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CASE STUDY

UTCN CASE STUDY BIM models of a building structure and a road section carrying out a life cycle sustainability assessment of different materials and waste materials

Part 1

1-Aims

The presentation is looking for ways to improve the engineering workflow and to make Building Information Modelling (BIM) a workable reality for all. BIM technology enables one or more accurate building models to be constructed digitally.

This section gives solutions for using BIM to conceptualize, plan, detail, create and guide the building of structures. In the process of designing and coordinating the execution of buildings is sought for a real and effective collaboration between architects and engineers. In this sense it is necessary to use a platform or a software tool that allows every team member to have access to the latest information and, based on authorization parameters, to share comments and suggestions and modify the model. It is necessary that every change to be tracked so every team member can understand the path of the project. BIM increase productivity through efficient collaboration thanks to seamless and transparent information exchange between architects and engineers.

2 – Description of the case study

The presentation will demonstrate the application of BIM technology in structural design and detailing. Students will have the opportunity to attend a comprehensive session covering software packages such as SCIA Engineer, Tekla Structures, and Idea StatiCa.

https://www.scia.net/en/scia-engineer
https://www.tekla.com/products/tekla-structures
https://www.ideastatica.com/ro/support-center-all/all?label=connection

Participants will become familiar with the key features and commands of these programs, gaining insight into how they facilitate seamless model exchange through powerful bi-directional links, IFC, SAF, or third-party plug-ins. The session will culminate with a detailed case study spotlighting the BIM capabilities of the software's. Required software: SCIA Engineer, Tekla Structures and Idea StatiCa.

Towards the end of the presentation, there will be an opportunity for questions and discussions.

The case studies were developed by our colleague Andreea Onea and Mihai Senila and in for training we envolved students from bachelor degree and master program.

Furthermore, this case study will serve as a guide for students in preparing their bachelor's and dissertation projects.

3 – State of the art use of BIM and LCA to assess the sustainability of a building.

3.1 – BIM in structural engineering: revolutionizing building design

Building Information Modeling (BIM) has emerged as a transformative force in the field of structural engineering, fundamentally changing the way we conceive, design, and construct buildings. This sophisticated digital toolset enables engineers to create comprehensive, accurate, and collaborative models of structures, resulting in enhanced efficiency, cost-effectiveness, and sustainability throughout the entire building lifecycle.

The concept of Building Information Modeling (BIM) has been around since the 1970s, with the introduction of the first computer-aided design (CAD) systems. However, it was not until the 1990s that the concept of BIM as we know it today began to take shape. The development of BIM has been influenced by advances in computer technology, 3D modeling, and collaborative tools. Over the years, BIM has evolved from a 3D modeling tool to a comprehensive process that integrates data, information, and workflows throughout the lifecycle of a construction project. As BIM gained ground, industry standards and protocols were developed to ensure interoperability and collaboration between different stakeholders. The evolution of BIM has also been driven by technological advances such as cloud computing, mobile devices, and artificial intelligence, which have facilitated real-time collaboration, improved data analysis capabilities, and better accessibility to BIM models.

BIM fosters a multidisciplinary approach by seamlessly integrating architectural, structural, and MEP (Mechanical, Electrical, and Plumbing) systems into a unified model. This collaborative environment enables stakeholders to work together from the earliest design stages, reducing conflicts and discrepancies, and ultimately leading to more efficient and innovative building designs.

With BIM, engineers can create detailed 3D representations of structures. This visual clarity allows for better analysis and evaluation of structural elements, facilitating early detection of potential issues and enabling precise adjustments to be made prior to construction. This not only ensures safety and compliance but also leads to more robust, well-optimized designs.

BIM provides accurate quantity take-offs and cost estimations based on the model, enabling more precise budgeting and financial planning. Additionally, it facilitates value engineering by identifying opportunities to optimize materials and construction methods, resulting in potential cost savings without compromising structural integrity.

Through BIM, engineers can generate detailed construction sequencing and phasing plans. This helps streamline the construction process, minimizing delays and reducing on-site conflicts. It also allows for better coordination between different trades, ensuring a smoother construction workflow.

BIM supports the integration of energy analysis tools, allowing engineers to assess the environmental performance of a building and explore opportunities for energy efficiency improvements. This empowers designers to make informed decisions regarding materials, systems, and layouts, leading to more sustainable and environmentally-friendly structures.

BIM extends its benefits beyond construction, providing a valuable tool for facility management and maintenance. The model serves as a comprehensive digital twin of the physical building, enabling owners and operators to efficiently plan and execute maintenance activities, manage assets, and make informed decisions for the long-term sustainability of the structure.

Core Principles Guiding BIM in Structural Engineering:

Common Digital Representation: BIM creates a unified digital representation of a building or structure throughout its lifecycle, encompassing not only the physical geometry but also the relevant data and information associated with its design, construction, and operation.

Collaboration: BIM fosters collaboration through the exchange and integration of data and information between different stakeholders, enabling efficient decision-making and reducing errors or conflicts.

Parametric Modelling: This principle allows for the creation of intelligent and dynamic objects that can be modified and updated throughout the project lifecycle, ensuring consistency and accuracy.

Data Interoperability: BIM emphasizes the importance of information exchange and sharing between different platforms and software systems, enabling the integration of different datasets and promoting efficient collaboration.

Information Management: BIM places emphasis on the importance of structured data, allowing stakeholders to extract valuable information and make informed decisions based on reliable and up-to-date information.

BIM in Structural Engineering: Advantages and Applications BIM offers a multitude of possibilities and advantages when applied to structural engineering projects:

Integrated Design and Collaboration: BIM seamlessly integrates architectural, structural, and MEP systems into a unified model, enabling stakeholders to work together from the earliest design stages, reducing conflicts, and leading to more efficient and innovative building designs.

Improved Visualization and Analysis: BIM allows for detailed 3D representations of structures, enabling better analysis and evaluation of structural elements, facilitating early detection of potential issues, and enabling precise adjustments to be made prior to construction.

Cost Estimation and Value Engineering: BIM provides accurate quantity take-offs and cost estimations based on the model, enabling more precise budgeting and financial planning. Additionally, it facilitates value engineering by identifying opportunities to optimize materials and construction methods.

Enhanced Construction Planning and Sequencing: Through BIM, engineers can generate detailed construction sequencing and phasing plans, helping to streamline the construction process and minimize delays.

Energy Efficiency and Sustainability: BIM supports the integration of energy analysis tools, allowing engineers to assess the environmental performance of a building and explore opportunities for energy efficiency improvements.

Facility Management and Maintenance: BIM serves as a valuable tool for facility management and maintenance, providing a comprehensive digital twin of the physical structure, enabling owners and operators to efficiently plan and execute maintenance activities, manage assets, and make informed decisions for the long-term sustainability of the structure.

Building Information Modeling has revolutionized the practice of structural engineering, empowering professionals with a powerful set of digital tools to create more efficient, sustainable, and cost-effective building designs. As BIM continues to evolve, it is poised to play an even more significant role in shaping the future of construction, ushering in an era of unprecedented innovation and efficiency in structural engineering.

4 – Regulations and standards

[1] https://www.scia.net/en/innovations/integrated-design-solution
[2] https://www.tekla.com/resources
[3] https://www.ideastatica.com/support-center
[4] https://oneclicklca.com/#:~:text=Largest%20construction%20LCA%20database%20Used%20in%20170+%20countries

[5] 1. Petran I., Senila M. – "DESIGN OF PITCHED ROOF STEEL PORTAL FRAME STRUCTURE", Editura Mediamira, ISBN: 978-973-713-359-5, Cluj-Napoca, România, 2017
[6] EN 1991-1-1:2002. Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings.
[7] EN 1991-1-3:2003. Eurocode 1: Actions on structures - Part 1-3: General actions - Snow loads and CR 1-1-3-2012: Design code. Assessing snow action on buildings.
[8] EN 1991-1-4:2005. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions and CR 1-1-4-2012: Design code. Assessing wind action on buildings.
[9] P100-1/2013: Seismic Design Code. Part I: Design provisions for buildings.
[10] EN 1993-1-1:2005. Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings

5 – Case study methodology.

The case study methodology was developed using a combination of advanced software tools tailored for both Building Information Modeling (BIM) and Life Cycle Assessment (LCA). Tekla Structures, SCIA, and IDEA StatiCa were utilized to model and analyze the structural elements of the project, enabling detailed BIM integration. For the LCA, the One Click LCA software was employed to assess the environmental impacts of the materials and construction processes. This combination of tools allowed for a comprehensive evaluation of the project's structural integrity and sustainability performance.

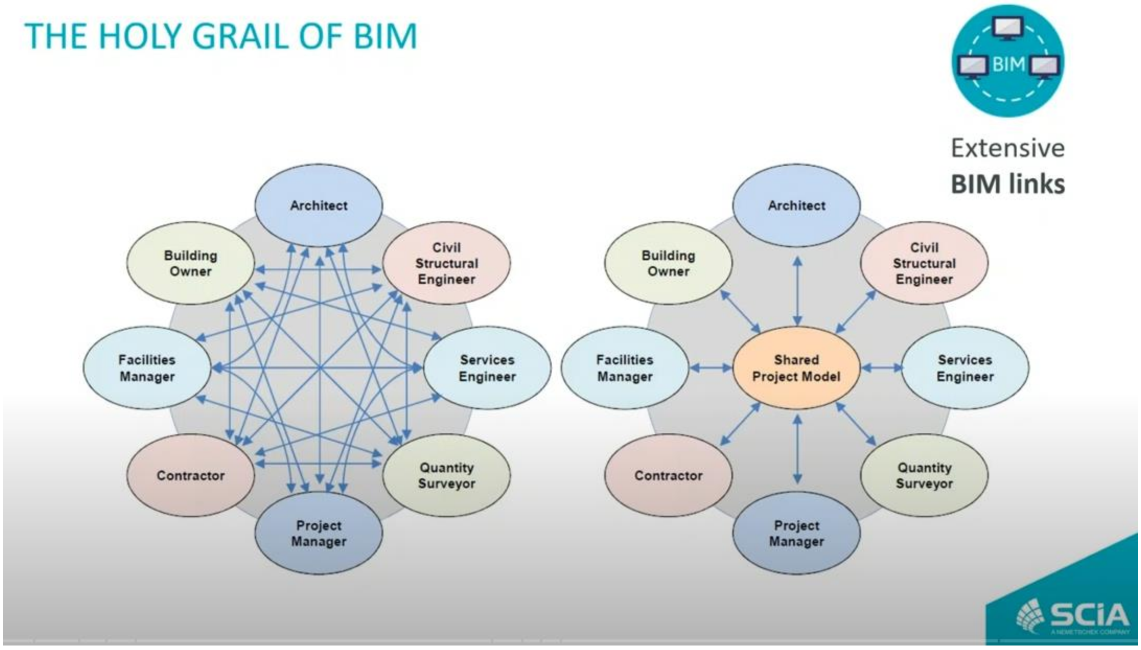
6 – Development of the case study.

6.1 – BIM models.From tools to building models: structural engineering programs and BIM

6.2.1 – SCIA Engineer

SCIA Engineer is an integrated, multi-material structural analysis software and design tool for all kinds of structures. Its wide range of functionality makes it the ideal partner for the design of office buildings, industrial plants, bridges or any other project, all within the same easy-to-use environment.

Scia Engineer offer a range of BIM Solutions to improve engineering workflows: the most important is to understand that collaboration between all disciplines, including architects, modellers, structural engineers, draughtsmen and others is at the heart of delivering a safe, sustainable built environment, which in turn leaves a positive lasting legacy.



The scope is to reduce the time it takes to create analysis models and to ensure consistent representation of reality between structural and analysis models at every stage of the project. Additionally, our objective is to facilitate smooth management of changes across disciplines.

6.2.2 – Tekla Structures

Tekla software is an advanced structural BIM software for construction.

Structural engineers, designers, detailers, fabricators, contractors and project managers can rise beyond traditional limits on every stage of construction. With Tekla Structures, they can create, combine, manage and share information with remarkable efficiency.

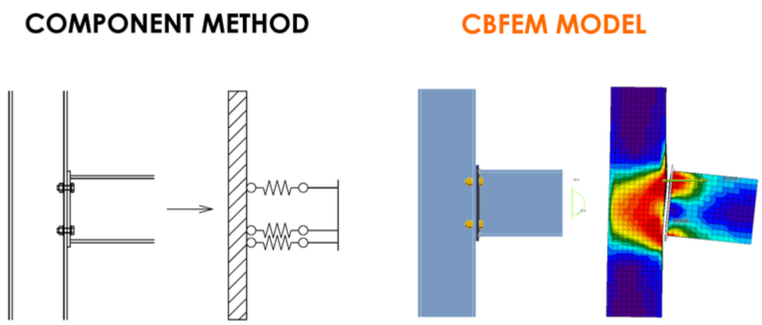
Tekla software offers everything that is needed to improve BIM accuracy, utilize data, and reduce costly surprises. It will enhance the profitability with the highest level of development (LOD) and reduce the uncertainty of uncoordinated construction documents.

Is simple to import, export and link your model data with other project parties, software, digital construction tools, and machinery for smoother workflows.

6.2.3 – Idea StatiCa Steel Connections

Idea StatiCa is a patented software designed for the analysis and structural design of steel connections. It excels in handling various types of connections, including welded and bolted joints, plates, footings, and anchors. Furthermore, it allows for the evaluation of buckling effects on steel components.

The Component-based Finite Element Method (CBFEM) that is based on, effectively combines all the code equations and conditions with finite elements, overcoming the topology and loading limits of the old methods.

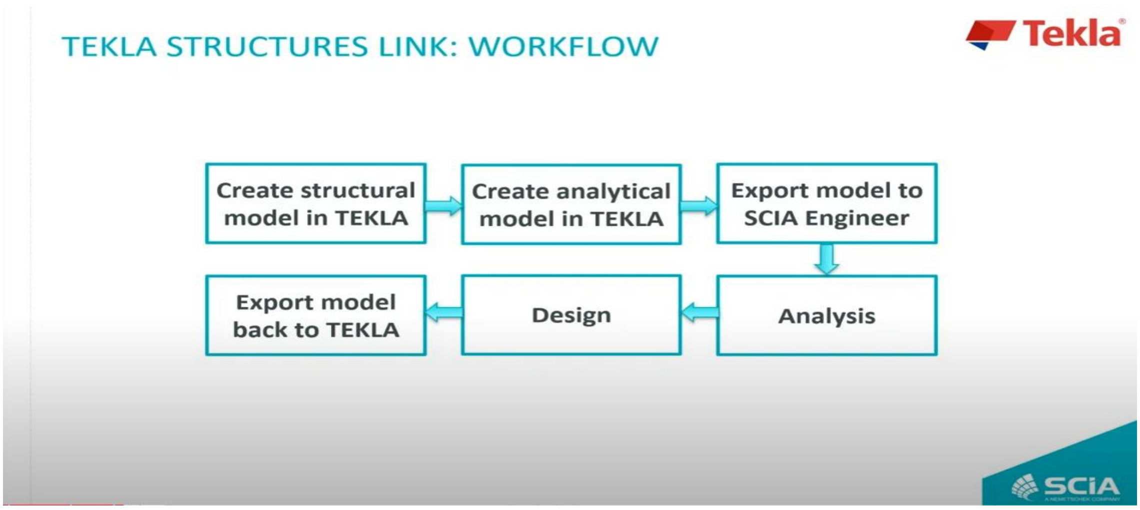


6.2.4 – Interoperability between SCIA Engineer, Tekla Structures and Idea StatiCa

6.2.4.1 – SCIA Engineer integration with Tekla Structures

SCIA and Tekla are both part of buildingSMART alliance's OpenBIM initiative and promote IFC as the preferable format for data exchange of 3D structural models. In addition, SCIA Engineer offers a bi-directional link that makes it easy exchange of steel models.

TEKLA TO SCIA ENGINEER:



SCIA Engineer offers a seamless workflow for modeling, analysing, and optimizing steel structures and components. It allows for easy integration with Tekla, enabling efficient final documentation and detailing. The software supports both Open BIM (based on

IFC format) and Closed BIM (proprietary links) interoperability options. One such example is the Tekla Structures link, facilitating smooth model transfer between Tekla and SCIA Engineer.

This bi-directional link is compatible with the last two versions of major releases for both platforms, allowing for simultaneous updates from either side. Users have the choice of direct transfer for real-time collaboration or file export for sharing with colleagues. The link also provides the flexibility to transfer the entire model or specific parts, such as steel or concrete components. Progress can be monitored through a dialogue window, and a comprehensive transfer report can be generated and saved.

Additionally, users can customize national standards for materials and cross-sections in SCIA Engineer, with the chosen settings preserved during the transfer process. The link supports mapping of materials and cross-sections between projects in both applications. It also accommodates parametric steel profiles, ensuring accurate representation. The mapping tables created are project-specific and stored for future use.

The current link capabilities include transferring 1D and 2D elements, constraints/support, hinges, rigid links, as well as exporting and importing reinforcement details for beams and columns between SCIA Engineer and Tekla. This integration significantly streamlines the workflow for structural engineers and designers

SCIA ENGINEER TO TEKLA

The link between SCIA Engineer and Tekla Structures is built upon the Tekla Structures API, allowing for the export of various structural elements. This includes the geometry of straight beams and columns (start and end nodes), materials through a mapping database, and cross-sections utilizing mapping or geometrical profiles (excluding twin profiles). Additionally, eccentricity (ey, ez), member system lines, welded cross-sections, and hinges are supported.

To initiate the export process, users can access the function via the path: File > Export > Tekla file. This straightforward procedure ensures a seamless transfer of structural data between SCIA Engineer and Tekla Structures, enhancing collaborative efforts in structural design and engineering projects.

6.2.4.2 – SCIA Engineer integration with Idea StatiCa

The link between SCIA Engineer and Idea StatiCa enables the design and code-checks of steel connections, as well as checks for entire steel members within Idea StatiCa applications. SCIA Engineer 21.1 introduces an enhanced version of this link, offering extended functionality.

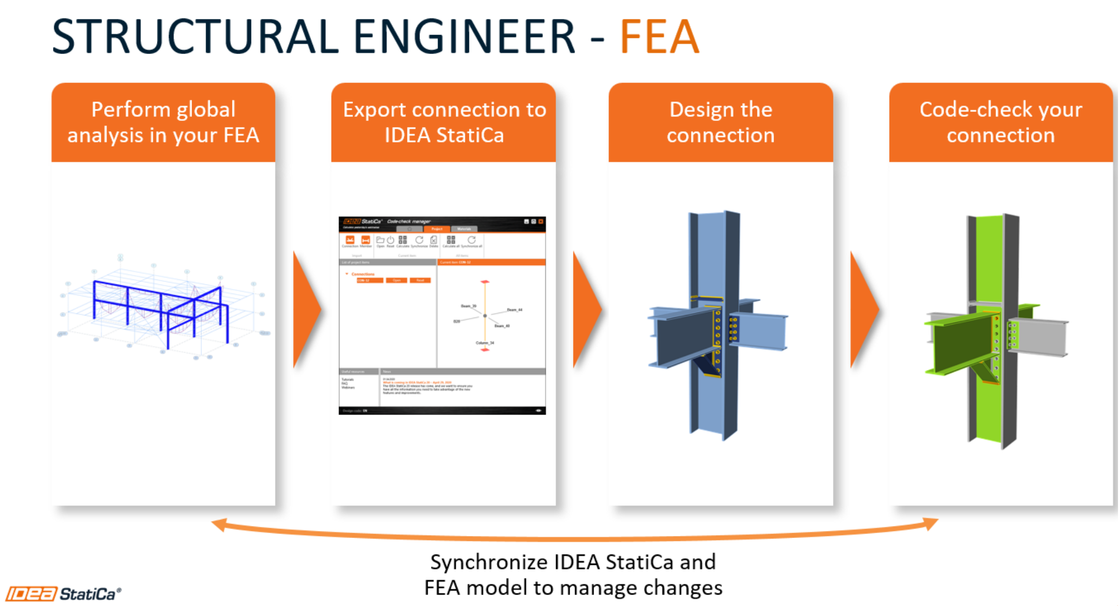
This updated link utilizes the SAF open-source format for exchanging analytical models, simplifying data transfer. To initiate the process, users simply execute the Idea StatiCa command within SCIA Engineer 21.1. A management application facilitates the connection between the two programs, allowing users to create a project.

Once the project is established, users can define connections and members for Idea StatiCa by selecting desired entities in SCIA Engineer and using the respective functions in the management application. SCIA Engineer and Idea StatiCa operate concurrently. Loads to be considered in Idea StatiCa can also be specified in the management application, preparing the model for design and code checks.

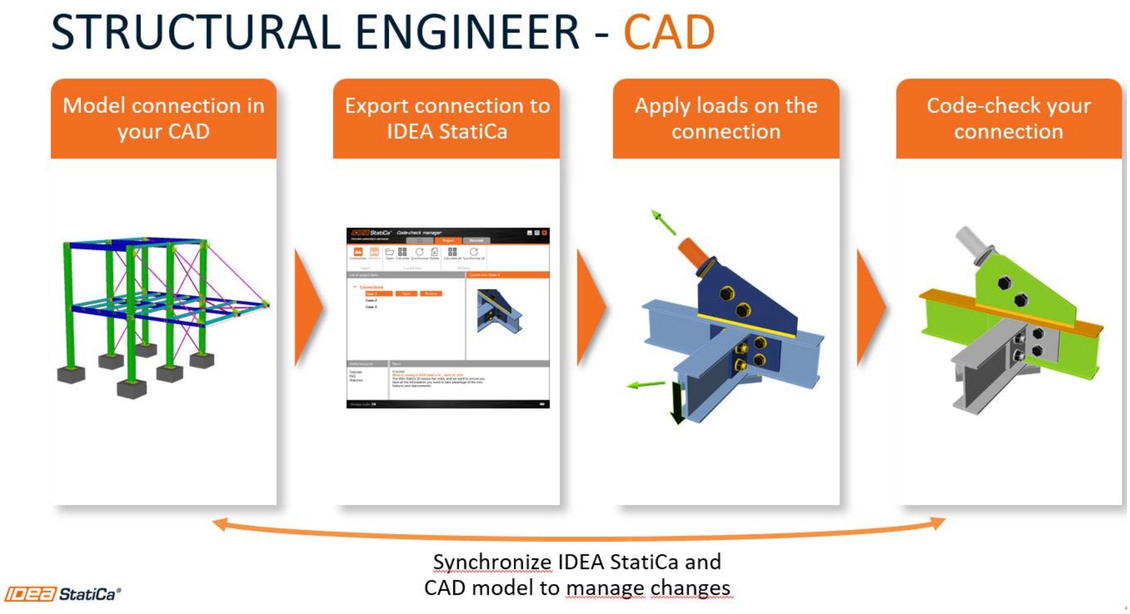
In the event of any model alterations in SCIA Engineer, users can easily update the connection or member through the management application's Synchronize function. The Idea StatiCa project is stored alongside the .ESA file of the SCIA Engineer project, ensuring their connected operation as long as they are kept together in one folder. This integration simplifies the design and code-check process for steel structures.

6.2.4.3 – Idea StatiCa SCIA Engineer integration with SCIA Engineer and Tekla Structures

Idea StatiCa integrates with SCIA Engineer, allowing you to easily export and code-check any steel connection from SCIA Engineer. This includes beams, cross-sections, and internal forces, which not only get exported but also stay synchronized even if there are changes in the SCIA Engineer model.



Idea StatiCa integrates with Tekla Structures, allowing you to easily export and code-check any steel connection from Tekla Structures. This includes beams, cross-sections, and internal forces, which not only get exported but also stay synchronized even if there are changes in the Tekla Structures model.

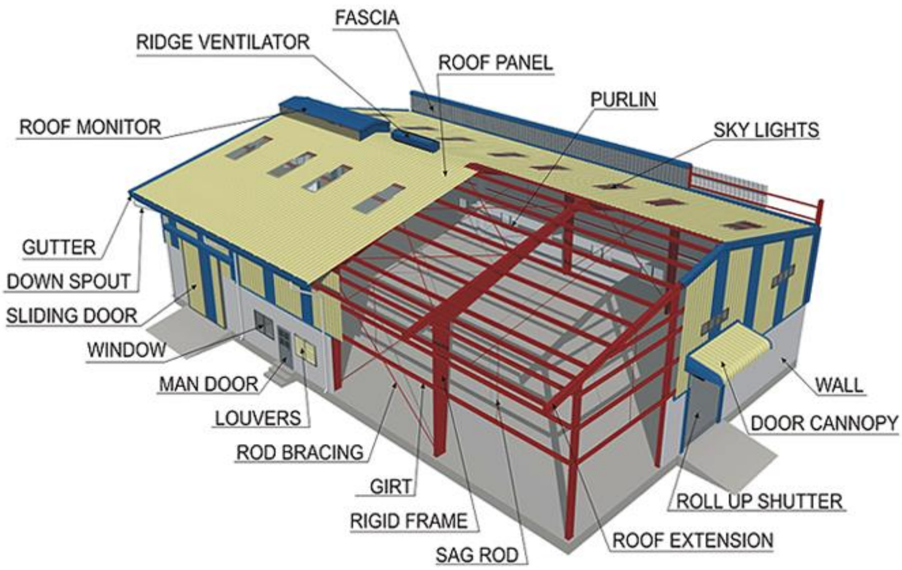


If you have the corresponding models of the structure in FEA and CAD, you can combine them in Idea StatiCa. This effective partnership between SCIA Engineer, Tekla Structures and Idea StatiCa optimizes your steel design process, ultimately saving both time and money.

6.3 – From Theory to Practice: pitched roof steel portal frame structures

6.3.1 – Generals

The purpose of this case study is to present the principles of design for pitched roof steel portal frame structures fabricated from hot rolled I and H sections with light-gauge steel cladding. This is generally the most economical form of construction for steel portal framed buildings.



These buildings find application in a diverse range of industries including industrial activities, warehouses, showrooms, agriculture, school facilities, and sport halls, among others. They come in various sizes, spanning from just a few hundred square meters to large-scale structures covering several thousand square meters.

In general, single storey buildings use steel framed structures and various types of cladding systems, providing large open spaces, which are efficient, easy to maintain and are adaptable to future changes.

The development of a design solution for a single storey building, such as a large enclosure or industrial facility is more dependent on the activity being performed and future requirements for the space than other building types, such as commercial and residential buildings. Although these building types are primarily functional, they are commonly designed with strong architectural involvement dictated by planning requirements and client 'branding'.

The following overall design requirements should be considered in the conceptual design stage of industrial buildings and large enclosures, depending on the building form and use:

- Space use, for example, specific requirements for handling of materials or components in a production facility;
- Flexibility of space in current and future use;
- Speed of construction;
- Environmental performance, including services requirements and thermal performance;
- Aesthetics and visual impact;
- Acoustic isolation, particularly in production facilities;
- Access and security;
- Sustainability considerations;
- Design life and maintenance requirements, including end of life issues.

A portal frame building comprises a series of unbraced transverse frames, braced longitudinally, which transfer loads to the foundations. The primary steelwork consists of columns and rafters, which form the portal frames (including flange bracings, connection bolts and anchor bolts) and roof and longitudinal bracing, as shown in Figure 3. The end frame (gable frame) can be either a portal frame or a braced arrangement of columns and rafters. The bases of the portal frames are generally pinned; however, certain circumstances may dictate the use of fixed constructions. The secondary steelwork supporting the cladding consists of side rails for walls and purlins for the roof. In general, the purlins and girts are galvanized Z profiles, produced by cold roll forming. The secondary steelwork also plays an important role in restraining the primary steelwork members against buckling out of plane.

When considering structural behaviour, the essential nature of a portal frame is that in the plane of the frame, rigid joints between the primary members at the eaves and apex of the roof form the structural system which resists loads in that plane. The portal frame members are orientated with their webs in the plane of the frame to benefit from the major axis strength and stiffness of the members and form a continuous structure. The structural stability of the frame in this plane therefore has to be considered as a whole. Perpendicular to the plane of the frame, the longitudinal bracing and secondary steelwork provide points of lateral restraint which define the lengths over which the primary members can buckle. The out-of-plane stability of the members can therefore be considered individually.

The roof and wall cladding separate the enclosed space from the external environment and provide thermal and acoustic insulation. The cladding transfers loads to secondary steelwork and restrains the flange of the purlin or rail to which it is attached.

The case study is showing all the design steps for elastic design of portal frames and some specific detailing.

In order to be able to fit in the estimated time for the presentation, the structure proposed for the case study was simplified at the plan level (2D).

6.3.2 – Basis of design

LIMIT STATES DESIGN

The design for limit states shall be based on the use of structural and load models for relevant limit states. It shall be verified that no limit state is exceeded when relevant design values for actions, material properties and geometrical data are used in these models. The verifications shall be carried out for all relevant design situations and load cases. The requirements for limit states should be achieved by using the partial factor method.

A limit state is formally defined by the description of a condition for which a particular structural member or an entire structure fails to perform the function that is expected of it. From the point of view of a structural designer, four types of limit states are considered for steel structures:

- ultimate limit state (ULS);
- serviceability limit state (SLS);
- fatigue limit state (FLS);
- accidental limit state (ALS).

According with SR EN 1990, a distinction shall be made between ultimate limit states and serviceability limit states. Appropriate partial factors shall be adopted for ultimate limit states and serviceability limit states.

ULS typically represents the collapse of the structure due to loss of structural stiffness and strength. Such loss of capacity may be related to:

- strength;
- stability against overturning and sway;
- fracture due to fatigue;
- brittle fracture.

When an ultimate limit state is reached, the whole structure or part of it collapses.

SLS conventionally represents failure states for normal operations due to deterioration of functionality. SLS considerations in design may address:

- deflection;
- vibration (for example wind-induced oscillation);
- repairable damage due to fatigue;
- corrosion and durability.

The serviceability limit states, when reached, make the structure or part of it unfit for normal use but do not indicate that collapse has occurred.

All relevant limit states should be considered, but usually it will be appropriate to design on the basis of strength and stability at ultimate loading and then check that deflection is not excessive under serviceability loading.

A structure must be designed to resist all loads expected to act on the structure during its service life. Thus, the design of a structure requires a balance of necessary reliability and reasonable economy.

In designing a steel portal frame structure, the designer has to manage several problems connected with ULS design criteria. Manual design may be useful for initial sizing of members but it is readily acknowledged that using software is a more realistic approach for efficient design which provides the means to achieve the greatest structural efficiency. These specific issues are:

- elastic global analysis, considering the second order effects;
- verification of the resistance of the cross-sections;
- verification of the buckling resistance of members;
- verification of connections;
- fire resistance.

LOADINGS

The European standards implemented in Romania SR EN 1991: Actions on structures provides comprehensive information on all actions that should normally be considered in the design of buildings and other civil engineering works. It is composed in four main parts, the first part being divided into sub-parts that cover densities, self-weight and imposed loads, actions due to fire, snow, wind, earthquake, thermal actions, loads during execution and accidental actions:

- SR EN 1991-1-1:2002. Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings;
- SR EN 1991-1-2:2002. Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire;
- SR EN 1991-1-3:2003. Eurocode 1: Actions on structures - Part 1-3: General actions - Snow loads and CR 1-1-3-2012: Design code. Assessing snow action on buildings;
- SR EN 1991-1-4:2005. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions and CR 1-1-4-2012: Design code. Assessing wind action on buildings;
- SR EN 1991-1-5:2003. Eurocode 1: Actions on structures - Part 1-5: General actions - Thermal actions;
- SR EN 1991-1-6:2005. Eurocode 1: Actions on structures - Part 1-6: General actions - Actions during execution;
- SR EN 1991-1-7:2006. Eurocode 1: Actions on structures - Part 1-7: General actions - Accidental actions.
- P100-1/2013: Seismic Design Code. Part I: Design provisions for buildings.

The actions and combinations of actions described in this section should be considered in the design of a single storey industrial building using a steel structure. Imposed, snow and wind loads are given in SR EN 1991-1-1, 1991-1-3 and 1991-1-4. Table 1 shows the relevant actions and structural components.

Action	**Applied to**
Self-weight	Cladding, purlins, rails, frames, foundation
Snow	Cladding, purlins, frames, foundation
Wind	Cladding, purlins, rails, frames, foundation, fixings
Thermal actions	Envelope, global structure
Service loads	Roofing, purlins, frames
Crane loads	Crane girders, frame
Seismic loads	Global structure, frames, bracing system, anchor bolts, foundation
Second order effects	Wall bracings, columns

Permanent actions

Permanent actions are the self-weight of the structure (usually considered automatic by the software), secondary steelwork and cladding. Where possible, unit weights of materials should be obtained from manufacturer's data. Where information is not available, these may be determined from data in SR EN 1991-1-1.

Variable actions

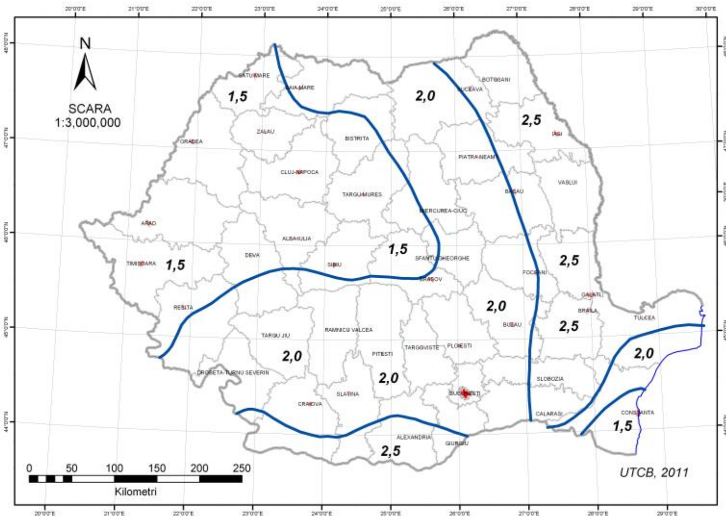
Imposed roof loads. The loading for roofs not accessible except for normal maintenance and repair with a roof slope bigger than 1:20 is q_k = 0.5 kN/m2, while for smaller ones q_k = 0.75 kN/m2. It should be noted that, following Clause 3.3.2(1) of SR

EN 1991-1-1, there is no requirement to combine imposed loads on roofs with either snow loads or wind actions.

Snow loads

Snow loads in Romania should be determined according to CR 1-1-3-2012: Design code. Assessing snow action on buildings [ref] and SR EN 1991-1-3:2003, Eurocode 1: Actions on structures - Part 1-3: General actions - Snow loads and its National Annex.

The characteristic snow load on the ground, s_k, depends on the site location and altitude. Figure presents the Romanian map and the characteristic values for altitudes A ≤ 1000 m.



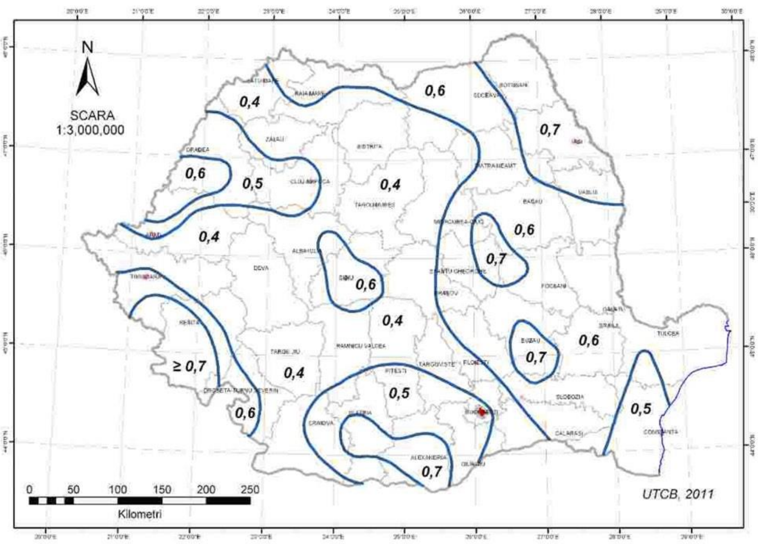
Wind actions.

Wind actions are presented in CR 1-1-4-2012 (Design code. Assessing wind action on buildings) and SR EN 1991-1-4 including its National Annex.

Wind loading, as single variable action, rarely determines the size of members in single span portal frames, but combining wind and snow loading is often critical. Wind uplift forces on cladding can be relatively high at the corner of the building and at the eaves and ridge. In these areas, it may be necessary to reduce the spacing of the purlins and side rails.

The procedure of calculating wind actions includes the following steps: (1) calculation of the peak velocity pressure; (2) determination of external pressure coefficients; (3) determination of internal pressure coefficients; (4) calculation of the structural factor; (5) calculation of wind pressure on surfaces and wind forces.

Wind pressures are calculated as the product of the peak velocity pressure, the structural factor and pressure coefficients. External and internal pressure coefficients are given in the CR 1-1-4-2012 or National Annex of SR EN 1991-1-4. The, coefficients are given for elements with loaded areas of up to 1 m2 and loaded areas of over 10 m2, with logarithmic interpolation for areas between the two. The National Annex simplifies this, allowing the use of the coefficients for 10 m2, known as c_{pe}, for any loaded area larger than 1 m2.

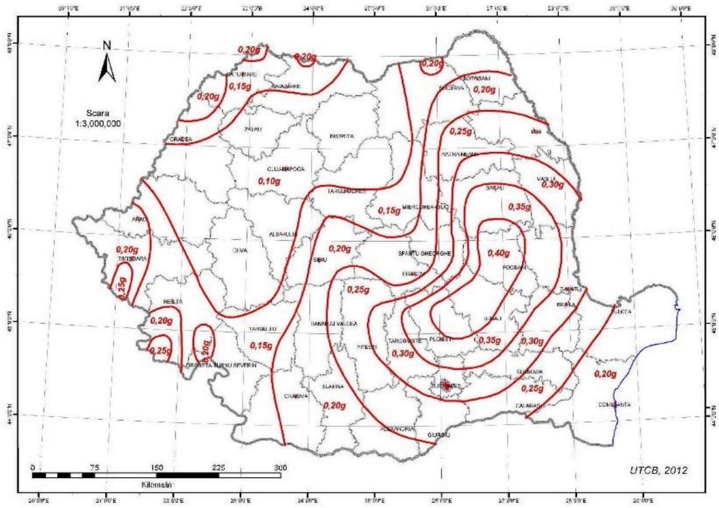


Seismic action

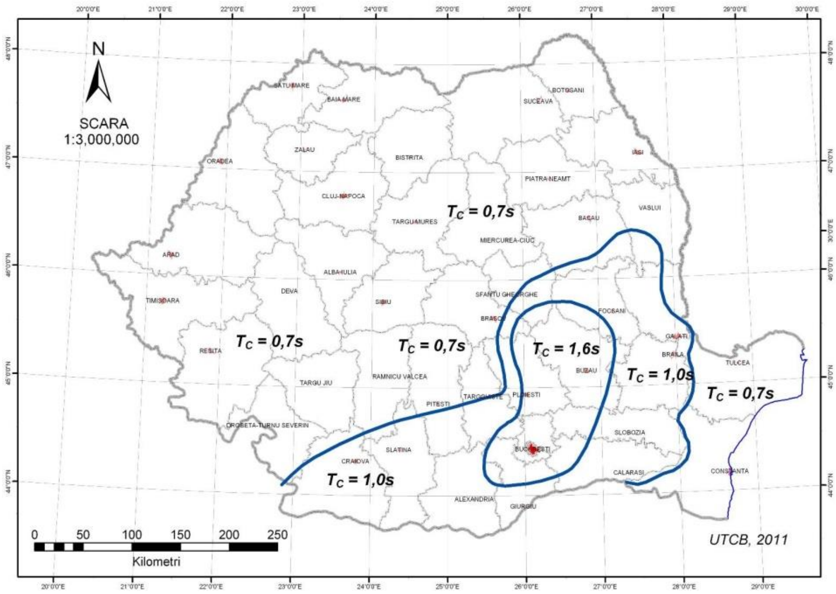
In case of seismic action, the design of buildings should be done according to P100-1/2013 “Code for the design of buildings for earthquake resistance. Design provisions for buildings” [ref], the Romanian territory is divided in seismic hazard zones.

The seismic hazard level in every zone is considered, in a simplified way, to be constant. The seismic design hazard is described by means of the value of the peak horizontal ground acceleration ag, determined for the mean recurrence (MRI) corresponding to the ultimate limit state, a value which is hereinafter referred to as “the design ground acceleration”.

The design ground acceleration, for every seismic hazard zone, corresponds to a reference mean recurrence interval of 225 years. The zonation of the design ground acceleration ag in Romania, for seismic events having the mean recurrence interval (of the magnitude) MRI = 225 years, is indicated in the Figure and is used for the design of buildings at the ultimate limit state.



Taking into account both the seismic and the ground conditions existing in Romania, for earthquakes having MRI = 225 years, the design zonation of the Romanian territory in terms of control period (corner period) TC of the response spectrum, obtained on the basis of the existing instrumental data for the horizontal components of the seismic movement, is presented in the Figure.



Imperfections

Equivalent horizontal forces have to be considered due to geometrical and structural imperfections. According to SR EN 1993-1-1 [ref] for frames sensitive to buckling in a sway mode, the effect of imperfections should be allowed for in frame analysis by means of an equivalent imperfection in the form of (1) initial sway deflections; and / or (2) individual bow imperfections of members.

6.3.3 – Case Study: STEEL PORTAL FRAME

In recent years, Building Information Modeling (BIM) has profoundly influenced the architecture, engineering, and construction industry, emerging as a leading information and communication technology within the field. One of the primary advantages of BIM lies in its ability to establish a singular source of truth for all stakeholders involved in the building process. Instead of depending on multiple sets of drawings and documents, everyone can access and utilize the same digital model to make well-informed decisions.

For our learning activity and for a better understanding of the BIM concept, we will attempt to apply it on a local level by simulating a scenario in a structural engineer's office. This involves the seamless exchange of information between Scia Engineer, a structural analysis software and design tool for a wide range of structures, Tekla Structures, employed to construct a comprehensive 3D model of a steel portal frame, and Idea StatiCa, which furnishes precise assessments, including results of strength, stiffness, and buckling analyses steel joints.

The objective is to perform the structural calculation for an industrial hall. The construction system consists of steel portal frames interconnected longitudinally with metal beams and braced both in the walls and roof planes. The perimeter enclosures will be constructed using 10cm vertical thermal insulation panels. The foundation is composed of elastic isolated foundations with reinforced concrete blocks, while the superstructure consists of flat metal frames with an opening of 22.00m, provided at the 5.0m span.

It is assumed that the participants are familiar with the basic functions of the programs and have completed beginner tutorials available on the producers' websites.

6.3.3.1 – SCIA ENGINEER

To simplify matters, we will conduct a basic 2D structural analysis on a central portal frame. Portal frames, being primarily planar structures, can be adequately represented using 2-D analysis. This approach serves to make the process more manageable. The key steps are outlined below.

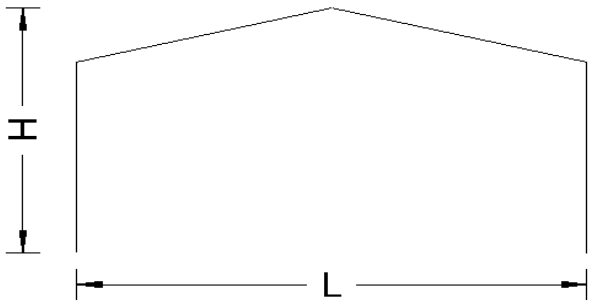
Portal frames are two-dimensional rigid structures characterized by a fixed joint between the column and beam. The main objective of this form of design is to reduce bending moment in the beam, which allows the frame to act as one structural unit.

The elastic theory serves as the prevalent foundation for analyzing general structures. Under the application of load, these structures maintain their elasticity, ensuring that load paths remain consistent regardless of load magnitude, and deflections are directly proportional to the load.

In this model, beam elements are represented by lines, which denote the axes of the members. It's crucial that these lines pass through the centroid of the cross-sections of the beams and columns. Consequently, the effective span length of the portal frame is determined by the distance between the centroid axes of the columns.

In many portal frames, enhancing the resistance of the rafter at the eaves is achieved by incorporating haunches, which are tapered sections of the rafter. The inclusion of haunches not only augments the overall stiffness of the frame but also has the potential to reduce displacements.

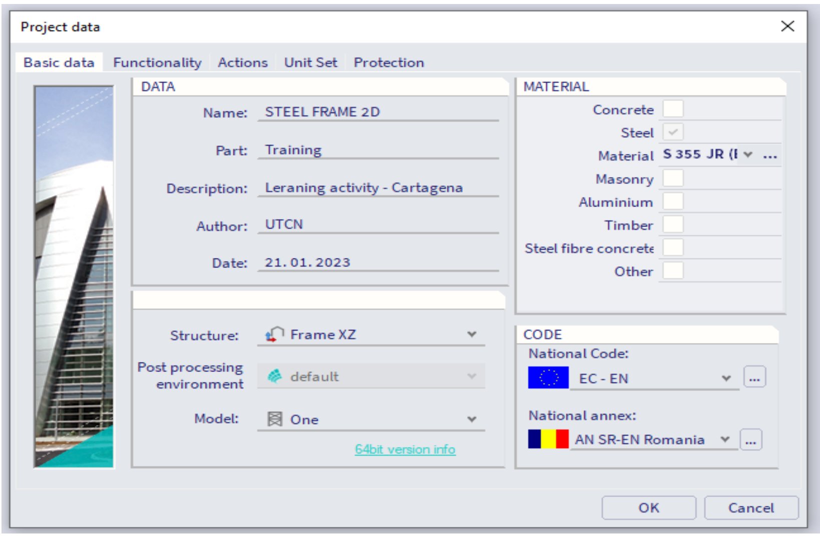
The following dimensions have been considered for structural design of portal frame:



- Span: L = 22 m
- Height: H = 7.4 m
- Bay: B = 5 m
- Roof slope: 6°
- Column: HEA 300
- Beam: IPE 400

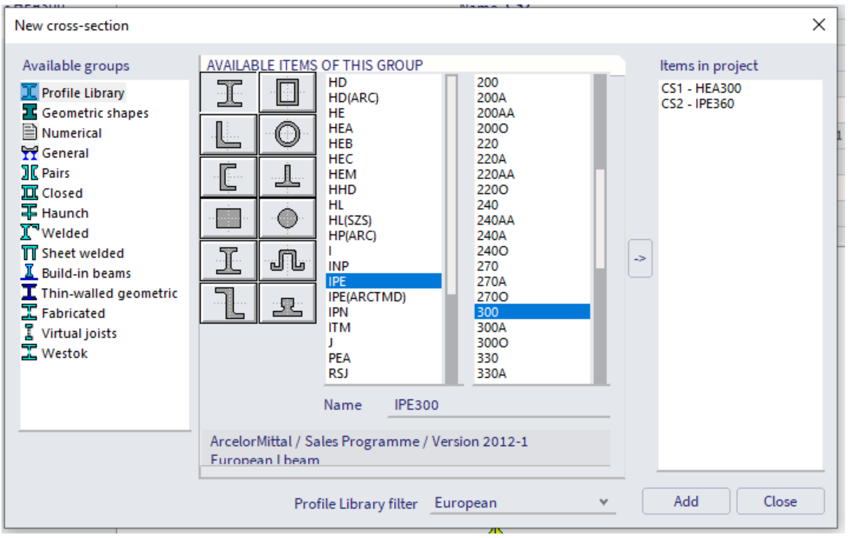
Step 1. Starting a new project:

After opening the program in project settings, you'll define general data such as the name, type of structure, select your material, and specify the national code and annex.

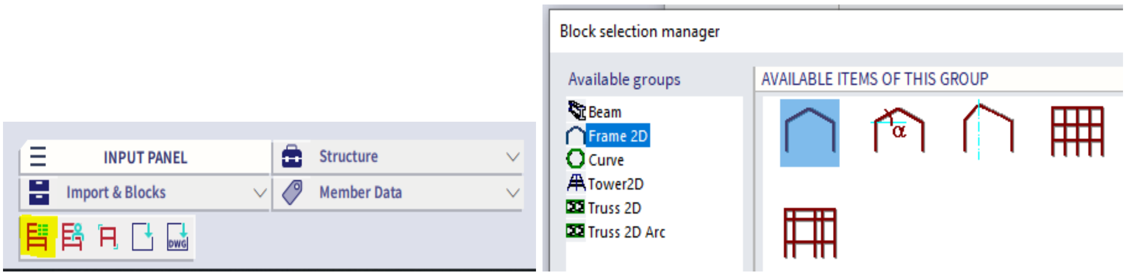


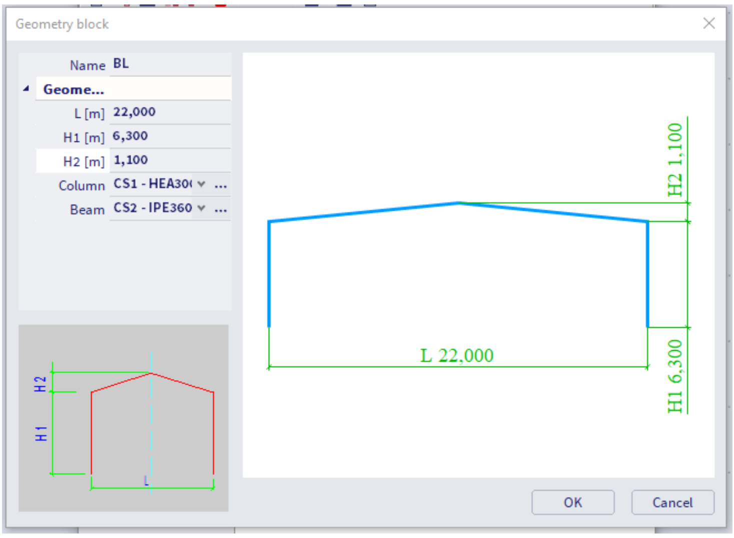
Step 2. Input of the geometry

S.2.1. Cross-sections: When entering one or more 1D members, a cross-section is immediately assigned to each member. By default, the active cross-section is represented. You can open the profile library to activate another cross section.



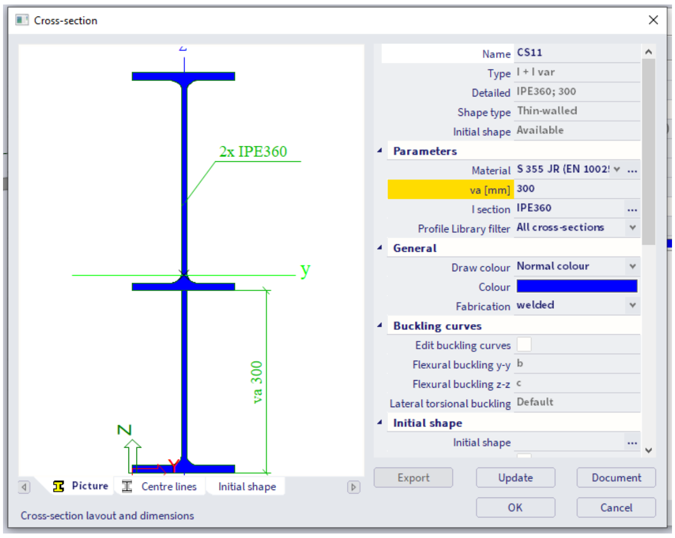
S.2.2. Geometry: You can use single columns and beams to enter the frame,but SCIA Engineer offers as well multiple Catalog blocks, allowing for a smooth and simple input of the structure.



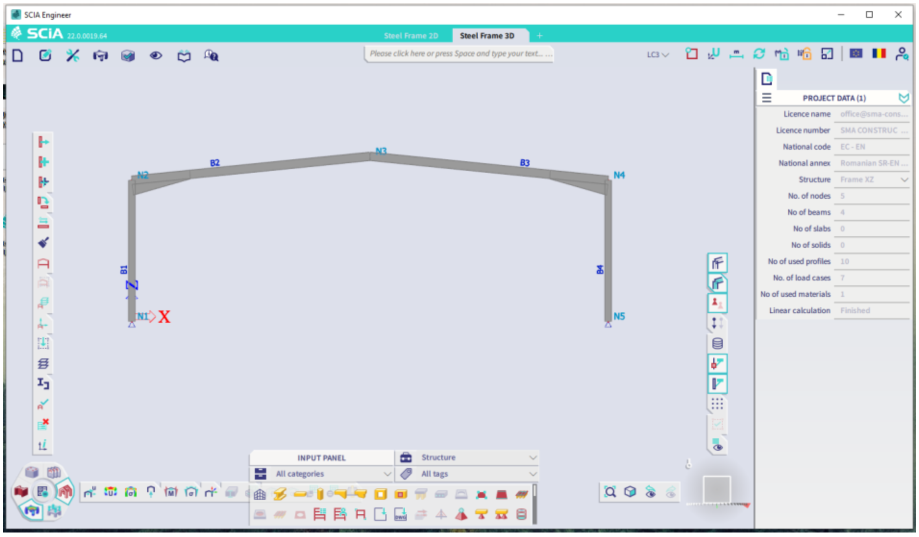


S.2.3. Additional data: The structure is completely set up. Now, we can finish the geometry input by adding end conditions, enter haunches, hinges and supports.

S.2.3.1. Haunches: In this SCIA Engineer project, each member is modelled as prismatic with a constant cross-section, unless a haunch is specified. Haunches have been incorporated into the design for the roof beams. These haunches are characterized by two key parameters: a cross-section with a variable height and a specified length, over which the height can vary by up to 0 units. The selected cross-section combines elements of both an I-section and a variable section, denoted as I + I var.



S.2.3.2. Hinges: In SCIA Engineer, every node where two or more members connect is regarded as fixed, until a hinge is entered and some translations and/or rotations are released. The geometry input can be completed with supports. The column bases are modelled with pinned hinges that allow rotation without transmitting moments.



Step 3. Check structure

After input of the geometry, the structure is checked for duplicate nodes, zero beams, duplicate members, wrong references of hinges or supports.

Step 4. Load cases and load groups

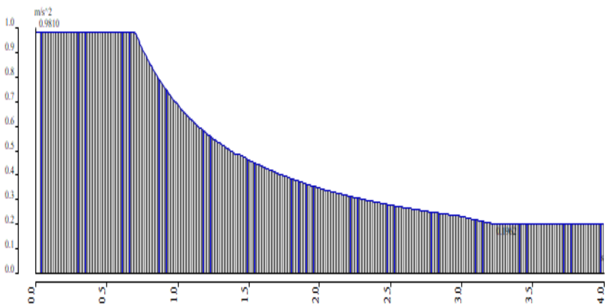
Each load is attributed to a load case with properties which are determinant for the automat generation of combinations. The action type of a load case can be permanent or variable.

Each load case is associated with a load group. The load group contains information about the category of the load (service load, wind, snow) and its appearance (default, together, exclusive). In an exclusive load group, the different load cases attributed to this load group cannot act together in a single combination when using envelope combinations or code combinations.

Load cases:

GROUP	NAME
Dead group	LC1-Self weight LC2-Permanent: 0.8kN/m
Snow group	LC3-Snow: 1.2kN/m
Wind group	LC4-Wind
Seismic group	LC5-Seism

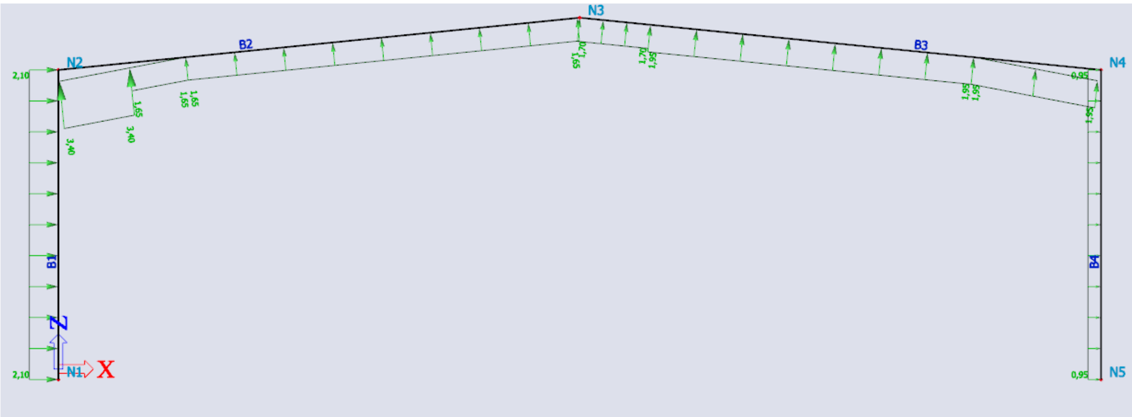
Seismic spectrum:

INFO	DRAWING
Type code – Romanian standard Spectrum type -Horizontal City – Cluj-Napoca Gamma – importance factor - 1 coeff accel. ag - 0.1 ag–nominal acceleration – 0.981 TB - 0.14 / TC - 0.7 / TD - 3 beta0 - 2.5 q behaviour factor – 2.5	

Mass groups:

NAME	LOAD CASE	DESCRIPTION
MG1	LC1 - Self weight	Self-weight mass
MG2	LC2 - Dead	Dead mass
MG3	LC3 - Snow	Snow mass

Wind load: While Scia Engineer offers an integrated 3D wind function, for our 2D structural analysis, we derived the wind forces and applied them as linear forces on the respective elements.



Combinations: Two automatic code combinations are created, one for the Ultimate Limit State and one for the Ultimate Serviceability State.

Step 5. Linear analysis:

Once the calculation model is fully prepared, proceed to initiate the calculation process. Ensure that all entities are properly interconnected and that the mesh setup is activated. After the analysis, a notification window will confirm the completion of the calculation, providing maximum deformation and rotation values for the normative load case.

Step 6. Results

S.6.1. Reactions

Linear calculation, Extreme: Global
Selection: All
Class: ULS class

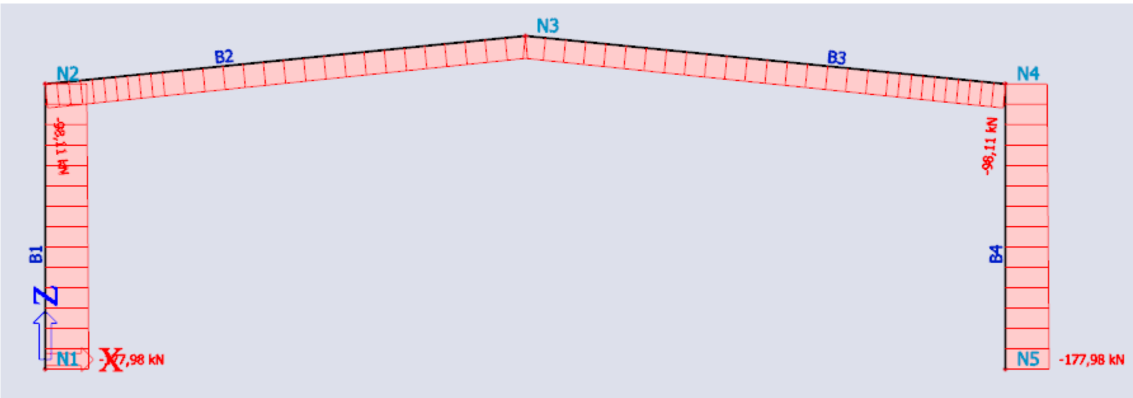
SUPPORT	CASE	Rx[kN]	Rz[kN]	My[kNm]
Sn2/N1	ULS-Set B(auto)/1	81.64	177.98	0.00
Sn2/N1	ULS-Set B(auto)/2	-7	22.14	0.00
Sn1/N5	ULS-Set B(auto)/1	-81.64	177.98	0.00

S.6.2. Internal forces on member

Linear calculation, Extreme: Global
Selection: All
Class: ULS class

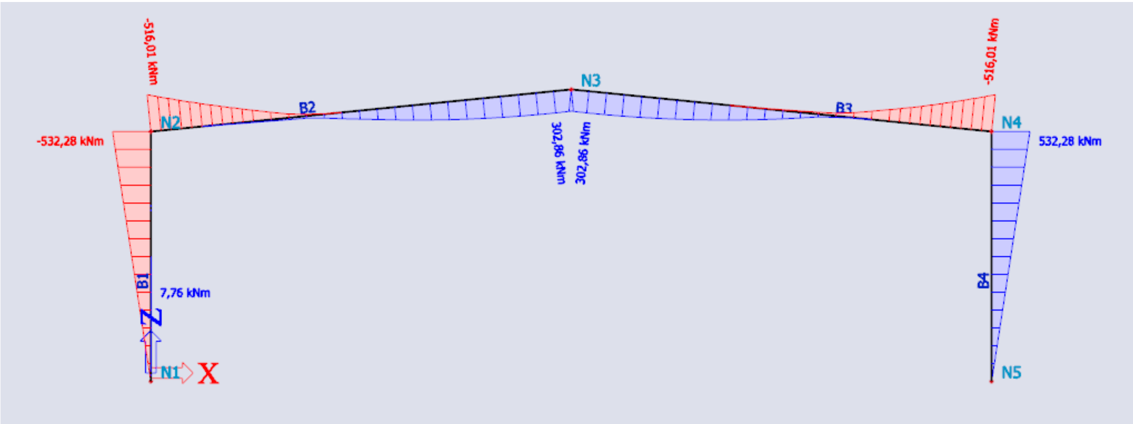
MEMBERS	CASE	N [kN]	Vz [kN]	My [kNm]
B1	ULS-Set B (auto)/1	-15,91	-13,54	-21,32
B1	ULS-Set B (auto)/2	-177,98	-81,64	0
B1	ULS-Set B (auto)/1	-22,14	7	0
B1	ULS-Set B (auto)/2	-169,57	-81,64	-532,28
B1	ULS-Set B (auto)/1	-19,92	-0,34	7,76
B2	ULS-Set B (auto)/1	-9,85	-6,37	39,55
B2	ULS-Set B (auto)/3	-80,51	-11,82	262,98
B2	ULS-Set B (auto)/2	-98,11	160,61	-516,01
B2	ULS-Set B (auto)/2	-91,37	-2,03	302,86
B3	ULS-Set B (auto)/1	-10,92	4,29	39,55
B3	ULS-Set B (auto)/2	-91,08	-9,11	300,28
B3	ULS-Set B (auto)/2	-98,11	160,61	-516,01
B3	ULS-Set B (auto)/2	-91,37	-2,03	302,86
B4	ULS-Set B (auto)/1	-26,17	13,58	118,86
B4	ULS-Set B (auto)/2	-177,98	81,64	0
B4	ULS-Set B (auto)/2	-169,57	81,64	532,28

Axial force N:



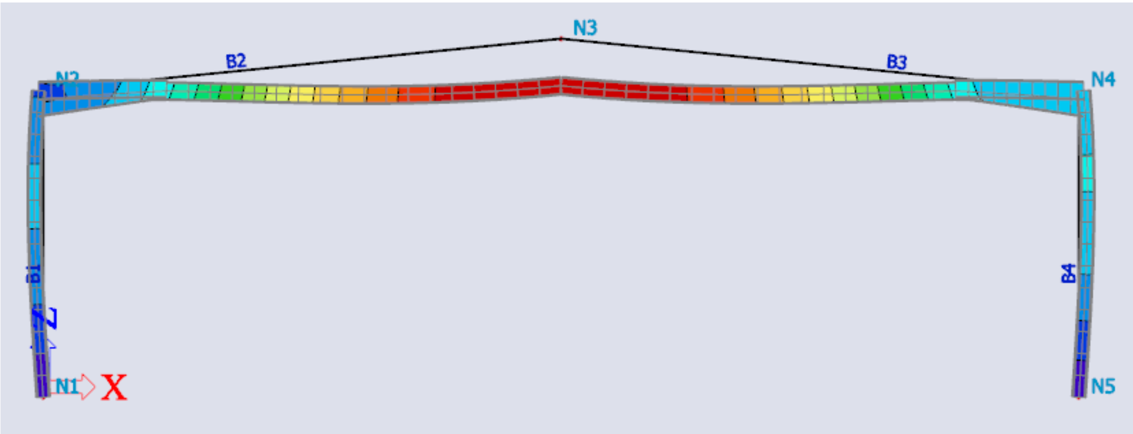
Shear forces Vz:

Moment My:



S.6.3. 3D deformations

Linear calculation, Extreme: Global
Selection: All
Class: SLS class



Step 7. Code checks

The steel modules include a number of tools to perform steel calculations in accordance with the chosen design code. The possibilities are as following:

- input of steel data per member;
- input and manipulation of buckling data;
- input of stiffeners, lateral-torsional buckling restraints, steel sheeting, …;
- performing a ULS unity check;
- optimization of the cross-section;
- performing a SLS unity check;
- performing a fire-resistance check;
- input, calculation and creation of drawings for connections;

For additional details on advanced steel calculations, such as 2nd order analysis and fire-resistance checks, you can refer to the Advanced Steel Training provided by the program's producer.

After performing an elastic analysis on a single-storey structure, it's imperative to verify the frame members, considering both cross-sectional resistance and member buckling resistance, commonly referred to as member stability. The steel member design process should strictly adhere to the guidelines outlined in SR EN 1990 [ref] and SR EN 1993-1-1 [ref].

S.7.1 Buckling parameters

The columns and rafters of portal frames are subject to combined axial force and bending moments. Consequently, the member verifications involve in/out of plane flexural buckling resistance, the lateral-torsional buckling resistance and the member resistance under combined axial force and bending. The secondary components (purlins and rails, flying braces, longitudinal beams) are used to provide intermediate restraints, to reduce the length of segments, increasing both the flexural and lateral-torsional buckling resistance.

Prior to performing steel code checks, it is essential to assign the buckling parameters for the rafter in relation to the position of purlins.

S.7.2 Steel code check

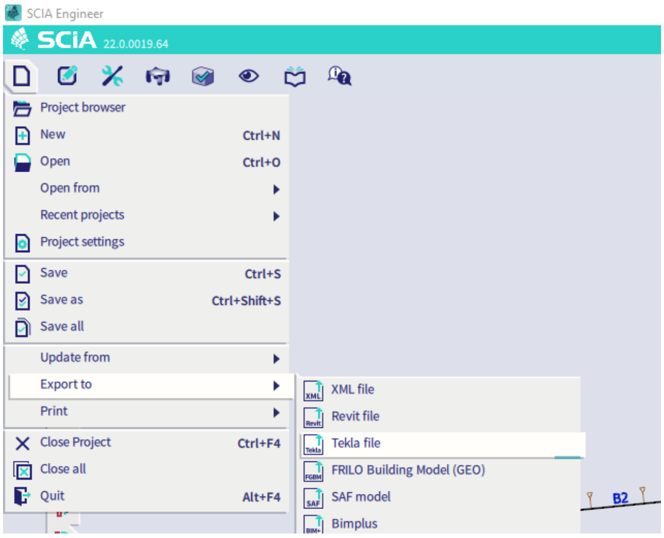
The ULS (Ultimate Limit State) unity check includes both a section and a stability check.

The detailed report following the Ultimate Limit State (ULS) checks revealed that the column does not meet the Combined Bending, Axial Force, and Shear Force check in accordance with EN 1993-1-1. SCIA Engineer allows for a simple and smooth optimization of the steel section, whether it does not satisfy or whether it is too "heavy" and overdesigned. The program automatically suggests a cross-section that satisfies the unity check; in our scenario, a HEA320 section was recommended.

After performing both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) checks, which include the comparison of relative deformations with predefined deflection limits set either in the steel settings or via the system lengths and buckling settings, an IPE400 beam with a haunch with a height of 365mm and a length of 2.7m was chosen.

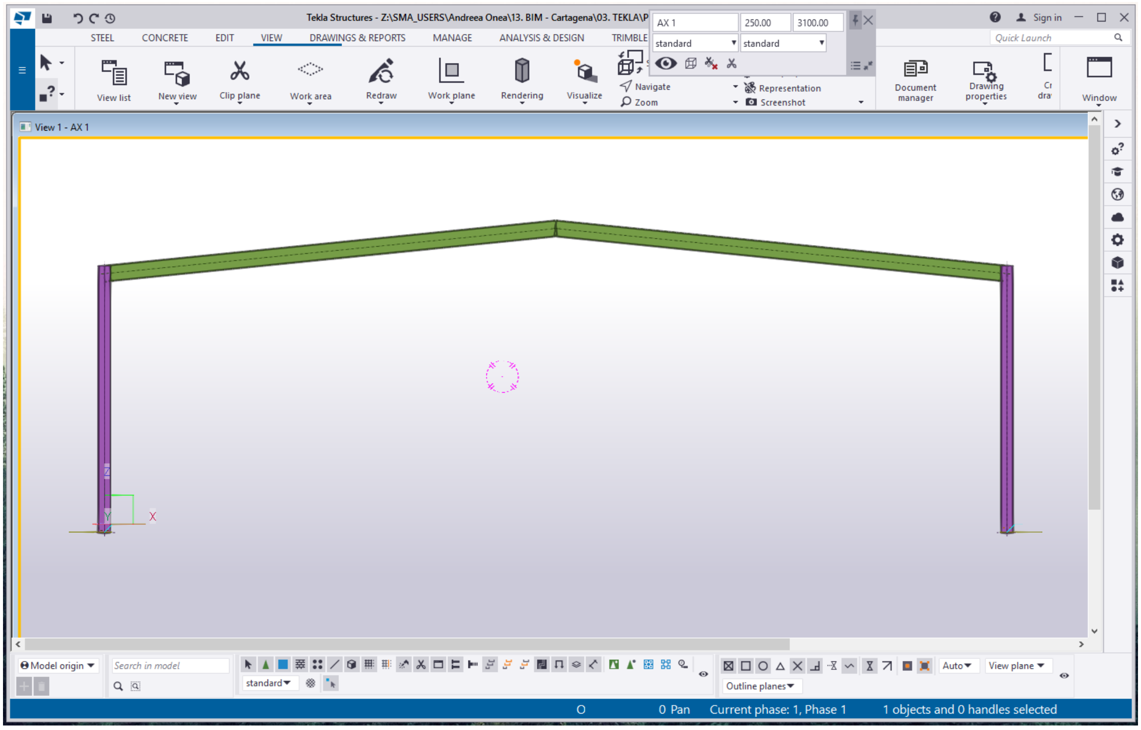
Step 8. Export to Tekla

- Open the ESA file in Scia Engineer.
- Follow the steps indicated in the provided picture.



- Save the file in s2t (Scia to Tekla) format for export.
- Import the S2t in Tekla Structures

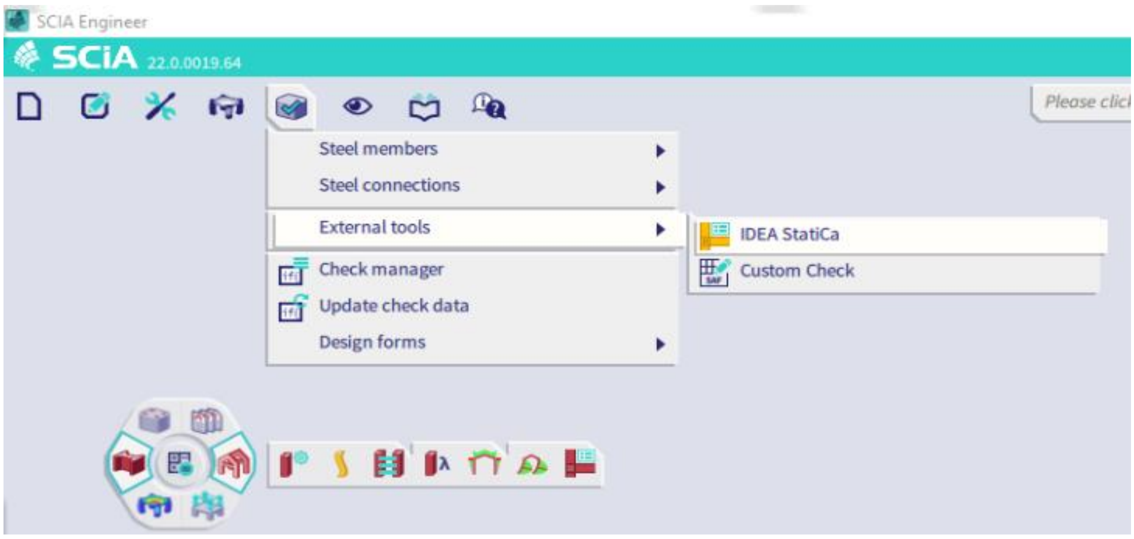
When exporting files from Scia Engineer to Tekla Structures, the haunches are not recognized. In Tekla Structures, haunches are considered components of joints.



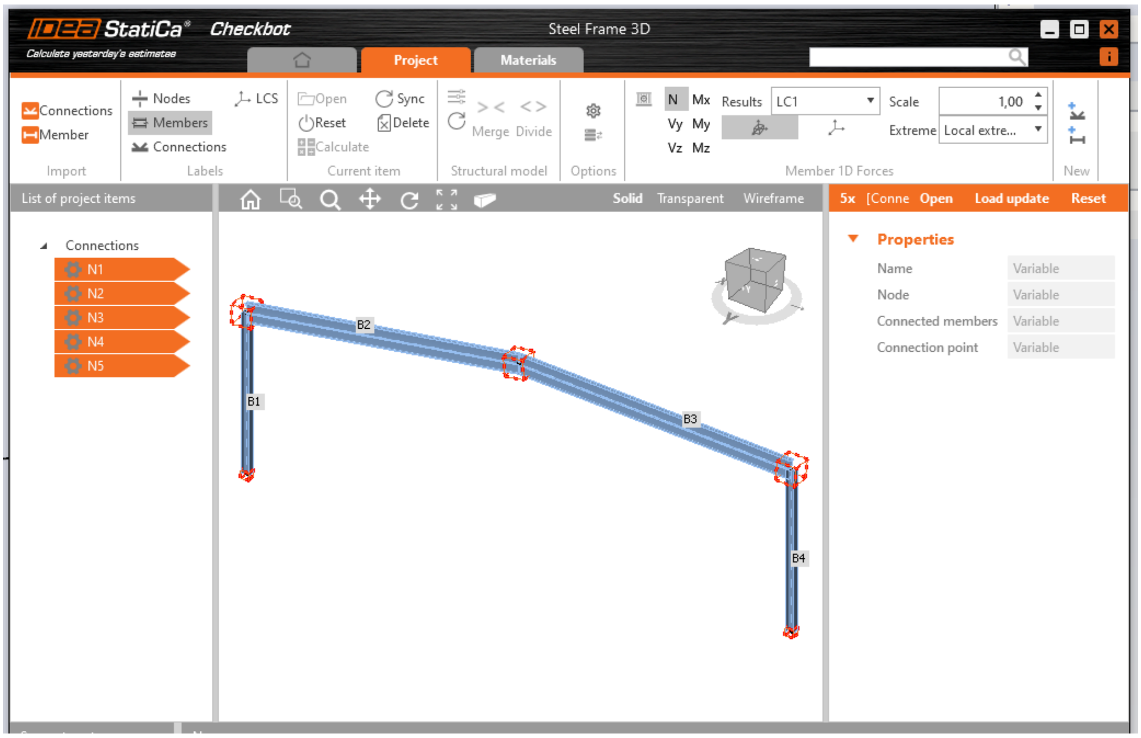
Step 9. Export to Idea Statica

To design and code-check a structural steel connection using the BIM link between SCIA Engineer and Idea StatiCa Connection, you need to activate the BIM links for software installed in the BIM link installer.

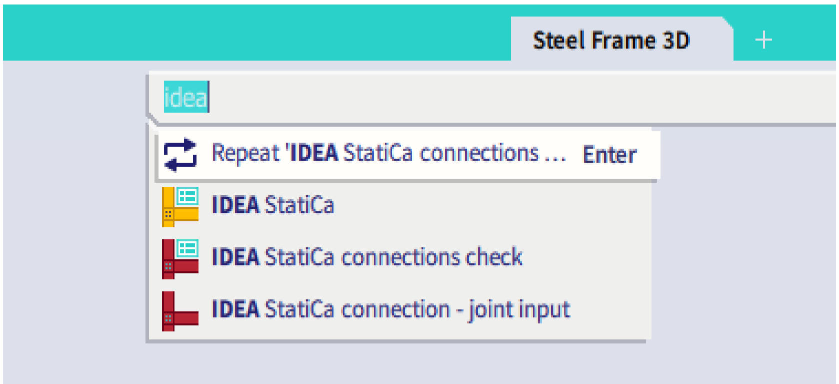
Once the linear analysis is completed and you have obtained the cross sections of the elements along with the internal forces acting on the structure, follow these steps:



This option will launch the Checkbot application. Select the "New" option with project type "Steel" and design code "EN". Then, click on "Create project". The new Checkbot project is now prepared to import connections from SCIA Engineer.

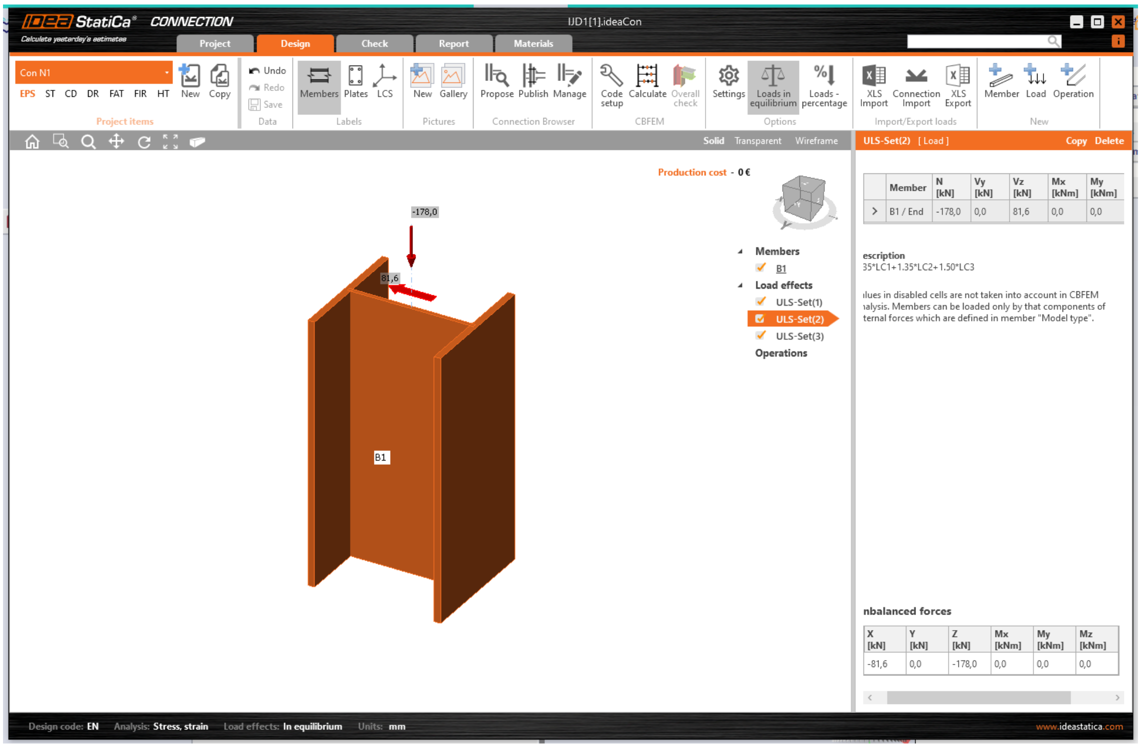


For various FEA/BIM solutions, you can import multiple connections into Checkbot by selecting several nodes and members using the application's selection methods. We recommend not importing all connections at once, but rather building them up incrementally. You can use Idea StatiCa Connection – Joint Input to define a connection in Scia Engineer, which will be exported with the assistance of Idea StatiCa Connections Check

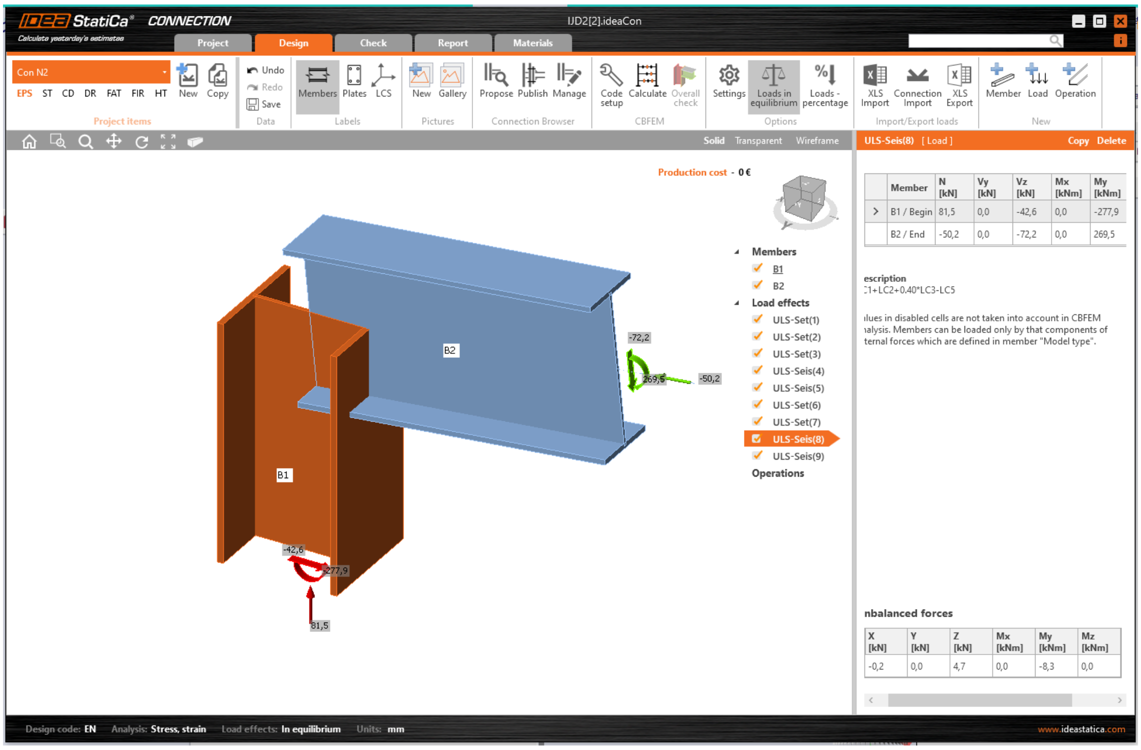


After following these steps, in Idea StatiCa, we will have the elements that need to be joined (beams, columns) as well as the loads required for the joint's dimensioning.

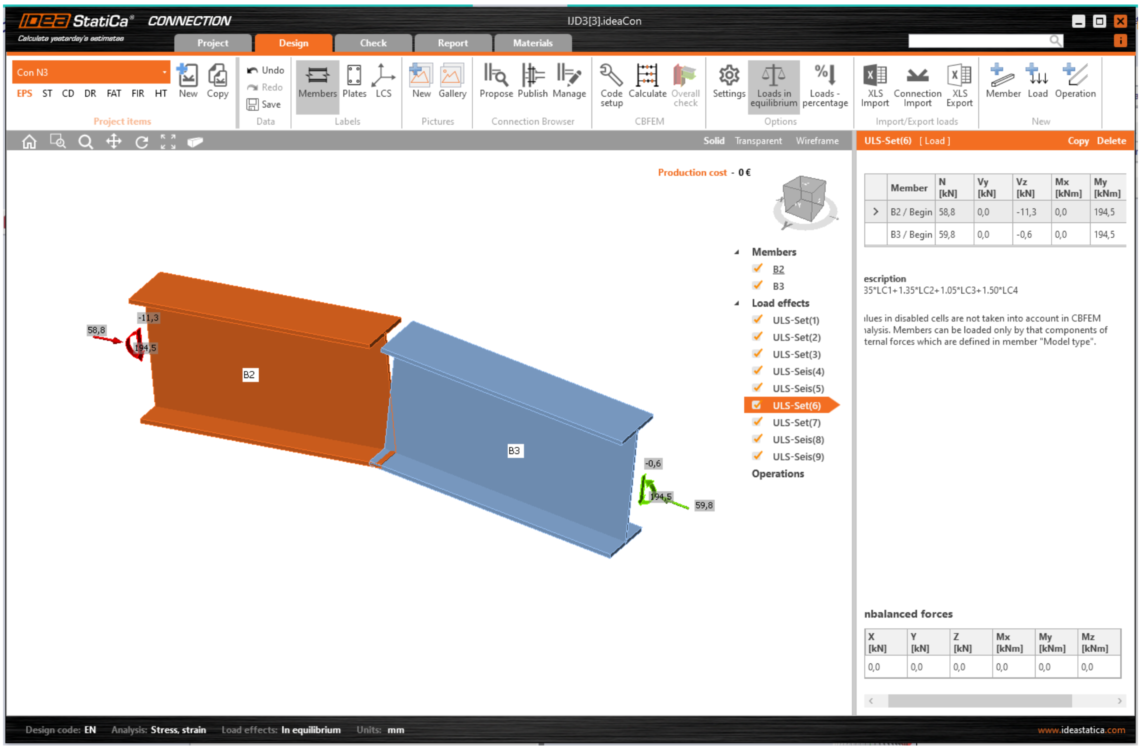
Column-base connections:



Eaves connections:



Apex connections:



6.3.3.2 – TEKLA STRUCTURES:

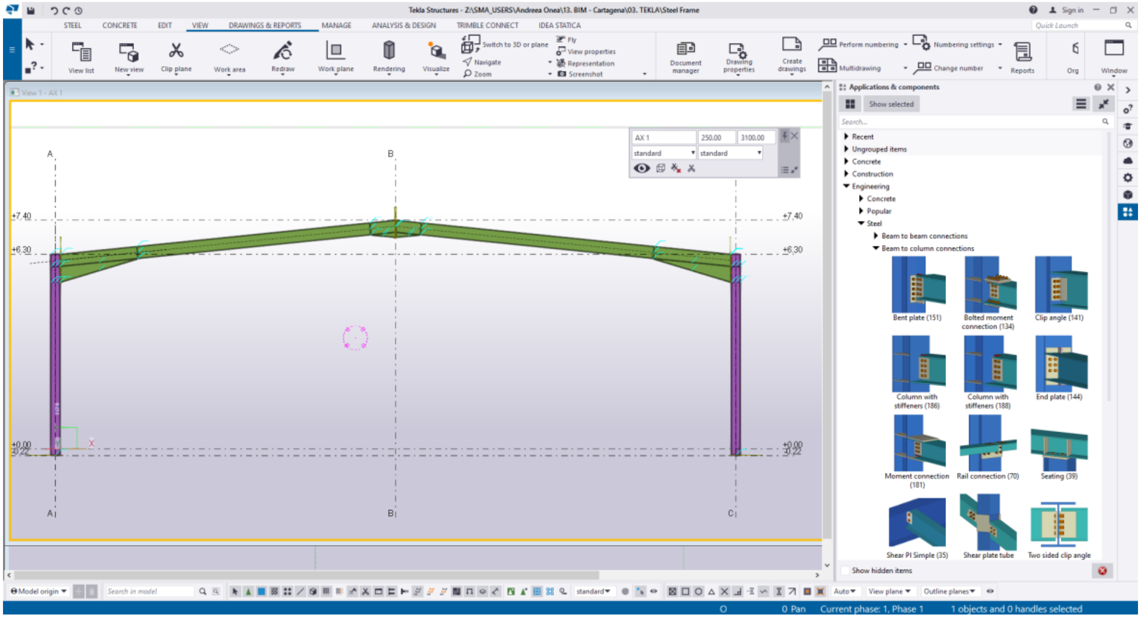
The connections in a portal frame are those at the eaves and the apex, which are both required to be moment-resisting and the column-base connections. The eaves connection in particular is generally subject to a very large design bending moment. Both the eaves and apex connections are likely to experience loading reversal in certain design situations and this can be an important design consideration for the connection. In the majority of cases, nominally pinned column-base connections are provided, because of the difficulty and expense of providing a rigid basis.

Column-base connections: Pinned connections are the most common solution, because of the difficulty and expense of providing a rigid base. A rigid base would involve a more expensive steelwork detail and, more significantly, the foundation would also have to resist the moment, which increases foundation costs significantly compared to a nominally pinned base.

Eaves connections: In addition to increasing the bending resistance of the rafter, the haunch increases the lever arms of the bolts in the tension zone. Generally, the bolts in the tension zone (the upper bolts under gravity loading) are nominally allocated only to carry tension, whilst the lower bolts (adjacent to the compression stiffener) are nominally allocated only to carry the vertical shear, which is generally modest. The compression force is transferred at the level of the bottom flange.

Apex connections: Under gravity loading, the bottom of the connection is in tension. The haunch below the rafter serves to increase the lever arms to the tension bolts, thus increasing the moment resistance. The haunch is usually small and short, and is not considered in the global analysis of the frame.

In Tekla Structures, open the project exported from SCIA Engineer. Then, select a predefined connection from "Applications and Components" and adjust its parameters as needed. Our structure will look like this:

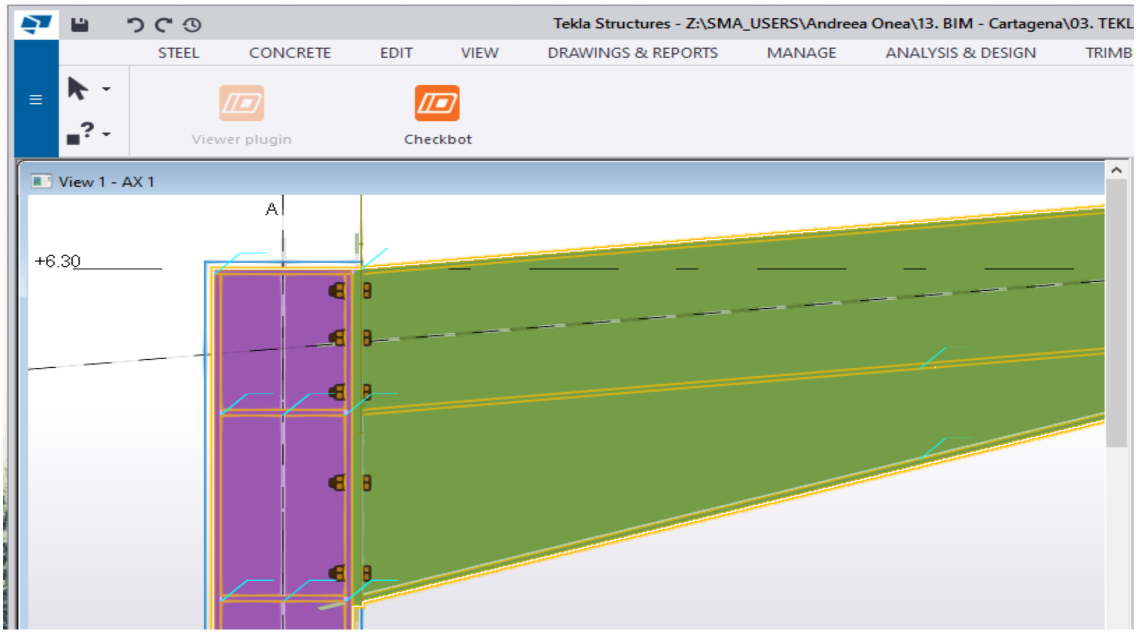


EXPORT TO IDEA STATICA

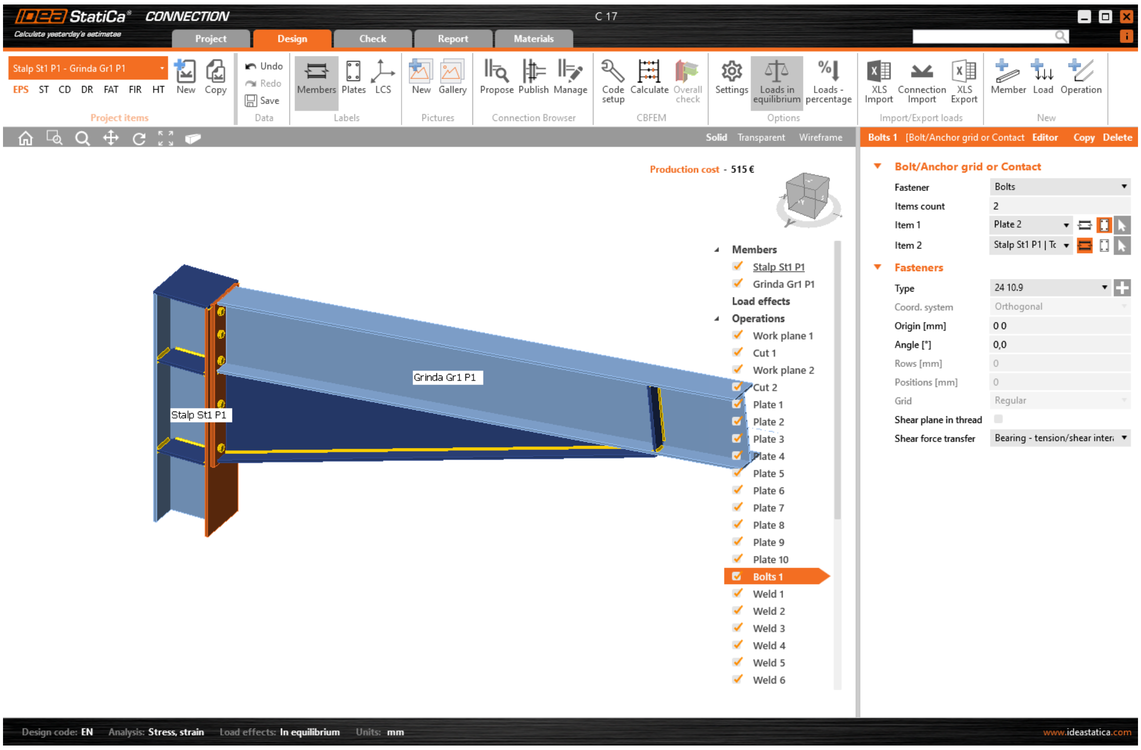
Idea StatiCa seamlessly integrates with Tekla Structures, allowing you to conveniently transfer steel connections and member data for structural design. This includes beams, cross-sections, and various operations like bolts, holes, welds, and cuts. Moreover, the synchronization ensures that any changes in the Tekla Structures model are reflected in Idea StatiCa.

Installing both applications on the same PC is all you need to get started. Idea StatiCa will automatically detect Tekla Structures and activate the plugin, enabling you to export and calculate steel connections without any difficulty.

After designing the steel connection, navigate to the Idea StatiCa tab in the top ribbon and select the Checkbot . This tool will assist you in exporting your connection.



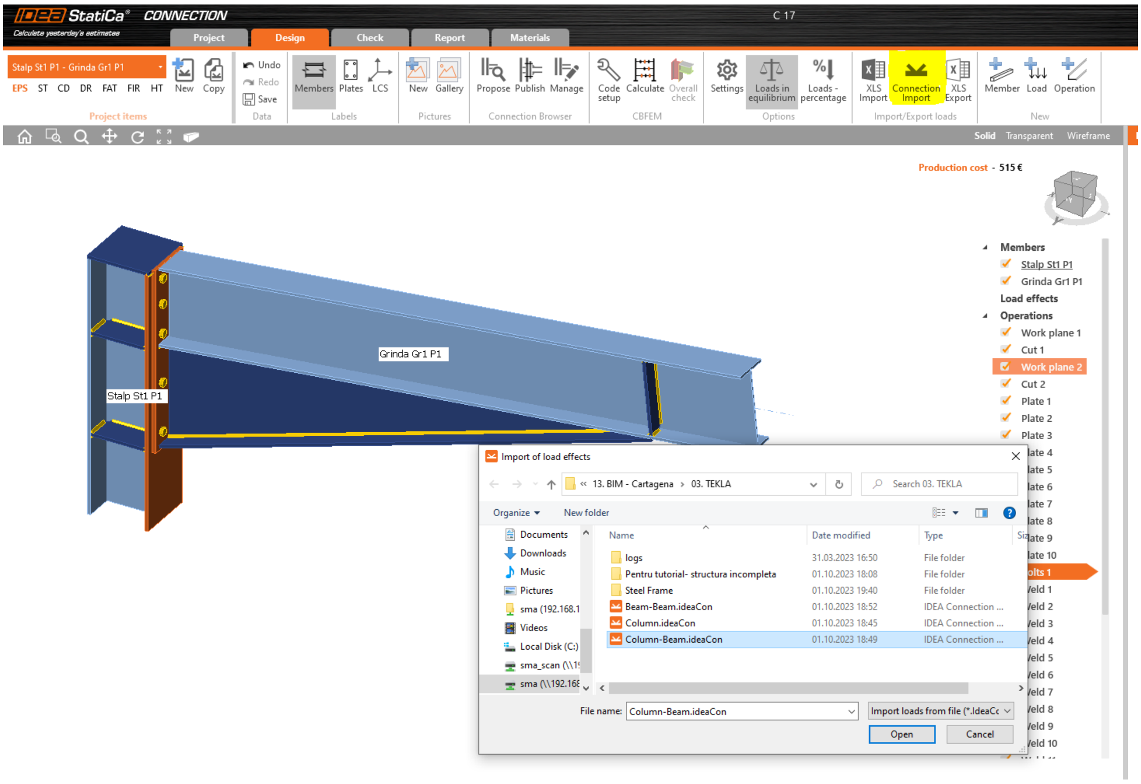
First, select the node that will represent the structural node of the joint. Confirm the selection by pressing the spacebar on your keyboard. In the next step, choose the members. The initially chosen member will be designated as the bearing one (which can be altered later). Once all members are selected, confirm with the spacebar. Finally, select all the remaining components of the connection such as plates, bolts, and welds, and again confirm with the spacebar. The connection in Idea StatiCa looks like this:



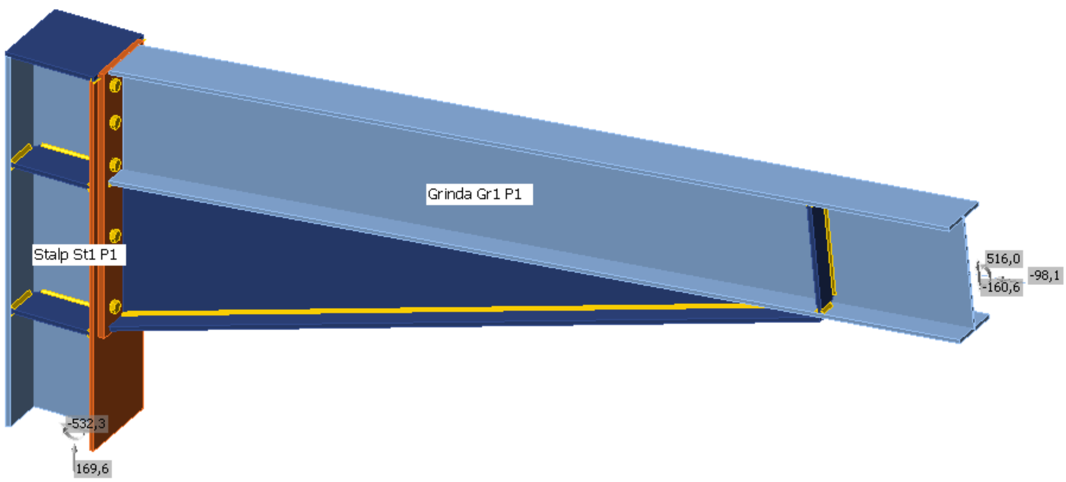
6.3.3.2 – IDEA STATICA:

Keep your connection model imported from Tekla Structures open. You can reopen it at any time in the CCM in Tekla Structures.

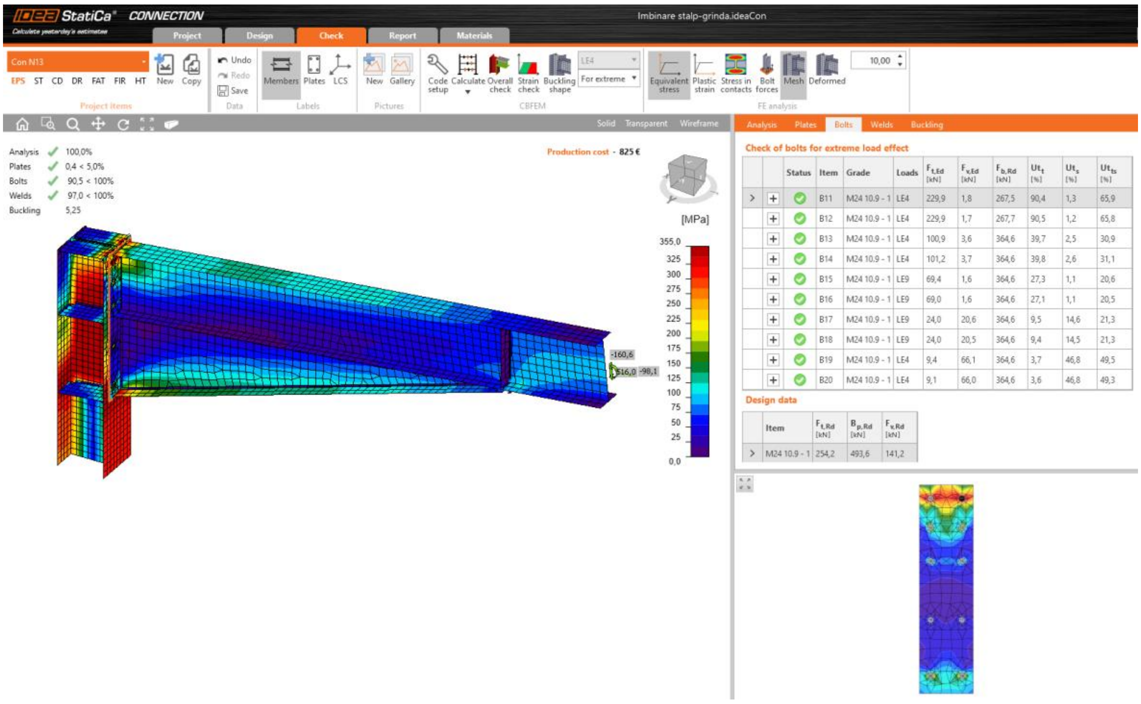
Select the "Connection Import" command and locate the path to the previously exported Scia Engineer connection model.



The load effects have been successfully imported and appropriately assigned to the members. The loads are balanced, ensuring that the joint is in a state of equilibrium.



To start the analysis, initiate the process by clicking the "Calculate" button. The analysis model will be automatically generated, and the calculation will be performed. After that, you'll be able to view the Overall check, along with basic values of check results. Navigate to the "Display" tab and activate the "Equivalent Stress" and "Mesh Model View" options from the ribbon. This will provide a comprehensive visual representation of what is transpiring in the joint. For a more detailed examination of the bolts, expand the details of bolt B3 by clicking the plus icon associated with it. This step will afford you a deeper insight into the performance of this specific bolt.

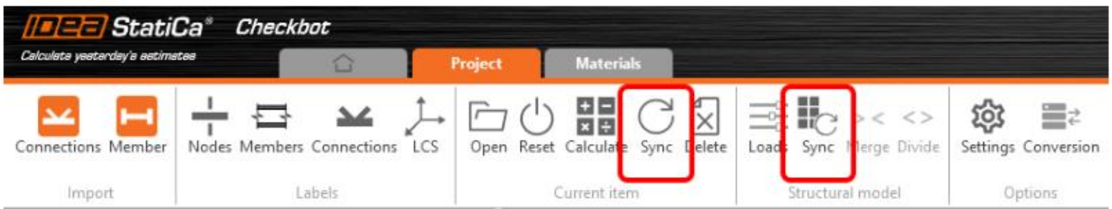


Synchronizing models in Idea Statica involves an iterative process for arranging structural components and load effects in a manner that satisfies the code-check requirements.

Sometimes, there are changes in FEA/BIM model such as different member section sizes or loads. These can be synchronized between Checkbot and the FEA/BIM model.

There are two possible alternatives:

- Synchronize the Current item (if one or more joints are selected)
- Synchronize the whole imported Structural model



6.4 – LCA Analysis

The Life Cycle Assessment (LCA) for the steel structure was conducted using the Open Click program. This software allowed for a detailed analysis of the environmental impacts associated with the structure. By using Open Click, the assessment was able to capture data from various stages of the steel structure's life cycle, providing valuable insights into its sustainability.

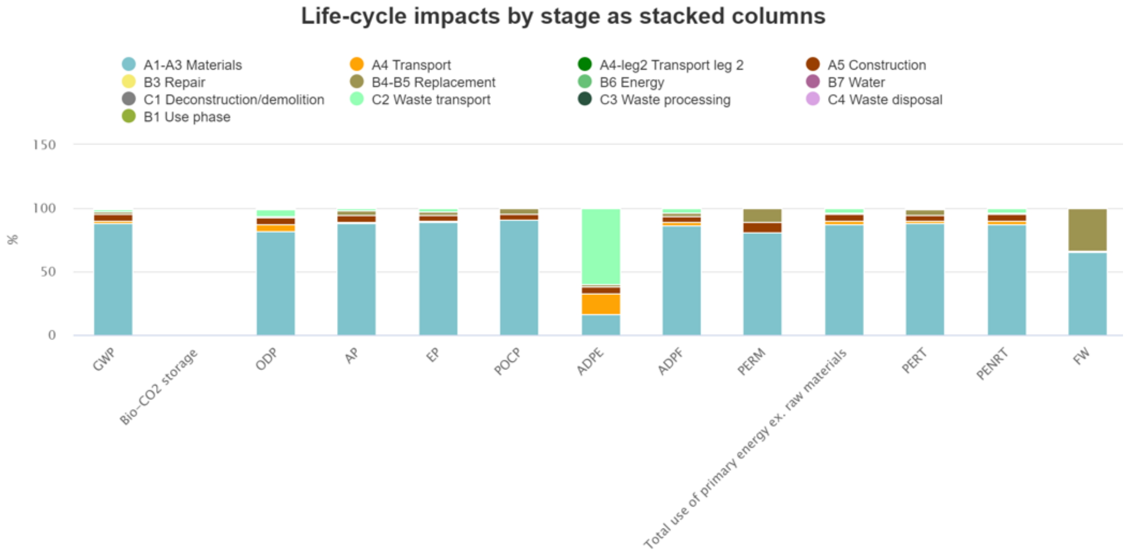
7 – Analysis of the different alternatives studied

The main go is to compare three different analyses of a steel structure. The initial analysis examines the structure built using non-recycled materials (foundations, beams, and columns), while the second and third analyses incorporate varying amounts of recycled materials. Descriptions of the recycled materials used and a comparison between the second and third stages are provided below. The recycled materials assessed include both infrastructure and superstructure components of the industrial building.

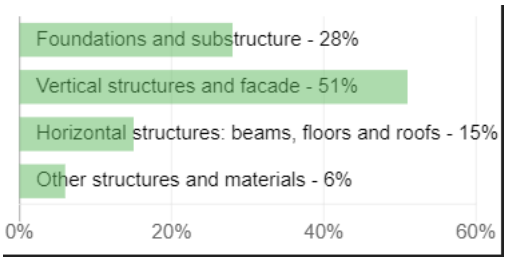
The objectives of this case studies are:

1. Conducting a Life Cycle Assessment (LCA) for the steel structure across three distinct stages.
    - **Stage 1:** Analyse the original steel structure as designed with non-recycled materials.
    - **Stage 2:**
        - Ready-mix concrete: 50% GGBS
        - Reinforcement steel (rebar): 60% recycled
        - Steel sheets: 60% recycled
        - XPS insulation panels: 20% recycled
        - Structural steel profiles: 60% recycled
    - **Stage 3:**
        - Ready-mix concrete: 30% fly ash
        - Rebar: 90% recycled
        - Steel sheets: 90% recycled
        - XPS insulation: 40% recycled
        - Structural steel: 90% recycled

The figure below illustrates the life cycle impacts at each stage, presented as stacked columns. This visual representation offers a clear and detailed view of the environmental impacts associated with each phase of the product or project life cycle. By breaking down the stages—such as raw material extraction, manufacturing, transportation, use, and end-of-life—it allows for a comprehensive analysis, highlighting the relative contribution of each phase to the overall environmental impact.



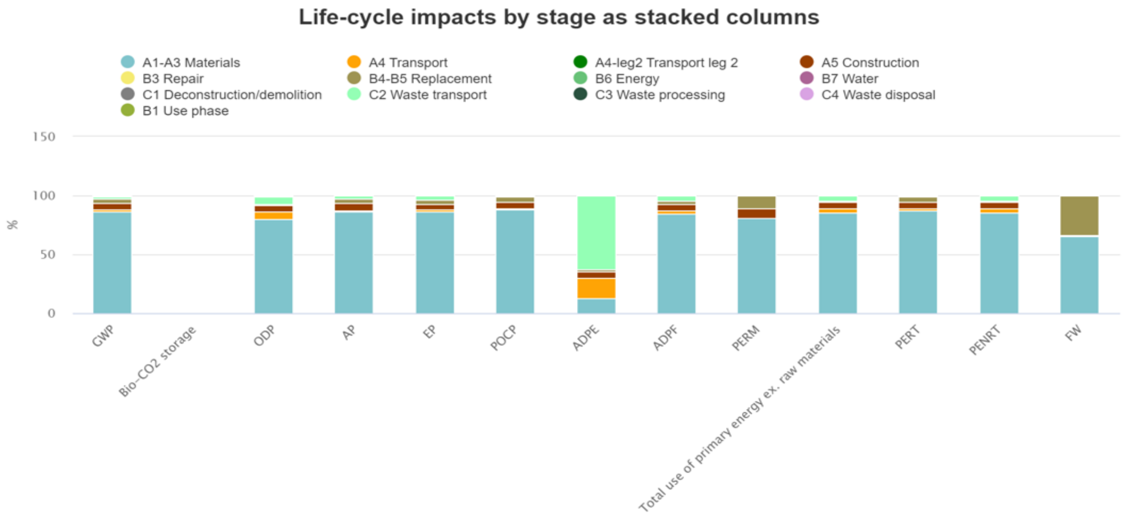
A comparison chart of infrastructure and superstructure elements is presented below. This chart provides a visual analysis, highlighting key differences and similarities between these two essential components of a construction project.



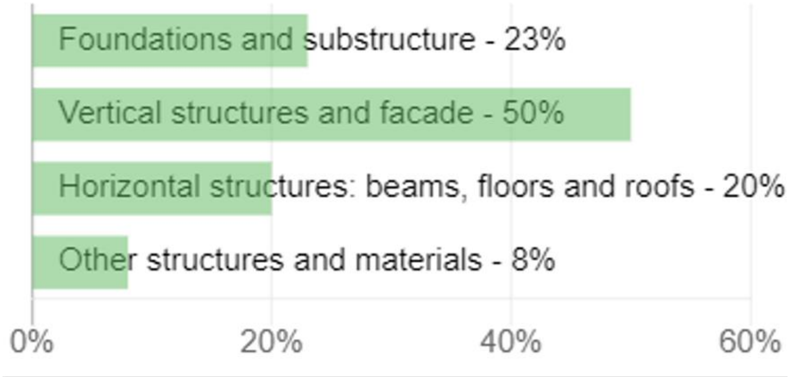
Results by life-cycle stage

The comparison chart provides a detailed analysis of key aspects related to infrastructure and superstructure components in construction projects.

The LCA analysis for the second stage is presented below.

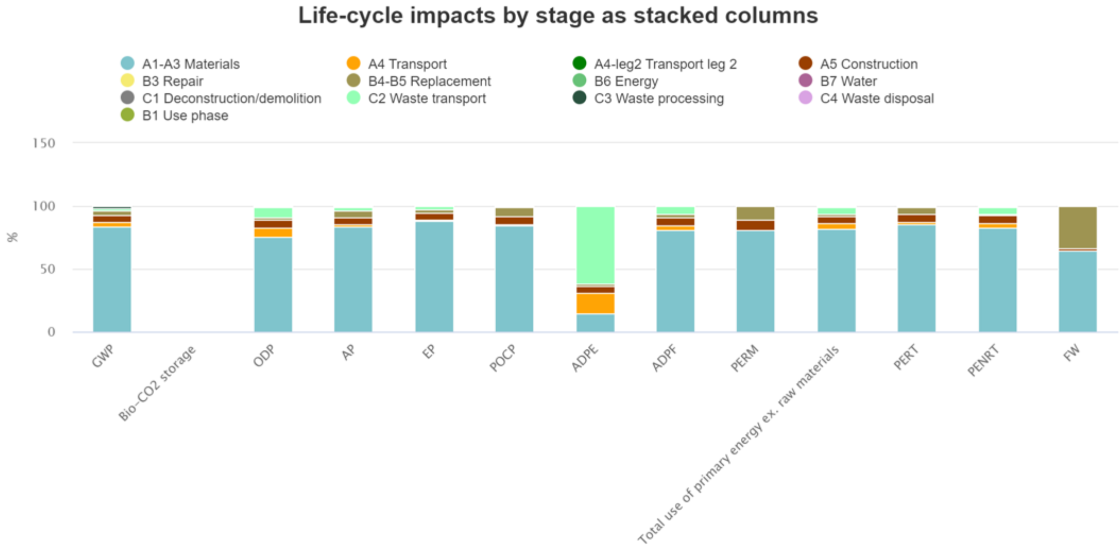


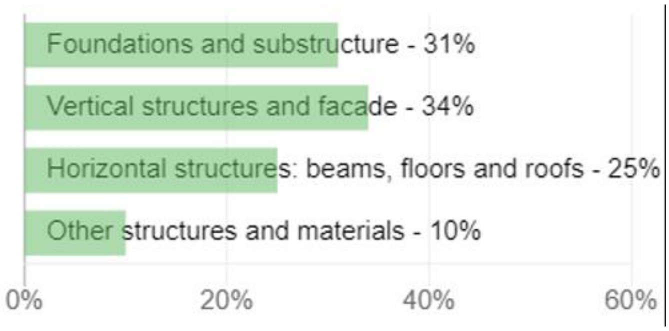
Materials use by source mass



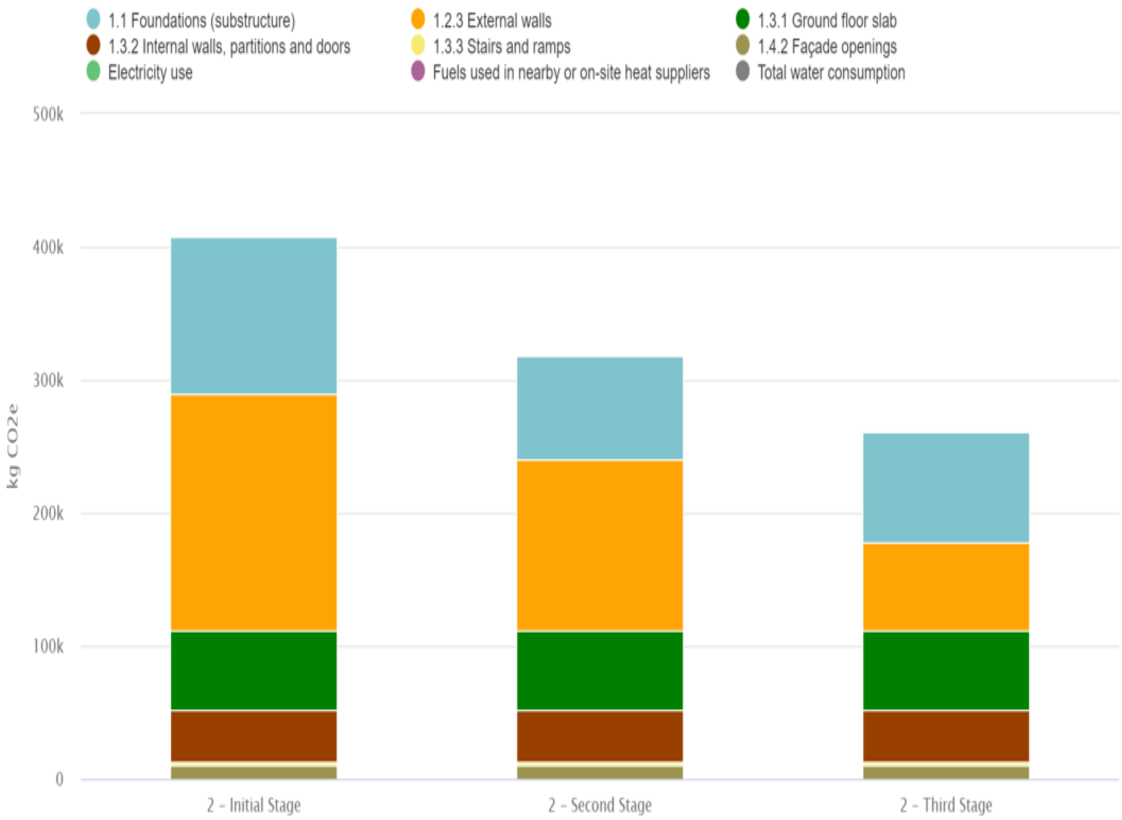
Results by life cycle stage

The third stage LCA analysis is shown below.





The comparison of the three stages centers on evaluating and contrasting key factors, such as waste management practices and greenhouse gas emissions (GWP), at each stage. This analysis seeks to highlight differences, similarities, and trends in waste management and its environmental impact in terms of GWP. By exploring these aspects, we gain valuable insights into the progression, evolution, and effectiveness of waste management strategies over time, as well as under varying conditions, all within the broader context of environmental sustainability.



The chart below includes the following results obtained: GWP - Global Warming Potential: A measure of the total impact a substance has on the Earth's climate over a specific time horizon, typically expressed in terms of carbon dioxide (CO_2) equivalents.

DDP - Delivered Duty Paid: An international trade term indicating that the seller is responsible for all costs associated with delivering goods to a specified location, including customs duties and taxes.

AP - Acidification Potential: The capacity of a substance to increase acidity in the environment, often associated with emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x).

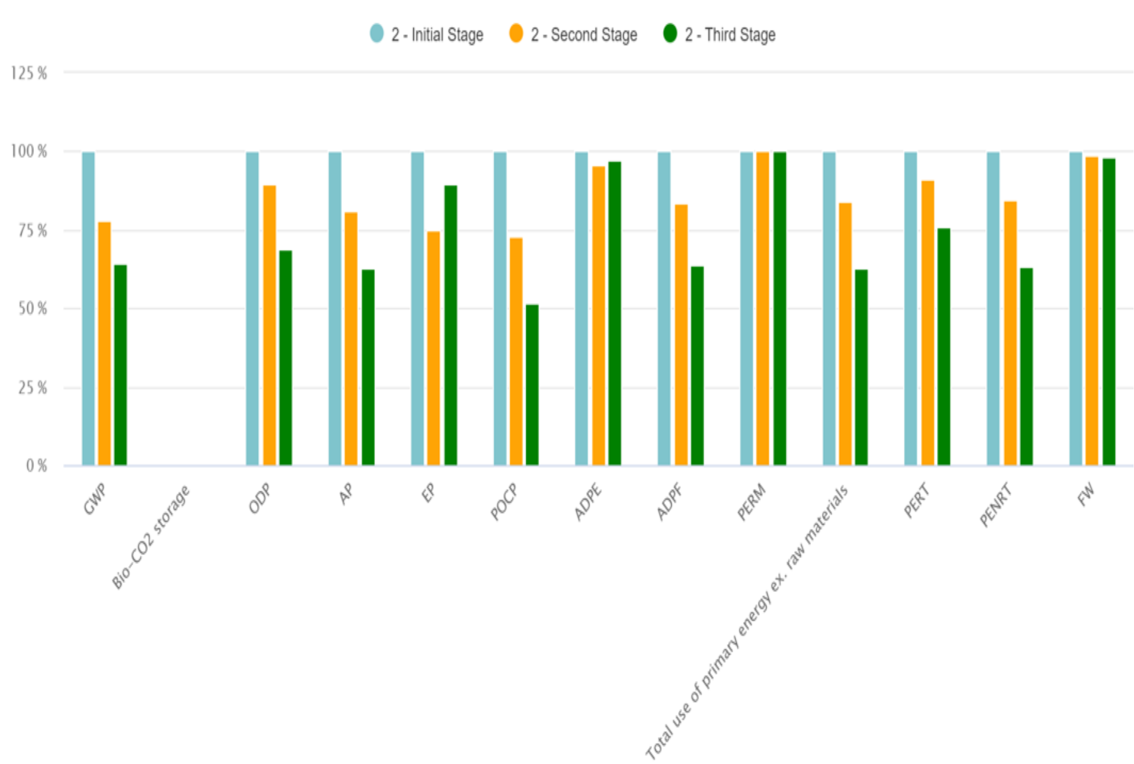
EP - Eutrophication Potential: The ability of a substance to promote excessive growth of algae and aquatic plants in water bodies, leading to oxygen depletion and ecological imbalances.

POCP - Photochemical Ozone Creation Potential: The potential of a substance to contribute to the formation of ground-level ozone (smog) through chemical reactions in the atmosphere.

PERM - Primary Energy Resource Mix: The composition of primary energy sources (e.g., fossil fuels, renewables) used to produce energy in a given region or context.

PER - Primary Energy Requirement: The total amount of primary energy (including both direct and indirect energy) required to produce, process, and use a product or service.

PENRT - Primary Energy Non Renewable Total



It is essential to consider using recycled elements and structures to mitigate global warming, as this approach can have a significant long-term impact on reducing environmental harm and promoting sustainability. Incorporating recycled materials into construction practices can contribute positively to efforts aimed at combating climate change and minimizing resource depletion over time.

8 – Conclusions and recommendations

A case study is a potent educational tool that offers an in-depth analysis of a specific instance or scenario. It serves as a practical context for theoretical concepts, promoting critical thinking, problem-solving, and the application of knowledge.

Students are directly exposed to real-world situations, requiring them to analyze, evaluate, and synthesize information, leading to a deeper understanding of the subject matter. This active participation in the learning process is invaluable.

Integrating theoretical knowledge with practical application through case studies bridges the gap between academic learning and real-world scenarios, preparing students for professional environments.

Furthermore, case studies foster the development of analytical skills. Students are tasked with identifying key issues, considering various perspectives, and proposing viable solutions. This process hones critical thinking, problem-solving abilities, and the capacity to make informed decisions.

In addition, case studies promote collaborative learning. They encourage students to collaborate, share insights, and engage in meaningful discussions. This collaborative approach not only enhances comprehension but also facilitates the exchange of diverse viewpoints and experiences.

In conclusion, incorporating case studies into learning activities is a dynamic and effective educational approach. It stimulates active learning, nurtures critical thinking, encourages collaboration, and bridges the gap between theory and practice. By adopting this methodology, educators can create enriching and engaging learning experiences that empower students to excel in their academic pursuits and beyond.

We contributed together to improve knowledge about BIM, about how it can be used successfully in structural design and not only, at the same time with the guidance in making an example about the interoperability between different software that have BIM technology implemented.

We all noticed that BIM is a process that allows project teams to collaborate with technology to provide better project results. BIM allow users to create intelligent, structured models that store information.

The deliverable files are the detailed report extracted from Scia Engineer for the calculation of beams and columns, the technical drawings for column, beam and joints from Tekla Structures, and the detailed report on the base joint, column-beam and beam-beam joint from Idea StatiCa.

In conclusion, using recycled materials in construction is really important for reducing global warming and supporting long-term environmental sustainability. By including recycled elements, we can lower the negative impact on the environment, help combat climate change, and save resources for the future. This is a key step toward making building practices more eco-friendly.