Figure 7.8: Design ratio of steel profiles obtained in RFEM.*

Referring to Figure 7.8, an optimization of most of the steel profiles used in the case of this project could be further done. However, as already mentioned before, this section provides only a preliminary structural analysis and design of the relevant chosen parts in the case of the Mall project. Therefore, only preliminary results obtained in RFEM are presented in this section.

The design of the simplified model of the mezzanine slab was done using the following Add-on Module in RFEM: RF-CONCRETE Surfaces - Design of concrete surfaces. While, in the case of designing the steel elements, Add-on module: RF-STEEL EC3 – Design of steel members according to Eurocode 3 has been used. Basic results obtained in RFEM software (including the used Add-on Modules), relevant to these partial models discussed in this section, can be further found in the Appendices.

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# 8 CONCLUSIONS

## 8.1 Brief description and purpose of the thesis

Before going into details of presenting key findings related to the main topic of this project, a brief description of the work and purpose of this thesis is given.

Firstly, a general overview of Building Information Modeling (BIM) and interoperability issues has been presented in the beginning sections of this thesis. The aim of these sections was to introduce the basic information of such important areas, which were considered very useful and applicable in the research we have done in this thesis.

In this thesis, two types of engineering software were used to cover the general purposes of the research. Tekla BIM software was chosen as the appropriate BIM software, to cover modeling and drawing parts, as well as creating relevant analytical models applied in the case of the entire and partial BIM models of the Mall project. Dlubal-Structural Engineering Software for Analysis and Design considered as FEM software, has been used in the case of importing analytical models created in Tekla BIM software, related to the case studies performed in this thesis. It was also utilized to perform further structural analysis and design (A&D) calculations, in the case of the partial analytical models of this project. A general description and overview of the used software have been introduced in Section 4.

In addition, Mall project has been described with the help of modeling functionalities that Tekla BIM softwares offers in general. Each phase of the Mall project has been modeled using Tekla BIM software standards and settings, relevant to this project. They were described and discussed in details in Section 5. Since documents and visualization of the project plays a very important role in the construction industry, different types of drawings and 3D visualization that contains detailed information were also described and included in this section. However, it should be noted that the BIM model of this project has been created and detailed with the help of 2D CAD architectural drawings as the input, which were prepared by Gravitas, design and engineering company Ltd (Gravitas d.o.o, 2017).

The most important parts of the research and major findings, related to the main topic of this thesis have been discussed in Section 6. A general description and procedure of creating different kinds of analytical models, relevant to entire and partial BIM models of this project were presented. Every problem that arose after the creation of such analytical models in TSL has been analyzed, and the relevant recommendations in case of avoiding or eliminating such problems were given in details in this section. Additionally, in the case of transferring analytical models from TSL to RFEM, various available data exchange methods were presented and practically elaborated. A procedure for updating the existing models in TSL using the direct interface from RFEM has also been included in the first study case of this project. Key findings and recommendations of using the relevant data exchange methods, related to the main topic of this thesis have been presented in this section and results are further summarized in Table 8.1.

In order to further investigate the capabilities of data exchange methods and the importance of importing the created analytical models in TSL, preliminary structural analysis and design (A&D) in the case of partial analytical models of this project were performed in RFEM. A brief description and some of the most important results obtained after performing such analysis were presented in Section 7 of this thesis.

After summing up all contents of the whole chapters, a summary of results, related to the key findings from the case studies used to explain the main topic of this thesis has been further elaborated in details in Section 8.2.

## 8.2 Summary of results

In this section, a conclusion that incorporates a summary of the major findings and recommendations from the case studies used in the case of a Mall project is presented.

In addition, the purpose of this section is to provide an evaluation of the case studies examined in the case of the entire and partial BIM models of the Mall project for each data exchange method separately.

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An evaluation of results obtained after creating various types of analytical models for each case study has also been presented in Table 8.1.

*Table 8.1: Summary of results regarding major findings related to interoperability.*

| CASE STUDY | Analytical model | Data exchange method | | |
|---|---|---|---|---|
| | | Direct link | DSTV (*.stp) | IFC |
| 1. Simple case – Concrete column | ☑ | ☑+ | ☒± | ☑- |
| 2. Partial model 1 – Ground and intermediate floor slabs | ☒* | | | |
| 3. Partial model 2 – Structural steel elements | ☑ | | | |
| 4. Partial model 3 – Structural concrete walls and columns | ☑* | | | |
| 5. Entire BIM model | ☒** | | | |

The evaluation of the obtained results included in Table 8.1, related to the key findings and recommendations for the case studies performed in the case of the Mall project, is given below:

- ☑ - The analytical models were generally correctly created.

  No additional improvements were required to be made in the case of the concrete column and structural steel elements of the project (except if the manual changes regarding boundary conditions of the structural elements were needed).
  Hence, before creating different kinds of analytical models in TSL, it is always recommended to set up necessary analysis properties of each structural element of the project individually, in a proper way that will decrease the number of manual modifications in the future.

- ☒* - Half of the physical models could be correctly transformed into analytical models.

  The main problem that arose during the creation of the analytical models in the case of the partial model 1 of this project was related to the depressed slabs. The way of creating such elements was not well recognized in TSL. Therefore the analytical model in the case of depressed slabs was not correctly created. It is recommended to avoid modeling of slabs in the form of depressed slabs when further structural analysis and design (A&D) are required to be performed in such cases. Hence, the depressed slab had to be simplified in the form as it is shown in Section 7.1.1, in case of being able to further perform relevant structural analysis and design.

- ☑* - The analytical model could be partially correctly created.

Unavoidable manual modifications were necessary to be made. Since the entire BIM model of this project has been created in the way that it shall be built in the real world, the connectivity of the elements included in the case study (Partial model 3 – Structural concrete walls and columns) was the main problem. To avoid such problems it is recommended to connect every element in accordance with their axes. Eventual gaps and the eccentricity of the elements, relevant to this study case, could be eliminated and manipulated by using the rigid links in TSL.

- ☒** - The analytical model could not be properly created.

In the case of the entire BIM model, the analytical model could be automatically created, but the number of problems that arose afterward was enormous. The nature of such problems was not manageable in an automated way in TSL. They could not even be manually eliminated. Hence, it is always recommended to break up the entire BIM model of the project into partial models, in case of being able to manage easily the process of creating analytical models in TSL.

- ☑+- Analytical models could be generally correctly transferred from TSL to RFEM, using the direct link data exchange method.

Based on the results obtained from the case studies performed in the case of this project, it can be stated that the direct link was definitely the best of the data exchange methods that were examined both in terms of technical capabilities and ease of use. It was possible to transfer the majority of data that was needed to perform further structural analysis and design. Only some of the unavoidable manual modifications such as the conversion of the unrecognized materials and cross-section types/properties between different software vendors and necessary interventions regarding boundary conditions of individual elements were required to be made before and after transferring relevant analytical models, using this data exchange method.

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- ☒± - The majority of the analytical models could not be correctly transferred from TSL to RFEM, using the DSTV data exchange method.
  Most of the elements included in different kinds of analytical models, relevant to this project, could not be imported in RFEM at all. Numerous of manual modifications were needed to be made in the case of the transferred elements. It must be noted that this data exchange method is mostly applicable for steel structures. Therefore, numerous of problems arose after using this data exchange in most case studies of this project. The technical capabilities of the DSTV (*.stp) data exchange method varies mostly based on the material used. Hence, it is recommended to avoid using this data exchange method, when the majority of the elements are not made of steel.
- ☑- - Not every element of different analytical models could be transferred from TSL to RFEM using the IFC data exchange method.
  Most of them could not be imported in a proper way. This means that some of the elements (referring mostly to the material and cross-section properties of the used elements) were not well recognized or could not be transferred at all. Numerous of manual modifications were necessary to be made, before and after transferring different analytical models created in the case of this project. Similarly to DSTV (*.stp) data exchange method, this data exchange scenario varies also in the material used. It must be stated that the IFC is a simple data exchange method and easy to use, provided that the default and potential edited settings can be used. It is advisable to avoid the use of this data exchange method when the BIM model such as entire BIM model in the case of the Mall project contains different types of materials, and the geometry of elements is complex.

In summary, a high-quality BIM model created in the case of each partial model of the Mall project was essential for the interoperability between BIM and FEM software to work. However, the imported partial models also needed to be thoroughly examined after import, and the necessary modifications had to be implemented. Once all of the above-mentioned processes could be well synchronized through the interoperability technique, less-complicated structural calculations in RFEM could be performed and the results obtained were satisfactory.

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`

# 10 APPENDICES

## 10.1 List of figures

`

`

## 10.2 List of tables



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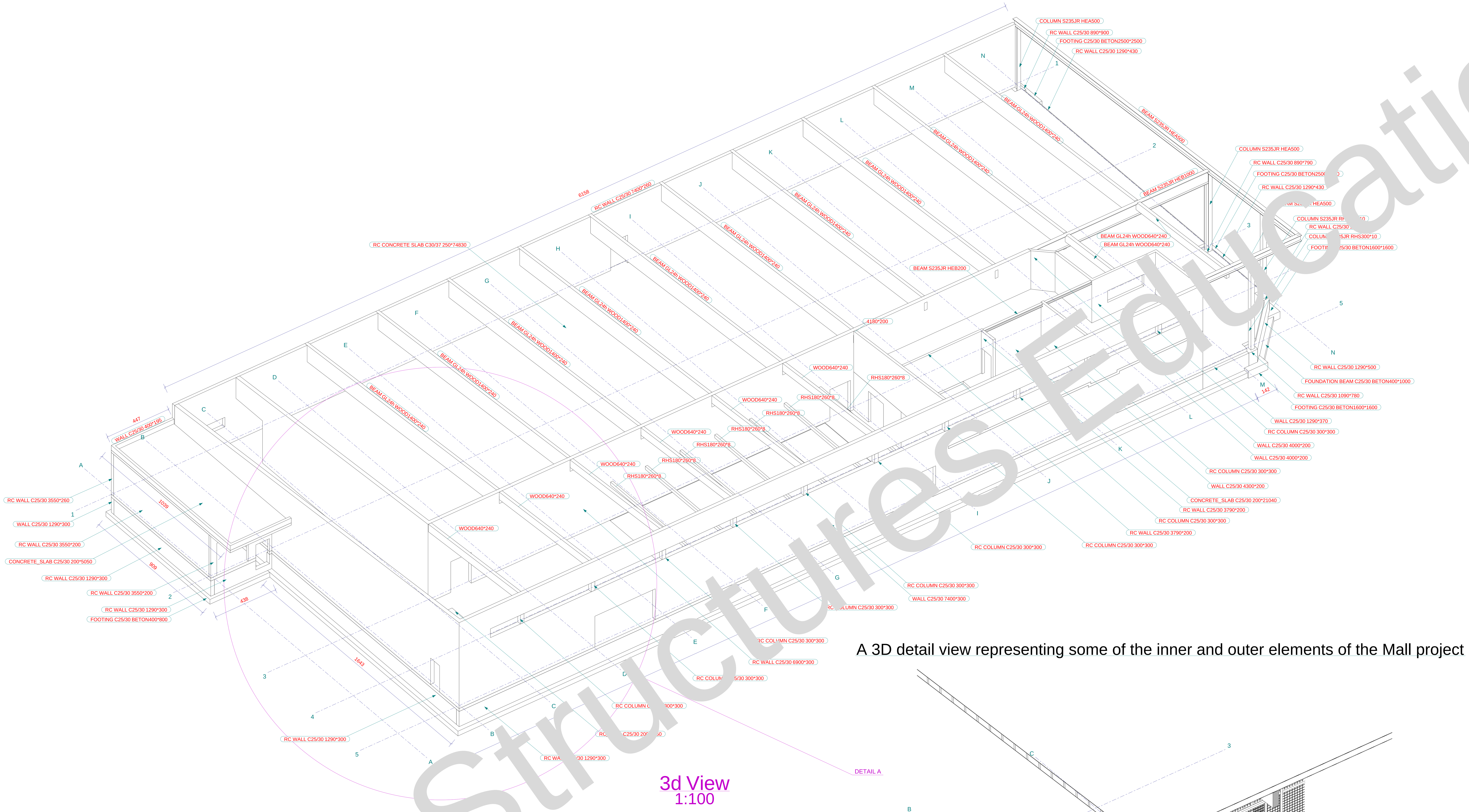
## 10.3 Examples of drawing types created in TSL

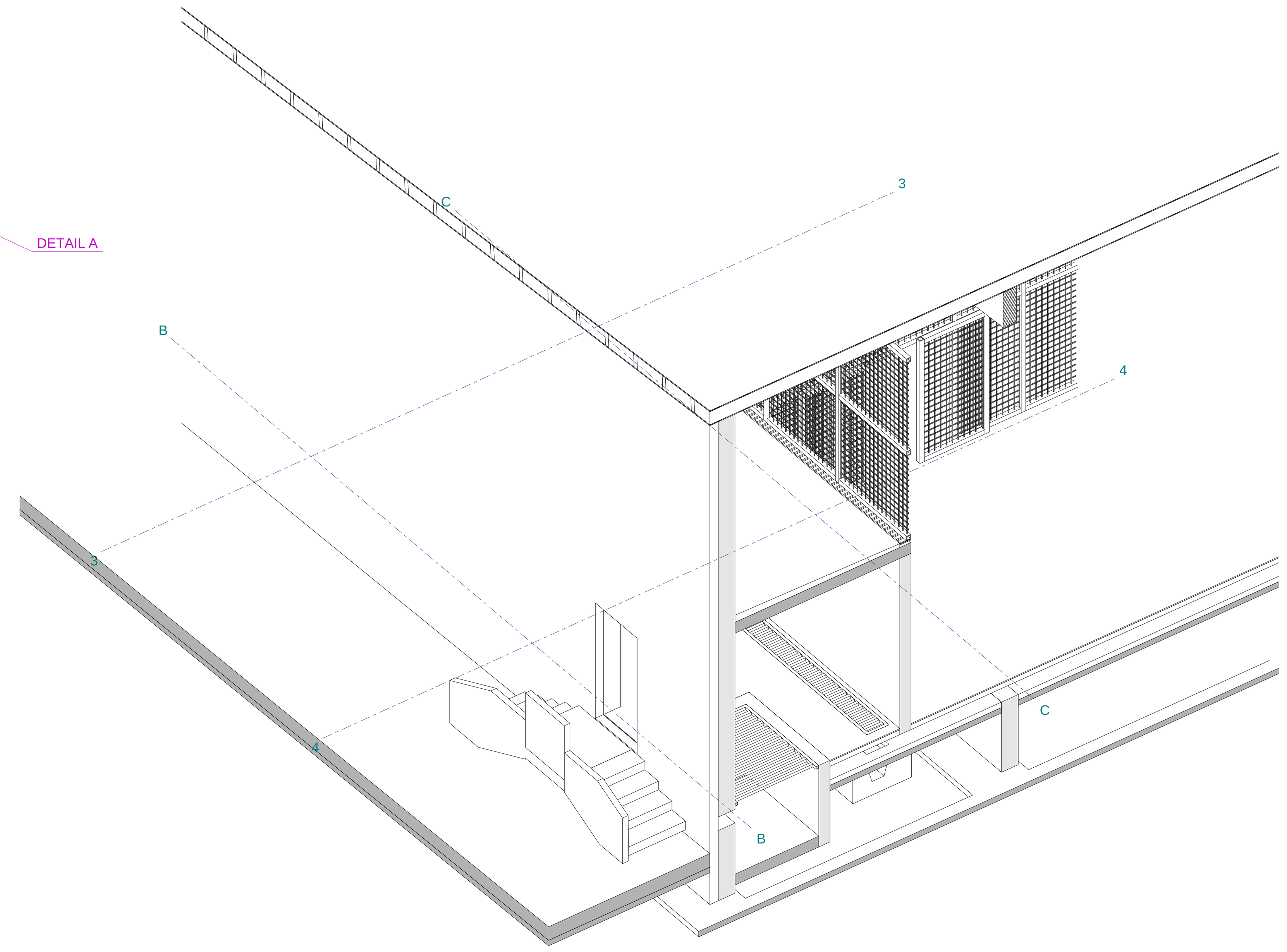
### 10.3.1 GA drawing

# 3D General Arrangement (GA) drawing - Structural elements of the Mall project




3d View
1:100

A 3D detail view representing some of the inner and outer elements of the Mall project



Detail A , 1:50



| | |
|---|---|
| Fabrication and erection acc. to NEN-EN 1090-2:2008+A1:2011 | |
| Execution class: EXC2 | |
| Effective tollerance class: XXX | |
| PROJECT: Master Thesis Model | Designer: Drilon Rraci |
| SUBJECT: 3D GA Drawing | Date: 30.11.2017 |
| | Scale: See view |
| BUILDER: Maribor, Slovenia | Powered by Trimble Tekla |

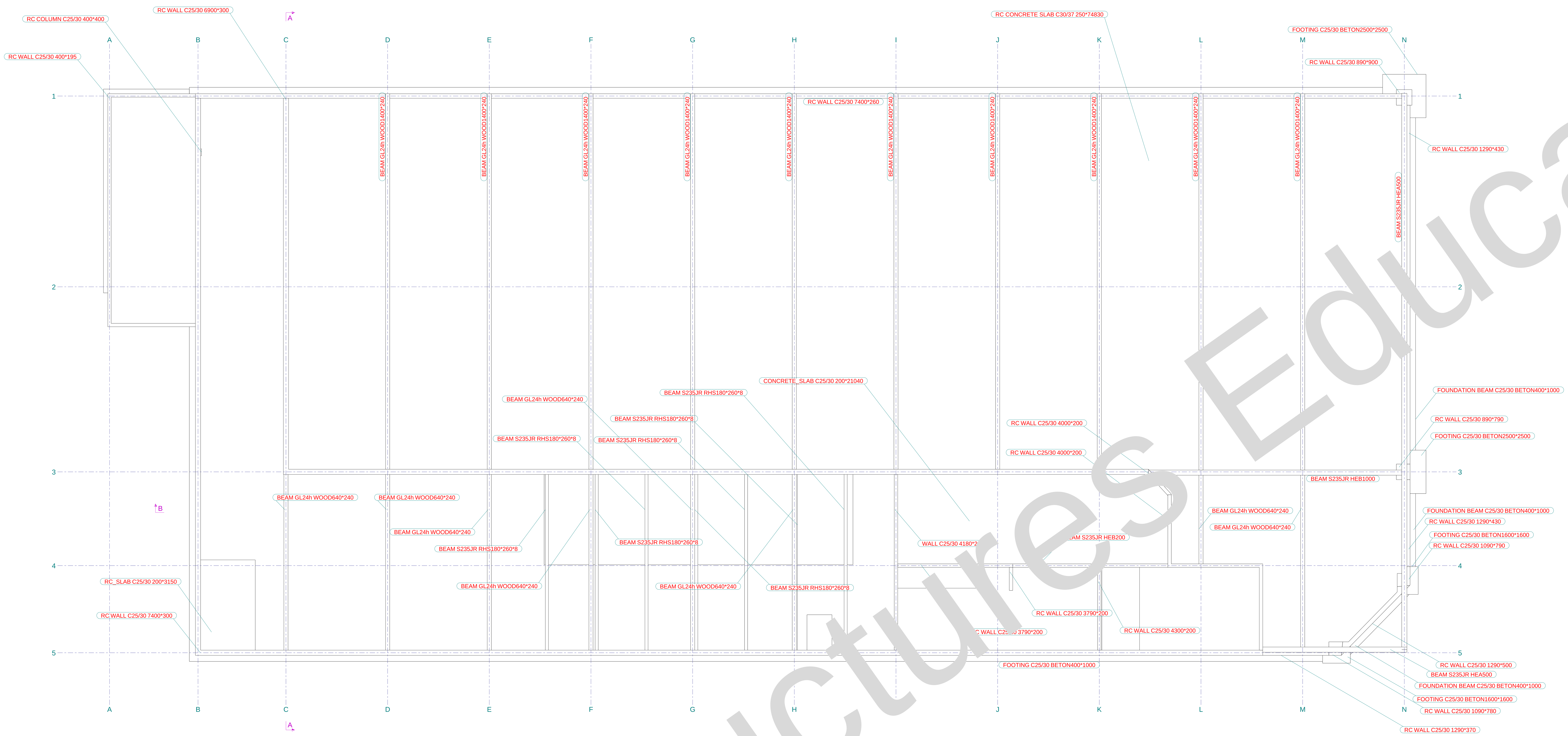
Material types and grades: Plates and profiles according to NEN-EN 10025-2, tubes and RHS profiles: according to NEN-EN 10210-1 (hot rolled) according to NEN-EN 10219-1 (cold rolled)
Welds a=4, unless mentioned different, according to NEN-EN-ISO 2553:2014. Bolt grade 8.8, unless mentioned different

Projection:

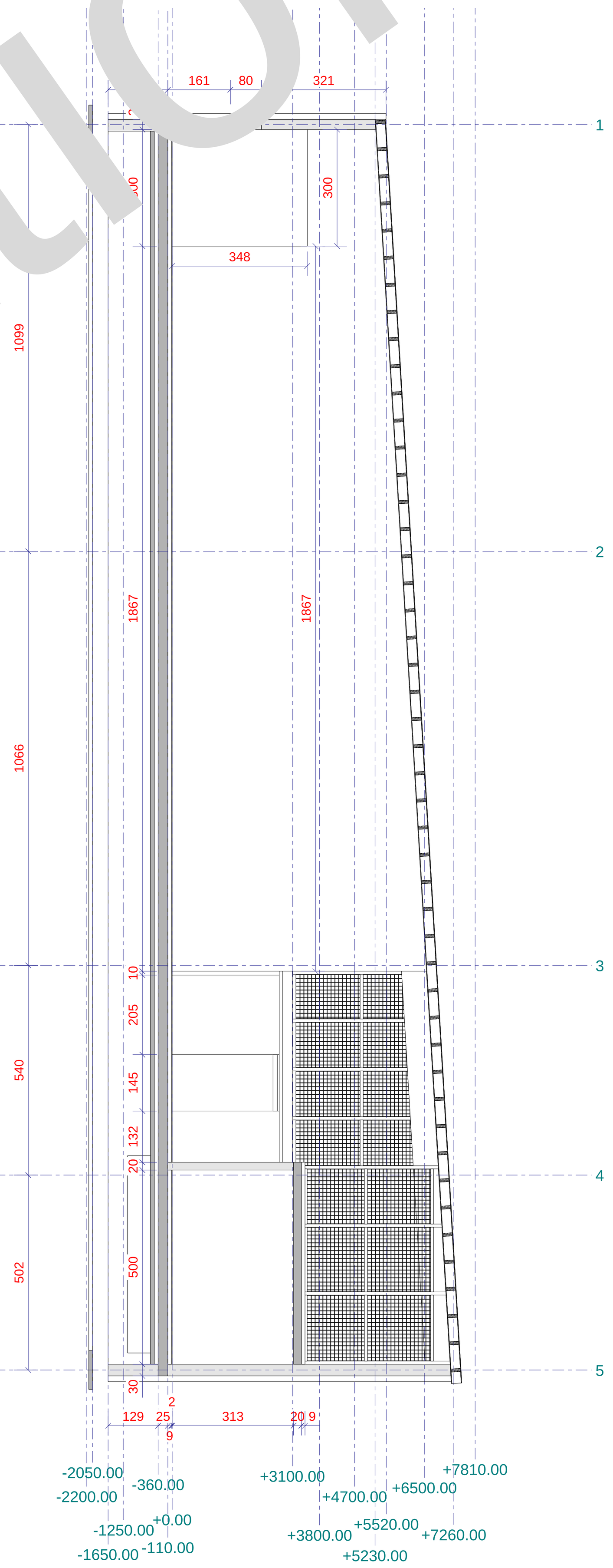
Univerza v Mariboru
Fakulteta za gradbeništvo, prometno inženirstvo in arhitekturo

Project: 1-1
Drawing: G [1]
Size: A0
Status: Approved

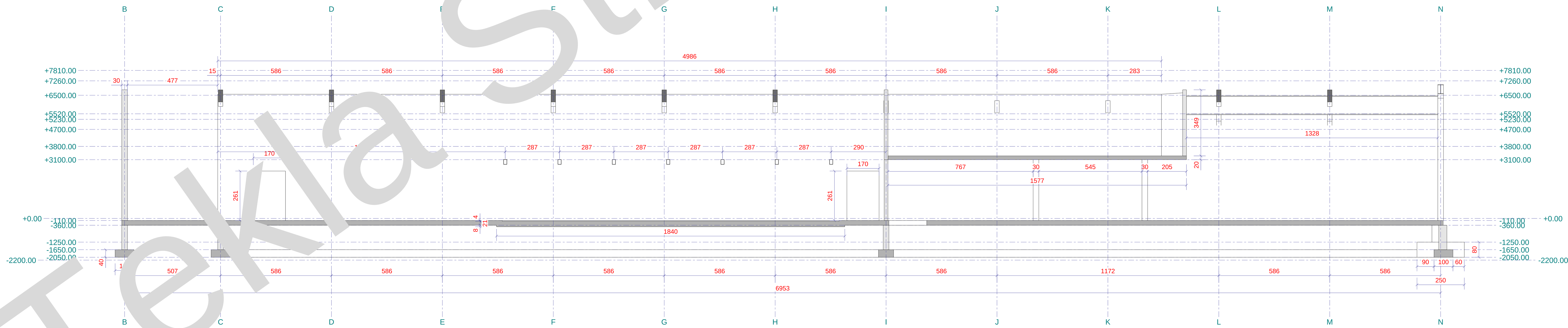
# 2D GA Drawing - Top and Section views of different elements of the Mall project




PLAN +0.00
1:100




View A - A
1:100




View B - B
1:100

| | |
|---|---|
| Fabrication and erection acc. to NEN-EN 1090-2:2008+A1:2011 | |
| Execution class: EXC2 | |
| Effective tollerance class: XXX | |
| PROJECT: Master Thesis Model | Designer: Drilon Rraci |
| SUBJECT: 2D GA Drawing | Date: 01.12.2017 |
| | Scale: See view |
| BUILDER: Maribor, Slovenia | Powered by Trimble Tekla |

Material types and grades: Plates and profiles according to NEN-EN 10025-2, tubes and RHS profiles: according to NEN-EN 10210-1 (hot rolled) according to NEN-EN 10219-1 (cold rolled)

Welds a=4, unless mentioned different, according to NEN-EN-ISO 2553:2014. Bolt grade 8.8, unless mentioned different

Projection:

Univerza v Mariboru
Fakulteta za gradbeništvo, prometno inženirstvo in arhitekturo

Project: 1-1
Drawing: G [2]
Size: A0
Status: Approved

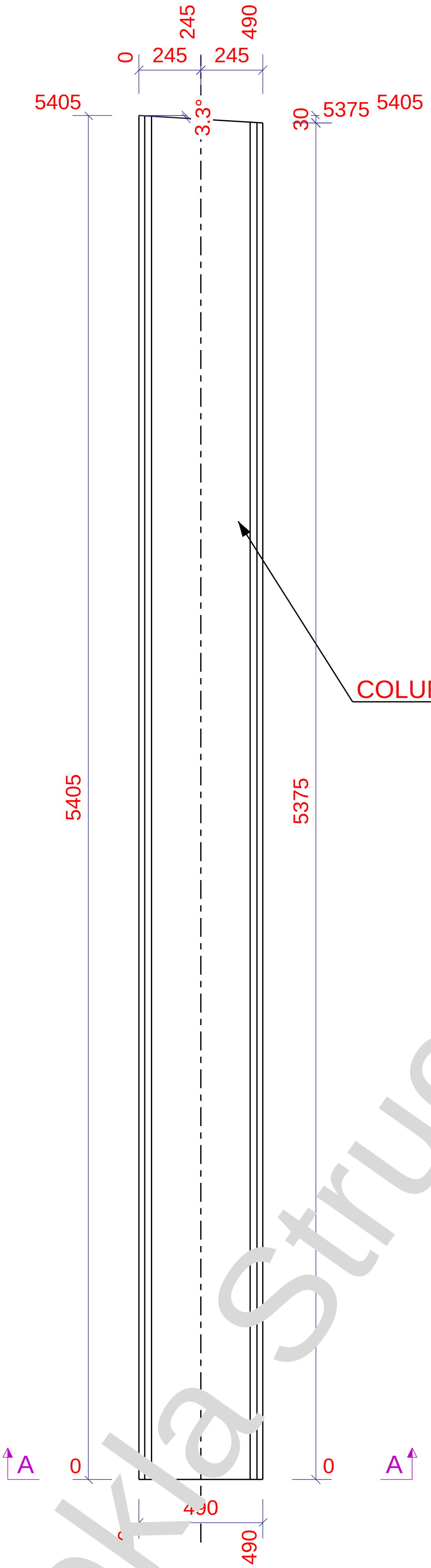
Tekla Structures model Master Thesis Model V7 plotted on 01.12.2017

### 10.3.2 Single-part drawing

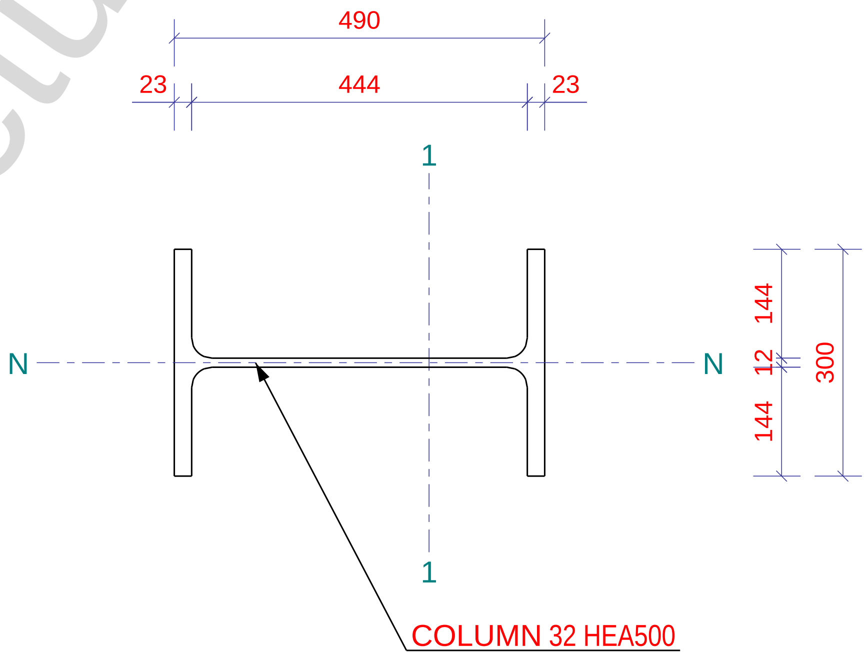
`

| Part | Profile | Length | Number | Assembly |
|---|---|---|---|---|
| 32 | HEA500 | 5405 | 1 | 32 |
| | | Total number: | 1 | |

# Single Part Drawing - A column (steel profile) in the case of the Mall project.




## View A-A
1:10




Fabrication and erection acc. to NEN-EN 1090-2:2008+A1:2011
Execution class: EXC2
Effective tollerance class: XXX

| | |
|---|---|
| PROJECT: Master Thesis Model | Designer: Drilon Rraci |
| SUBJECT: Single-part drawing | Date: 30.10.2017 |
| | Scale: 1:10 1:25 |
| BUYER: Maribor, Slovenia | Powered by Trimble Tekla |

Material types and grades: Plates and profiles according to NEN-EN 10025-2, tubes and RHS profiles: according to NEN-EN 10210-1 (hot rolled) according to NEN-EN 10219-1 (cold rolled)
Welds a=4, unless mentioned different, according to NEN-EN-ISO 2553:2014. Bolt grade 8.8, unless mentioned different

Projection:

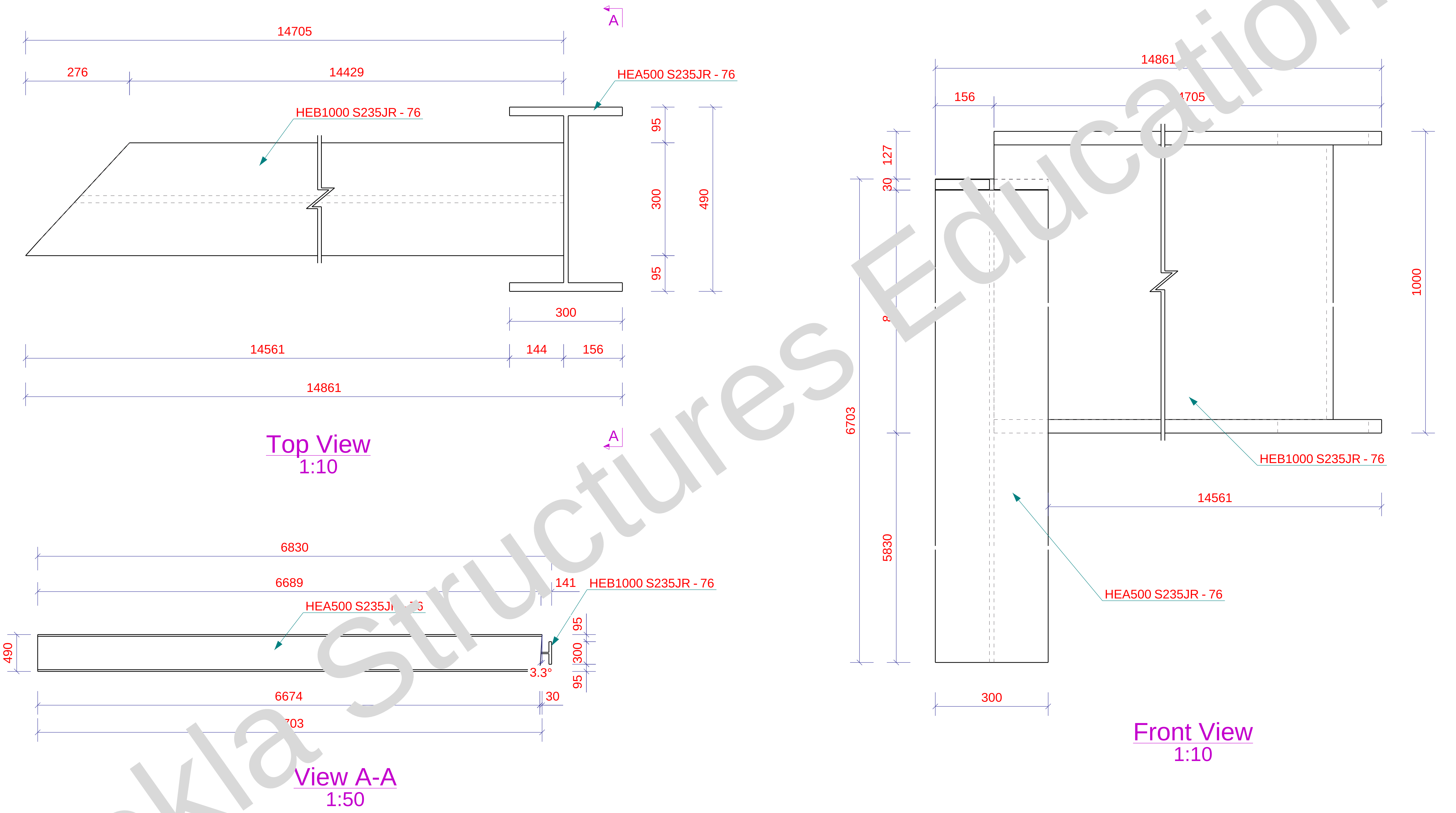
Univerza v Mariboru
Fakulteta za gradbeništvo, prometno inženirstvo in arhitekturo

Project: 1-1
Drawing: W [32]
Size: A4
Status: Approved

### 10.3.3 Assembly drawing

`

# Assembly Drawing - Welded steel (column and beam) elements in the case of the Mall project






ASSEMBLY PART LIST Assembly: 76 Length (mm): 14861
Finish: Number: 1

| Part | Profile | Material | Number | Length (mm) | Weight (kg) |
|---|---|---|---|---|---|
| 12 | HEA500 | S235JR | 1 | 6703 | 1039.3 |
| 77 | HEB1000 | S235JR | 1 | 14705 | 4617.4 |
| | | | | Total per assembly | 5656.7 |

Tekla Structures

Fabrication and erection acc. to NEN-EN 1090-2:2008+A1:2011
Execution class: EXC2
Effective tollerance class: XXX

PROJECT: Master Thesis Model
SUBJECT: Assembly drawing
BUILDER:
Maribor, Slovenia

Designer: Drilon Rraci
Date: 23.11.2017
Scale: 1:10 1:50

Powered by Trimble Tekla

Material types and grades: Plates and profiles according to NEN-EN 10025-2, tubes and RHS profiles: according to NEN-EN 10210-1 (hot rolled) according to NEN-EN 10219-1 (cold rolled)
Projection:
Welds a=4, unless mentioned different, according to NEN-EN-ISO 2553:2014. Bolt grade 8.8, unless mentioned different

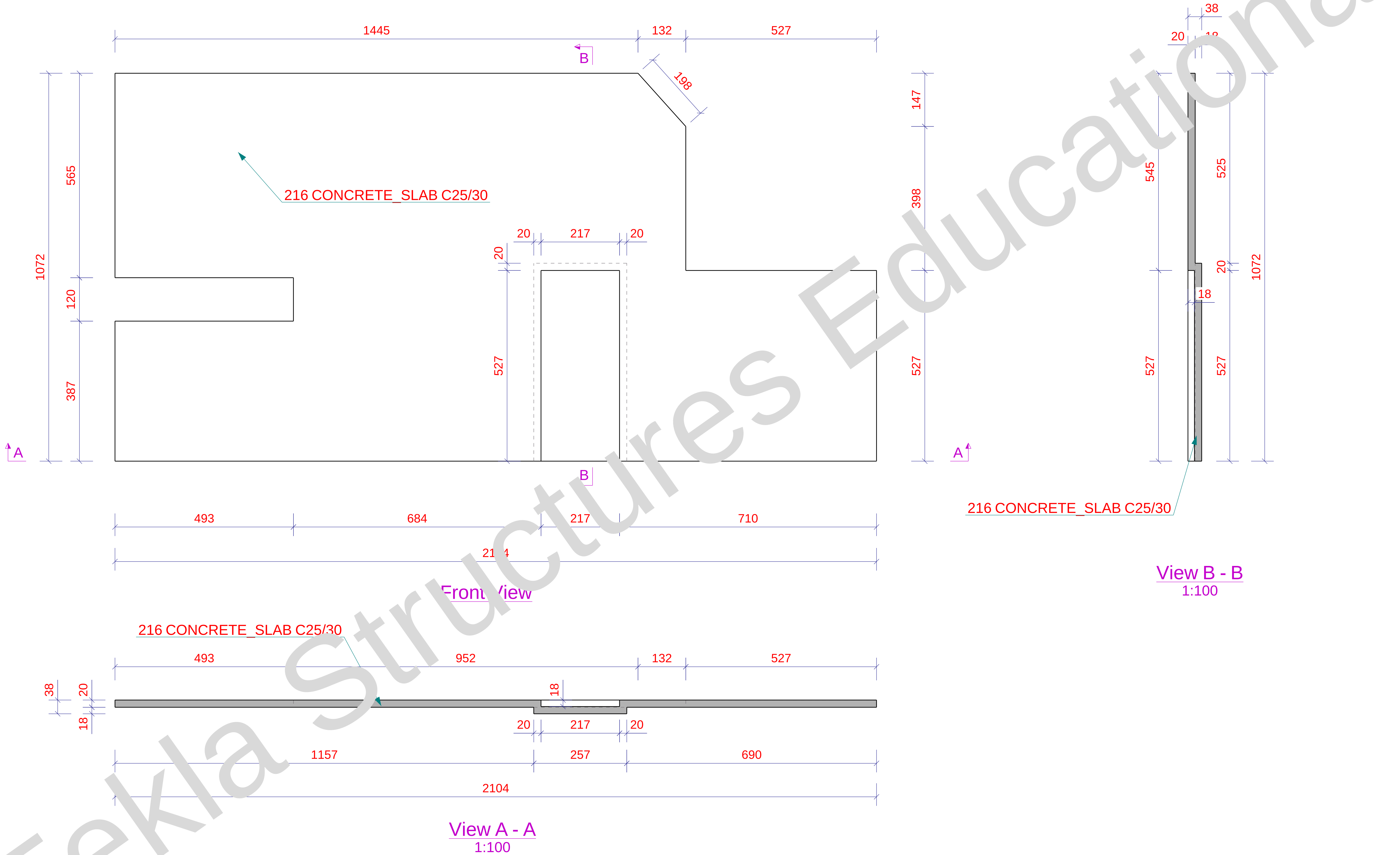
Univerza v Mariboru
Fakulteta za gradbeništvo, prometno inženirstvo in arhitekturo

Project: 1-1
Drawing: A [76]
Size: A3
Status: Approved

### 10.3.4 Cast unit drawing

`

# Cast unit drawing (excluding reinforcements) - Mezzanine ( Intermediate floor) slab of the Mall project






BENDING SCHEDULE WITH REBAR SHAPES

| Partnr | Diameter | Number | Grade | Length | Kg/p | Weight | Bending shape |
|---|---|---|---|---|---|---|---|

| CASTUNIT: 216 | | Cover thickness: |
|---|---|---|
| w*h*l 200*200*21040 | | Env. class: |
| Quantity: 1 | Volume (m³): 38.46 | Finish castside: |
| Grade: C25/30 | Weight (kg): 92304 | Finish moldside: |

PROJECT: Master Thesis Model
SUBJECT: CAST UNIT DRAWING
BUILDER:
Maribor, Slovenia

Designer: Drilon Rraci
Date: 30.11.2017
Scale: 1:100

Powered by Trimble Tekla

REINFORCEMENT: B500A, UNLESS MENTIONED DIFFERENT
BEND RADIUS BARS: till Ø16: 4*Øk and >Ø16: 5*Øk
OVERLAP AND BENDS ACCORDING TO EC2
PROJECTION

Univerza v Mariboru
Fakulteta za gradbeništvo, prometno inženirstvo in arhitekturo

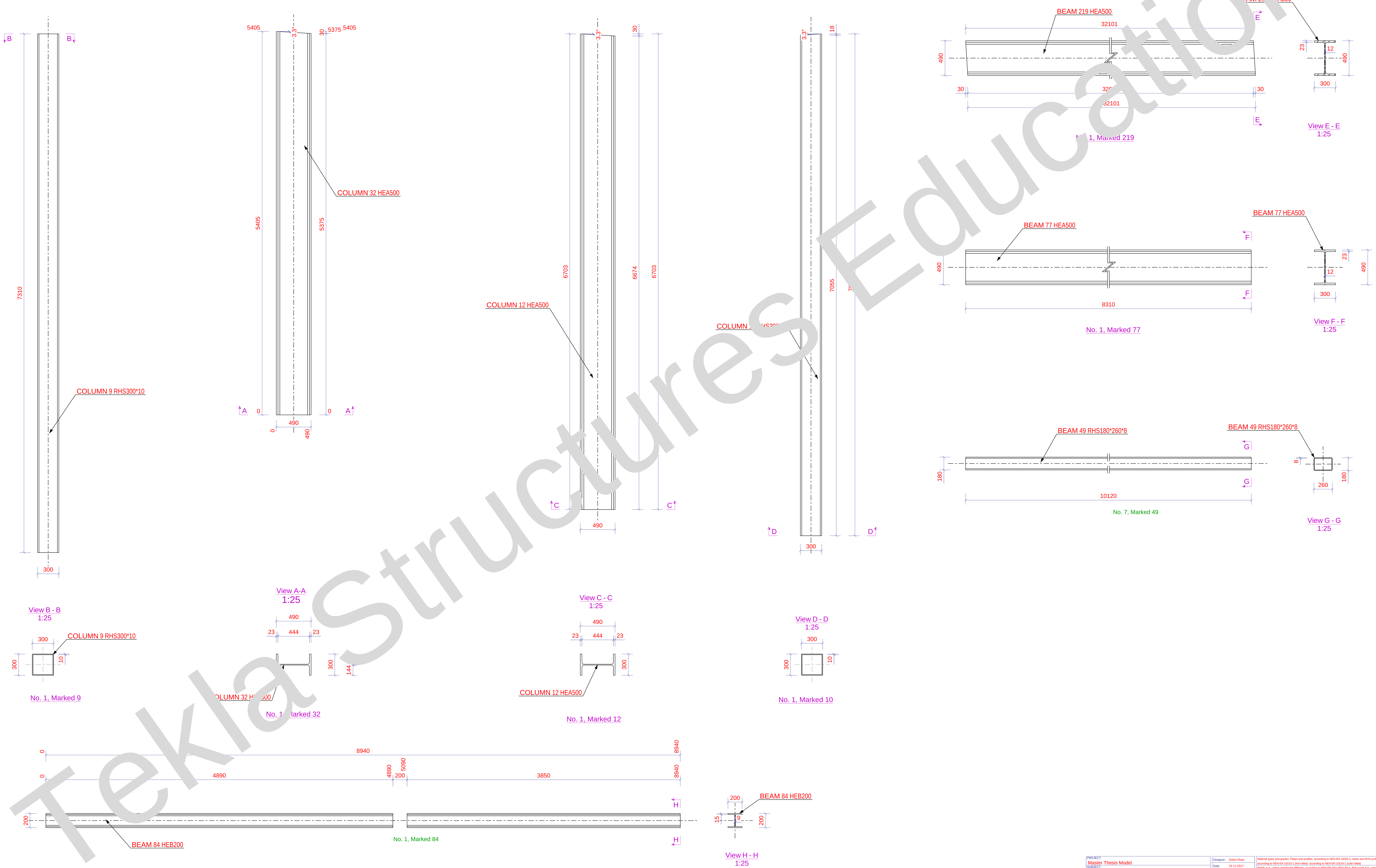
Project: 1-1
Drawing: C [216 - 1]
Size: A3
Status: Approved

### 10.3.5 Multidrawing

`

# Multidrawing - Structural steel elements in the case of the Mall project

| Part | Profile | L[illegible] | Number | Assembly |
|---|---|---|---|---|
| 9 | RHS300*10 | 7[illegible] | 1 | 9 |
| 10 | RHS300*10 | 70[illegible] | 1 | 10 |
| 12 | HEA500 | 670[illegible] | 1 | 76 |
| 32 | HEA500 | 5405 | 1 | 32 |
| 49 | RHS180*260*8 | 10120 | 7 | 49 |
| 77 | HEA500 | 8310 | [illegible] | 77 |
| 84 | HEB200 | 8940 | [illegible] | 84 |
| 219 | HEA500 | [illegible]131 | [illegible] | 219 |
| | | Tota[illegible] [illegible]er: | 1[illegible] | |






Fabrication and erection acc. to NEN-EN 1090-2:2008+A1:2011
Execution class: EXC2
Effective tollerance class: XXX

| | | | |
|---|---|---|---|
| PROJECT: Master Thesis Model | Designer: Drilon Rraci | Material types and grades: Plates and profiles according to NEN-EN 10025-2, tubes and RHS profiles: according to NEN-EN 10210-1 (hot rolled) according to NEN-EN 10219-1 (cold rolled) | Projection: |
| SUBJECT: Multidrawing | Date: 24.11.2017 | Welds a=4, unless mentioned different, according to NEN-EN-ISO 2553:2014. Bolt grade 8.8, unless mentioned diffentent | |
| | Scale: 1:25 | | |
| BUILDER: | Powered by Trimble Tekla | Univerza v Mariboru Fakulteta za gradbeništvo, prometno inženirstvo in arhitekturo | Project: 1-1 |
| | | | Drawing: M [2] Size: A1 |
| Maribor, Slovenia | | | Status: Approved |

Tekla Structures

## 10.4 Analysis and Design (A&D) report

### 10.4.1 Mechanical properties of materials and cross-sections

The characteristics of the materials used in the case of structural analysis and design of the chosen partial models of the Mall project, such as concrete and structural steel are presented below.

Materials used in the case of the structural partial models of the Mall project:

- Concrete C 25/30
- Structural steel S 235

In addition, characteristics of the cross-sections of the structural elements, such as columns and beams, used in the case of structural steel elements of this project, are presented as follows:

Cross-sections of structural elements:

- Steel columns HEA 500,
- Steel beams HEA 500,
- Steel beam HEB 1000,
- Steel beam HEB 200,
- Steel columns RHS 300/300/10 mm adopted as QRO 300x10 in RFEM,
- Steel beams RHS 260/180/8 mm adopted as PRO 260x180x8 in RFEM.

The characteristics of the materials and cross-sections of the partial elements, used to perform (A&D) in the case of chosen partial models of this project are presented and included in the relevant RFEM reports below (see Section 10.4.4 and Section 10.4.5).

`

### 10.4.2 Actions

**Actions according to Eurocode 1 (EC 1)**

Actions have been set out in accordance with the European Standard EN1991. Gamma partial safety factors are set out as suggested values in the relevant part of Eurocode. They were then added and generated in FEA software RFEM.

### 10.4.3 Load Analysis

**Densities, self-weight, and imposed loads**

Self-weight of construction elements

In the event of determining the self-weight of the partial structural elements, the RFEM Software automatically takes them into account, once the adequate data of cross-sections of line elements, as well as the relevant thickness of the planar components and the specific weight, has been appropriately set out. Thus, in the case of reinforced concrete, it consists of **25 kN/m$^3$**, while for the structural steel is taken as **78,5 kN/m$^3$**.

Permanent loads

Additional permanent load based on the finishing, pavement, embedded services, partitions acting as the pressure on the mezzanine (intermediate floor) slab have been taken into consideration with the following value: **$g_1$ = 2,00 kN/m$^2$.**

In addition, the weight per square meter of glued timber panels as part of roofing elements has been taken into consideration as approx. 0.80 kN/m$^2$, while the weight of photovoltaic cells placed on the roof is estimated at about 0,20 kN/m$^2$, and the weight of installations suspended in the area of roof structure consists of 0.20 kN/m$^2$. Thus, the total weight of this part consists of **$g_2$ = 1.20 kN/m$^2$**, which has been taken as additional permanent load acting on the relevant steel member types of the structure.

Finally, permanent loads acting on the area as distributed loads in the relevant steel members (RHS 260*180*8) are considered to be **1.00 kN/m$^2$,** while the loads result of the equipment placed in the area of such structural elements has been considered as **2.00 kN/m$^2$**.

### Variable loads

Values of Imposed Loads

Values of imposed loads have been set out in accordance with EN1991-1.1, based on the relevant National annex recommendations, adopted for the region of Slovenia (SIST EN). In this case, values for $q_k$ and $Q_k$ are can be found below.

| Categories of loaded areas | $q_k$ [kN/m$^2$] | $Q_k$ [kN] |
|---|---|---|
| **Category A** | | |
| **- Floors** | 1,5 to2,0 | 2,0 to 3,0 |
| **- Stairs** | 2,0 to4,0 | 2,0 to 4,0 |
| **- Balconies** | 2,5 to 4,0 | 2,0 to 3,0 |
| **Category B** | 2,0 to 3,0 | 1,5 to 4,5 |
| **Category C** | | |
| - C1 | 2,0 to 3,0 | 3,0 to 4,0 |
| - C2 | 3,0 to 4,0 | 2,5 to 7,0 (4,0) |
| - C3 | 3,0 to 5,0 | 4,0 to 7,0 |
| - C4 | 4,5 to 5,0 | 3,5 to 7,0 |
| - C5 | 5,0 to 7,5 | 3,5 to 4,5 |
| **category D** | | |
| - D1 | 4,0 to 5,0 | 3,5 to 7,0 (4,0) |
| - D2 | 4,0 to 5,0 | 3,5 to 7,0 |

Since the mezzanine (intermediate floor) are of the Mall project is considered as an office area, it was further categorized in the category B, and based on the Slovenian National annex, the following value of imposed loads acting in this area have been taken into consideration:

- Mezzanine (intermediate floor) slab $q_{k,B}$ **= 3,0 kN/m$^2$**

**NOTE**: Where a range is given in this table 6.1., the value may be set by the National annex. The recommended values, intended for separate application, are underlined. $q_k$ is intended for the determination of general effects and $Q_k$ for local effects. The National annex may define different conditions of use of this Table.

The load cases and load combinations which are considered in the case of the above-mentioned partial models have been generated automatically and set out in accordance with the structural analysis program RFEM. In this case, RFEM provided automatic generation of load and result combinations according to Eurocode 0 (EN 1990) and the National annex for Slovenia (SIST EN) in compliance with the corresponding combination expressions.

`

### 10.4.4 RFEM report in the case of the simplified mezzanine slab of the Mall project

Project: Master Thesis project
The simplified mezzanine (intermediate floor) slab of the Mall project
Model: Simplified mezzanine slab A&D
Date: 11/30/2017

# STRUCTURAL ANALYSIS

**PROJECT**

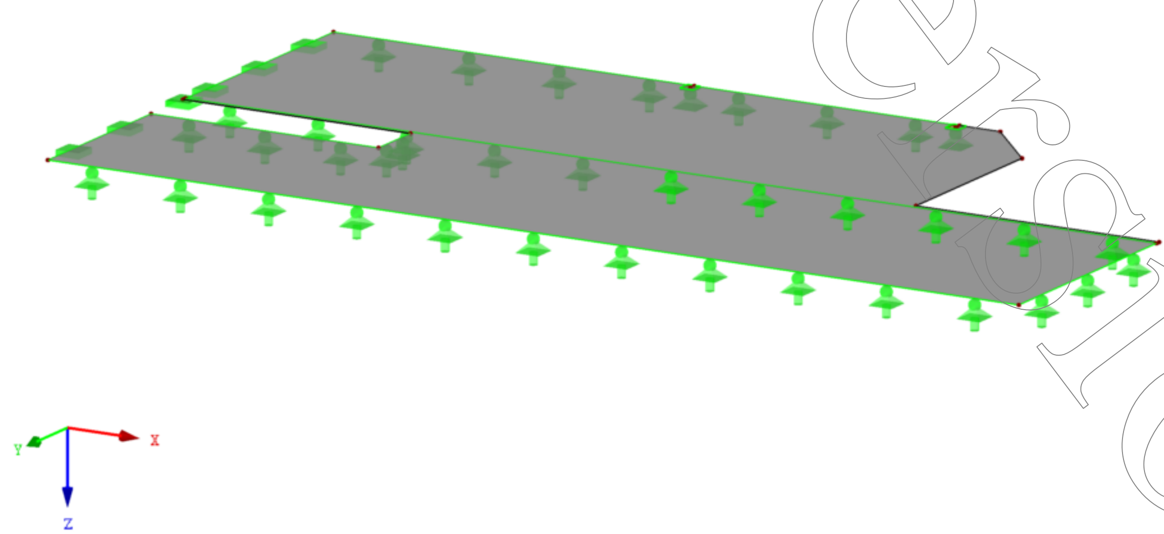
**Master Thesis project - The simplified mezzanine (intermediate floor) slab in the case of a Mall project.**

**CLIENT**

**CREATED BY**

**Drilon Rraci**

Isometric



Project: Master Thesis project — The simplified mezzanine (intermediate floor) slab of the Mall project
Model: Simplified mezzanine slab A&D
Date: 11/30/2017



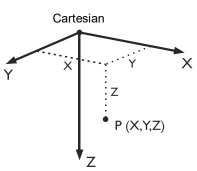
## MODEL - GENERAL DATA

| | | | |
|---|---|---|---|
| General | Model name | : | Simplified mezzanine slab A&D |
| | Project name | : | Examples |
| | Project description | : | Sample structures |
| | Type of model | : | 3D |
| | Positive direction of global axis Z | : | Downward |
| | Classification of load cases and combinations | : | According to Standard: EN 1990<br>National Annex: SIST - Slovenia |
| | ☒ Automatically create combinations | : | ☒ Load Combinations |
| Options | ☐ RF-FORM-FINDING - Find initial equilibrium shapes of membrane and cable structures | | |
| | ☐ RF-CUTTING-PATTERN | | |
| | ☐ Piping analysis | | |
| | ☐ Use CQC Rule | | |
| | ☐ Enable CAD/BIM model | | |
| | Standard Gravity | | |
| | g | : | 10.00 m/s² |

## FE MESH SETTINGS

| | | | | |
|---|---|---|---|---|
| General | Target length of finite elements | $l_{FE}$ | : | 50.0 cm |
| | Maximum distance between a node and a line to integrate it into the line | $\varepsilon$ | : | 0.1 cm |
| | Maximum number of mesh nodes (in thousands) | | : | 500 |
| Members | Number of divisions of members with cable, elastic foundation, taper, or plastic characteristic | | : | 10 |
| | ☒ Activate member divisions for large deformation or post-critical analysis | | | |
| | ☒ Use division for members with node lying on them | | | |
| Surfaces | Maximum ratio of FE rectangle diagonals | $\Delta_D$ | : | 1.80 |
| | Maximum out-of-plane inclination of two finite elements | $\alpha$ | : | 0.50 ° |
| | Shape direction of finite elements | | : | Triangles and quadrangles<br>☒ Same squares where possible |

## 1.1 NODES




| Node No. | Node Type | Reference Node | Coordinate System | X [cm] | Y [cm] | Z [cm] | Comment |
|---|---|---|---|---|---|---|---|
| 1 | Standard | - | Cartesian | 5036.00 | -372.00 | -320.00 | |
| 2 | Standard | - | Cartesian | 5036.00 | -492.00 | -320.00 | |
| 3 | Standard | - | Cartesian | 4543.00 | -492.00 | -320.00 | |
| 4 | Standard | - | Cartesian | 4543.00 | -1057.00 | -320.00 | |
| 5 | Standard | - | Cartesian | 5988.00 | -1057.00 | -320.00 | |
| 6 | Standard | - | Cartesian | 6120.00 | -910.00 | -320.00 | |
| 7 | Standard | - | Cartesian | 6120.00 | -512.00 | -320.00 | |
| 8 | Standard | - | Cartesian | 6647.00 | -512.00 | -320.00 | |
| 9 | Standard | - | Cartesian | 6647.00 | 15.00 | -320.00 | |
| 10 | Standard | - | Cartesian | 4543.00 | 15.00 | -320.00 | |
| 11 | Standard | - | Cartesian | 4543.00 | -372.00 | -320.00 | |
| 12 | Standard | - | Cartesian | 6647.00 | -502.00 | -320.00 | |
| 13 | Standard | - | Cartesian | 4543.00 | -502.00 | -320.00 | |
| 31 | Standard | - | Cartesian | 5325.00 | -1057.00 | -320.00 | |
| 32 | Standard | - | Cartesian | 5325.00 | -1042.00 | -320.00 | |
| 33 | Standard | - | Cartesian | 5900.00 | -1057.00 | -320.00 | |
| 34 | Standard | - | Cartesian | 5900.00 | -1042.00 | -320.00 | |

## 1.2 LINES

| Line No. | Line Type | Nodes No. | Line Length L [cm] | | Comment |
|---|---|---|---|---|---|
| 1 | Polyline | 12,13 | 2104.00 | X | |
| 2 | Polyline | 13,4 | 555.00 | Y | |
| 3 | Polyline | 12,9 | 517.00 | Y | |
| 15 | Polyline | 11,1 | 493.00 | X | |
| 16 | Polyline | 1,2 | 120.00 | Y | |
| 17 | Polyline | 2,3 | 493.00 | X | |
| 18 | Polyline | 3,13 | 10.00 | Y | |
| 19 | Polyline | 4,31 | 782.00 | X | |
| 20 | Polyline | 5,6 | 197.57 | XY | |
| 21 | Polyline | 6,7 | 398.00 | Y | |
| 22 | Polyline | 7,8 | 527.00 | X | |
| 23 | Polyline | 8,12 | 10.00 | Y | |
| 24 | Polyline | 9,10 | 2104.00 | X | |
| 25 | Polyline | 10,11 | 387.00 | Y | |
| 26 | Polyline | 31,33 | 575.00 | X | |

Project: Master Thesis project — The simplified mezzanine (intermediate floor) slab of the Mall project
Model: Simplified mezzanine slab A&D
Date: 11/30/2017

## 1.2 LINES

| Line No. | Line Type | Nodes No. | Line Length L [cm] | | Comment |
|---|---|---|---|---|---|
| 27 | Polyline | 33,5 | 88.00 | X | |

## 1.3 MATERIALS

| Matl. No. | Modulus E [MPa] | Modulus G [MPa] | Poisson's Ratio ν [-] | Spec. Weight γ [kN/m³] | Coeff. of Th. Exp. α [1/°C] | Partial Factor $\gamma_M$ [-] | Material Model |
|---|---|---|---|---|---|---|---|
| 1 | Concrete C25/30 \| EN 1992-1-1:2004/A1:2014 | | | | | | |
| | 31000.0 | 12916.7 | 0.200 | 25.00 | 1.00E-05 | 1.00 | Isotropic Linear Elastic |
| | C25/30 | | | | | | |
| 2 | Masonry (Brick, Group 2, Standard Mortar, M2,5 - M9, <> 0,5 - 3 mm) \| EN 1996-1-1 | | | | | | |
| | 2700.0 | 1350.0 | 0.000 | 1.96 | 6.00E-06 | 1.00 | Isotropic Linear Elastic |
| | User-Defined Material | | | | | | |

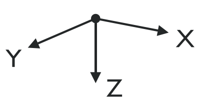
## 1.4 SURFACES

| Surface No. | Surface Type Geometry | Surface Type Stiffness | Boundary Lines No. | Matl. No. | Thickness Type | Thickness d [cm] | Area A [cm²] | Weight W [kg] |
|---|---|---|---|---|---|---|---|---|
| 2 | Plane | Standard | 15-18,2,19,26,27,20-23, 3,24,25 | 1 | Constant | 20.00 | 1897610.00 | 94880.60 |

## 1.4.2 SURFACES - INTEGRATED OBJECTS

| Surface No. | Integrated Objects No. Nodes | Lines | Openings | Comment |
|---|---|---|---|---|
| 2 | 32,34 | 1 | | |

## 1.7 NODAL SUPPORTS




| Support No. | Nodes No. | Axis System | Column in Z | Support Conditions $u_X$ | $u_Y$ | $u_Z$ | $\varphi_X$ | $\varphi_Y$ | $\varphi_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 34 | Global X,Y,Z | ☒ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2 | 32 | Global X,Y,Z | ☒ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

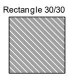
## 1.7.1 NODAL SUPPORTS - COLUMNS

| Support No. | Column Type Dimensions [cm] | Height H [cm] | Model of Support by | Matl. No. | Support Conditions Head | Base | Shear Stiffness |
|---|---|---|---|---|---|---|---|
| 1 | b / h = 30 / 30 | - | Nodal by adapted FE mesh | - | - | - | - |
| 2 | b / h = 30 / 30 | - | Nodal by adapted FE mesh | - | - | - | - |

## 1.8 LINE SUPPORTS

| Support No. | Lines No. | Reference System | Rotation β [°] | Wall in Z | Support Conditions $u_X$ | $u_Y$ | $u_Z$ | $\varphi_X$ | $\varphi_Y$ | $\varphi_Z$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2,18,25 | Global | | ☐ | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ |
| 9 | 1,3,15,16,19,24,26 | Global | | ☐ | ☒ | ☒ | ☒ | ☐ | ☐ | ☐ |

## 1.13 CROSS-SECTIONS

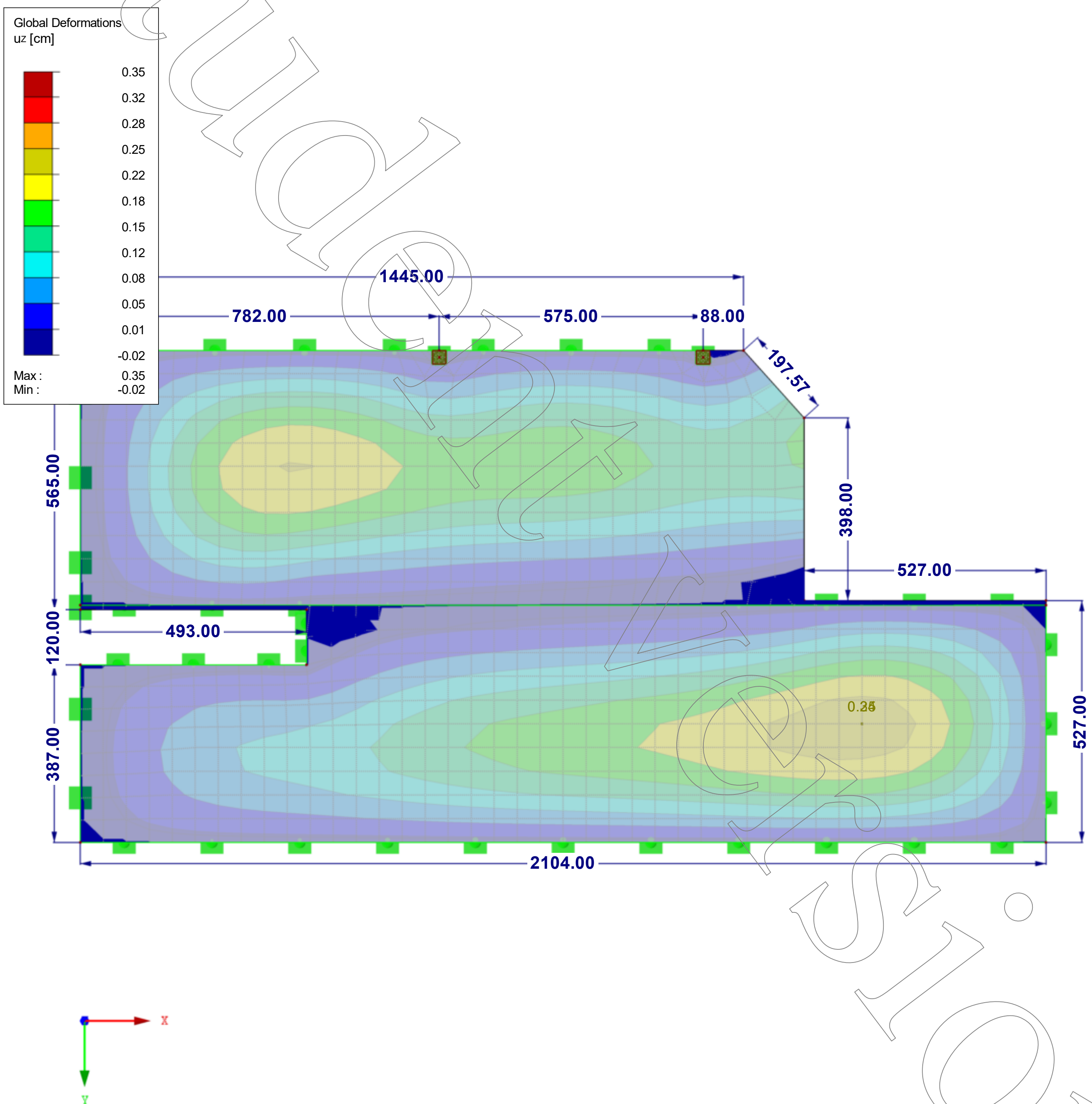
Rectangle 30/30


| Section No. | Matl. No. | J [cm⁴] / A [cm²] | $I_y$ [cm⁴] / $A_y$ [cm²] | $I_z$ [cm⁴] / $A_z$ [cm²] | Principal Axes α [°] | Rotation α' [°] | Overall Dimensions [cm] Width b | Height h |
|---|---|---|---|---|---|---|---|---|
| 1 | Rectangle 30/30 | | | | | | | |
| | 1 | 113940.00 | 67500.00 | 67500.00 | 0.00 | 0.00 | 30.00 | 30.00 |
| | | 900.00 | 750.00 | 750.00 | | | | |
| | 300*300 | | | | | | | |

## ■ GLOBAL DEFORMATIONS $u_Z$, SUPPORT REACTIONS

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Global Deformations u-Z
Support Reactions[kN]
Result Combinations: Max and Min Values

In Z-direction

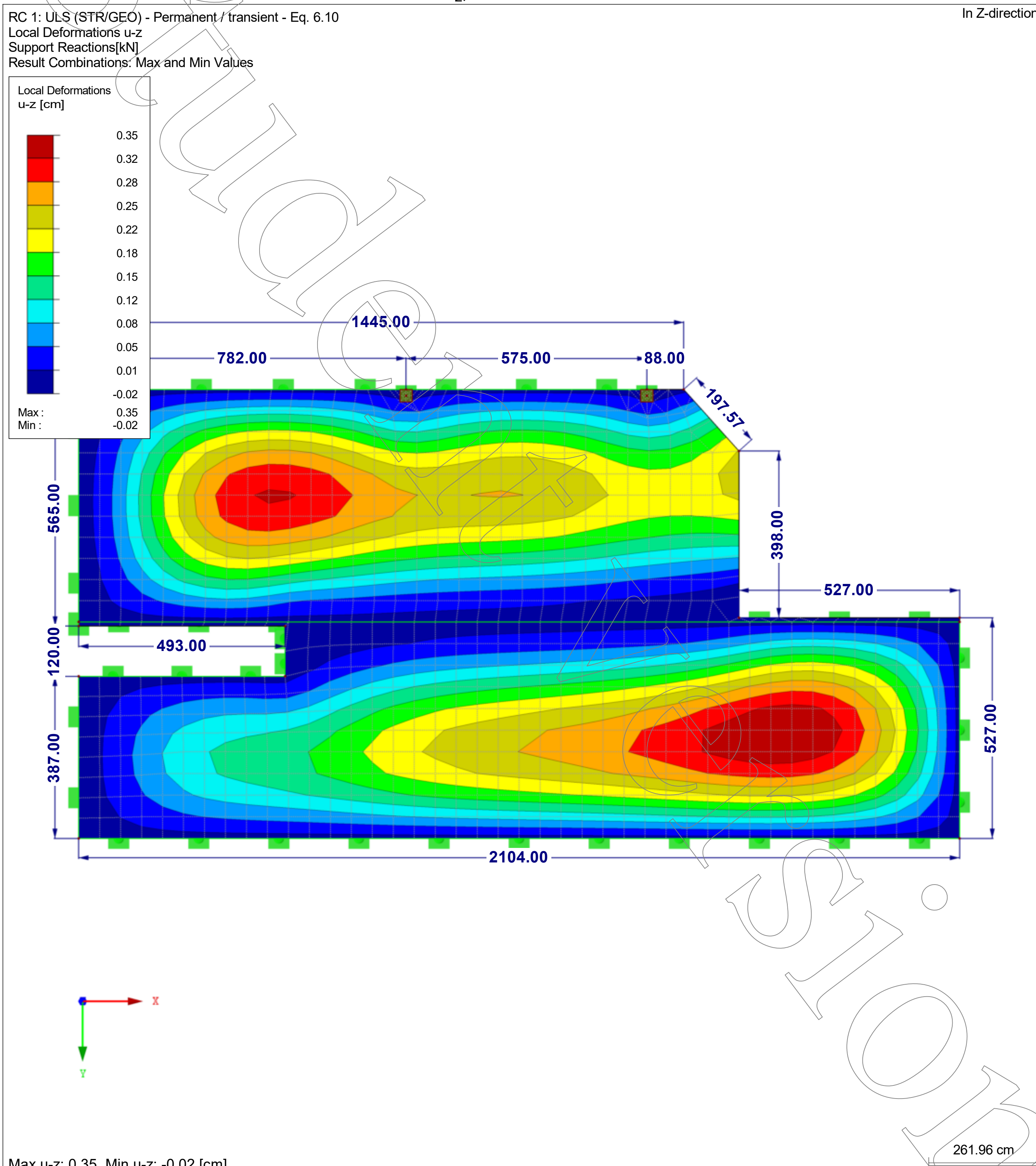



Max u-Z: 0.35, Min u-Z: -0.02 [cm]
Factor of deformations: 630.00

261.96 cm

Project: Master Thesis project
The simplified mezzanine (intermediate floor) slab of the Mall project
Model: Simplified mezzanine slab A&D
Date: 11/30/2017

## ■ LOCAL DEFORMATIONS $u_z$, SUPPORT REACTIONS

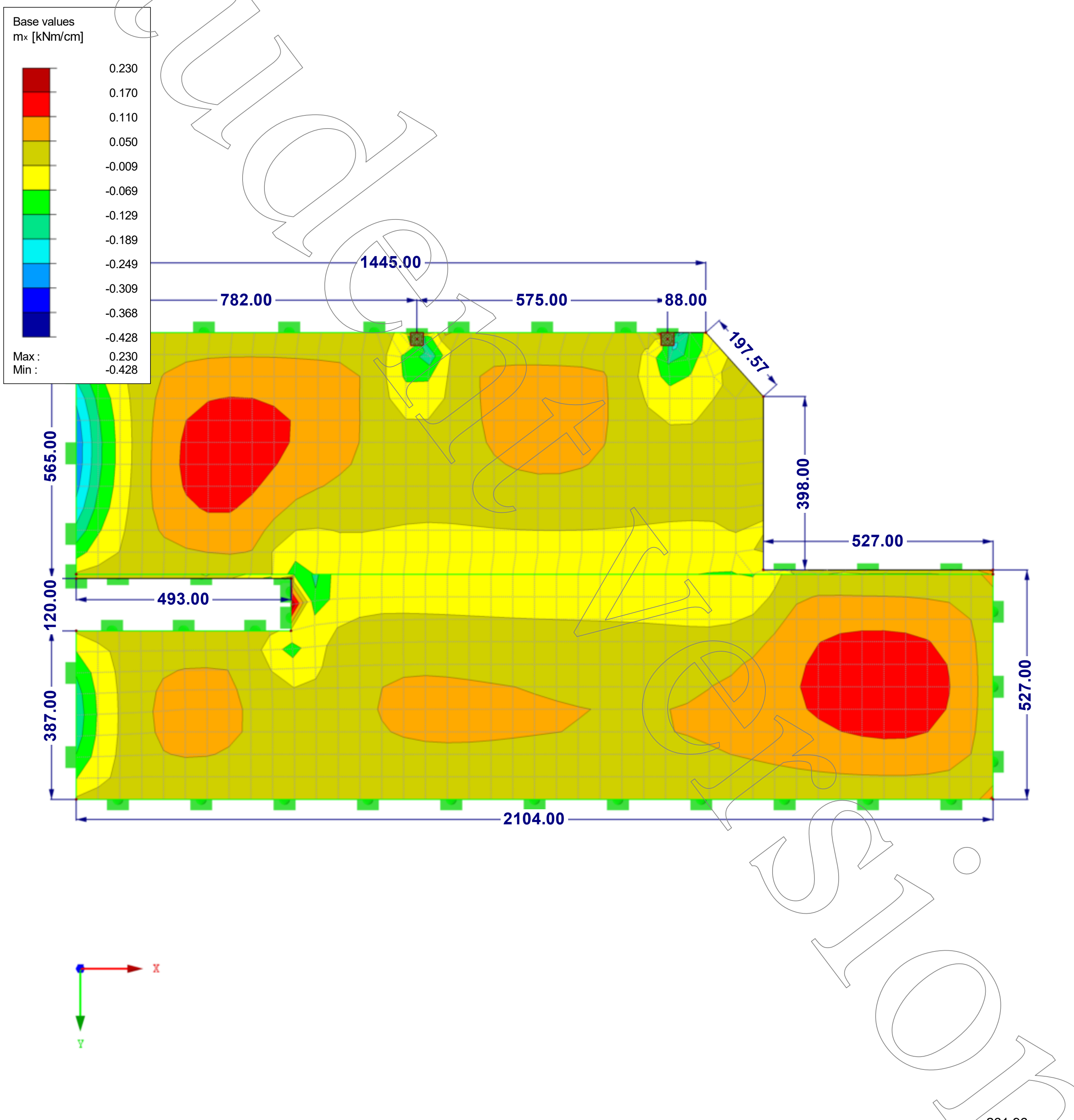



Max u-z: 0.35, Min u-z: -0.02 [cm]

## ■ BASE VALUES $m_x$, SUPPORT REACTIONS

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Basic Internal Forces m-x
Support Reactions[kN]
Result Combinations: Max and Min Values

In Z-direction



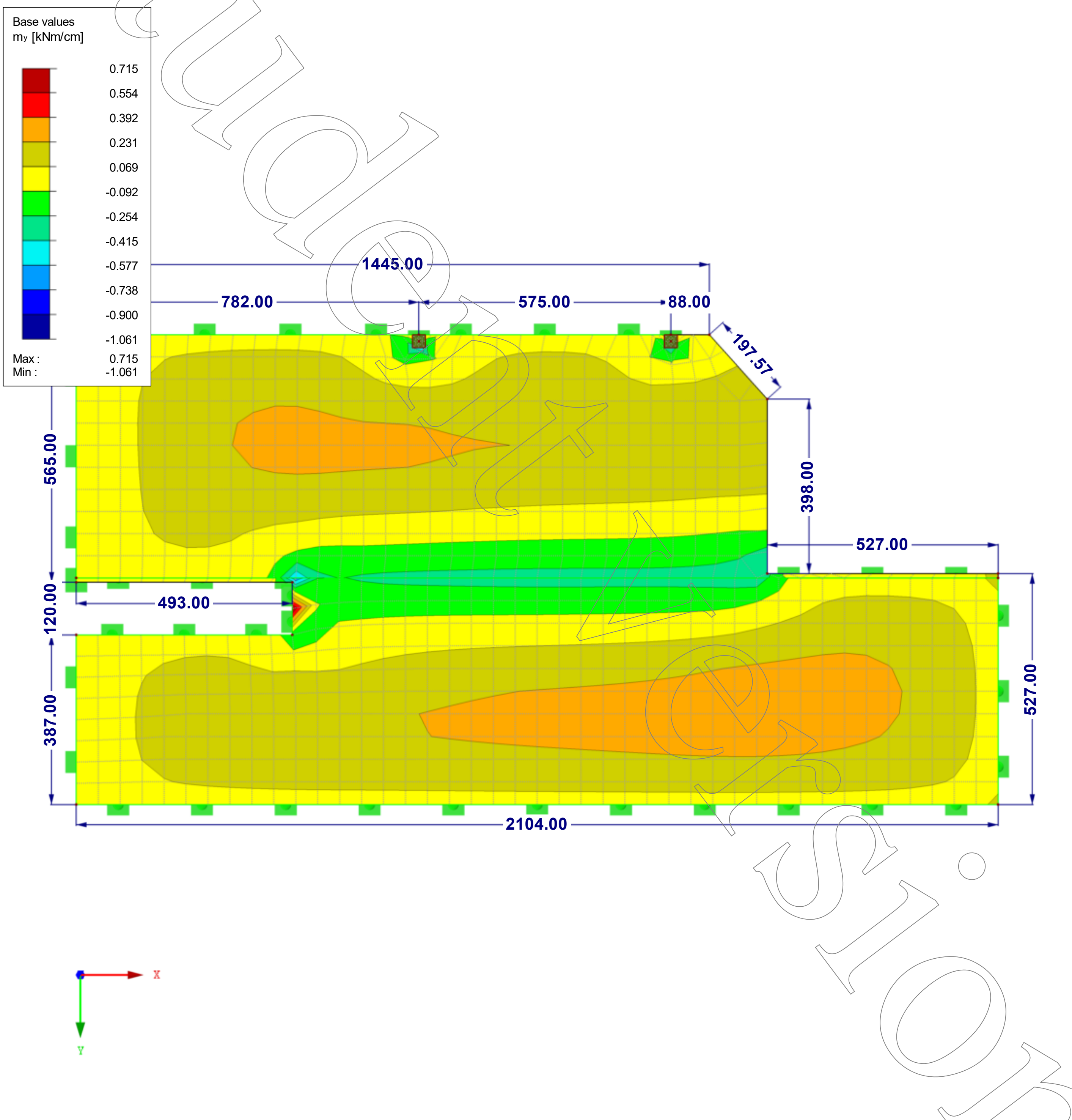

Max m-x: 0.230, Min m-x: -0.428 [kNm/cm]

Project: Master Thesis project
The simplified mezzanine (intermediate floor) slab of the Mall project
Model: Simplified mezzanine slab A&D
Date: 11/30/2017

## ■ BASE VALUES $m_y$, SUPPORT REACTIONS

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Basic Internal Forces m-y
Support Reactions[kN]
Result Combinations: Max and Min Values

In Z-direction



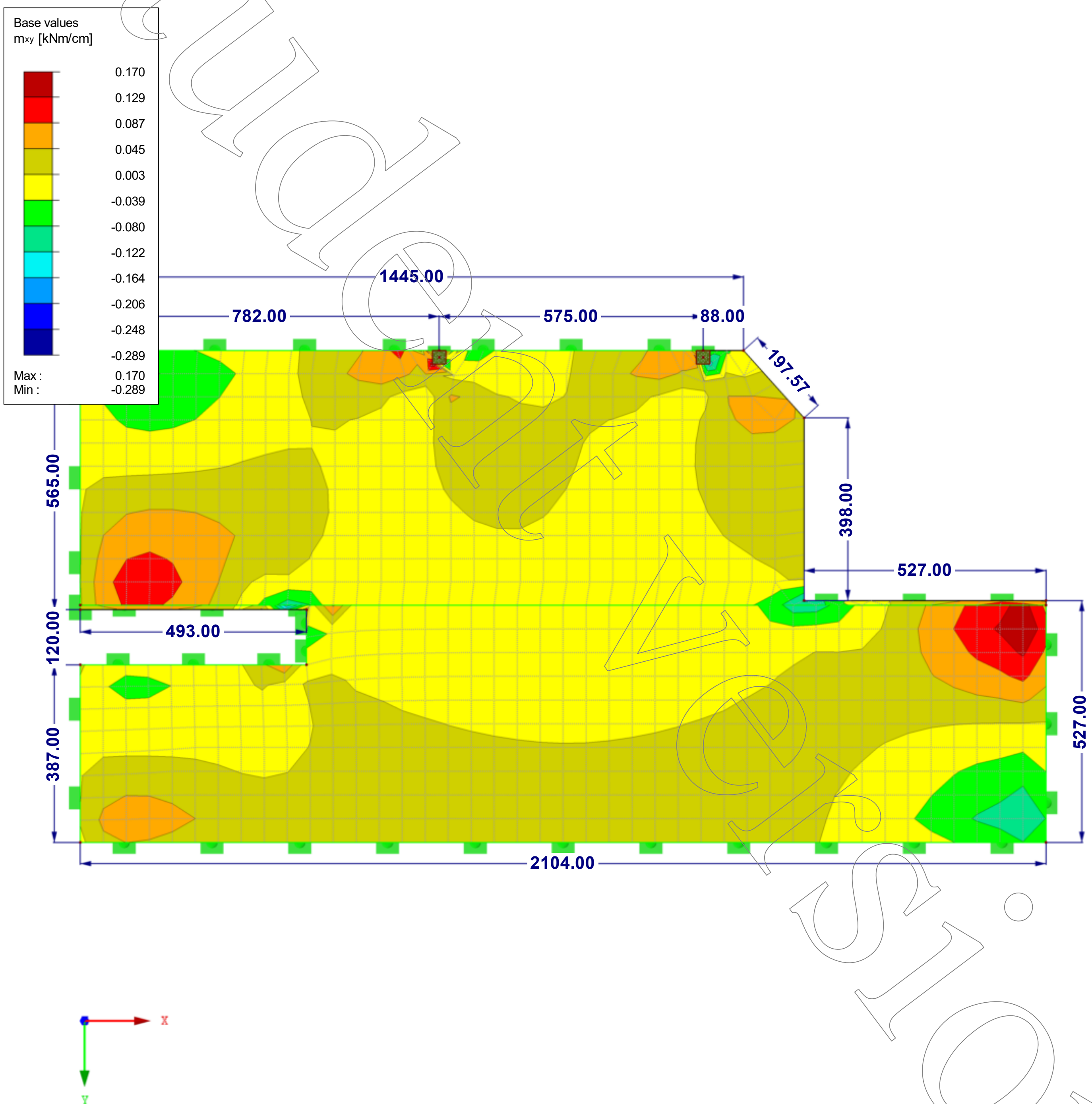

Max m-y: 0.715, Min m-y: -1.061 [kNm/cm]

Project: Master Thesis project
The simplified mezzanine (intermediate floor) slab of the Mall project
Model: Simplified mezzanine slab A&D
Date: 11/30/2017

## ■ BASE VALUES $m_{xy}$, SUPPORT REACTIONS

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Basic Internal Forces m-xy
Support Reactions[kN]
Result Combinations: Max and Min Values

In Z-direction




261.96 cm

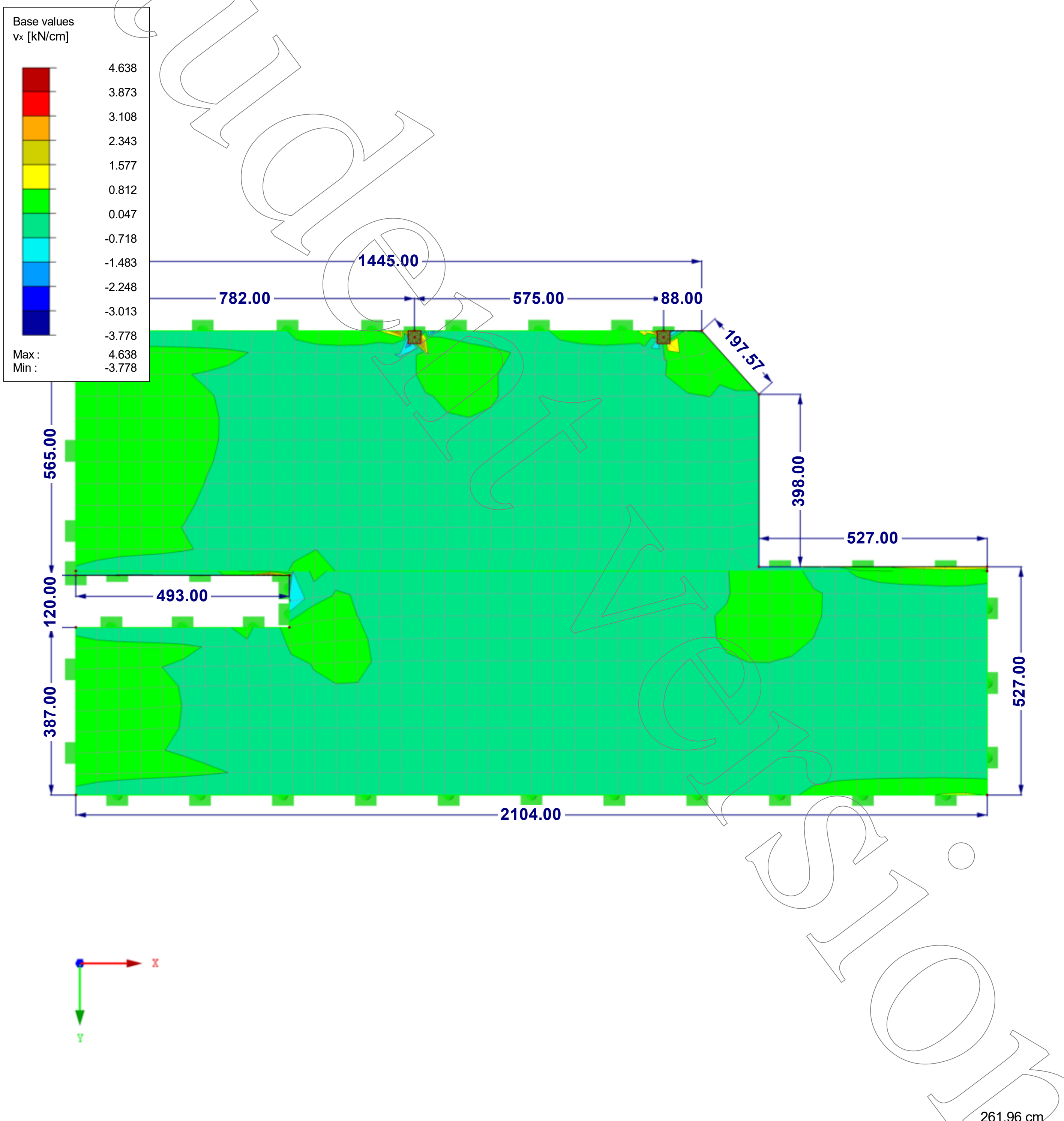
Max m-xy: 0.170, Min m-xy: -0.289 [kNm/cm]

| | | | | | |
|---|---|---|---|---|---|
| Project: | Master Thesis project | Model: | Simplified mezzanine slab A&D | Date: | 11/30/2017 |
| | The simplified mezzanine (intermediate floor) slab of the Mall project | | | | |

## ■ BASE VALUES $v_x$, SUPPORT REACTIONS

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Basic Internal Forces v-x
Support Reactions[kN]
Result Combinations: Max and Min Values

In Z-direction

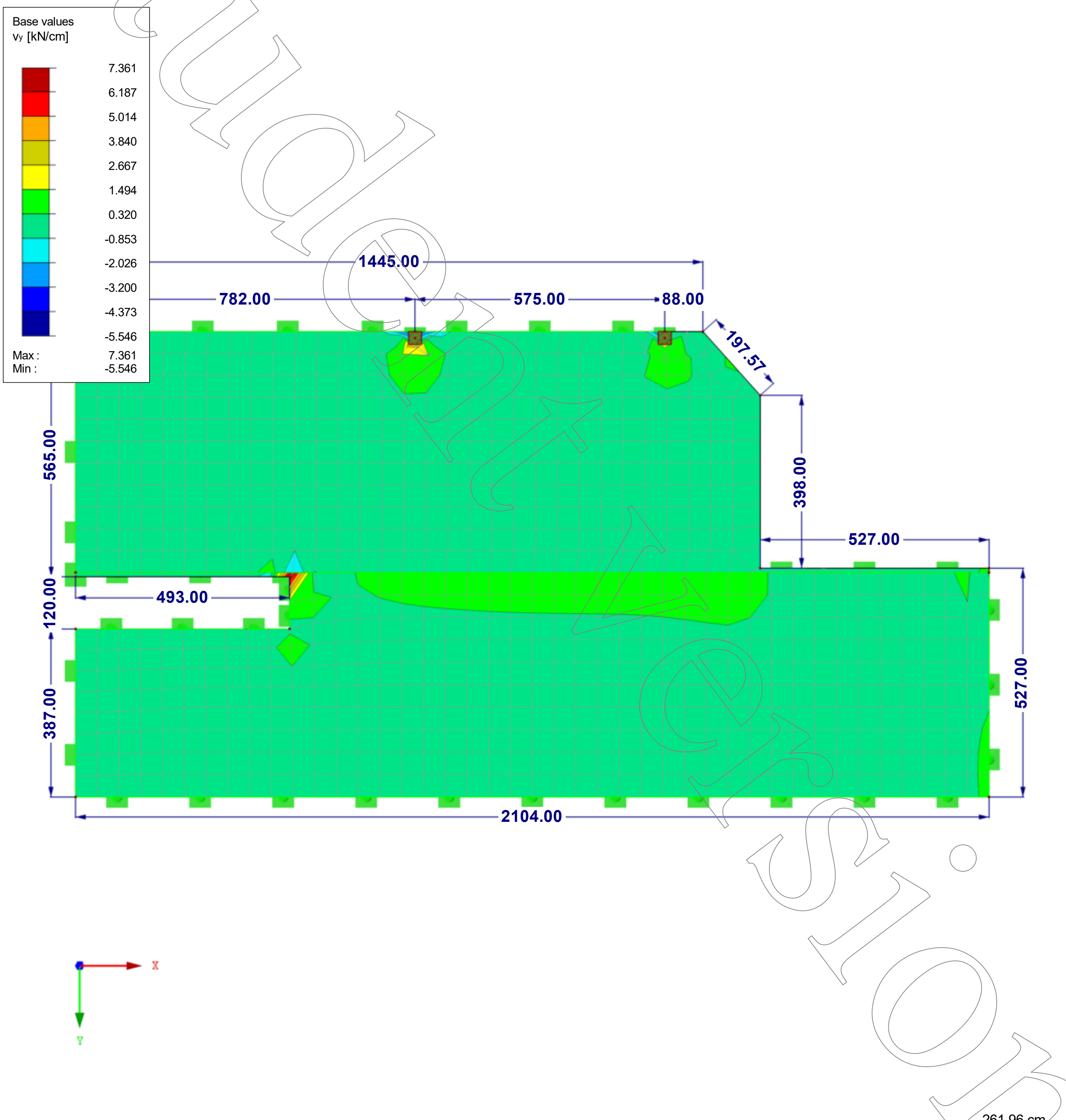



Max v-x: 4.638, Min v-x: -3.778 [kN/cm]

## ■ BASE VALUES $v_y$, SUPPORT REACTIONS

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Basic Internal Forces v-y
Support Reactions[kN]
Result Combinations: Max and Min Values

In Z-direction




Max v-y: 7.361, Min v-y: -5.546 [kN/cm]

Project: Master Thesis project — The simplified mezzanine (intermediate floor) slab of the Mall project
Model: Simplified mezzanine slab A&D
Date: 11/30/2017

**RF-CONCRETE Surfaces**
CA1
Reinforced concrete design

## 1.1 GENERAL DATA

| | | |
|---|---|---|
| Design according to Standard: | SIST EN 1992-1-1:2005/A101:2006 | |
| ULTIMATE LIMIT STATE | | |
| Result combination for design: | RC1 | ULS (STR/GEO) - Permanent / transient - Eq. 6.10 Persistent and Transient |
| SERVICEABILITY LIMIT STATE | | |
| Result combination for design: | RC4 | SLS - Quasi-permanent Quasi-permanent, $k_t$ 0.600 |
| Definition of Provided Additional Reinforcement | Automatic arrangement according to the specifications in Table 1.4 | |
| Type of SLS method: | Analytical Method By assuming an identical deformation ratio of the longitudinal reinforcement | |
| Design of | | |
| Concrete Stress Analysis | ☐ | |
| Steel Stress Analysis | ☒ | |
| Crack widths | ☒ | |
| Deformation Analysis | ☐ | |
| Layout of longitudinal reinforcement | | |
| Required longitudinal reinforcement automatically increased for serviceability limit state design: | ☒ | |
| DETAILS | | |
| Analysis Method for Reinforcement Envelope | Mixed | |
| Apply the internal forces without the rib components | ☐ | |
| Design Situation Settings for Serviceability Limit State Checks | | |
| Load combination: | | |
| Characteristic with direct load | Checks: $k_1*f_{ck}$, $k_3*f_{yk}$ | |
| Characteristic with imposed deformation | Checks: $k_1*f_{ck}$, $k_4*f_{yk}$ | |
| Frequent | Checks: $w_k$ | |
| Quasi-permanent | Checks: $k_2*f_{ck}$, $w_k$, $u_l$ | |

## 1.2 MATERIALS

| Material No. | Material Description: Concrete Strength Class | Steel Description | Comment |
|---|---|---|---|
| 1 | Concrete C25/30 | B 500 S (A) | |

## 1.2.1 MATERIAL PARAMETERS

| Material No. | Description | Name | Size | Unit |
|---|---|---|---|---|
| 1 | **Concrete Strength Class: Concrete C25/30** | | | |
| | Characteristic Cylinder Compressive Strength | $f_{ck}$ | 25.000 | MPa |
| | 5 % Fractile of Axial Tensile Strength | $f_{ctk,0.05}$ | 1.800 | MPa |
| | Characteristic for Nonlinear Calculations | | | |
| | Mean Secant Modulus of Elasticity | $E_{cm}$ | 31000.000 | MPa |
| | Mean Cylinder Compressive Strength | $f_{cm}$ | 33.000 | MPa |
| | Mean Axial Tensile Strength | $f_{ctm}$ | 2.600 | MPa |
| | Ultimate Strain for Pure Compression | $\varepsilon_{c1}$ | -2.100 | ‰ |
| | Ultimate Strain at Failure | $\varepsilon_{c1u}$ | -3.500 | ‰ |
| | Shear Modulus | G | 12916.700 | MPa |
| | Poisson's Ratio | $\nu$ | 0.200 | - |
| | Characteristic Strains for Parabolic-Rectangular Diagram | | | |
| | Ultimate Strain for Pure Compression | $\varepsilon_{c2}$ | -2.000 | ‰ |
| | Ultimate Strain at Failure | $\varepsilon_{cu2}$ | -3.500 | ‰ |
| | Parabola Exponent | n | 2.000 | - |
| | Specific Weight | $\gamma$ | 25.00 | kN/m^3 |
| | **Reinforcing Steel: B 500 S (A)** | | | |
| | Modulus of Elasticity | $E_s$ | 200000.000 | MPa |
| | Yield Stress Mean Value | $f_{ym}$ | 550.000 | MPa |
| | Characteristic Yield Stress | $f_{yk}$ | 500.000 | MPa |
| | Tensile Strength Mean Value | $f_{tm}$ | 551.250 | MPa |
| | Characteristic Tensile Strength | $f_{tk}$ | 525.000 | MPa |
| | Limiting Strain | $\varepsilon_{uk}$ | 25.000 | ‰ |

## 1.3 SURFACES

| Surface No. | Matl. No. | $f_{ct,eff,wk}$ [MPa] | $f_{ct,eff,As,min}$ [MPa] | $w_{k,+z\,(top)}$ [cm] / $w_{k,-z\,(bottom)}$ [cm] | Effects due to Restraint: Apply | $k_c$ [-] | Notes |
|---|---|---|---|---|---|---|---|
| 2 | Thickness Type: Constant, Thickness: 20.000 cm | | | | | | |
| | 1 | 2.600 | 2.600 | 0.030 0.030 | ☒ | var. | 6) |

Notes:
6) Calculation of minimum reinforcement for effects due to restraint

## ■ 2.1 REQUIRED REINFORCEMENT TOTAL

| Surface | Point | Point Coordinates [cm] | | | | Required Reinforcement | | | Basic | Additional Reinforcement | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | No. | X | Y | Z | Symbol | ULS | SLS | ULS/SLS | Reinf. | Required | Provided | Unit | Notes |
| 2 | M37 | 5915.000 | -1027.000 | -320.000 | $a_{s,1,-z\ (top)}$ | 7.460 | 5.898 | 7.460 | 3.350 | 4.110 | - | $cm^2/m$ | |
| 2 | M150 - E12 | 5043.950 | -502.000 | -320.000 | $a_{s,2,-z\ (top)}$ | 18.016 | 10.959 | 18.016 | 3.350 | 14.666 | - | $cm^2/m$ | |
| 2 | M46 | 5036.000 | -432.000 | -320.000 | $a_{s,1,+z\ (bottom)}$ | 4.683 | 4.493 | 4.683 | 0.000 | 4.683 | - | $cm^2/m$ | |
| 2 | M46 | 5036.000 | -432.000 | -320.000 | $a_{s,2,+z\ (bottom)}$ | 12.482 | 7.567 | 12.482 | 0.000 | 12.482 | - | $cm^2/m$ | |
| 2 | M2 | 5036.000 | -492.000 | -320.000 | $a_{sw}$ | Not designable | - | Not designable | - | - | - | $cm^2/m^2$ | 7) |

## ■ 2.2 REQUIRED REINFORCEMENT BY SURFACE

| Surface | Point | Point Coordinates [cm] | | | | Required Reinforcement | | | Basic | Additional Reinforcement | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | No. | X | Y | Z | Symbol | ULS | SLS | ULS/SLS | Reinf. | Required | Provided | Unit | Notes |
| 2 | M37 | 5915.000 | -1027.000 | -320.000 | $a_{s,1,-z\ (top)}$ | 7.460 | 5.898 | 7.460 | 3.350 | 4.110 | - | $cm^2/m$ | |
| | M150 - E12 | 5043.950 | -502.000 | -320.000 | $a_{s,2,-z\ (top)}$ | 18.016 | 10.959 | 18.016 | 3.350 | 14.666 | - | $cm^2/m$ | |
| | M46 | 5036.000 | -432.000 | -320.000 | $a_{s,1,+z\ (bottom)}$ | 4.683 | 4.493 | 4.683 | 0.000 | 4.683 | - | $cm^2/m$ | |
| | M46 | 5036.000 | -432.000 | -320.000 | $a_{s,2,+z\ (bottom)}$ | 12.482 | 7.567 | 12.482 | 0.000 | 12.482 | - | $cm^2/m$ | |
| | M2 | 5036.000 | -492.000 | -320.000 | $a_{sw}$ | Not designable | - | Not designable | - | - | - | $cm^2/m^2$ | 7) |

## ■ 3.2 SERVICEABILITY CHECK BY SURFACE

| Surface | Point | Point Coordinates [cm] | | | Load | Design | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | No. | X | Y | Z | Case | Type | Exist. Value | Limit Value | Unit | Ratio | Notes |
| 2 | M1 | 5036.000 | -372.000 | -320.000 | | $\sigma_s$ | Not designable | 0.000 | MPa | 0.0 | 236) 239) |
| | M3 | 4543.000 | -492.000 | -320.000 | RC4 | $a_{s,min}$ | 4.411 | 4.517 | $cm^2/m$ | 1.1 | 233) |
| | M128 - E727 | 6146.050 | -502.000 | -320.000 | RC4 | lim $d_s$ | 0.829 | 1.408 | cm | 0.6 | 214) 235) 236) |
| | M462 | 6095.950 | -191.800 | -320.000 | RC4 | lim $s_l$ | 16.007 | 19.174 | cm | 0.9 | 235) 236) |
| | M37 | 5915.000 | -1027.000 | -320.000 | RC4 | $w_k$ | 0.022 | 0.030 | cm | 0.8 | 235) 236) |

### 10.4.5 RFEM report in the case of the structural steel elements of the Mall project

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# STRUCTURAL ANALYSIS

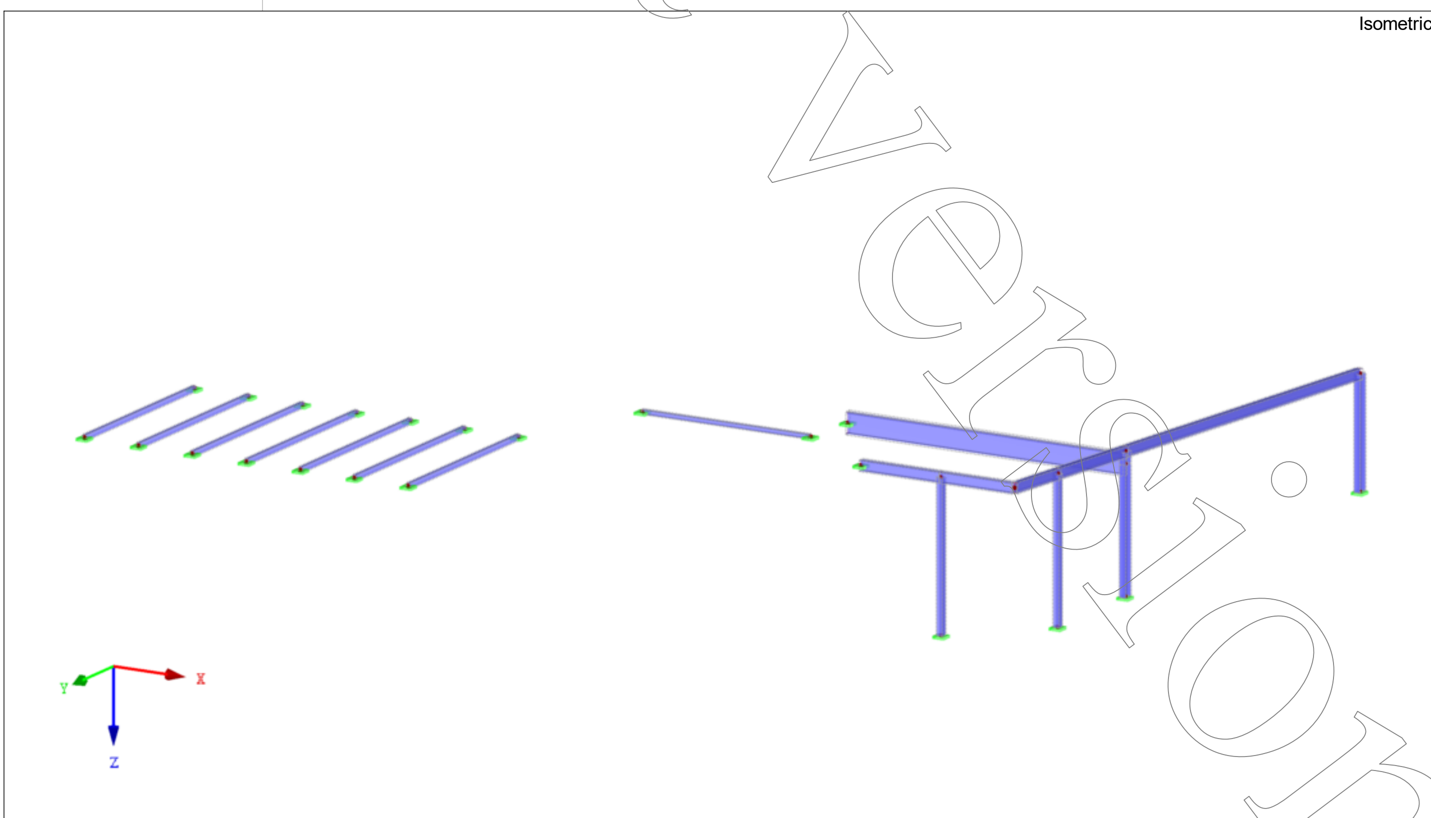
**PROJECT**

**Master Thesis project - Structural steel elements in the case of a Mall project**

**CLIENT**

**CREATED BY**

**Drilon Rraci**

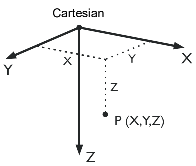


Project: Master Thesis project
Structural steel elements of the Mall project
Model: A&D of steel elements of the Mall project
Date: 11/30/2017

## ■ MODEL - GENERAL DATA

| | | | |
|---|---|---|---|
| General | Model name | : | A&D of steel elements of the Mall project |
| | Project name | : | Examples |
| | Project description | : | Sample structures |
| | Type of model | : | 3D |
| | Positive direction of global axis Z | : | Downward |
| | Classification of load cases and combinations | : | According to Standard: EN 1990<br>National Annex: SIST - Slovenia |
| | ☒ Automatically create combinations | : | ☒ Load Combinations |
| Options | ☐ RF-FORM-FINDING - Find initial equilibrium shapes of membrane and cable structures | | |
| | ☐ RF-CUTTING-PATTERN | | |
| | ☐ Piping analysis | | |
| | ☐ Use CQC Rule | | |
| | ☐ Enable CAD/BIM model | | |
| | Standard Gravity | | |
| | g | : | 10.00 m/s² |

## ■ 1.1 NODES




| Node | | Reference | Coordinate | Node Coordinates | | | |
|---|---|---|---|---|---|---|---|
| No. | Node Type | Node | System | X [cm] | Y [cm] | Z [cm] | Comment |
| 1 | Standard | - | Cartesian | 7463.00 | -3197.80 | 36.00 | |
| 2 | Standard | - | Cartesian | 7073.00 | -18.00 | 36.00 | |
| 3 | Standard | - | Cartesian | 7463.00 | -416.00 | 36.00 | |
| 4 | Standard | - | Cartesian | 7463.00 | -1037.65 | 36.00 | |
| 5 | Standard | - | Cartesian | 2521.00 | -1027.00 | -298.00 | |
| 6 | Standard | - | Cartesian | 2521.00 | -15.00 | -298.00 | |
| 7 | Standard | - | Cartesian | 2808.00 | -1027.00 | -298.00 | |
| 8 | Standard | - | Cartesian | 2808.00 | -15.00 | -298.00 | |
| 9 | Standard | - | Cartesian | 3095.00 | -1027.00 | -298.00 | |
| 10 | Standard | - | Cartesian | 3095.00 | -15.00 | -298.00 | |
| 11 | Standard | - | Cartesian | 3382.00 | -1027.00 | -298.00 | |
| 12 | Standard | - | Cartesian | 3382.00 | -15.00 | -298.00 | |
| 13 | Standard | - | Cartesian | 3669.00 | -1027.00 | -298.00 | |
| 14 | Standard | - | Cartesian | 3669.00 | -15.00 | -298.00 | |
| 15 | Standard | - | Cartesian | 3956.00 | -1027.00 | -298.00 | |
| 16 | Standard | - | Cartesian | 3956.00 | -15.00 | -298.00 | |
| 17 | Standard | - | Cartesian | 4243.00 | -1027.00 | -298.00 | |
| 18 | Standard | - | Cartesian | 4243.00 | -15.00 | -298.00 | |
| 19 | Standard | - | Cartesian | 6647.00 | -18.00 | -719.50 | |
| 20 | Standard | - | Cartesian | 5988.40 | -1037.65 | -597.00 | |
| 21 | Standard | - | Cartesian | 5206.00 | -502.00 | -669.00 | |
| 22 | Standard | - | Cartesian | 6100.00 | -502.00 | -669.00 | |
| 23 | Standard | - | Cartesian | 7463.00 | -3197.80 | -527.54 | |
| 24 | Standard | - | Cartesian | 7073.00 | -18.00 | -719.50 | |
| 25 | Standard | - | Cartesian | 7463.00 | -416.00 | -695.43 | |
| 26 | Standard | - | Cartesian | 7463.00 | -1037.65 | -657.91 | |
| 27 | Standard | - | Cartesian | 7463.00 | -18.00 | -719.46 | |
| 28 | Standard | - | Cartesian | 7463.00 | -1037.65 | -597.00 | |

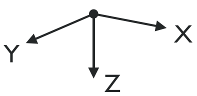
## ■ 1.2 LINES

| Line | | | Line Length | | |
|---|---|---|---|---|---|
| No. | Line Type | Nodes No. | L [cm] | | Comment |
| 1 | Polyline | 21,22 | 894.00 | X | |
| 2 | Polyline | 20,28 | 1474.60 | X | |
| 3 | Polyline | 19,24 | 426.00 | X | |
| 4 | Polyline | 24,27 | 390.00 | X | |
| 5 | Polyline | 23,26 | 2164.08 | YZ | |
| 6 | Polyline | 26,25 | 622.78 | YZ | |
| 7 | Polyline | 25,27 | 398.73 | YZ | |
| 8 | Polyline | 17,18 | 1012.00 | Y | |
| 9 | Polyline | 15,16 | 1012.00 | Y | |
| 10 | Polyline | 13,14 | 1012.00 | Y | |
| 11 | Polyline | 11,12 | 1012.00 | Y | |
| 12 | Polyline | 9,10 | 1012.00 | Y | |
| 13 | Polyline | 7,8 | 1012.00 | Y | |
| 14 | Polyline | 5,6 | 1012.00 | Y | |
| 15 | Polyline | 4,28 | 633.00 | Z | |
| 16 | Polyline | 28,26 | 60.91 | Z | |
| 17 | Polyline | 3,25 | 731.43 | Z | |
| 18 | Polyline | 2,24 | 755.50 | Z | |
| 19 | Polyline | 1,23 | 563.54 | Z | |

## 1.3 MATERIALS

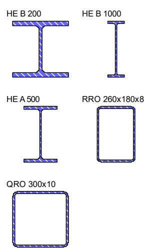
| Matl. No. | Modulus E [MPa] | Modulus G [MPa] | Poisson's Ratio ν [-] | Spec. Weight γ [kN/m³] | Coeff. of Th. Exp. α [1/°C] | Partial Factor $\gamma_M$ [-] | Material Model |
|---|---|---|---|---|---|---|---|
| 1 | Steel S 235 \| EN 1993-1-1:2005-05 | | | | | | |
| | 210000.0 | 80769.2 | 0.300 | 78.50 | 1.20E-05 | 1.00 | Isotropic Linear Elastic |
| | S235JR | | | | | | |

## 1.7 NODAL SUPPORTS



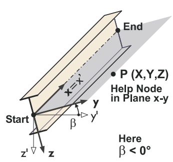

| Support No. | Nodes No. | Axis System | Column in Z | $u_X$ | $u_Y$ | $u_Z$ | $\varphi_X$ | $\varphi_Y$ | $\varphi_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1-22 | Global X,Y,Z | ☐ | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ |

## 1.13 CROSS-SECTIONS




| Section No. | Matl. No. | J [cm⁴] / A [cm²] | $I_y$ [cm⁴] / $A_y$ [cm²] | $I_z$ [cm⁴] / $A_z$ [cm²] | Principal Axes α [°] | Rotation α' [°] | Overall Dimensions [cm] Width b | Height h |
|---|---|---|---|---|---|---|---|---|
| 1 | HE B 200 \| Euronorm 53-62 | | | | | | | |
| | 1 | 59.50 | 5700.00 | 2000.00 | 0.00 | 0.00 | 20.00 | 20.00 |
| | | 78.10 | 50.04 | 15.35 | | | | |
| | HEB200 | | | | | | | |
| 2 | HE B 1000 \| Euronorm 53-62 | | | | | | | |
| | 1 | 1260.00 | 644700.00 | 16280.00 | 0.00 | 0.00 | 30.00 | 100.00 |
| | | 400.00 | 181.44 | 179.09 | | | | |
| | HEB1000 | | | | | | | |
| 3 | HE A 500 \| Euronorm 53-62 | | | | | | | |
| | 1 | 310.00 | 86970.00 | 10370.00 | 0.00 | 0.00 | 30.00 | 49.00 |
| | | 198.00 | 115.05 | 53.82 | | | | |
| | HEA500 | | | | | | | |
| 4 | RRO 260x180x8 \| EN 10219-2:2006 | | | | | | | |
| | 1 | 7267.00 | 6145.00 | 3493.00 | 0.00 | 0.00 | 18.00 | 26.00 |
| | | 65.60 | 21.00 | 36.14 | | | | |
| | RHS180*260*8 | | | | | | | |
| 5 | QRO 300x10 \| EN 10219-2:2006 | | | | | | | |
| | 1 | 24970.00 | 15520.00 | 15520.00 | 0.00 | 0.00 | 30.00 | 30.00 |
| | | 113.00 | 48.87 | 48.87 | | | | |
| | RHS300*10 | | | | | | | |

## 1.17 MEMBERS




| Mbr. No. | Line No. | Member | Rotation Type | β [°] | Cross-Section Start | Cross-Section End | Hinge No. Start | Hinge No. End | Ecc. No. | Div. No. | Length L [cm] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 BEAM | Beam | Angle | 180.00 | 1 | 1 | - | - | - | - | 894.00 | X |
| 2 | 2 BEAM | Beam | Angle | 180.00 | 2 | 2 | - | - | - | - | 1474.60 | X |
| 3 | 3 BEAM | Beam | Angle | 180.00 | 3 | 3 | - | - | - | - | 426.00 | X |
| 4 | 4 BEAM | Beam | Angle | 180.00 | 3 | 3 | - | - | - | - | 390.00 | X |
| 5 | 5 BEAM | Beam | Angle | 180.00 | 3 | 3 | - | - | - | - | 2164.08 | YZ |
| 6 | 6 BEAM | Beam | Angle | 180.00 | 3 | 3 | - | - | - | - | 622.78 | YZ |
| 7 | 7 BEAM | Beam | Angle | 180.00 | 3 | 3 | - | - | - | - | 398.73 | YZ |
| 8 | 8 BEAM | Beam | Angle | 0.00 | 4 | 4 | - | - | - | - | 1012.00 | Y |
| 9 | 9 BEAM | Beam | Angle | 0.00 | 4 | 4 | - | - | - | - | 1012.00 | Y |
| 10 | 10 BEAM | Beam | Angle | 0.00 | 4 | 4 | - | - | - | - | 1012.00 | Y |
| 11 | 11 BEAM | Beam | Angle | 0.00 | 4 | 4 | - | - | - | - | 1012.00 | Y |
| 12 | 12 BEAM | Beam | Angle | 0.00 | 4 | 4 | - | - | - | - | 1012.00 | Y |
| 13 | 13 BEAM | Beam | Angle | 0.00 | 4 | 4 | - | - | - | - | 1012.00 | Y |
| 14 | 14 BEAM | Beam | Angle | 0.00 | 4 | 4 | - | - | - | - | 1012.00 | Y |
| 15 | 15 COLUMN | Beam | Angle | 90.00 | 3 | 3 | - | - | - | - | 633.00 | Z |
| 16 | 16 COLUMN | Beam | Angle | 90.00 | 3 | 3 | - | - | - | - | 60.91 | Z |
| 17 | 17 COLUMN | Beam | Angle | 0.00 | 5 | 5 | - | - | - | - | 731.43 | Z |
| 18 | 18 COLUMN | Beam | Angle | 0.00 | 5 | 5 | - | - | - | - | 755.50 | Z |

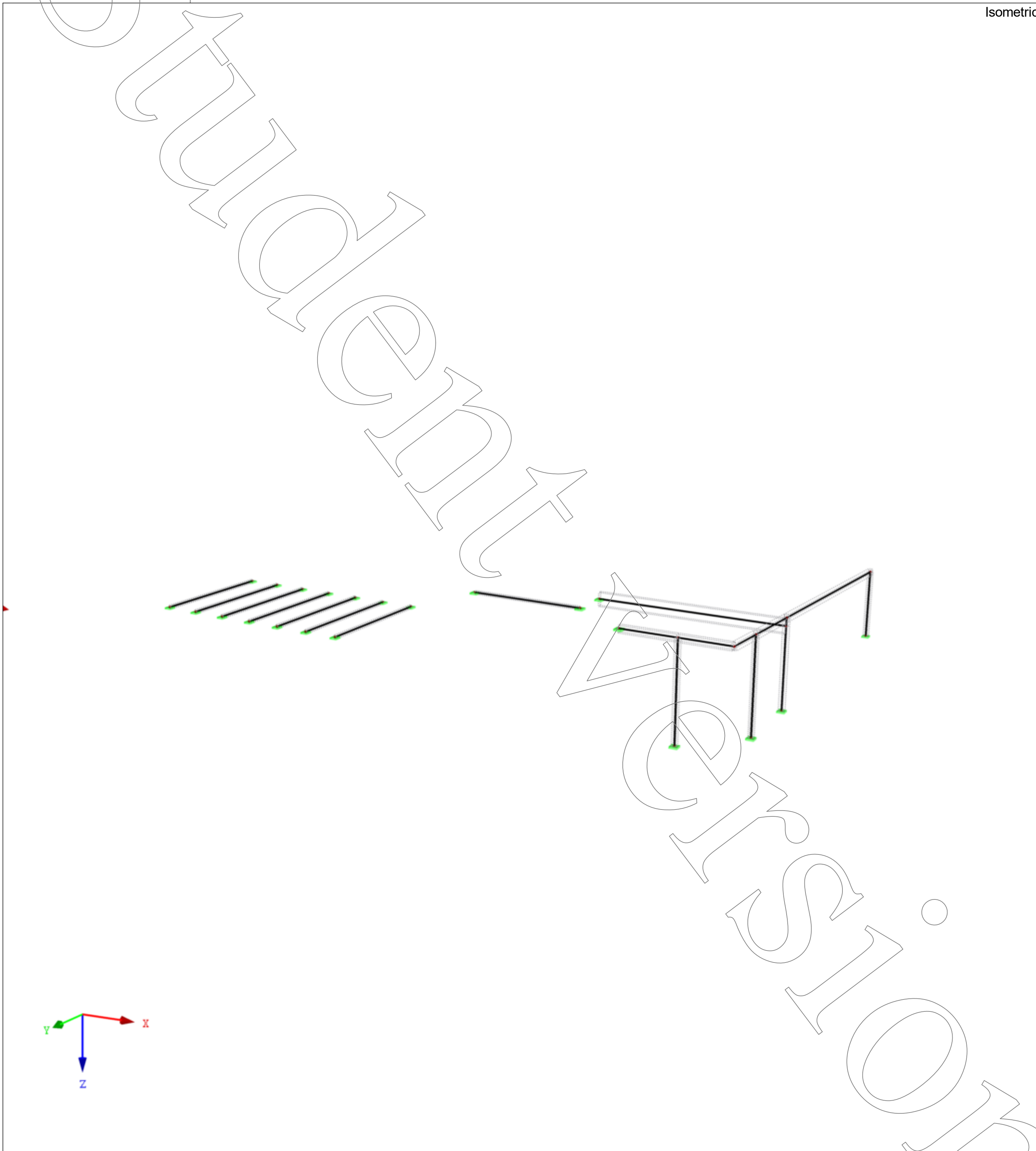
## 1.17 MEMBERS

| Mbr. | Line | | Rotation | | Cross-Section | | Hinge No. | | Ecc. | Div. | Length | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | No. | Member | Type | β [°] | Start | End | Start | End | No. | No. | L [cm] | |
| 19 | 19<br>COLUMN | Beam | Angle | 90.00 | 3 | 3 | - | - | - | - | 563.54 | Z |

## 1.21 SETS OF MEMBERS

| Set No. | Set of Members Description | Type | Member No. | Length [cm] | Comment |
|---|---|---|---|---|---|
| 1 | BEAM | Contin. member | 1 | 894.00 | 383804472 |
| 2 | BEAM | Contin. member | 2 | 1474.60 | 383804501 |
| 3 | BEAM | Contin. member | 3,4 | 816.00 | 383804515 |
| 4 | | Contin. member | 5-7 | 3185.59 | 383804529 |
| 5 | BEAM | Contin. member | 8 | 1012.00 | 383804550 |
| 6 | BEAM | Contin. member | 9 | 1012.00 | 383804564 |
| 7 | BEAM | Contin. member | 10 | 1012.00 | 383804578 |
| 8 | BEAM | Contin. member | 11 | 1012.00 | 383804592 |
| 9 | BEAM | Contin. member | 12 | 1012.00 | 383804606 |
| 10 | BEAM | Contin. member | 13 | 1012.00 | 383804620 |
| 11 | BEAM | Contin. member | 14 | 1012.00 | 383804634 |
| 12 | COLUMN | Contin. member | 15,16 | 693.91 | 383804648 |
| 13 | COLUMN | Contin. member | 17 | 731.43 | 383804666 |
| 14 | COLUMN | Contin. member | 18 | 755.50 | 383804680 |
| 15 | COLUMN | Contin. member | 19 | 563.54 | 383804694 |

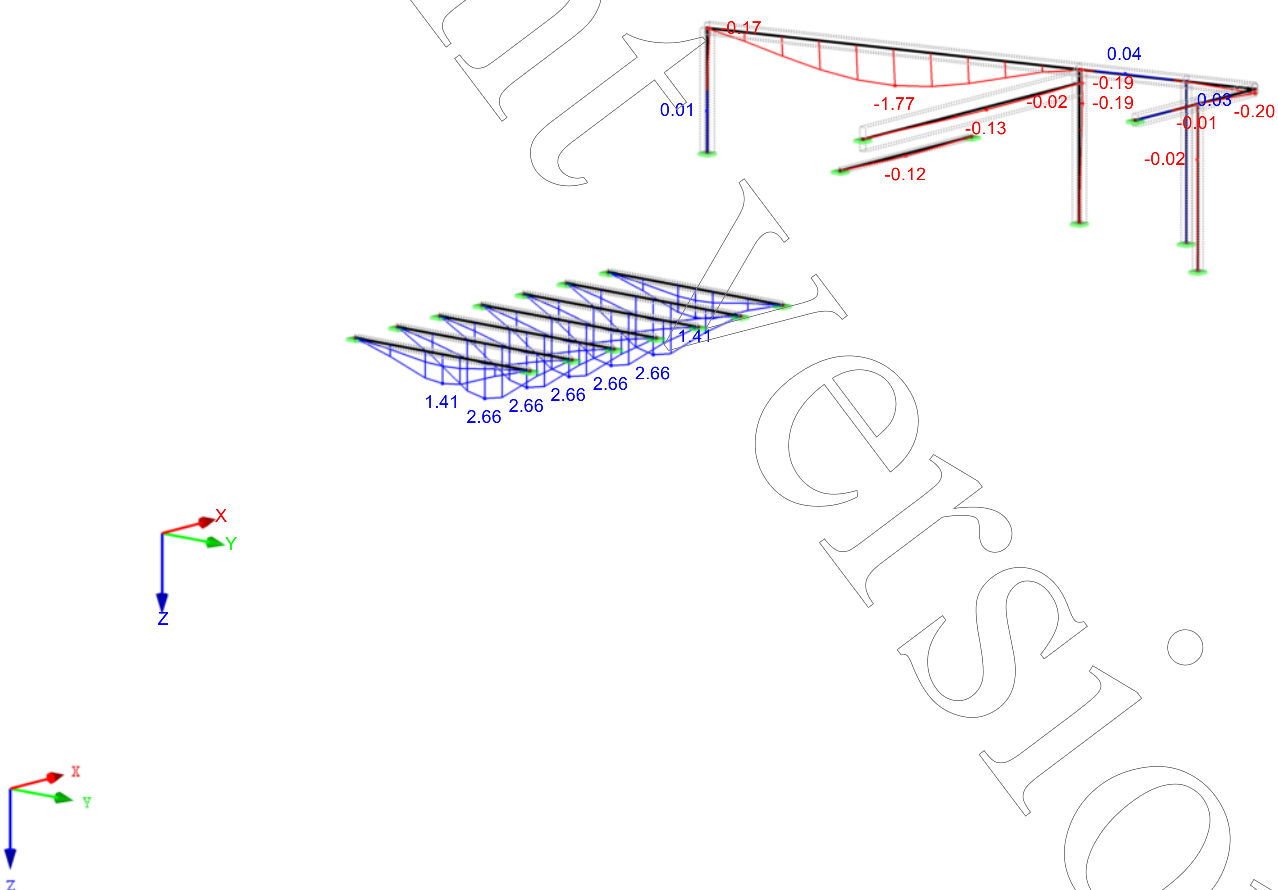
■ MODEL



## ■ LOCAL DEFORMATIONS $u_z$

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Local Deformations u-z
Result Combinations: Max and Min Values

Isometric



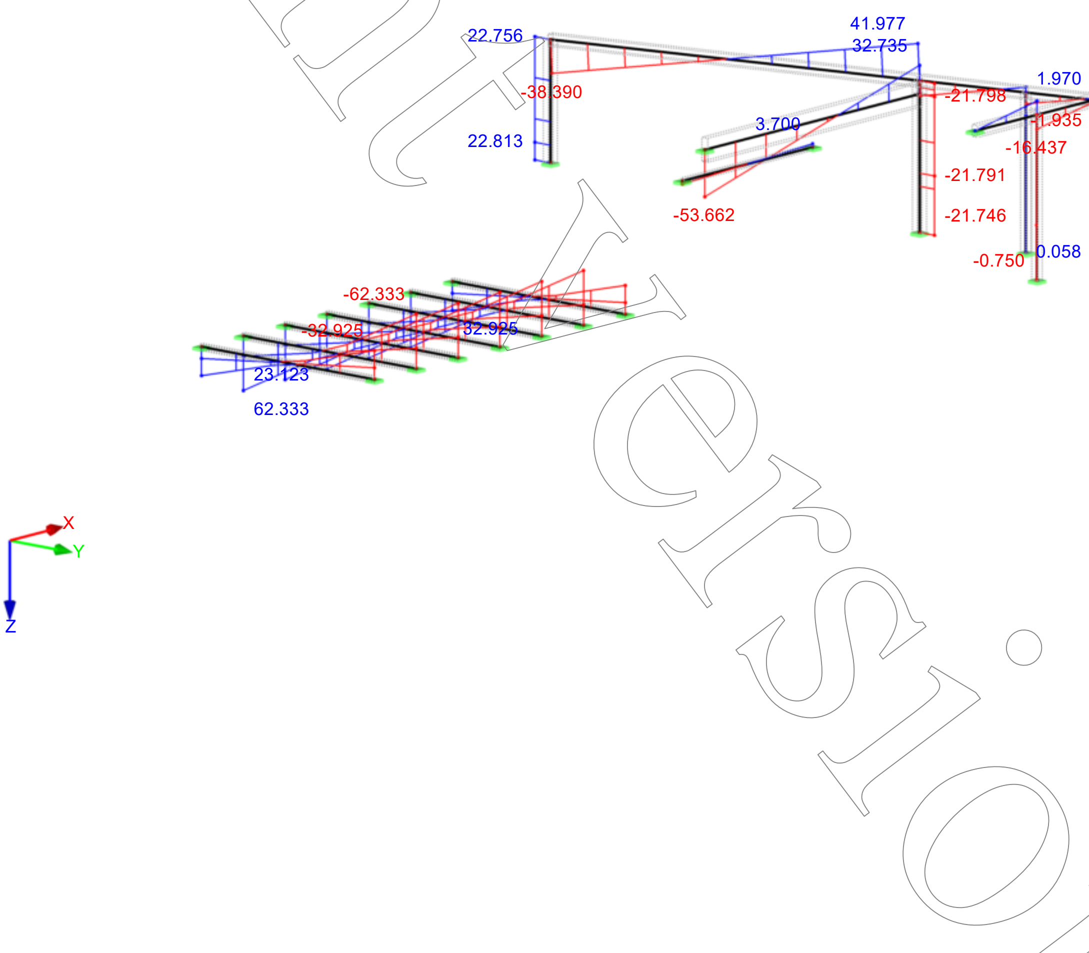

Max u-z: 2.66, Min u-z: -1.77 [cm]

Project: Master Thesis project
Structural steel elements of the Mall project
Model: A&D of steel elements of the Mall project
Date: 11/30/2017

## INTERNAL FORCES $V_z$

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Internal Forces V-z
Result Combinations: Max and Min Values

Isometric



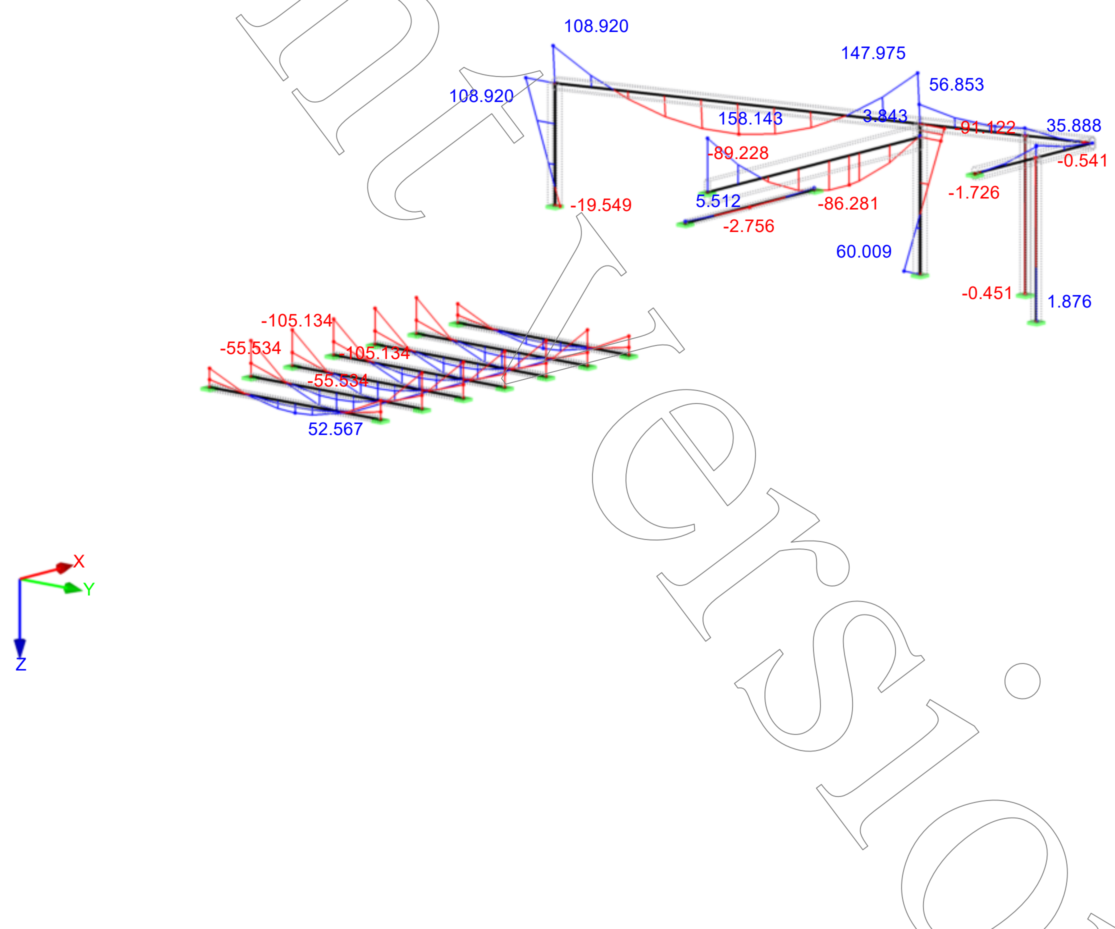

Max V-z: 62.333, Min V-z: -62.333 [kN]

Project: Master Thesis project
Structural steel elements of the Mall project
Model: A&D of steel elements of the Mall project
Date: 11/30/2017

## INTERNAL FORCES $M_y$

RC 1: ULS (STR/GEO) - Permanent / transient - Eq. 6.10
Internal Forces M-y
Result Combinations: Max and Min Values

Isometric




Max M-y: 158.143, Min M-y: -105.134 [kNm]

## 1.1 GENERAL DATA

| | | |
|---|---|---|
| Members to design: | All | |
| Sets of members to design: | All | |
| National Annex: | SIST | |
| Ultimate Limit State Design | | |
| Result combinations to design: | RC1 | ULS (STR/GEO) - Permanent / transient - Eq. 6.10 |

### 1.1.1 DETAILS

| | |
|---|---|
| **Stability Analysis** | |
| Stability Check | ☒ |
| **Bending About the Major y-Axis** | |
| Equivalent Member Method acc. to 6.3 | ☒ |
| Include second-order effects acc. to 5.2.2(4) by increasing bending moment | ☐ |
| **Bending About the Minor z-Axis** | |
| Equivalent Member Method acc. to 6.3 | ☒ |
| Include second-order effects acc. to 5.2.2(4) by increasing bending moment | ☐ |
| **Determination of elastic critical moment for lateral-torsional buckling** | |
| For members: | Automatically by Eigenvalue Method |
| Load application of positive transverse loads: | On cross-section edge directed to shear center (e.g. top flange, destabilizing effect) |
| **Model type acc. to Table B.3** | |
| Sway y - y ($C_{my}$ = 0.9) | ☐ |
| Sway z - z ($C_{mz}$ = 0.9) | ☐ |
| **Limit Load for Special Cases** | |
| Unsymmetric cross-sections with compression and bending | |
| $M_{y,Ed} / M_{pl,y,Rd} \leq$ | 0.01 |
| $M_{z,Ed} / M_{pl,z,Rd} \leq$ | 0.01 |
| $N_{c,Ed} / N_{pl} \leq$ | 0.01 |
| Non-Symmetrical Cross-Sections, Tapered Members or Sets of Members | |
| $M_{z,Ed} / M_{pl,z,Rd} \leq$ | 0.05 |
| Cross-Sections with Torsion | |
| $\tau_{t,Ed} / \tau_{t,Rd} \leq$ | 0.05 |
| Stability analysis method for sets of members acc. to | 6.3.4 General Method |
| **Classification of Cross-Sections** | |
| Type of determination of $\psi$ and $\alpha$ acc. to Table 5.2: | Increase $N_{Ed}$ and $M_{Ed}$ uniformly |
| For limit c/t of Class 3, increase material factor $\varepsilon$ acc. to 5.5.2(9) | ☒ |
| Use SHAPE-THIN for classification of all supported cross-section types (only Classes 3 and 4 possible) | ☐ |
| Ignore classification of curved parts | ☒ |
| if c/t $\leq$ | 5.00 |
| **Options** | |
| Elastic Design (also for cross-sections of Class 1 or 2) | ☐ |
| Stability Analyses with Second-Order Internal Forces | |
| Use $\gamma_{M1}$ for determination of the cross-section resistance | ☐ |
| Cross-section check for M+N | |
| Use linear interaction acc. to 6.2.1(7) | ☐ |
| Cross-sections with Class 4 and torsion | |
| $\tau_{t,Ed} / \tau_{t,Rd} \leq$ | 0.05 |
| **Member Slendernesses** | |
| Members with | $\lambda_{limit}$ |
| Tension only: | 300 |
| Compression / flexure: | 200 |
| **Design of Welds** | |
| Allow design of welds | ☐ |

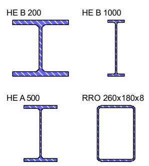
## 1.2 MATERIALS

| Matl. No. | Material Description | E- Modulus E [MPa] | Shear Modulus G [MPa] | Poisson's Ratio $\nu$ [-] | Yield Stress $f_{yk}$ [MPa] | Max. Thickness t [cm] |
|---|---|---|---|---|---|---|
| 1 | Steel S 235 \| EN 1993-1-1:2005-05 | 210000.000 | 80769.200 | 0.300 | 235.000 | 4.00 |
| | | | | | 215.000 | 8.00 |
| | | | | | 215.000 | 10.00 |
| | | | | | 195.000 | 15.00 |

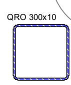
## 1.2 MATERIALS

| Matl. No. | Material Description | E- Modulus E [MPa] | Shear Modulus G [MPa] | Poisson's Ratio ν [-] | Yield Stress $f_{yk}$ [MPa] | Max. Thickness t [cm] |
|---|---|---|---|---|---|---|
| | S235JR | | | | 185.000<br>175.000<br>165.000 | 20.00<br>25.00<br>40.00 |

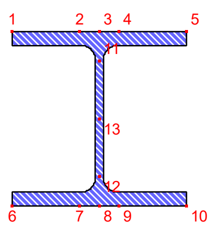
## 1.3 CROSS-SECTIONS




| Sect. No. | Matl. No. | Cross-Section Description | Cross-Section Type | Max Design Ratio | Comment |
|---|---|---|---|---|---|
| 1 | 1 | HE B 200 \| Euronorm 53-62 | I-section rolled | 0.04 | HEB200 |
| 2 | 1 | HE B 1000 \| Euronorm 53-62 | I-section rolled | 0.10 | HEB1000 |
| 3 | 1 | HE A 500 \| Euronorm 53-62 | I-section rolled | 0.82 | HEA500 |
| 4 | 1 | RRO 260x180x8 \| EN 10219-2:2006 | Box rolled | 0.78 | RHS180*260*8 |
| 5 | 1 | QRO 300x10 \| EN 10219-2:2006 | Box rolled | 0.03 | RHS300*10 |



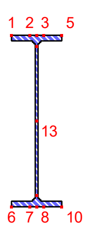

HE B 200




## STRESS POINTS — HE B 200 | Euronorm 53-62

| S-Point No. | Coordinates [cm] y | z | Stat. Moments of Area [cm³] $Q_y$ | $Q_z$ | Thickness t [cm] |
|---|---|---|---|---|---|
| 1 | -10.00 | -10.00 | 0.00 | 0.00 | 1.50 |
| 2 | -2.25 | -10.00 | -107.45 | -71.19 | 1.50 |
| 3 | 0.00 | -10.00 | -139.34 | -75.26 | 1.50 |
| 4 | 2.25 | -10.00 | -107.45 | 71.19 | 1.50 |
| 5 | 10.00 | -10.00 | 0.00 | 0.00 | 1.50 |
| 6 | -10.00 | 10.00 | 0.00 | 0.00 | 1.50 |
| 7 | -2.25 | 10.00 | -107.53 | 71.20 | 1.50 |
| 8 | 0.00 | 10.00 | -139.34 | 75.26 | 1.50 |
| 9 | 2.25 | 10.00 | -107.53 | -71.20 | 1.50 |
| 10 | 10.00 | 10.00 | 0.00 | 0.00 | 1.50 |
| 11 | 0.00 | -6.70 | -301.08 | 0.00 | 0.90 |
| 12 | 0.00 | 6.70 | -301.10 | 0.00 | 0.90 |
| 13 | 0.00 | 0.00 | -321.28 | 0.00 | 0.90 |

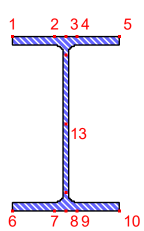
HE B 1000




## STRESS POINTS — HE B 1000 | Euronorm 53-62

| S-Point No. | Coordinates [cm] y | z | Stat. Moments of Area [cm³] $Q_y$ | $Q_z$ | Thickness t [cm] |
|---|---|---|---|---|---|
| 1 | -15.00 | -50.00 | 0.00 | 0.00 | 3.60 |
| 2 | -3.95 | -50.00 | -1917.83 | -376.90 | 3.60 |
| 3 | 0.00 | -50.00 | -2585.53 | -405.78 | 3.60 |
| 4 | 3.95 | -50.00 | -1917.83 | 376.90 | 3.60 |
| 5 | 15.00 | -50.00 | 0.00 | 0.00 | 3.60 |
| 6 | -15.00 | 50.00 | 0.00 | 0.00 | 3.60 |
| 7 | -3.95 | 50.00 | -1917.40 | 376.92 | 3.60 |
| 8 | 0.00 | 50.00 | -2585.53 | 405.78 | 3.60 |
| 9 | 3.95 | 50.00 | -1917.40 | -376.92 | 3.60 |
| 10 | 15.00 | 50.00 | 0.00 | 0.00 | 3.60 |
| 11 | 0.00 | -43.40 | -5630.30 | 0.00 | 1.90 |
| 12 | 0.00 | 43.40 | -5628.71 | 0.00 | 1.90 |
| 13 | 0.00 | 0.00 | -7427.58 | 0.00 | 1.90 |

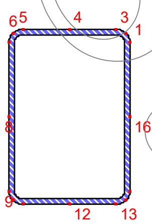
HE A 500




## STRESS POINTS — HE A 500 | Euronorm 53-62

| S-Point No. | Coordinates [cm] y | z | Stat. Moments of Area [cm³] $Q_y$ | $Q_z$ | Thickness t [cm] |
|---|---|---|---|---|---|
| 1 | -15.00 | -24.50 | 0.00 | 0.00 | 2.30 |
| 2 | -3.30 | -24.50 | -627.63 | -246.17 | 2.30 |
| 3 | 0.00 | -24.50 | -813.45 | -259.81 | 2.30 |
| 4 | 3.30 | -24.50 | -627.63 | 246.17 | 2.30 |
| 5 | 15.00 | -24.50 | 0.00 | 0.00 | 2.30 |
| 6 | -15.00 | 24.50 | 0.00 | 0.00 | 2.30 |
| 7 | -3.30 | 24.50 | -628.35 | 246.23 | 2.30 |
| 8 | 0.00 | 24.50 | -813.45 | 259.81 | 2.30 |
| 9 | 3.30 | 24.50 | -628.35 | -246.23 | 2.30 |
| 10 | 15.00 | 24.50 | 0.00 | 0.00 | 2.30 |
| 11 | 0.00 | -19.50 | -1746.29 | 0.00 | 1.20 |
| 12 | 0.00 | 19.50 | -1749.77 | 0.00 | 1.20 |
| 13 | 0.00 | 0.00 | -1974.44 | 0.00 | 1.20 |

RRO 260x180x8

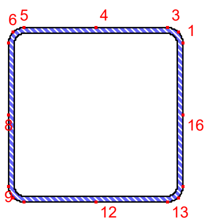



## STRESS POINTS

RRO 260x180x8 | EN 10219-2:2006

| S-Point | Coordinates [cm] | | Stat. Moments of Area [cm³] | | Thickness | Cell Area |
|---|---|---|---|---|---|---|
| No. | y | z | $Q_y$ | $Q_z$ | t [cm] | A* [cm²] |
| 1 | 9.00 | -11.00 | -94.64 | -75.68 | 0.80 | 431.15 |
| 2 | 8.41 | -12.41 | -83.06 | -84.11 | 0.80 | 431.15 |
| 3 | 7.00 | -13.00 | -70.56 | -91.74 | 0.80 | 431.15 |
| 4 | 0.00 | -13.00 | 0.00 | -111.34 | 0.80 | 431.15 |
| 5 | -7.00 | -13.00 | 70.56 | -91.74 | 0.80 | 431.15 |
| 6 | -8.41 | -12.41 | 82.99 | -84.16 | 0.80 | 431.15 |
| 7 | -9.00 | -11.00 | 94.64 | -75.68 | 0.80 | 431.15 |
| 8 | -9.00 | 0.00 | 143.04 | 0.00 | 0.80 | 431.15 |
| 9 | -9.00 | 11.00 | 94.64 | 75.68 | 0.80 | 431.15 |
| 10 | -8.41 | 12.41 | 83.06 | 84.11 | 0.80 | 431.15 |
| 11 | -7.00 | 13.00 | 70.56 | 91.74 | 0.80 | 431.15 |
| 12 | 0.00 | 13.00 | 0.00 | 111.34 | 0.80 | 431.15 |
| 13 | 7.00 | 13.00 | -70.56 | 91.74 | 0.80 | 431.15 |
| 14 | 8.41 | 12.41 | -82.99 | 84.16 | 0.80 | 431.15 |
| 15 | 9.00 | 11.00 | -94.64 | 75.68 | 0.80 | 431.15 |
| 16 | 9.00 | 0.00 | -143.04 | 0.00 | 0.80 | 431.15 |

QRO 300x10




## STRESS POINTS

QRO 300x10 | EN 10219-2:2006

| S-Point | Coordinates [cm] | | Stat. Moments of Area [cm³] | | Thickness | Cell Area |
|---|---|---|---|---|---|---|
| No. | y | z | $Q_y$ | $Q_z$ | t [cm] | A* [cm²] |
| 1 | 15.00 | -12.50 | -224.37 | -181.25 | 1.00 | 837.42 |
| 2 | 14.27 | -14.27 | -203.70 | -203.57 | 1.00 | 837.42 |
| 3 | 12.50 | -15.00 | -181.25 | -224.37 | 1.00 | 837.42 |
| 4 | 0.00 | -15.00 | 0.00 | -302.50 | 1.00 | 837.42 |
| 5 | -12.50 | -15.00 | 181.25 | -224.37 | 1.00 | 837.42 |
| 6 | -14.27 | -14.27 | 203.57 | -203.70 | 1.00 | 837.42 |
| 7 | -15.00 | -12.50 | 224.37 | -181.25 | 1.00 | 837.42 |
| 8 | -15.00 | 0.00 | 302.50 | 0.00 | 1.00 | 837.42 |
| 9 | -15.00 | 12.50 | 224.37 | 181.25 | 1.00 | 837.42 |
| 10 | -14.27 | 14.27 | 203.70 | 203.57 | 1.00 | 837.42 |
| 11 | -12.50 | 15.00 | 181.25 | 224.37 | 1.00 | 837.42 |
| 12 | 0.00 | 15.00 | 0.00 | 302.50 | 1.00 | 837.42 |
| 13 | 12.50 | 15.00 | -181.25 | 224.37 | 1.00 | 837.42 |
| 14 | 14.27 | 14.27 | -203.57 | 203.70 | 1.00 | 837.42 |
| 15 | 15.00 | 12.50 | -224.37 | 181.25 | 1.00 | 837.42 |
| 16 | 15.00 | 0.00 | -302.50 | 0.00 | 1.00 | 837.42 |

## 1.5 EFFECTIVE LENGTHS - MEMBERS

| Member | Buckling | Buckling About Axis y | | | Buckling About Axis z | | | Lateral-Torsional Buckling | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Possible | Possible | $k_{cr,y}$ | $L_{cr,y}$ [cm] | Possible | $k_{cr,z}$ | $L_{cr,z}$ [cm] | Possible | $k_z$ | $k_w$ | $L_w$ [cm] | $L_T$ [cm] |
| 1 | ☒ | ☒ | 1.00 | 894.00 | ☒ | 1.00 | 894.00 | ☒ | 1.0 | 1.0 | 894.00 | 894.00 |
| 2 | ☒ | ☒ | 1.00 | 1474.60 | ☒ | 1.00 | 1474.60 | ☒ | 1.0 | 1.0 | 1474.60 | 1474.60 |
| 3 | ☒ | ☒ | 1.00 | 426.00 | ☒ | 1.00 | 426.00 | ☒ | 1.0 | 1.0 | 426.00 | 426.00 |
| 4 | ☒ | ☒ | 1.00 | 390.00 | ☒ | 1.00 | 390.00 | ☒ | 1.0 | 1.0 | 390.00 | 390.00 |
| 5 | ☒ | ☒ | 1.00 | 2164.08 | ☒ | 1.00 | 2164.08 | ☒ | 1.0 | 1.0 | 2164.08 | 2164.08 |
| 6 | ☒ | ☒ | 1.00 | 622.78 | ☒ | 1.00 | 622.78 | ☒ | 1.0 | 1.0 | 622.78 | 622.78 |
| 7 | ☒ | ☒ | 1.00 | 398.73 | ☒ | 1.00 | 398.73 | ☒ | 1.0 | 1.0 | 398.73 | 398.73 |
| 8 | ☒ | ☒ | 1.00 | 1012.00 | ☒ | 1.00 | 1012.00 | ☐ | 1.0 | 1.0 | 1012.00 | 1012.00 |
| 9 | ☒ | ☒ | 1.00 | 1012.00 | ☒ | 1.00 | 1012.00 | ☐ | 1.0 | 1.0 | 1012.00 | 1012.00 |
| 10 | ☒ | ☒ | 1.00 | 1012.00 | ☒ | 1.00 | 1012.00 | ☐ | 1.0 | 1.0 | 1012.00 | 1012.00 |
| 11 | ☒ | ☒ | 1.00 | 1012.00 | ☒ | 1.00 | 1012.00 | ☐ | 1.0 | 1.0 | 1012.00 | 1012.00 |
| 12 | ☒ | ☒ | 1.00 | 1012.00 | ☒ | 1.00 | 1012.00 | ☐ | 1.0 | 1.0 | 1012.00 | 1012.00 |
| 13 | ☒ | ☒ | 1.00 | 1012.00 | ☒ | 1.00 | 1012.00 | ☐ | 1.0 | 1.0 | 1012.00 | 1012.00 |
| 14 | ☒ | ☒ | 1.00 | 1012.00 | ☒ | 1.00 | 1012.00 | ☐ | 1.0 | 1.0 | 1012.00 | 1012.00 |
| 15 | ☒ | ☒ | 1.00 | 633.00 | ☒ | 1.00 | 633.00 | ☐ | 1.0 | 1.0 | 633.00 | 633.00 |
| 16 | ☒ | ☒ | 1.00 | 60.91 | ☒ | 1.00 | 60.91 | ☒ | 1.0 | 1.0 | 60.91 | 60.91 |
| 17 | ☒ | ☒ | 1.00 | 731.43 | ☒ | 1.00 | 731.43 | ☐ | 1.0 | 1.0 | 731.43 | 731.43 |
| 18 | ☒ | ☒ | 1.00 | 755.50 | ☒ | 1.00 | 755.50 | ☐ | 1.0 | 1.0 | 755.50 | 755.50 |
| 19 | ☒ | ☒ | 1.00 | 563.54 | ☒ | 1.00 | 563.54 | ☒ | 1.0 | 1.0 | 563.54 | 563.54 |

## 1.7 NODAL SUPPORTS

| | Nodes | Support | Lateral Restraint | Restraint | | Warping | Eccentricity | | Comment |
|---|---|---|---|---|---|---|---|---|---|
| No. | No. | Rotation β [°] | $u_{Y'}$ | $\varphi_{X'}$ | $\varphi_{Z'}$ | Restraint ω | $e_{X'}$ [cm] | $e_{Z'}$ [cm] | |
| | **Set of Members No. 1 - BEAM** | | | | | | | | |
| 1 | 22 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 21 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 2 - BEAM** | | | | | | | | |
| 1 | 20 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 28 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 3 - BEAM** | | | | | | | | |
| 1 | 19 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 27 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 4** | | | | | | | | |
| 1 | 27 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 23 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 5 - BEAM** | | | | | | | | |
| 1 | 18 | 0.00 | ☒ | ☒ | ☐ | ☐ | 0.00 | 0.00 | |

## 1.7 NODAL SUPPORTS

| No. | Nodes No. | Support Rotation β [°] | Lateral Restraint $u_{Y'}$ | Restraint $\varphi_{X'}$ | Restraint $\varphi_{Z'}$ | Warping Restraint ω | $e_{X'}$ [cm] | $e_{Z'}$ [cm] | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 17 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 6 - BEAM** | | | | | | | | |
| 1 | 15 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 16 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 7 - BEAM** | | | | | | | | |
| 1 | 14 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 13 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 8 - BEAM** | | | | | | | | |
| 1 | 11 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 12 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 9 - BEAM** | | | | | | | | |
| 1 | 9 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 10 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 10 - BEAM** | | | | | | | | |
| 1 | 7 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 8 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 11 - BEAM** | | | | | | | | |
| 1 | 6 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 5 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 12 - COLUMN** | | | | | | | | |
| 1 | 4 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 26 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 13 - COLUMN** | | | | | | | | |
| 1 | 3 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 25 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 14 - COLUMN** | | | | | | | | |
| 1 | 2 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 24 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| | **Set of Members No. 15 - COLUMN** | | | | | | | | |
| 1 | 1 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |
| 2 | 23 | 0.00 | ⊠ | ⊠ | ☐ | ☐ | 0.00 | 0.00 | |

## 1.12 PARAMETERS - MEMBERS

| Member No. | Description | Parameter |
|---|---|---|
| 1 | Cross-Section | 1 - HE B 200 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 2 | Cross-Section | 2 - HE B 1000 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 3 | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 4 | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 5 | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 6 | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 7 | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 8 | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 9 | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 10 | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |

## 1.12 PARAMETERS - MEMBERS

| Member No. | Description | Parameter |
|---|---|---|
| | Cross-sectional area for tension design | ☐ |
| 11 | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 12 | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 13 | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 14 | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 15 | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 16 | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 17 | Cross-Section | 5 - QRO 300x10 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 18 | Cross-Section | 5 - QRO 300x10 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |
| 19 | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| | Cross-sectional area for tension design | ☐ |

## 1.13 PARAMETERS - SETS OF MEMBERS

| Set No. | Description | Parameter |
|---|---|---|
| 1 | Set of Members | BEAM |
| | Cross-Section | 1 - HE B 200 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 2 | Set of Members | BEAM |
| | Cross-Section | 2 - HE B 1000 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 3 | Set of Members | BEAM |
| | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 4 | Set of Members | Set of Members 4 |
| | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 5 | Set of Members | BEAM |
| | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 6 | Set of Members | BEAM |
| | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 7 | Set of Members | BEAM |
| | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |

## ■ 1.13 PARAMETERS - SETS OF MEMBERS

| Set No. | Description | Parameter |
|---|---|---|
| 8 | Set of Members | BEAM |
| | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 9 | Set of Members | BEAM |
| | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 10 | Set of Members | BEAM |
| | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 11 | Set of Members | BEAM |
| | Cross-Section | 4 - RRO 260x180x8 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 12 | Set of Members | COLUMN |
| | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 13 | Set of Members | COLUMN |
| | Cross-Section | 5 - QRO 300x10 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 14 | Set of Members | COLUMN |
| | Cross-Section | 5 - QRO 300x10 \| EN 10219-2:2006 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |
| 15 | Set of Members | COLUMN |
| | Cross-Section | 3 - HE A 500 \| Euronorm 53-62 |
| | Shear panel | ☐ |
| | Rotational restraint | ☐ |

## ■ 2.1 DESIGN BY LOAD CASE

| LC/CO/ RC | Load Case or CO/RC Description | Member No. | Location x [cm] | Design | | Design No. | Description |
|---|---|---|---|---|---|---|---|
| | **Ultimate Limit State Design** | | | | | | |
| RC1 | ULS (STR/GEO) - Permanent / transient - Eq. 6.10 | 5 | 1298.45 | 0.82 | ≤ 1 | ST371) | PT |

## ■ 2.2 DESIGN BY CROSS-SECTION

| Sect. No. | Member No. | Location x [cm] | LC/CO/ RC | Design | | Design No. | Description |
|---|---|---|---|---|---|---|---|
| 1 | **HE B 200 \| Euronorm 53-62 - HEB200** | | | | | | |
| | 1 | 0.00 | RC1 | 0.04 | ≤ 1 | CS111) | Cross-section check - Bending about y-axis acc. to 6.2.5 - Class 1 or 2 |
| | 1 | 0.00 | RC1 | 0.01 | ≤ 1 | CS121) | Cross-section check - Shear force in z-axis acc. to 6.2.6 |
| | 1 | 0.00 | RC1 | 0.00 | ≤ 1 | CS126) | Cross-section check - Shear buckling acc. to 6.2.6(6) |
| | 1 | 0.00 | RC1 | 0.04 | ≤ 1 | CS141) | Cross-section check - Bending and shear force acc. to 6.2.5 and 6.2.8 |
| | 1 | 0.00 | RC1 | 0.04 | ≤ 1 | ST331) | Stability analysis - Lateral torsional buckling acc. to 6.3.2.1 and 6.3.2.3 - I-Section |
| | 1 | 0.00 | RC1 | 0.04 | ≤ 1 | ST371) | Stability analysis - Bending and compression acc. to 6.3.4, General Method |
| 2 | **HE B 1000 \| Euronorm 53-62 - HEB1000** | | | | | | |
| | 2 | 842.63 | RC1 | 0.02 | ≤ 1 | CS111) | Cross-section check - Bending about y-axis acc. to 6.2.5 - Class 1 or 2 |
| | 2 | 0.00 | RC1 | 0.02 | ≤ 1 | CS121) | Cross-section check - Shear force in z-axis acc. to 6.2.6 |
| | 2 | 0.00 | RC1 | 0.00 | ≤ 1 | CS126) | Cross-section check - Shear buckling acc. to 6.2.6(6) |
| | 2 | 842.63 | RC1 | 0.02 | ≤ 1 | CS141) | Cross-section check - Bending and shear force acc. to 6.2.5 and 6.2.8 |
| | 2 | 0.00 | RC1 | 0.00 | ≤ 1 | CS161) | Cross-section check - Biaxial bending and shear force acc. to 6.2.6, 6.2.7 and 6.2.9 |
| | 2 | 842.63 | RC1 | 0.08 | ≤ 1 | ST331) | Stability analysis - Lateral torsional buckling acc. to 6.3.2.1 and 6.3.2.3 - I-Section |
| | 2 | 0.00 | RC1 | 0.09 | ≤ 1 | ST363) | Stability analysis - Biaxial bending acc. to 6.3.3, Method 2 |
| | 2 | 0.00 | RC1 | 0.10 | ≤ 1 | ST371) | Stability analysis - Bending and compression acc. to 6.3.4, General Method |
| 3 | **HE A 500 \| Euronorm 53-62 - HEA500** | | | | | | |
| | 15 | 0.00 | RC1 | 0.02 | ≤ 1 | CS102) | Cross-section check - Compression acc. to 6.2.4 |
| | 6 | 0.00 | RC1 | 0.06 | ≤ 1 | CS111) | Cross-section check - Bending about y-axis acc. to 6.2.5 - C |

Project: Master Thesis project
Structural steel elements of the Mall project
Model: A&D of steel elements of the Mall project
Date: 11/30/2017

## ■ 2.2 DESIGN BY CROSS-SECTION

| Sect. No. | Member No. | Location x [cm] | LC/CO/ RC | Design | | Design No. | Description |
|---|---|---|---|---|---|---|---|
| | | | | | | | Class 1 or 2 |
| | 3 | 0.00 | RC1 | 0.01 | ≤ 1 | CS116) | Cross-section check - Bending about z-axis acc. to 6.2.5 - Class 1 or 2 |
| | 5 | 2164.08 | RC1 | 0.04 | ≤ 1 | CS121) | Cross-section check - Shear force in z-axis acc. to 6.2.6 |
| | 3 | 213.00 | RC1 | 0.00 | ≤ 1 | CS126) | Cross-section check - Shear buckling acc. to 6.2.6(6) |
| | 6 | 0.00 | RC1 | 0.06 | ≤ 1 | CS141) | Cross-section check - Bending and shear force acc. to 6.2.5 and 6.2.8 |
| | 3 | 0.00 | RC1 | 0.01 | ≤ 1 | CS151) | Cross-section check - Bending about z-axis and shear force acc. to 6.2.5 and 6.2.8 |
| | 4 | 0.00 | RC1 | 0.01 | ≤ 1 | CS161) | Cross-section check - Biaxial bending and shear force acc. to 6.2.6, 6.2.7 and 6.2.9 |
| | 5 | 2164.08 | RC1 | 0.16 | ≤ 1 | CS181) | Cross-section check - Bending, shear and axial force acc. to 6.2.9.1 |
| | 15 | 633.00 | RC1 | 0.02 | ≤ 1 | CS221) | Cross-section check - Biaxial bending, shear and axial force acc. to 6.2.10 and 6.2.9 |
| | 5 | 2164.08 | RC1 | 0.31 | ≤ 1 | ST331) | Stability analysis - Lateral torsional buckling acc. to 6.3.2.1 and 6.3.2.3 - I-Section |
| | 6 | 622.78 | RC1 | 0.06 | ≤ 1 | ST363) | Stability analysis - Biaxial bending acc. to 6.3.3, Method 2 |
| | 19 | 0.00 | RC1 | 0.13 | ≤ 1 | ST364) | Stability analysis - Bending and compression acc. to 6.3.3, Method 2 |
| | 5 | 1298.45 | RC1 | 0.82 | ≤ 1 | ST371) | Stability analysis - Bending and compression acc. to 6.3.4, General Method |
| 4 | **RRO 260x180x8 \| EN 10219-2:2006 - RHS180*260*8** | | | | | | |
| | 9 | 0.00 | RC1 | 0.78 | ≤ 1 | CS111) | Cross-section check - Bending about y-axis acc. to 6.2.5 - Class 1 or 2 |
| | 9 | 0.00 | RC1 | 0.12 | ≤ 1 | CS121) | Cross-section check - Shear force in z-axis acc. to 6.2.6 |
| | 8 | 0.00 | RC1 | 0.00 | ≤ 1 | CS126) | Cross-section check - Shear buckling acc. to 6.2.6(6) |
| | 9 | 0.00 | RC1 | 0.78 | ≤ 1 | CS141) | Cross-section check - Bending and shear force acc. to 6.2.5 and 6.2.8 |
| | 9 | 0.00 | RC1 | 0.78 | ≤ 1 | ST371) | Stability analysis - Bending and compression acc. to 6.3.4, General Method |
| 5 | **QRO 300x10 \| EN 10219-2:2006 - RHS300*10** | | | | | | |
| | 18 | 0.00 | RC1 | 0.02 | ≤ 1 | CS102) | Cross-section check - Compression acc. to 6.2.4 |
| | 18 | 755.50 | RC1 | 0.01 | ≤ 1 | CS181) | Cross-section check - Bending, shear and axial force acc. to 6.2.9.1 |
| | 17 | 0.00 | RC1 | 0.01 | ≤ 1 | CS201) | Cross-section check - Bending about z-axis, shear and axial force acc. to 6.2.9.1 |
| | 18 | 0.00 | RC1 | 0.00 | ≤ 1 | CS221) | Cross-section check - Biaxial bending, shear and axial force acc. to 6.2.10 and 6.2.9 |
| | 18 | 0.00 | RC1 | 0.03 | ≤ 1 | ST364) | Stability analysis - Bending and compression acc. to 6.3.3, Method 2 |
| | 18 | 755.50 | RC1 | 0.03 | ≤ 1 | ST371) | Stability analysis - Bending and compression acc. to 6.3.4, General Method |

## 10.5 Short CV (Curriculum Vitae)

Born: 17.09.1989 in Gjakova (Kosovo)

Education: 1996 – 2005 Elementary School “Emin Duraku”

2005 – 2008 High School-Gymnasium “Hajdar Dushi”

2008 – 2011 Faculty of Civil Engineering and Architecture, University of Prishtina, Bachelor Degree in Civil Engineering

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2014 – 2017 Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Master Degree in Civil Engineering

## 10.6 Declaration of authorship

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