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POLITECNICO DI TORINO

Collegio di Ingenieria Civile

Corso di Laurea Magistrale
in Civil Engineering (Structures and Infrastructures)

Master of Science degree Thesis

Design of a Corten steel pedestrian bridge in Piedicavallo (Biella) with the use of the BIM Methodology

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Academic Year 2021-2022

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1. Abstract

The objective of the following thesis is to design a Corten steel pedestrian bridge in Piedicavallo (Biella), with the use of the BIM Methodology. The case study aims to respond to a current need in the area, since in October 2020 a major flood hit Valle Cervo and caused the collapse of many structures. The flood caused also the collapse of the pedestrian bridge that served as a pedestrian crossing. The project consists of the construction of a walkway in a remote area with difficult access since the location of the case study area is approximately one kilometer from the nearest town, Piedicavallo. It's only possible to reach the zone on foot, through a mountain path, by car, through a road with precarious conditions, or by helicopter.

With the case study completely described, the BIM methodology was developed for a real scenario. Firstly, architectural design was held, where it has been intended for the pedestrian bridge not just to accomplish the necessity of crossing the river, but also to create added value for the area, for this, Glulam wood has been used to beautify the structure. Then, the structural analysis was done, checking the proposed sections on Corten steel, designing and performing local analysis of the structural connections and finally, the foundation has been designed and correspondingly verified.

The principal focus of the present project corresponds to the construction management of the pedestrian bridge, then, continuing the BIM methodology, the time analysis has been performed, detailing every step that must be followed during the construction phase. Additionally, the cost analysis has been developed using data on unitary prices of the Piedmont region.

The Piedicavallo pedestrian bridge it is being separately designed and will be built by an engineering and design studio, which has a specific budget determined by contract. For this reason, a comparison has been made between the two different approaches to the structure in terms of design and costs that were achieved for the project. Finally, it has been proposed as future developments to continue with the BIM Methodology considering the 6D dimension that corresponds to sustainability and the 7D dimension that corresponds to the maintenance plans for the pedestrian bridge.

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2. Introduction

The objective of this thesis is to define the projection and characterization of a BIM Methodology for a solution of a project known as the Pedestrian bridge in Piedicavallo (Biella). Piedicavallo is a municipality in the Province of Biella, in the Piedmont region, located about 70 kilometers from Turin. The exact location that would be used for the development of the work is 30 minutes by walking from Piedicavallo a small village. The river that passes through the case study zone is part of the Valle Mologna. In the following figure, it will be shown a point cloud that was taken for the zone, where the exact point of the case study is marked with a red cross.

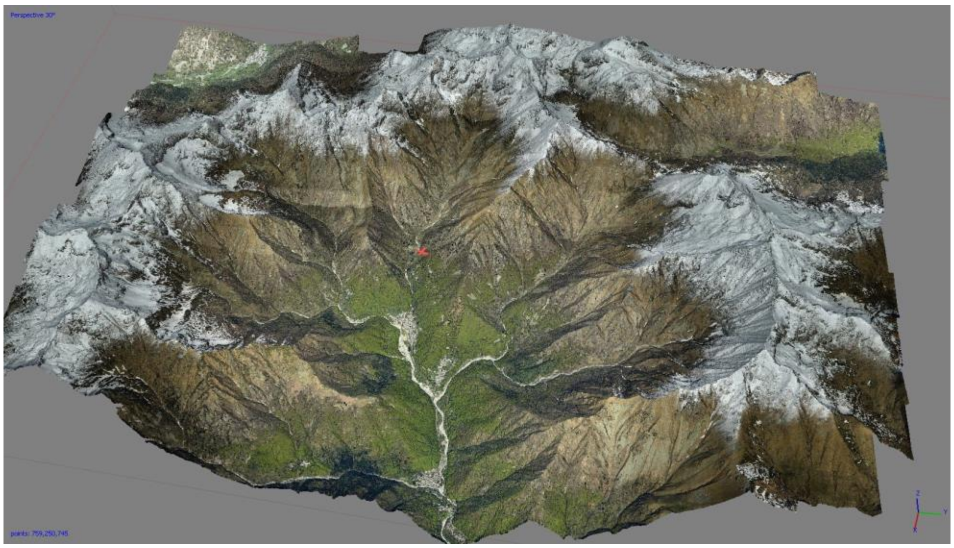


Figure 1. Position of case study

The development of the BIM methodology aims to respond to a necessity of the area in terms of mobility for habitants and also hikers that use the route. It's important to mention that a large flood hit the Valle Cervo in October 2020. This flood caused the destruction of many structures in the zone, including the pedestrian bridge of the case study. In the following images, will be shown the actual aspect of the zone.

Figure 2. Actual aspect of pedestrian bridge in Valle Mologna

For the preparation of the case study, a visit was made in order account all different aspects that are part of the complexity of the project. During this visit, it was evidenced the conditions presented not only around the pedestrian bridge site but also trough the river path. The floods and action of the river of the Valle Mologna, has caused many rivers banks erosion which occasioned at the time the damage to pedestrian routes and also structures. In the following figures, it will be shown many conditions evidenced during the visit.

Figure 3. River banks erosion in Valle Mologna

With all case study characteristics completely recognized, bibliographical research of pedestrian bridges with combined materials will be presented. Considering different cases of pedestrian bridges around the world that use at least two different materials. Additionally, it's important to mention that the Piedicavallo pedestrian bridge it is being separately designed and will be built by an engineering and design studio. Then, it will be positive to use the same materials that the described design presents in order to allow a comparison in terms of design and costs between the two different projects. However, the decision of materials, design and project management will be held taking into account all necessities and limitations of the case study.

The project will be managed following the BIM methodology. The development of this methodology covers all different dimension of the BIM process, reaching a solution that intends to respond the necessity of pedestrian users and also to give an added value to the case study zone.

The architectural design will be developed considering two different approaches using the software from Autodesk family Revit and Sketchup. Where, it aims to reach a high level of detail, combining the materials for each part of the structure. On the other hand, the design process continues with the structural design, where again Autodesk Revit can be used for drawings and detailing. Additionally, SAP2000 will be used for structural analysis, Idea Statica for design of connections and Excel for design of foundations.

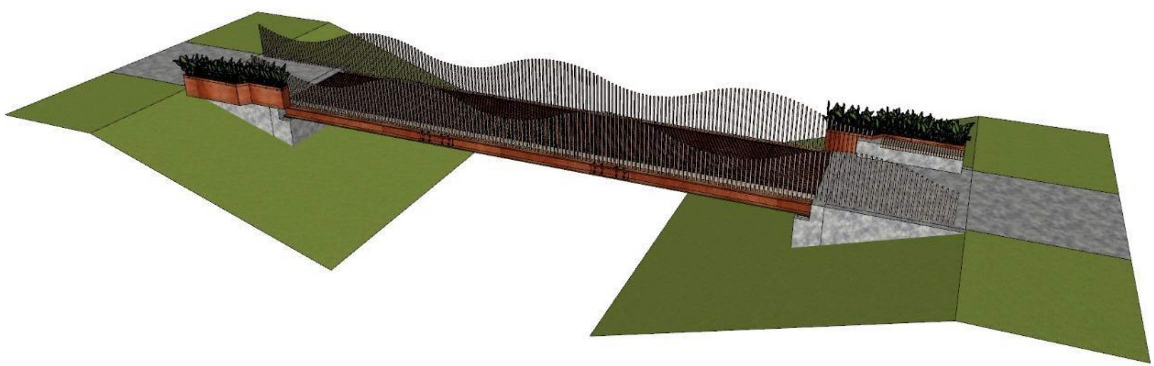


Figure 4. Architectural design of Piedicavallo pedestrian bridge

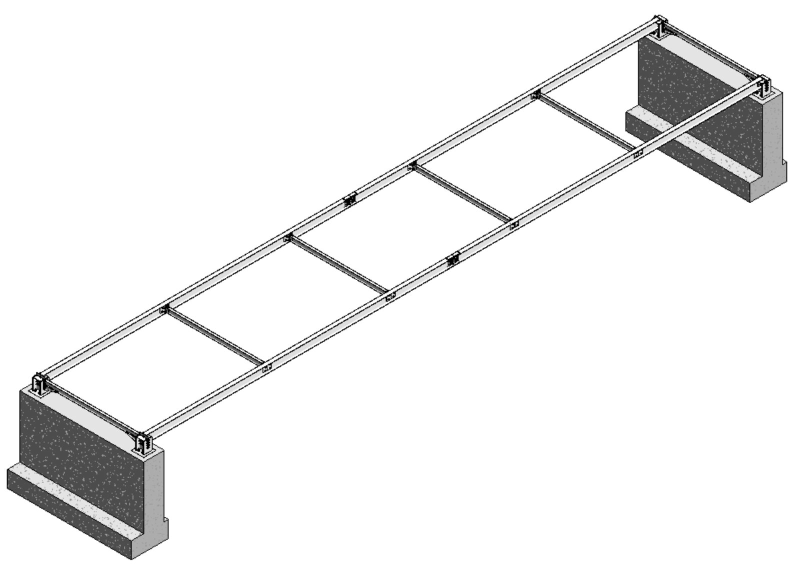


Figure 5. Structural design of Piedicavallo pedestrian bridge

The principal objective of the present thesis corresponds to the construction management of the pedestrian bridge, which presents many challenges due to the difficult conditions that are part of the case study. Then, the BIM methodology will focus on the 4D dimension that corresponds to the time analysis. Were, following the methodology Program Evaluation and Review Technique (PERT) on Microsoft Project, it will be detailed every step that must be followed during the construction phase.

To continue with the project management of the pedestrian bridge, the cost analysis that correspond to the 5D dimension of the BIM methodology may be developed. For this analysis, the data of “Prezzario di Piemonte, edizione Luglio 2022” will be used on the software Primus. These evaluations of costs, correspond to an evaluation of estimated metric computation, where it was assigned costs to all different activities that are part of the construction process.

Once all different proposed BIM dimensions are reached, the software used may be identify and their interoperability must be analyzed. Theses software that are mentioned, can be listed and described the interoperability between them.

As it was mentioned, a comparison in intended to be made between the approach reached by the engineer and design studio that is in charge of the construction of the pedestrian bridge and the present approach of this thesis. This comparison, evaluates the structure in terms of design and costs. Finally, some considerations are suggested as future developments to continue with the BIM Methodology considering the 6D dimension that corresponds to sustainability and the 7D dimension that corresponds to the maintenance plans for the pedestrian bridge.

3. Case study

3.1. Problematic of case study

In order to have a better understanding of the case study, it will be described the consequence and damages suffered by the pedestrian bridge in Piedicavallo, Biella and also in the around areas. Then, it will be explaining the natural causes and also the human factors that implied the destruction of this important pedestrian bridge.

Finally, the solution that refers to the design and management of construction area, will be disaggregated in two main parts described in this document as the management of working site and architectural importance.

3.1.1. Consequence and damage to Pedestrian Bridge

The principal problem as was seen on figures, is that on the Valle Mologna the river has caused that the river banks erode and then caused damages to structures as the bridge in mention. This fact is produced due to floods and landslides, which at the time, are caused by natural events as extensive rainfalls or snow thawing.

As it can be seen, one of the piles and actually foundation was completely destroyed due to the power of the flood, which caused a landslide in this specific zone. It can be also said that the flood could reach the level of the girder of the bridge and as it will be explained, the flooding in union with the transport of sediments, trees and debris increase the power of the waterfall and can induce on the destruction when the smash between the structure and this mix of materials plus the water with its force occurred.

In the following figures, it will be shown not just the zone of the destroyed pedestrian bridge but also the problems presented through the crosswalk between Piedicavallo and the village.

Figure 6. Defense for crosswalk and Landslide of River embankment

Figure 7. Landslide of River embankment and Closure of Pedestrian walkway due to landslide

Additionally, it can be said that the pedestrian bridge that was destroyed did not have a proper protection against the flood, also it is notable from images shown that the foundations were not safety at all. Then it will be necessary to design a proper foundation for bridge and also a protection against a possible water runoff on one of the sides of the bridge.

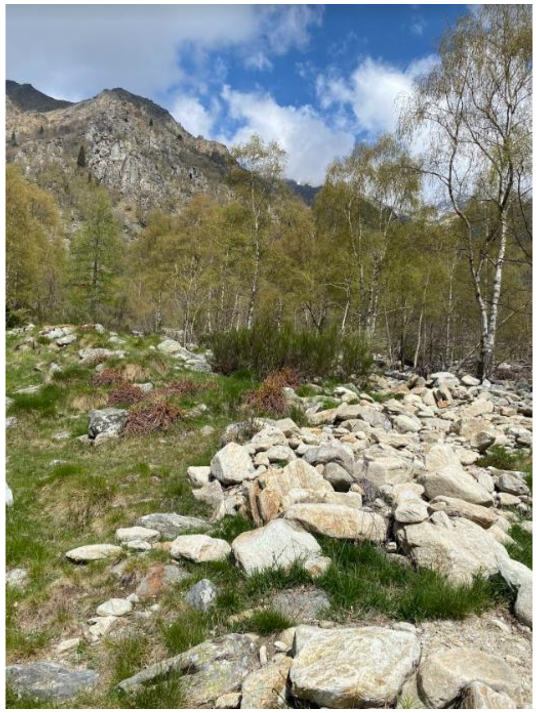


Figure 8. Side of bridge with possible water runoff

It is also important to take into account that an event (flow) as the one that caused the destruction of the bridge in mention and many other destructions of structures, have a return period of 20 to 25 years, and also the small flows with a return period of 6 to 8 years.

3.1.2. Bridge damage causes

As it was presented, the pedestrian bridge that is part of the case study was destroyed by a flood. It's important to understand what is a flood and what are the causes that induce on heavily damages to structures as a river bridge.

A flood is an overflow of water that submerges lands that are usually dry and also a water level increase due to a rise of flow discharge. Floods are a hot topic for hydrology research and have a significant impact on public health, civil engineering, and agriculture.

Floods can cause several damages to structures in many different ways, during this event rivers suffers an overflow, then it can be picked up debris, trees and many other materials, increasing the power of the water against any structure when a smash is occurred. An impact like this may not destroy immediately a structure like a bridge, but the weight of the piled up combined with the power of the increasing waterfall starts to apply a force that can induce damages. In case of bridges, when the water level reaches the lower girder of the bridge deck due to a severe flooding, the flow is no longer a free flow but a pressurized flow. Under these conditions, the transport of sediment on river bed under bridge deck can significantly be affected.

Not only the impact of the power of the overflow combined with a piled-up damages a structure, also these events can gradually wear away the earth around and underneath the underwater structures, this process is known as scour, it's clear that the natural flow can also create this problem but a big increase of force and volume as the presented by a flood, can accelerate the process and also induce a collapse in terms of low time and even immediately.

Additionally, landslides and flooding are closely associated because both are related to intense rainfall, runoff and ground saturation. By obstructing valleys and stream channels and causing a water backup, debris flow can lead to flooding. This results in backwater flooding in the upstream region and, if the obstruction releases, rapid flooding downstream as well. As a result of the swiftly flowing floodwaters that frequently undercut slopes or abutments, flooding can also result in landslides. Land sliding frequently occurs after the base of saturated slopes are no longer supported.

Studies show that the principal reasons of failure or damage of river bridges are hydraulic factors. Among all factors presented before, flooding is the most important and destructive factor. Scouring around bridge piers and degradation at river bed are the worst situations that induce the biggest damages and also collapses to a river bridge. 53 percent of all bridge collapses, according to a report by the American Society of Civil Engineers, are due to flooding and scour.

3.1.3. Management of working site

The most principal problem that needs to be faced is the management of the working site, because as it was said, the study case zone is located by 30 minutes by walking to the closest town that is Piedicavallo, then all materials will need to be transported by helicopter and the construction machinery will be placed on a close road that will need to be adequate in order to reach the construction site. In the following images, is shown the road mentioned and also the place where the helicopter can land and leave the construction materials.

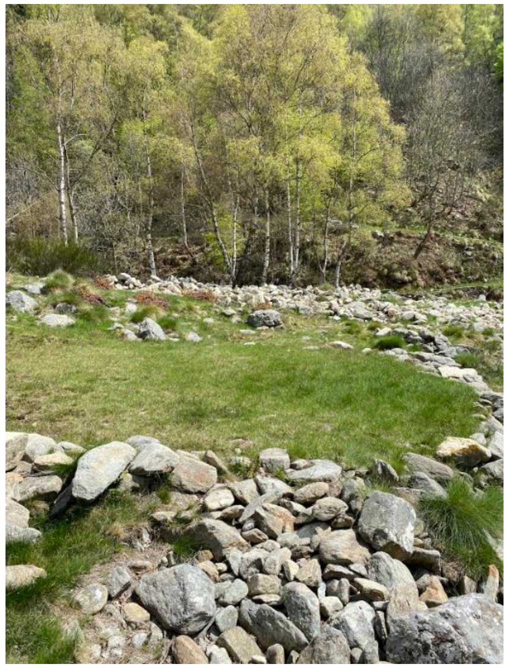


Figure 9. Helicopter landing zone

Figure 10. Nearest rode for construction machinery

3.1.4. Architectural importance

Another important factor that will be taken into account for the possible solution is not only the functionality of the pedestrian bridge, but also a solution that gives added value to the region. Then, additionally to a safety pedestrian bridge in terms of structural analysis, it will be considered a proper architectural design that combines at least 2 different materials and adapt to the environment.

Then, it's necessary to considered different possible solutions that meet the requirements described above. In order to accomplish it, bibliographical research was done where were took into account pedestrian bridges manufactured in at least two conventional materials and innovative due to their aesthetic design so away from a traditional wood or steel pedestrian bridge.

3.2. Bibliographical research of pedestrian bridges with combined materials

3.2.1. Literature review for pedestrian bridge design around the world

Then, it's necessary to considered different possible solutions that meet the requirements described above. In order to accomplish it, bibliographical research was done where were took into account pedestrian bridges manufactured in at least two conventional materials and innovative due to their aesthetic design so away from a traditional wood or steel pedestrian bridge.

- **CAN GILI – SPAIN**

Figure 11. Can Gili Pedestrian Bridge

The Can Gili Pedestrian Bridge it's a 40 mts bridge that solves an urban and social requirement in a remarkable way, integrating two banks of the city on a road trench through an unrepeatable structure. The client and the designers sought a solution with low environmental impact in the life cycle. This is the reason why Corten steel was chosen for the structure -whose oxidized skin is protected from corrosion and polymerized wood (almost maintenance-free) for the flooring.

- **ZAPALLAR – CHILE**

Figure 12. Zapallar Pedestrian Bridge

This pedestrian bridge was built as a result of a request to provide connection to a group of social housing located on the eastern side of Route F 30-E on small hills in the traditional spa of Zapallar. The walkway is transversely arched and is accompanied by a main beam in its lower part that works by bending. The interior elements are compressed or pulled, and the cut in the support is formed by the set of structural elements that reach said place.

- **THE BOSTANLI PEDESTRIAN BRIDGE - KARŞIYAKA, TURQUÍA**

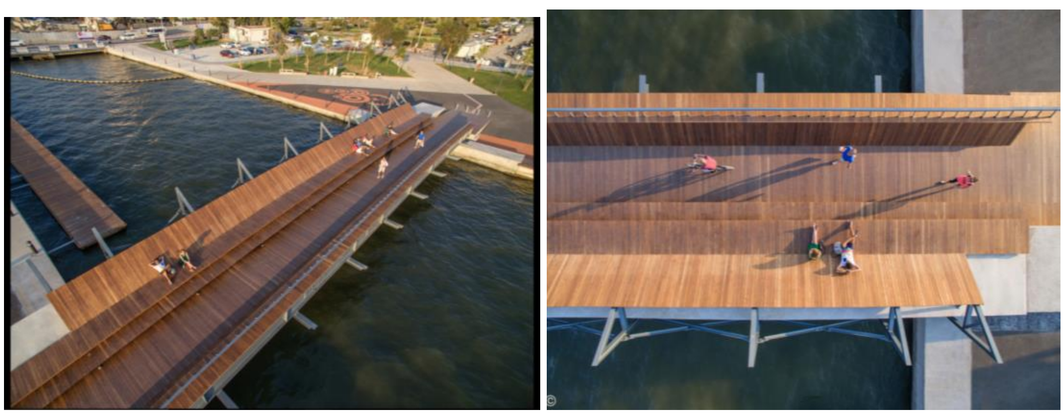


Figure 13. THE BOSTANLI PEDESTRIAN BRIDGE

The Bostanlı pedestrian bridge and recreational space have been designed by Studio Evren Başbuğ Architects as part of the 'Karşıkıyı' concept created for the 'İzmirSea' coastal regeneration project. These two architectural interventions that are placed in close proximity and in reference to each other, have generated a new integrated coastal attraction, where the Bostanlı stream flows into the bay, in a very special and unique place due to the geometric shape of the coast and the urban memory. The site has become one of the favorite public attraction spots in Karşıyaka, İzmir and has been embraced and visited by residents from all over the city since its opening in July 2016. The Bostanlı pedestrian bridge was constructed in steel and wood.

- **Bayraklı Coast Pedestrian Bridge – Turkey**

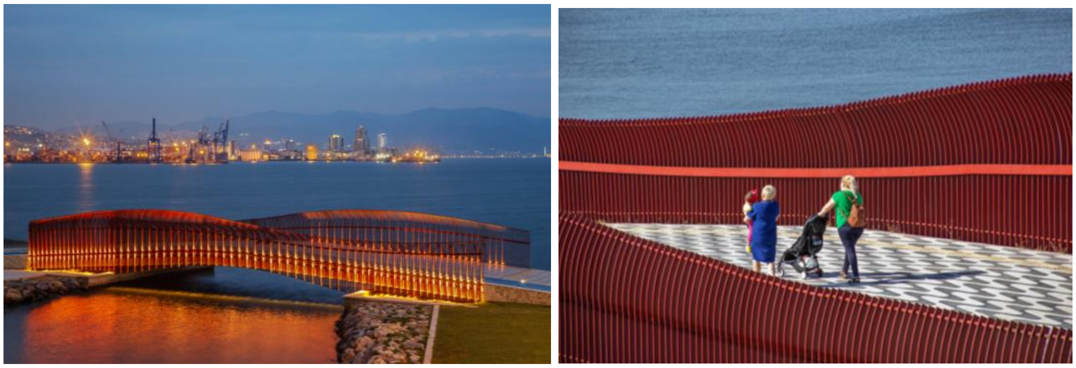


Figure 14. Bayraklı Coast Pedestrian PEDESTRIAN BRIDGE

The Bayrakli Bicycle and Pedestrian Bridge was designed with the aim of making the coastline more accessible for pedestrians, cyclists and vehicles. The distance between the support points of the bridge is 33 meters. When considered together with the connecting ramps, it is 74 meters long. The bridge is 10.9 meters wide and 3.5 meters of it is intended for a bike path. All the materials (Steel and concrete) used in the project are resistant to weathering and possible acts of vandalism. The need to use the bridge without requiring maintenance during the service period is reflected in the design.

- **Campo Volantin Footbridge, Bilbao, Spain, 1994 — 1997**

Figure 15. Campo Volantin PEDESTRIAN BRIDGE

The Developer Campo Volantín S.L. was the company that brought competition to build a bridge over the river not far from the site Nervión. Where, today is located the famous Guggenheim Museum in Bilbao. The key benefit of this project was that the bridge would be tall enough to allow medium- or small-sized ships to sail beneath it. The 50 cm-diameter circular steel arch. reaches a final height of 15 meters, the runway, with a total length of 75 meters, rises to 8.5 meters high with respect to its high water to make way for ships under its underpass. Two ramps in two sections of 2 meters wide each, with a slope of 7%, saving the high slope that provides the bridge to cross from one side to another.

- **ZHANGJIAJIE GRAND CANYON GLASS BRIDGE – China**

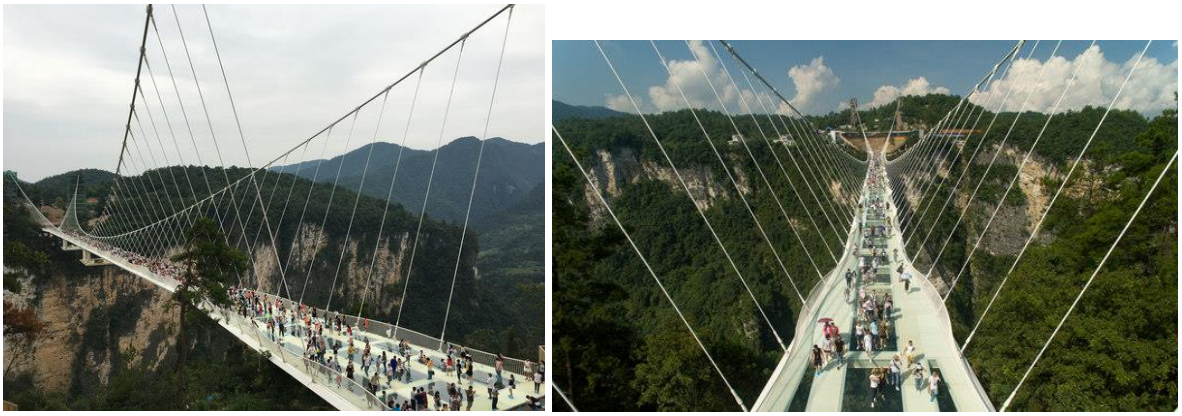


Figure 16. ZHANGJIAJIE GRAND CANYON GLASS PEDESTRIAN BRIDGE

The tallest and longest pedestrian glass bridge in China and the entire world is the Zhangjiajie Grand Canyon Glass Bridge. The Zhangjiajie glass bridge, which is 300 meters above the canyon bottom and is situated close to Zhangjiajie City in Hunan Province, People's Republic of China, is 385 meters long, 6 meters wide, and situated there. The bridge can hold up to 800 people. It will host the highest bungee jump in the globe as well as fashion presentations and other events. A suspension bridge with a medium span is the Zhangjiajie Glass Bridge. It is situated in a typical Karst region. The two ends of the bridge are surrounded by numerous flaws and sinkholes.

- The bridge is composed of typical large size glass panels, 3 meters x 4 meters laminated glass.
- 50 mm thick, composed of 3 layers of 16 mm glass with 2 layers of SGP film in between.
- The glass was tested for safety under extreme heavy loads (40 tons on a 3x4 meter panel).
- The glass is Iron Free, 100% clear glass (ultra-clear glass).
- According to the deformation test, a 3-meter x 4-meter glass deforms by 2.16 cm under 20 tons.

As it was seen, in all around the world there are many examples of pedestrian bridges that are not only functional but give an added value to a zone or a city as it can be to Piedicavallo (Biella).

The aim of the present step of the case study is to choose the materials that will be used for the structure and also a type of architectural design of the pedestrian bridge. Once going thru the bibliographical research, it is possible to see different solutions that can fix to the environment of the zone. As the pedestrian bridge will cross a river and it is surrounded by many threes and a mountain, it is necessary to take into account materials that fix and do not go against the environment, then steel, wood and glass are the materials that better comply the requirements. Also, it is necessary to take into account the climatological conditions in order to avoid damage due to climate and nature.

3.2.2. Approach to Design Studio in charge of construction of Pedestrian Bridge

During the visit to the zone of the case study we had the opportunity to meet the engineer and architect from actual design studio that will be in charge of the construction of the pedestrian bridge. The bridge was assigned to the mentioned studio and it has been designed entirely in COR-TEN Steel due as the engineer of the project said, this material was selected due to its behavior una der complicated environment as the case study, which means that this material will have less necessity to do many works of maintenance.

The engineer in charge of the construction of the bridge mentioned many important data that the pedestrian bridge will contain. The pedestrian bridge will have a length of around 15 meters, the budget runs between 77.500 euros. Also, several factors about the transport of material were mentioned as the time and the cost that takes for a helicopter to load the materials on Piedicavallo and finally unload the load on the case of the study zone.

The actual design of the pedestrian bridge was also presented and it will be shown in the following figure.

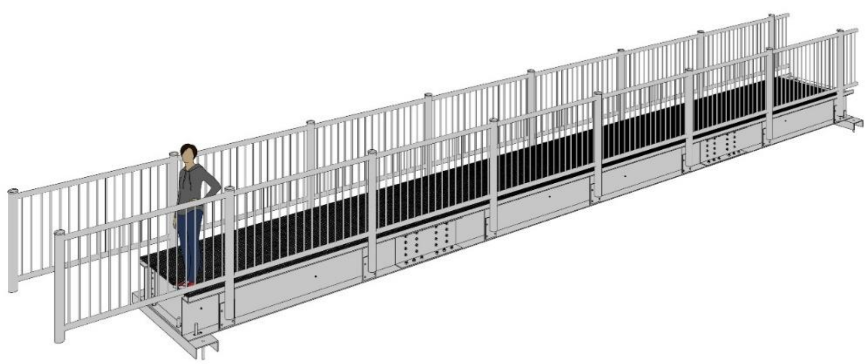


Figure 17. Design of Pedestrian bridge by design studio (Dott. Ing. Garizzio, 2022)

3.2.3. COR-TEN steels or Weathering material

- **History and description**

In 1933, a steel corporation developed a steel with improvements of mechanical resistance. Firstly, the material was intended to be used in railroad hopper cars, for the handling of heavy bulk loads including coal, metal ores, other mineral products and grain.

A family of steel alloys known as corten steel was created to do away with the requirement for painting and to produce a stable rust-like look over time. Its name (COR-TEN) alludes to the material's ability to withstand corrosion and have tensile strength. Although surface treatments can speed up the oxidation to as short as one hour, weathering steel's surface oxidation takes six months.

Since then, the usage of weathering steel has become more widespread throughout the world. It is now a non-proprietary product that is sold in Europe as "structural steel with better atmospheric corrosion resistance”. This material is now also known as Weathering steel.

- **Properties**

The Corten steel or weathering material with its chemical composition, allows to increased resistance to atmospheric corrosion compared to other steels due to the protective layer on its surface under the influence of weather When steel is exposed to the elements, it develops a protective patina that adheres to the surface and prevents further corrosion. The protective layer's unique distribution and concentration of alloying elements results in its corrosion-retarding properties. When exposed to weather influences, the layer defending the surface continuously develops and regenerates.

The rate of corrosion is so low that bridges made of unpainted weathering steel can last 120 years as intended with very little upkeep. Therefore, a well-designed weathering steel bridge in a suitable setting offers an appealing, incredibly low maintenance, and cost-effective alternative.

In the presence of moisture and air, all low alloy steels have a tendency to rust, but its rate depends on the access of oxygen, moisture and atmospheric contaminants to the metal surface. As the process progresses, the rust layer forms a barrier to the ingress of those components, making harder to enter and then the rusting slows down.

A conventional steel structure presents a rust layer on the surface and after a critical time this surface detach and the process starts again which presents a weakness on the steel structure. This process has a progress as an incremental curve approximating to a straight line, and the slope of which depends on the aggressiveness of the environment. The weathering steel, presents the same initial process, but its alloys allow to maintain this layer with the base metal and make it less porous. This rust produces a protective barrier against access of oxygen and moisture. The resulting reduction in corrosion rates is clearly illustrated in next figure.

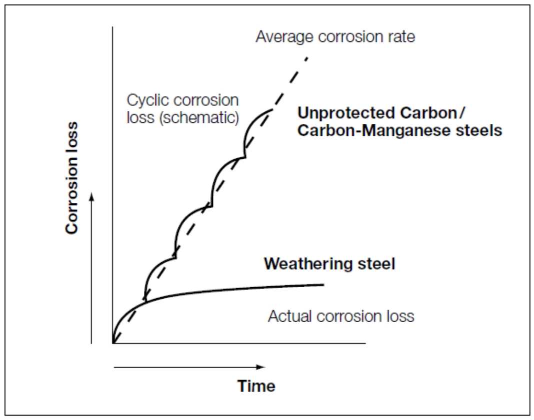


Figure 18. Schematic comparison between the corrosion loss of weathering and carbon steels

- **Benefits of Corten Steel**

Weathering steel structures presents all conventional steel structures advantages due to advances in automated fabrication and construction techniques. Additionally, this material presents future use flexibility, minimum maintenance, short construction depth, attractive look, and speedy construction are further benefits.

Corten steel structures presents very low maintenance taking into account that periodic inspection and cleaning should be the only maintenance required to ensure a good performance during lifetime of bridge. Hence, weathering steel bridges are ideal where access is difficult or dangerous, and where future works needs to be minimized.

Also, on the cost point of view presents high benefits, there are many cost savings from the elimination of the protective paint system outweigh the additional material costs. Typically, the costs of weathering steel bridges are approximately 5% lower than conventional painted steel alternatives.

Another important point to note is the speed of construction, also the not necessity of paintings operations reduces the time on the sitework. A mature weathering steel bridge's beautiful aspect frequently becomes better with age and mixes well with the surroundings.

In terms of environmental problems, it can be reach also benefits due to problems associated with paint VOC emissions, and the disposal of blast cleaning debris from future maintenance work are avoided. Finally, also a safety benefits are reached due to initial painting are avoided, and the risks associated with future maintenance are minimized.

- **Disadvantages of Corten Steel**

Using weathering steel in construction presents several challenges. Ensuring that weld-points weather at the same rate as the other materials may require special welding techniques or material, this fact leads to a necessity sometimes of the use of bolted connections.

As normal steel, the Corten steel when is in contact with other materials such concrete (mostly used) needs to have some considerations such an interface between steel and concrete should be sealed with an appropriate sealant.

It's need to be clear that the Corten Steel has also some limitations on its use. Steel that has been weathered is not inherently rust-proof; if water is allowed to pool on its surface, corrosion will occur more quickly, necessitating the need for drainage. For the adhering "patina" to form, alternate wet/dry cycles are necessary. Where this is impossible because of persistently moist or damp conditions, a corrosion rate resembling that of standard carbon steel may be anticipated.

There are certain environments which can lead to durability problems as marine environment where it can be exposed to high concentrations of chloride ions, where the hygroscopic nature of salt negatively impacts the patina since it keeps the metal's surface permanently moist. Also, the use of de-icing salt on roads may lead to problems in extreme cases. These include leaking expansion joints where salt laden run-off flows directly over the steel, and salt spray from roads under wide bridges where 'tunnel like' conditions are created.

Finally, Corten steel should not be used in zones where high extreme concentration of pollution is presented (specifically SO2), such an industrial area.

- **Uses**

Weathering steel is popularly used in outdoor constructions as sculptures, bridges and other large structural applications due to its distressed antique appearance and resistance to weathering conditions. Some examples we can find are the Chicago Picasso sculpture, the New River Gorge Bridge on United States and also the Australian Centre for Contemporary Art (ACCA) and MONA.

Figure 19. Chicago Picasso sculpture

Figure 20. New River Gorge Bridge, United States

Figure 21. Slochd Beag Bridge Inverness, Scotland

Figure 22. Shanks Millennium Bridge Peterborough, England.

This wide use of Corten steel is presented due to its benefits but also due to it availability on market around the world. Also weathering steel plates and bolts (essential part of Corten steel structures) are readily available, but it is important to mention that exist some limitation on the sections and geometry.

Once knowing the properties of Corten Steel and also the fact that the pedestrian bridge will be constructed in this material, it has been decided to start the project for case study in this material. As it was mentioned previously, one of the aims of the case study it's also to manage the project on an architectural point of view, where again the weathering material offers an attractive appearance of mature weathering steel bridges blends in well with the surrounding countryside, but to reach a higher appearance, it can be proposed the use of another for barriers of pedestrian bridge.

Taking into account the several particularities and challenges of the case study as the weight of materials, facility and assemble of parts, and also the duration of the material, wood properly used can be perfect for the project.

3.3. Solutions for problematics in case study and choice of materials

The following, are the problematics presented in the case study and also the choice of materials taking into account the facts presented before and the solutions given.

3.3.1. Stability of slopes and foundations of bridge

The main reason the pedestrian bridge was destructed was because of a landslide due to a big flood in the place where one of the two foundations or columns where placed. This is shown in the next picture, where it can be seen that on the left part of the river, a piece of the river embankment is missing.

Figure 23. Instability of slopes

Then is completely obvious that the foundations and columns of the bridge must be on a place where it will be safer in terms of stability, that's why, the length of the bridge must be projected on a distance of 15 meters and its foundations will be placed around the following marked points.

Figure 24. Position Piles and Foundations for new pedestrian bridge

3.3.2. Protection of bridge foundation against flood

Also, in the left part of the river, there is a path that implies a possible run water on this direction, then it's necessary to create a proper protection for this foundation. This will imply that not only the foundation will need to be moved where it was lately but also protected with a structure. In the following picture, is shown how the path marked by rocks, tells that historically, the river reached this section of the zone.

Figure 25. Possible run water path

3.3.3. Manage of working site

First, it's necessary to define the exact point that will be given to the helicopter to land and unload materials. This activity, will be done on an area very close to one of the possible foundation's points (around 10 meters). Also, this space mentioned will be the space where it will be storing all materials, this because it needs to be as closer as it can be to the construction site taking into account that it won't be many constructions machinery or the zone to move the materials is not as proper as it should be to the machinery. In the following pictures, it will be shown the zone for helicopter and also the proper zone for storing the materials of construction site.

Figure 26. Working site and helicopter landing positions

3.3.4. Architectural point of view and choice of materials

Once knowing the properties of Corten Steel and also the fact that the pedestrian bridge will be constructed in this material, it has been decided to start the project for case study in this material. As it was mentioned previously, one of the aims of the case study it's also to manage the project on an architectural point of view, then it will be proposed to use another material for barriers of pedestrian bridge and occasionally to beautify the structure.

Taking into account the several particularities and challenges of the case study as the weight of materials, facility and assemble of parts, and also the duration of the material, it's considered that wood properly used fix perfectly for the project.

Wood is one of the most used materials in Italian construction sector for new buildings and refurbishment activities, especially for pavers and coverings. Wood fiber material, which is obtained from woodworking scraps and sawdust, is being used as synthetic material on insulating purposes. Additionally, his material can be considered as more sustainable due to their natural primary raw materials, referring to sustainable constructive solutions, wood has been considered as a natural material with lower environmental impact. Wood was employed as a structural material in Italy up to the 1920s. Later, with the development of reinforced concrete, its use has fallen. Only after 2008, wood was considered again as a structural material, although its use in Italy is still very limited and concentrated in the north of Italy (OERCO2 - Erasmus+ European Union, s.f.).

As it was explained, wood fiber materials present good properties for sustainability and also resistance from environment. Now, is necessary to choose the specific type of wood that can be used for pedestrian bridge barriers and also many architecture decisions that will be held during the design process.

Glued laminated timber or Glulam material, is a type of wood with load-bearing capacity and low density which means that is easily managed, then, it can be assembled with simple tools, two properties that are perfect for barriers and also for floor, because of the necessity of resistance of loads and also for the fact that lower weights are needed taking into account the conditions of the construction site. Additionally, Glulam wood have advantages in terms of durability, stability, fire resistance and chemical resistance, very important properties in order to avoid many maintenance works. Finally, as wood will be used mainly for architectural design purposes, Glulam is a perfect chose due to the large variety of shapes and small component dimensions with high strength levels that gives architectural and constructional versatility. It's known that this material is wide used for structural purposes, however, looking into its many advantages of durability, low density and also loadbearing capacity, it is decided to use it for the architectural design parts where it can be needed.

In the following figure, is shown an example of a pedestrian bridge, where the complete structure (structural system, barriers and floor) was constructed with Glulam wood material.

Figure 27. Glulam Beam Pedestrian Bridges (Taken from Custom Park & Leisure Ltd.)

4. Pedestrian bridge – Dimensions and Load analysis

There are fewer restrictive functional and static demands on pedestrian bridges than there are on roads and railway bridges. Then, is possible to find more "architectural" aspects on this type of structures as seating, niches, platforms or beautiful views.

Historically, wood and stone were the most used material to build pedestrian bridges, but now on, concrete and steel have predominated, been this last material the better due to its potential on mechanical properties and also facilities on construction sites.

4.1. Bridge width

The bridge width of a pedestrian bridge depends on its use. According to EFA a path's width will depend on whether it is to be used purely as a cycle path, a foot path or a mixed-use path Footpaths should be 1.80 meters wide, bicycle lanes should be 2 meters wide, and shared pedestrian and bicycle lanes should be 2.50 meters wide. By the contrary, DIN 18 024-1 on »Barrier-free Construction « makes further very general stipulations on the minimum width of barrier-free routes in public spaces. It prescribes total widths of 2 to 3 m, which result from the movement area of 1.20 to 1.50 m required by wheelchair users, plus the necessary meeting and passing spaces. International variances could, however, affect these requirements. For pedestrian and bicycle pathways, Great Britain accepts widths of 1.80 to 2 m, whereas Australia requires widths of up to 3 m.

standard	country	min. path width [m]	clearance [m]	max. gradient [%]
Austroads 13, 14, 92	Australia	1.5–1.8 (Pedestrians) 1.5–3.0 (Cyclists) 2.5–3.0 (Mixed)	2.1–2.4 (Pedestrians) 2.5–3.0 (Cyclists)	12.5 (Pedestrians) 5.0 (Cyclists) 3.0 (Mixed)
Structures Design Manual	Hong Kong	2.0 (Pedestrians) 3.0 (In metro stations)	–	5.0–8.3 (Pedestrians) 4.0–8.0 (Cyclists)
Japanese Footbridge Design Code (1979)	Japan	3.0 (Pedestrians)	–	5.0
Design Specifications of Road Structures	South Korea	1.5–3.0 (Pedestrians) 3.0 (Cyclists)	2.5	–
British Standard 5400	Great Britain	1.8 (Pedestrians) 2.0 (Mixed) 2.7 (Pedestrians and cy-clists with separate path)	–	5.0–8.3 (Pedestrians)
DIN 18024-1	Germany	2.0 (Pedestrians) 3.0 (Mixed)	2.5	6.0

1

Figure 28. Widths regulation on countries (Keil, 2013)

Besides to the recommended sections by regulations, different considerations must be taken into account in order to understand better the real necessities presented in the zone.

In addition to pedestrian users, the structure could be also used by animals such as cows, mules and horses that are present in the zone. In this case, the United States Department of Agriculture stands that the minimum suggested bridge width on animals' trails in areas with low levels of development is 1.5 meters. In areas with high levels of development, 3.6 meters, is preferred and for bridges in areas with moderate levels of development often range between 1.5 and 2.4 meters wide. The British Horse Society (2005) prefers bridges that are 2 meters wide for streams and ditches in the United Kingdom (United States Department of Agriculture, 2007).

For the case study, it can be also analyzed the behavior of the Piedicavallo population through the recent years, in order to understand the use that will have the bridge by pedestrians.

Anno	Residenti	Variazione	Note
1861	1.527		
1871	1.436	-6,0%	
1881	1.572	9,5%	Massimo
1901	1.372	-12,7%	
1911	1.427	4,0%	
1921	1.259	-11,8%	
1931	1.029	-18,3%	
1936	691	-32,8%	
1951	565	-18,2%	
1961	471	-16,6%	
1971	328	-30,4%	
1981	260	-20,7%	
1991	191	-26,5%	
2001	187	-2,1%	Minimo
2016 ind	187	0,0%	Minimo

Table 1. Variation of population in Piedicavallo (Biella) (taken from: comuni-italiani.it)

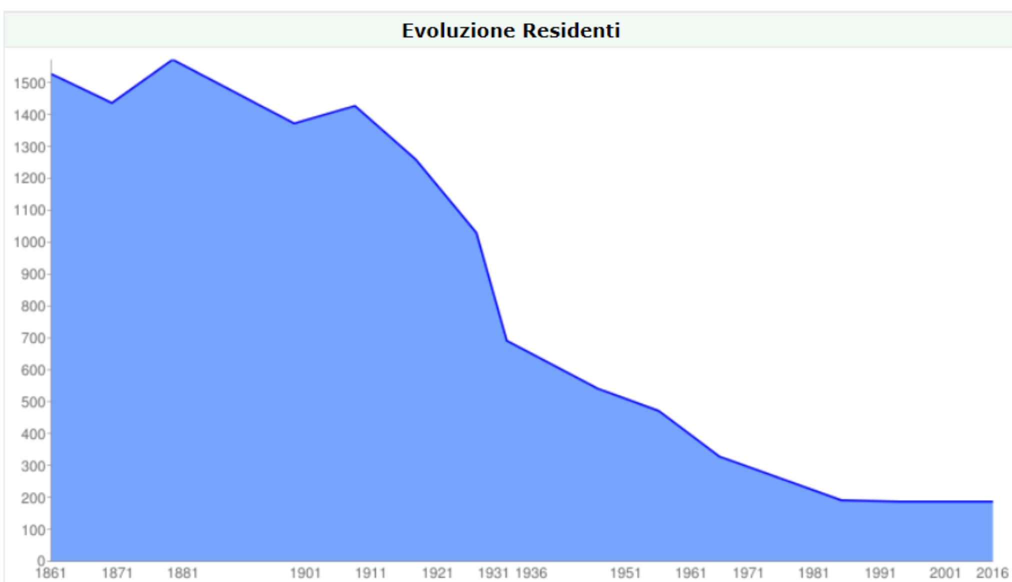


Figure 29. Variation of population in Piedicavallo (Biella) (taken from: comuni-italiani.it)

As can be seen, the population of Piedicavallo (Biella) has been declining over the last 60 years and has lately remained without a significant increase. However, it is important to note that the presence of tourists in the area is significant due to the existence of highly used hiking trails.

In addition to pedestrian users, it can be said that the bridge could be used by cyclists seeking the path as a sport. For this consideration, the article "Cycling Master Plans in Italy: The I-BIM Feasibility Tool for Cost and Safety Assessments" by the University of Enna, says that in accordance with ministerial decree 557/1999, for Italy a promiscuous path (pedestrian + cyclist) should have 2.5 m (1.5 cyclist + 1.0 pedestrian).

Once knowing the regulations on many countries, its recommended sections, and the different considerations for several users, it has been decided that the width of the pedestrian bridge correspond to a measure of 2.5 meters.

4.2. Bridge height

The height of the bridge refers to the distance between the pedestrian platform and the bottom of the river that is present in the case study. In order to determine this height, a hydraulic check must be performed taking into account the regulatory aspects. The described check requires to determine several hydraulic factors of the stream as the maximum liquid flow rates, the transport of solids and the overall maximum full flow rates.

Following the *"4 direttiva contenente i criteri per la valutazione della compatibilità idraulica delle infrastrutture",* a hydraulic check in case of a bridge project, must be determined with a return period not inferior of 100 years. In exceptional cases, when dealing with small water streams as the case study, a lower return period can be considered, verifying that there is not worsening of the general conditions for the scope relating to the return time of 200 years. However, as a safety condition, all calculations will be managed with a return period equal to 200 years.

- Maximum liquid flow rates:

The evaluation of the maximum liquid flow rate is one of the most important problems and also most complex in the study of a basin, in the case of rivers and streams, a precipitation of strong intensity can cause a rapid rise an increase in flow rates. To evaluate the correspondent measures the following relation can be used:

$$Q = \frac{\varphi * A * h}{3{,}6 * tc}$$

Equation 1. Maximum liquid flow rate

Where:

- φ corresponds to the assumed outflow coefficient, for the case study, it has been assumed equal to 1, that corresponds to the worst scenario, with no capacity of absorption of the soil of the basin.

- A, the area of the basin which is 5,41 km2.
- h, represents the height of rainfall. For the case study, the Oropa climatic station suggest the following relation:

$$h = 73{,}65 * tc^{0{,}5151}$$

Equation 2. Height of rainfall for a return period of 200 years

- tc, corresponds to the basin's correction time in hours. This is the time that takes for the generic drop of rain to fall on the spot hydraulically farther to reach the closing section of the basin in question. For this value, it has been followed the next relations.

$$tc = \frac{4 * A^{0.5} + 1.5 * L}{0.8 * (Qmed - Qmin)^{0.5}}$$

Equation 3. Formula of Giandotti

$$tc = 0{,}1272 * \sqrt{\frac{A}{ia}}$$

Equation 4. Formula of Ventura

Where A is the area of the basin, L is the length of the main shaft, Q med the Average share of the basin area, Q min the minimum share of the basin area and ia, the Average slope of the main shaft. Once performing both calculations, it was reached the following results.

Basin's correction time in hours	
A (km2)	5,41
L (km)	3,15
ia (m/m)	0,52
Qmed (m)	1944
Q min (m)	1284
tc giand (hours)	0,683
tc vent (hours)	0,410
tc avg (hours)	0,546

Table 2. Basin’s correction time in hours

The maximum liquid flow rates have been calculated for a return period of 200 years and it was reached a value of Q=150,51 m3/s.

- Transport of solids:

As the transport of solids in a stream is difficult to determine, it’s normally considered as a percentage (10-20%) from the liquid flow. However, during the visit to the case study zone, it has been evidenced the presence of trees in the river bed, caused by landslides on the bank, meaning that a conservative value must be reached in order to avoid a deficiency in the outflow of trees and debris. Additionally, it can be said that the choice made during the evaluation of stability of slopes and foundations, of enlarging the section of the bridge in 15 meters, will allow a greater outflow in case of extraordinary events.

The flow of transport of solids for the basin has been considered as 20% of the maximum liquid flow rates, meaning a value of 30,1 m3/s.

- Overall maximum full flow rates:

The maximum full flow rates, correspond to the sum of the maximum liquid flow rates and the transport of solids, then, for the case study, it has been reached a value of 180,61 m3/s for a return period of 200 years.

With the determined hydraulic factors, it can be performing the hydraulic verification to find the maximum height of the river. For this purpose, the check can be carried out by applying the usual hydraulic formula as follows.

$$Q = A * V$$

Equation 5. Equation of flow

Where:

- A is the area of the section in m2.
- V is the medium velocity of the liquid in m/s.

In order to determine the maximum height of the river, it's different sections and measurements must be known. For the case, it has been used the "*tavola 2 – Relazione idraulica",* by Dott. Ing. GARIZZO Pier Giorgio, where it's presented the following figure.

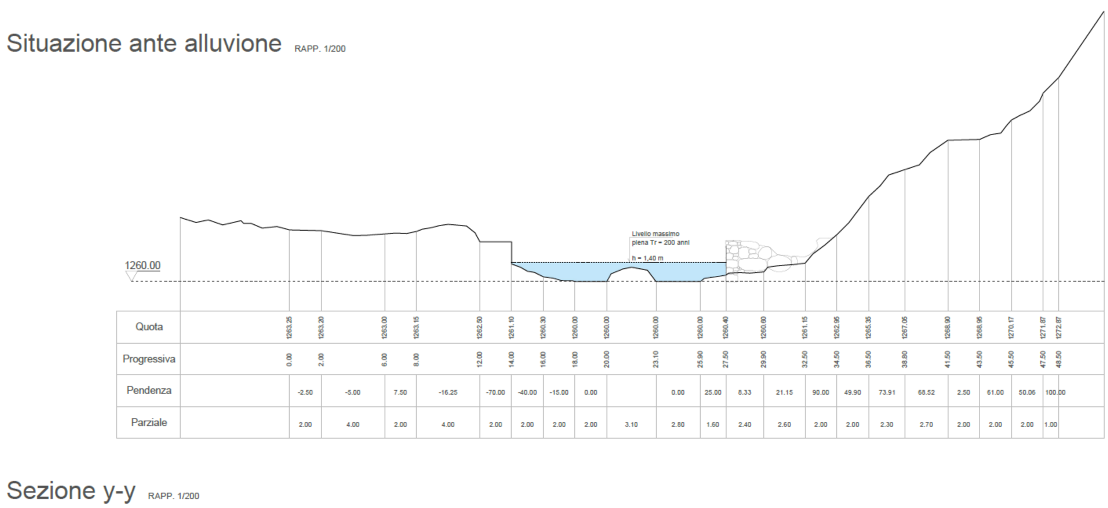


Figure 30. Measurement of river section (Dott. Ing. Garizzio, 2022)

For the determination of the velocity, it can be used the Chézy formula, which estimates mean flow velocity in open channel conduits and is written as:

$$V = C\sqrt{R * S}$$

Equation 6. Chézy formula

Where:

- R, is the hydraulic radius which is the cross-sectional area of flow divided by the wetted perimeter (red line in following figure).

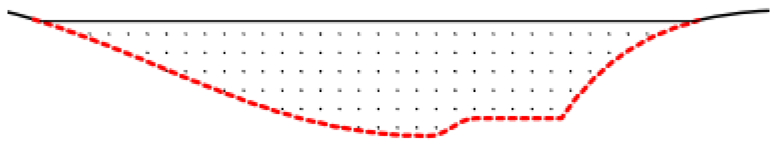


Figure 31. Hydraulic radius

$$R = \frac{section}{wetted\ perimeter} 0{,}9723$$

Equation 7. Hydraulic radius

- S, is the hydraulic gradient, which for uniform normal depth of flow is the slope of the channel bottom, and for the case study it has been taken a value of 15,5% (Garizzo, 2022).
- C, is the value of the coefficient of resistance and can be obtained following the Strickler formula where appears also the roughness coefficient k.

$$C = k * R^{\frac{1}{6}}$$

Equation 8. Formula of Strickler

Where the roughness coefficient k, depends on the type of soil that of the canal (river for the case study). In the figure *"Coefficients values for Strickler formula (Chow, 1959)",* are shown the different values of the coefficient. For the case, it has been chosen a normal value for natural water course, clean, undulating, with some bunkers and benches, with bushes and stones. Corresponding a roughness coefficient of 20.

Using the values that were calculated, it has been found the coefficient of resistance C with a value of 21,897 and the velocity of the water in the section of interest as 8,5 m/s. Now, is possible to determine the maximum height that will reach the river flow in an extreme condition.

Height of water	
s (m/m)	0,155
section (m)	13,500
Wetted p (m)	13,884
R	0,972
k	22,000
C	21,897
V (m/s)	8,501
h (m)	1,574

Table 3. Maximum height of river flow calculation

Tipo di canale	massimo	normale	minimo
Canali artificiali			
Canali in terra lisciata e uniforme			
Pulita, scavata di recente	62	56	50
Pulita, dopo prolungata esposizione	56	45	40
Ghiaia, sezione uniforme, pulita	45	40	33
Erba corta, pochi cespugli	45	37	30
Canali in terra con ondulazioni o irregolari			
Senza vegetazione	43	40	33
Con erba e pochi cespugli	40	33	30
Cespugli o piante acquatiche in canali profondi	33	29	25
Fondo in terra e sponde in pietrisco	36	33	29
Fondo in pietrame e sponde in cespugli	40	29	25
Fondo in ciottoli e sponde pulite	33	25	20
Canali scavati o dragati			
Senza vegetazione	40	36	30
Cespugli sparsi sulle sponde	29	20	17
Canali in roccia			
Lisci e uniformi	40	29	25
Frastagliati e irregolari	29	25	20
Canali senza manutenzione, sterpaglia e cespugli			
Sterpaglia densa, alta quanto il tirante idrico	20	12	8
Fondo pulito, cespugli sulle sponde	25	20	12
Fondo pulito, cespugli sulle sponde, in piena	22	14	9
Cespugli densi e acque profonde	12	10	7
Corsi d'acqua naturali			
Corsi d'acqua minori (tirante inferiore a 3.5 m)			
Corsi d'acqua di pianura			
Puliti, rettilinei, in piena senza scavi localizzati	40	33	30
Puliti, rettilinei, in piena senza scavi localizzati, con sassi e sterpaglia	33	29	35
Puliti, ondulati, con alcune buche e banchi	30	25	22
Puliti, ondulati, con alcune buche e banchi, con cespugli e pietre	29	22	20
Puliti, ondulati, con alcune buche e banchi, in magra	25	21	18
Puliti, ondulati, con alcune buche e banchi, con cespugli e più pietrame	22	20	17
Tratti lenti, sterpaglia e buche profonde	20	14	12
Tratti molto erbosi, buche profonde e grossi arbusti e cespugli	13	10	7
Corsi d'acqua montani, senza vegetazione in alveo, sponde ripide, alberi e cespugli lungo le sponde sommergibili durante le piene			
Fondo: ghiaia, ciottoli e massi sparsi	33	25	20
Fondo: ciottoli e massi grossi	25	20	14

Figure 32. Coefficients values for Strickler formula (Chow, 1959)

Once all calculations are expressed, it can be seen that the correspondent maximum height that can reach the stream with a return period of 200 years is 1,574 meters.

Additionally, it can be analyzed that the pedestrian bridge that collapsed had a height of 2,4 mts and a section of 4,5 mts, while for the case study, it's been decided to use a section of 15 mts and a height of 3 mts, which will allow to have a distance of 1,4 mts between the above part of the river in conditions of maximum flow and the pedestrian bridge.

4.3. Load bearing capacity

The load bearing capacity of a pedestrian bridge its calculated depending on the pedestrian traffic and its speed. There are reference values for concentrations that specify how many people should be on each 1 m2 of bridge.

$$Q = v \cdot d \ [P/m \cdot s]$$

Equation 9. Load bearing capacity

Where:

- Q Flow rate [P/m · s]
- v Traffic velocity [m /s]
- d Traffic density [P/m2]

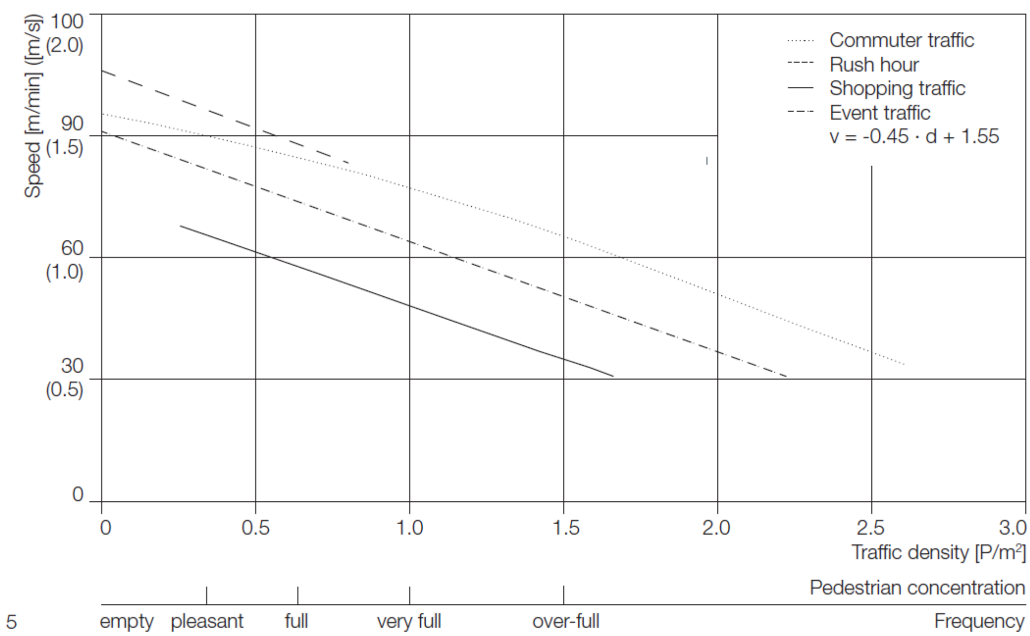


Figure 33. Relation between traffic density and speed (Keil, 2013)

Last figure. shows dependencies of various pedestrian flows, which is a relation between speed and the traffic density. In this way, we find the velocity for pedestrian bridge as follows:

$$v = - 0.45 \cdot d + 1.55 \ [m /s]$$

Equation 10: Pedestrian traffic velocity

For the case of designing a pedestrian bridge, its recommended suppose a maximum flow capacity. In order to accomplish it, it's needed both equations, which gives a quadratic function for the event traffic.

$$Q = - 0{,}45 \cdot d2 + 1{,}55 \cdot d \ [P/m \cdot s]$$

Equation 11: Quadratic function for event traffic

The function described, has maximum capacity of 4.928 P/h·m as presented in the following figure.

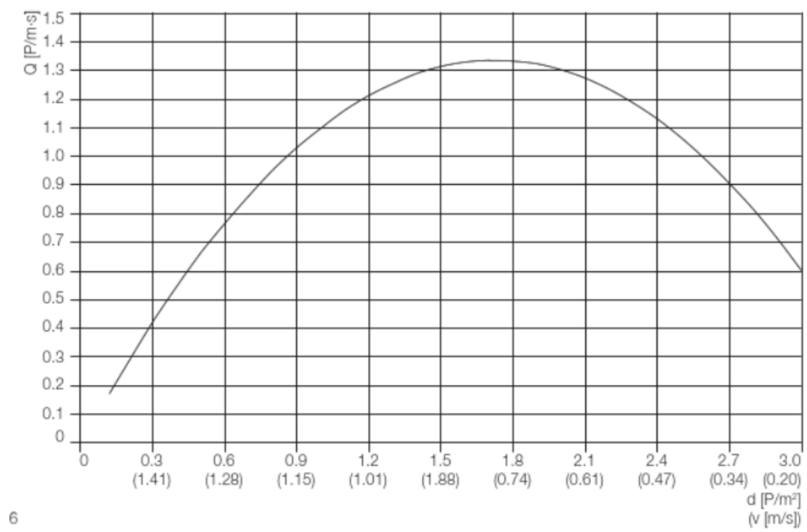


Figure 34. Maximum flow Q (P/m·s) (Keil, 2013)

It should also be noted that these are maximum values, which should be used to manage large numbers of pedestrians and prevent the risk of panic breaking out in very dense crowds of people. Many pedestrian bridges rarely or never reach the limits of their capacity and as is known, the pedestrian bridge presented in the case study does not have a large amount of flow. However, we must ensure that pedestrians or pedestrians and cyclists can move easily on the bridge without getting in each other's way. This results in most cases in usable widths of 2.50 to 3.50m, reason why a width of 2.5 meters could be easily maintained.

4.4. Factors to take into account

In order to design a proper pedestrian bridge, several factors are proposed by Keil (2013) and are presented next.

4.4.1. Stairs

For the case study, the architectural design of the bridge can require the use of stairs in one of the sides. In order to have a proper design, the following values are stipulated.

- Staircase pitch s of at least 14 cm, or a maximum of 19 cm
- Stair tread a of at least 26 cm, or a maximum of 37 cm
- Rise-to run ratio of 59 to 65 cm in accordance with step length measurements 2 s + a (s = rise [cm]; a = tread run [cm])
- Minimum useable flight width r of 100 cm

- If there are more than 18 steps, intermediate landing with a length of 90 cm is required
- Handrail on both sides at a height of 85 cm above the deck surface.

4.4.2. Ramps

The following values are stipulated:

- Maximum ramp gradient 6 %
- Minimum useful flight width between edge deflectors 120 cm (suitable for wheelchair users)
- For ramps longer than 600 cm an intermediate landing 150 cm in length is required
- 10 cm high edge deflectors
- Handrails on both sides at a height of 85 cm above the deck surface
- At the beginning and end of the ramp free space of 150 cm

The possibility for the architectural design to have stairs and a ramp will depend on the height considered and also on the level curves.

4.4.3. Railings

Railings must be used on a pedestrian bridge, on the one hand they serve to protect people from falling off the bridge, so they must be able to withstand horizontal loads of up to 0.8 kN/m. On the other hand, they are designed to offer support and guidance, especially for people whose mobility is impaired. The following values are stipulated.

Minimum dimensions for steel railings

Railing height	• at a fall height of < 12 m	≥ 1000 mm
	• at a fall height of > 12 m	≥ 1100 mm
	• for cycle paths and pedestrian and cycle paths	≥ 1200 mm
Post positioning	• for infill rods and cross-beam railings and railings with wire netting infill	2000–2500 mm
	• for short-post filled-rod railings	≤ 2000 mm
	• for tubular railings	1500–2000 mm
	• for vertical extension rails	2670 mm
Handrail width	• for bridges over roads and paths	≥ 120 mm
	• for pedestrian and cycle path bridges	≥ 80 mm
	• for tubular railings and service roads	≥ 60.3 mm
	• Clearance of infill rods	≤ 120 mm
Clearance between bases and ledges		120 mm
	• for short-post filled-rod railings	80 mm
	• for railings with wire netting infill	50 mm
Distance between the axes of the posts and the joint or end of the wing		≥ 250 mm
Projection of the handrail (lower section) above end posts		50 mm

Figure 35. Minimum dimensions for steel railings (Keil, 2013)

Structural element	Profile [mm]	
	Cold profiles	Tubes
Handrail, not shared	120/28/27, 5/23/65/23/27, 5/28 × 4 or equivalent or 80/30/17, 5/12/45/12/17, 5/30 × 4 for pedestrian and cycle path bridges	60.3 × 2.9
Handrail shared • Upper section • Lower section	 18/25/120/25/18 × 4 15/50/80/50/15 × 4	
Cross beam	60 × 40 × 4	60.3 × 2.9
Posts	70 × 70 × 5	60.3 × 2.9
Short posts	60 × 60	
Infill rods	15 × 30	

Figure 36. Cross-sections and thickness for steel railings (Keil, 2013)

- Prescribed height for pedestrians 1.00 m.
- Prescribed height for cyclists 1.20 m.
- Must present railing infill for security of small children.

Pedestrian bridges must be static and dynamic in design. To test their stability, various impacts are simulated and a static calculation is used to determine the bridge's dimensions and behavior.

4.5. Static and dynamic loads

Pedestrian bridges design must take into account static and dynamic loads in order to determine the dimensions and behavior.

4.5.1. Static loads

Individual country standards that specify the weight of a bridge's own construction, traffic loads, wind, temperature, impact, and snow loads are prescribed for pedestrian bridges. For this case, the Eurocode must be used for the structural design, however, Keil (2013) considers the following statements.

- Vertical load

A bridge's own weight and traffic loads are the main vertical loads. The vertical traffic load on a pedestrian bridge is estimated at 5 kN/m2 for bridges with spans of up to 10 m and 4.18 kN/m2 for bridges with spans of up to 25 m (Keil,2013). As can be seen, the longer the bridge, the lower vertical traffic load is needed to consider. This is due to the more space that users will have to transit the bridge. The case study pedestrian bridge, corresponds to a length of 15 meters, However, as it was mention during the bridge width analysis, the pedestrian bridge could be also used by animals as cows, horses and mules. For this reason, it’s necessary to account the weight of a large group of stock. The United States Department of Agriculture (2007), stands that an animal as the mentioned, including their riders or loads usually weigh from 400 to 500 kilograms.

Once both factors have been presented, it has been decided to use a vertical load of 5 kN/m2. This vertical load will be used during the structural design and will correspond to the live loads.

- Horizontal, wind and snow loads

Pedestrian bridges usually have a low width to length ratio, so horizontal transverse loads influence highly the dimensions in contrary to horizontal longitudinal forces which are not as important.

Horizontal traffic loads are estimated usually with a longitudinal direction at 10% of the vertical distributed area load.

For the wind loads, the bridge location must be taken into account (wind load zone). In the following figure, is shown values for the respective zone, values that must be used on following chapters on the structural design.

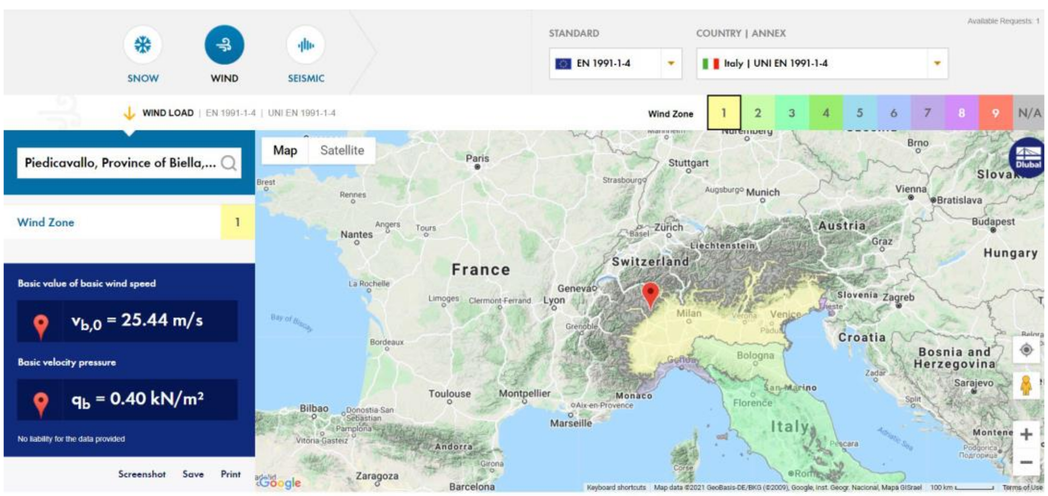


Figure 37. Wind load zone Piedicavallo (Dlubal, structural analysis and design software)

So, for the structural analysis, a basic value of speed of 25.44 m/s and a basic velocity pressure of 0.40 kN/m2 will be taken into account.

Snow loads, act only on surfaces in contact with the external environment, this load also depends on the zone of the case study and the values found are shown next.

Figure 38. Snow load zone Piedicavallo (Dlubal, structural analysis and design software)

The snow load is presented in the following equation.

$$q_s = \mu_i * q_{sk} * Ce * Ct$$

Equation 12: Equation for snow load (European committee for standardization)

Where:

- q_s: Snow load
- μ_i: Coefficient of form = 1
- q_{sk}: Reference value of ground snow load [kN/m2] = 4.25
- Ce: Exposure coefficient = 1
- Ct: Thermal coefficient = 1.

So, for the structural analysis, the snow load will be 4.25 kN/m2.

4.5.2. Dynamic loads

Dynamic loads on pedestrian are the vibrations which are an important topic but usually subjected, for the present case study, it will be taking into account only general information.

Two dynamic excitations are the most significant, human-induced vibrations, including deliberate excitation and vandalism and the wind-induced vibrations.

In order to have a vibration control of the bridge, Keil (2013) presented available options as:

- Changing the frequencies by modifying the bridge's mass or reinforcing it
- Increasing structure damping, by installing a damping surface.
- Installing additional damping elements
- Active vibration control, which uses devices to feed active forces into the system to counteract vibrations and reduce their amplitudes.

As it was said, the present project will not evaluate the design of dampers, however, there will be presented the damping elements suggested by Keil (2013), that can be installed in order to avoid a possible changing of bridge’s frequency or mass, which often involves an extensive and undesirable intervention in a bridge’s overall design.

- viscous dampers
- tuned mass dampers
- tuned pendulum dampers
- tuned liquid column dampers
- liquid dampers.

5. BIM Methodology

Building Information Modelling is defined by US National BIM Standards Committee (NBIMS) as the digital representation of physical and functional characteristics of a facility. Establishing a trustworthy foundation for decisions throughout all stages of its life cycle, from initial conception through demolition, and developing a shared knowledge repository for information about it.

To understand the concept just presented, it must be known that digital representation, sharing knowledge, reliability, decision making and lifecycle are very important. BIM, is not just a 3D geometry model, it is about all asset information around the lifecycle.

As presented on "The future of drawing with BIM for engineers and architects" (Osello, 2012), Building Information Modelling it's a new opportunity to exchange data among diverse software applications thanks to interoperability. BIM is one of the most promising advancements in the architecture, engineering and construction (AEC) industries due to the possibility of creating an accurate virtual model of a building digitally and in order to be considered as well, the model most need two essential characteristics, the first is that must be a three-dimensional representation of a building based on objects and second, it must include information and properties about the 3D representation. In the following figure, is shown an example of what is needed for a representation of an object to be considered as BIM model and its differences with respect a 2D CAD and a 3D CAD.

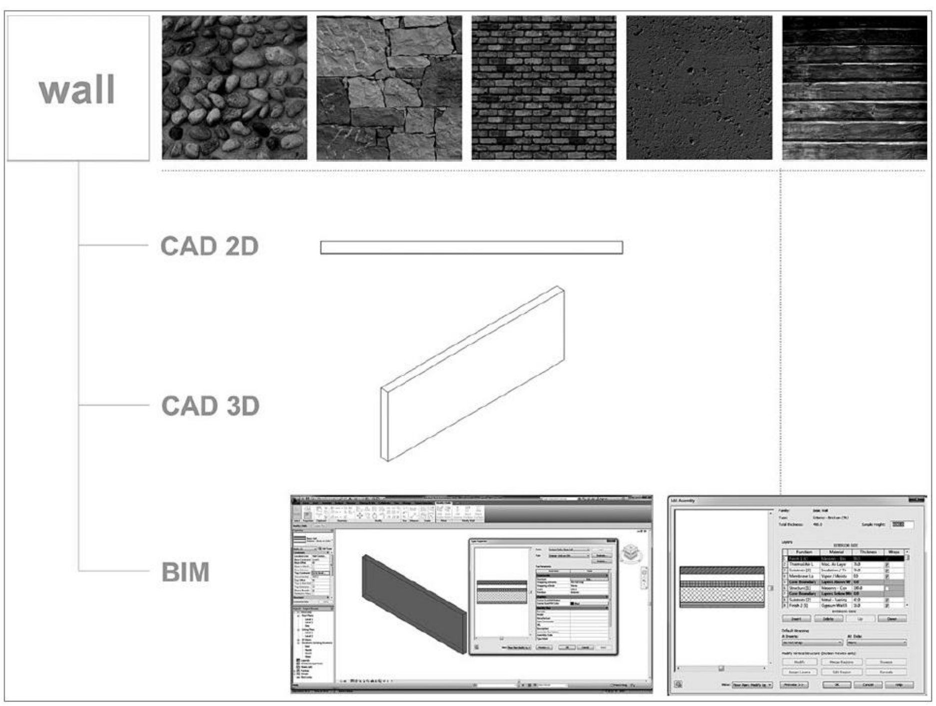


Figure 39. Conceptual scheme of represetation object with CAD 2D, CAD 3D AND BIM MODEL (Osello, 2012)

Once, the definition of Building Information Modelling is known, it is required to understand BIM as the model in order to separate both concepts. As presented by Osello (2012), Building Information Model is a digital representation of physical and functional characteristics of a facility. A basic premise of BIM is the collaboration between the many parts (human resources) at the different phases of a design procedure, each part should be able to insert, extract, update and modify information of the project.

Then, BIM is truly about creating, maintaining and using information and data, seamlessly and efficiently, by all the stakeholders over the entire lifecycle. Now, the term "Common Data Environment" must be introduced, understanding that all data, over the lifecycle, must be in a common environment and available to all on an organized, coherent, consistent, transferrable and efficient way.

Now, it's necessary to define the process to know how to accomplish a Building Information Modelling. Technology plays a fundamental role on BIM, but is not just necessary to introduce new information technology systems but the use of this tools on an integrate way between the parties. The first challenge is to make all parts of the project to think in terms of life cycle, which means that architect's or engineer's responsibilities do not end when their work is complete, instead, each part must understand how their own work will be used and modified by other professionals.

As it was said, it's necessary to combine work between all process of the design and construction process, then, for tools that are used for architecture, engineering and construction, the term interoperability must be presented. First, it's important to notice that there is not a computer application that can support all work by the construction industry, then, the tools used by the parts must support the data exchange and for multiple applications, to jointly contribute to the work at hand. Parts of the internal data structures of each participating application are mapped to a universal data model and vice versa to ensure interoperability.

Interoperability becomes an essential requirement to allow for a larger number of projects to be developed with an effective BIM Methodology instead of a simple object-based model using just during design phase. However, is not possible yet to have an automatic data exchange between all technological tools, then, tools that are chosen for a project must have a good interoperability in order to have availability to pass information without losing any details.

The information can be managed as work-sharing by work sets which mean that each for each user is required to share information on a common database. Also, the information must present links which is each user share data every time with each other without updating any central file. The common database is the presented before Common data environment (CDE), which is the environment professional use for the purpose.

As it has been presented, a BIM project should have many stakeholders and each part, the engineering, the architectural and the construction, should be composed by its own professionals, this will also allow to have a better and more complete project. For this case study, just one person is in charge of the several steps of the design and management of the entire project, reason why not all goals of BIM modelling will be reached. First, as is just a person who will manage all project, it will not be necessary to have a CDE, but all files will be saved on a personal central database.

Now, is time to define the software and technological tools that will be used in order to face the several requirements of the pedestrian bridge of the case study.

Software used	**Function**
SketchUp	Architectural design and 3D modelling
Revit	Executive design
Robot Structural Analysis	Structural design
Sap 2000	Structural design
Advance Steel	Drawing and detailing
Autocad Civil 3D	Drawing and planes
Microsoft Project	Project management, scheduling and budget
Navisworks	Time depending modelling
Primus	Costing analysis

Table 4. List of software to perform BIM Methodology

Each software presented before, will be explained as the project will be developing. Once defining the list of software, is necessary to define the level of detail and the level of development of the entire project.

The level of detail is the amount of detail that is included in the model element. The LOD (level of development) is the degree of what extent the model can be reliable geometrically and it's classified by USA regulation as:

- LOD 100: Symbolic representation
- LOD 200: Generic system
- LOD 300: Precise geometry
- LOD 400: Fabrication
- LOD 500: Verified representation as-built

The LOD consists of 2 elements:

- The geometry or visual representation of a project – LOG (Level of Geometry);
- The data attached to the objects of the BIM model – LOI (Level of Information).

Basically, the LOD defines the content of a BIM project in different stages of its development and it's at the time developed as the project is enriched with details, evolving from a simple initial concept to a construction model.

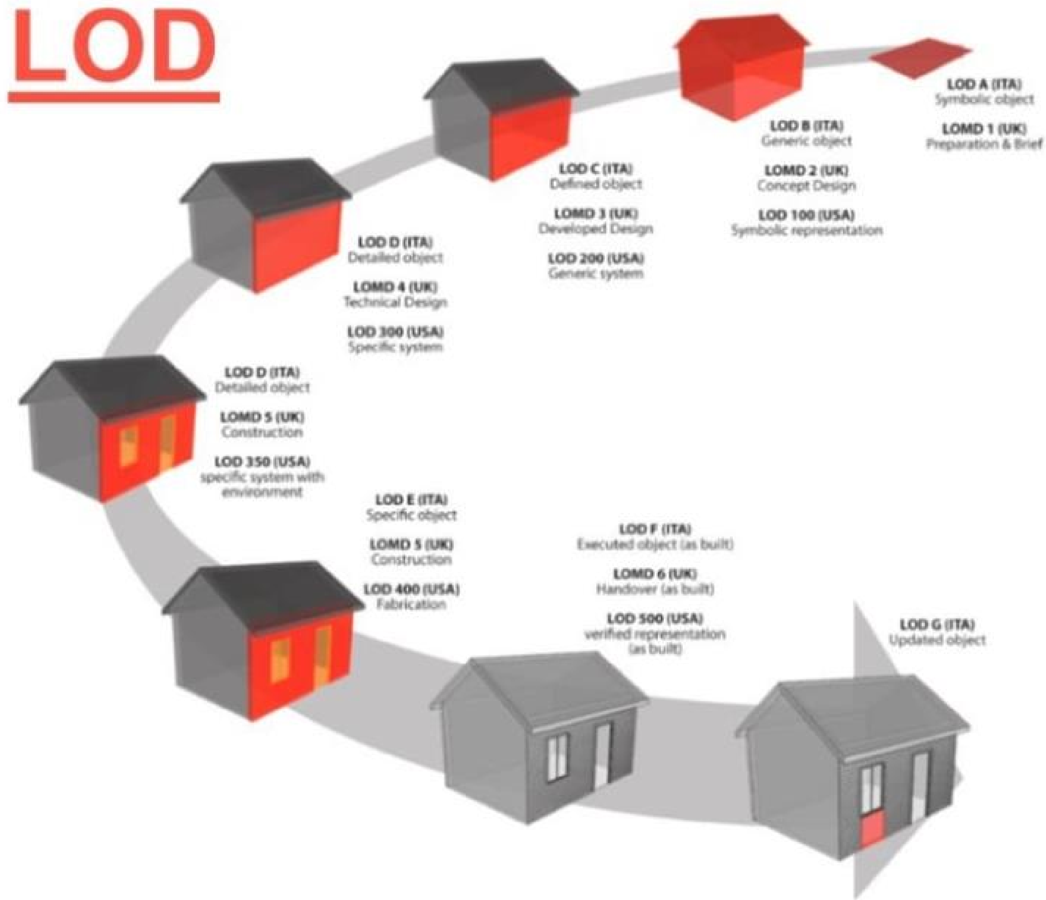


Figure 40. LOD in USA, UK and in Italy (Built Information Modeling for the 3D Reconstruction of Modern Railway Stations, Phd, Arch. Michele Russo)

The figure that was just presented, shows the difference between how regulations of each country denotates the LOD of a BIM Modelling.

In addition to the LOD of the BIM methodology of the case study, is necessary also to define the type of information or the dimension that the project must contain, its classification is the following:

- 3D: Geometry (three-dimensional geographical structure)
- 4D: Time (timeline, scheduling and duration)
- 5D: Cost (Cost estimation and budget analysis)
- 6D: Sustainability (Self-sustainable and energy efficient)
- 7D: Facility Management (Management information)

For the pedestrian bridge, the dimensions considered will reach up to 5D. The project will contain the 3D three-dimension design, including the 4D which are the management of timeline and activities during the different phases of construction and finally, the 5D which are the analysis of unitary prices of all materials and activities for the development of the project.

6. Architectural Design

In order to start the architectural design, all different data about measurements of the pedestrian bridge must be clarified. This data that is about to be presented was already chose in last chapters following the different regulations and also by proper criteria.

Description	Measurement (m)
Length of bridge	15
Width of bridge	2,5
Height between bottom of the river and bridge	3
Railing height	1,2

Table 5. Input data of Pedestrian Bridge

Once all first data is known, two possible solutions were developed for the architectural design. These solutions will be presented and also explained in order to be in the capacity to choose the solution that most fix for the case study taking into account all different conditions and difficulties that were presented during the development and explanation of the case study.

Additionally, is important to take into account that for the architectural design will be considered a foundation of a wall footing, however, this important structural part will be deeply analyzed during the development of the structural design, more specifically, the design of the foundations of the pedestrian bridge.

6.1. Architectural design 1

The first architectural design is been proposed as a simple beam and slab bridge which is the oldest form of pedestrian bridges. On this type of structures, the supports can consist of a single-span or multi-span girder. For this architectural design, the entire structure as beams and slabs are considered in Corten steel and the walkway and railings are considered in wood.

This approach that is about to be presented, was designed on Revit, which following the Autodesk description (industrial technology company developer), is a software that helps the AEC industry to create a high-quality building and infrastructure design, with Revit, is possible to create model shapes, structures and systems in 3D with parametric accuracy, precision and ease. In the following figure, is shown the reached model.

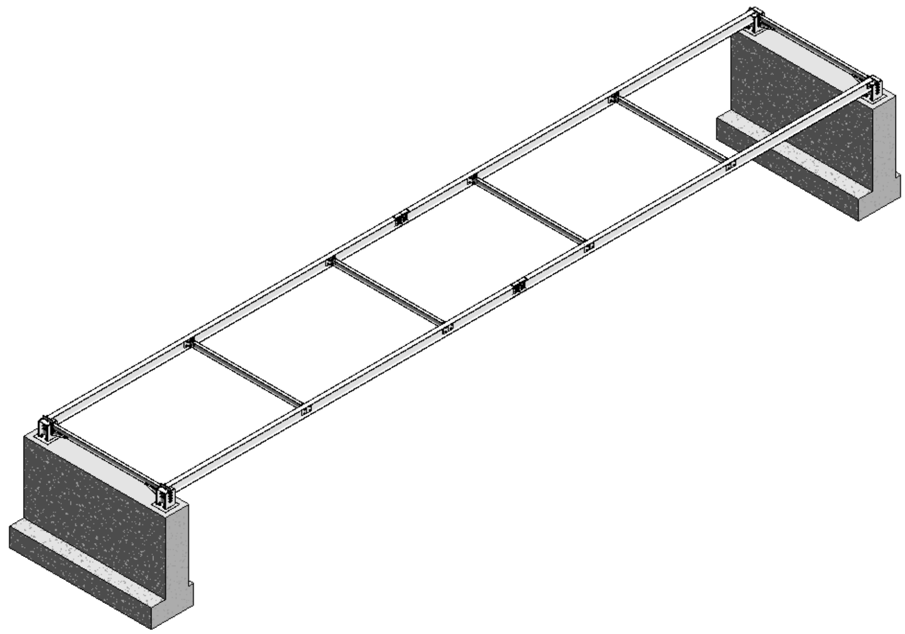


Figure 41. Architectural design 1 (structure) with Revit (3D view)

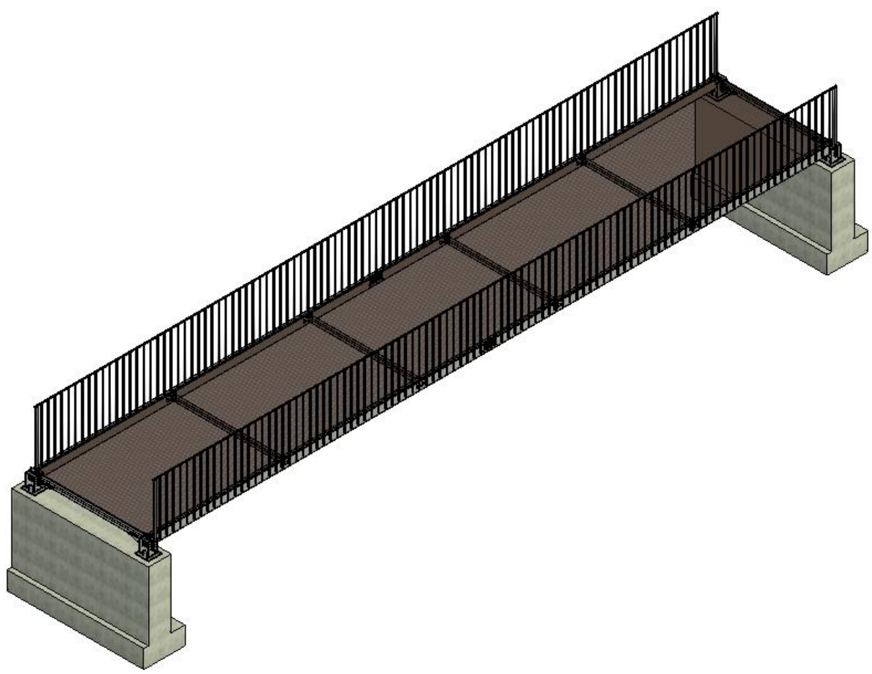


Figure 42. Architectural design 1 with Revit (3D view)

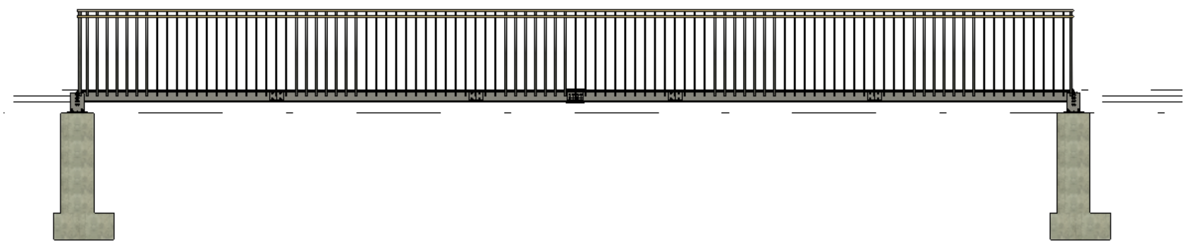


Figure 43. Architectural design 1 with Revit (lateral view)

The architectural design that was just presented, is composed by the following parts. First, the foundation is primarily proposed by the architectural definition as a concrete structure, as it can be seen in the lateral view. Following with the description of the proposed architectural design, "the super structure" is proposed in Corten steel, the runway is presented also in Corten steel and finally the railings are presented in wood.

The first architectural approach, was also performed in SketchUp in order to see in a better way all architectural details of the structure. In order to do it, it can be exported the Revit file to SketchUp. This procedure requires first an exportation to a DWG file (Autocad) and then it can be imported from SketchUp as it's presented in following figures.

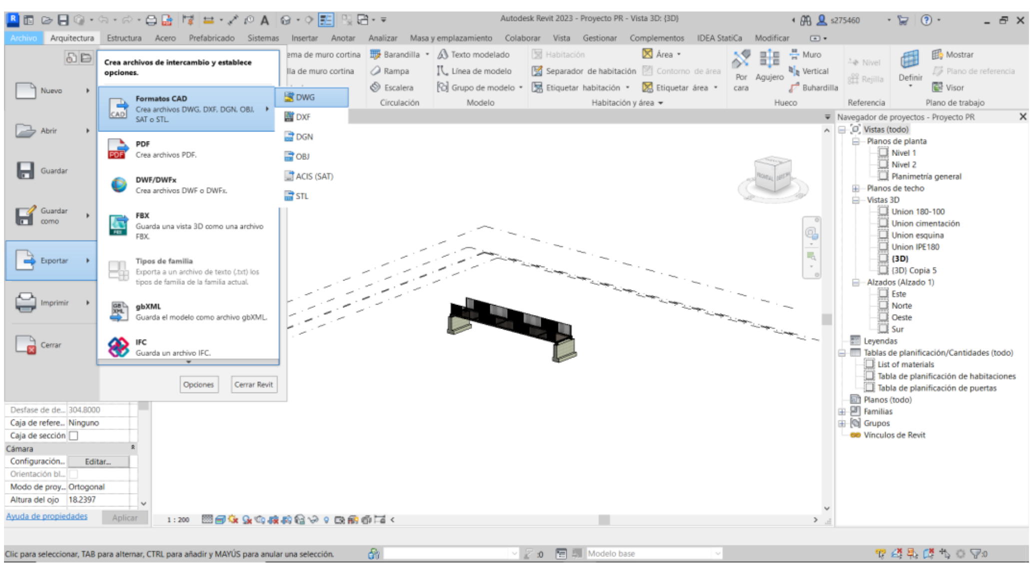


Figure 44. Export process from Revit to CAD format 1 (Revit)

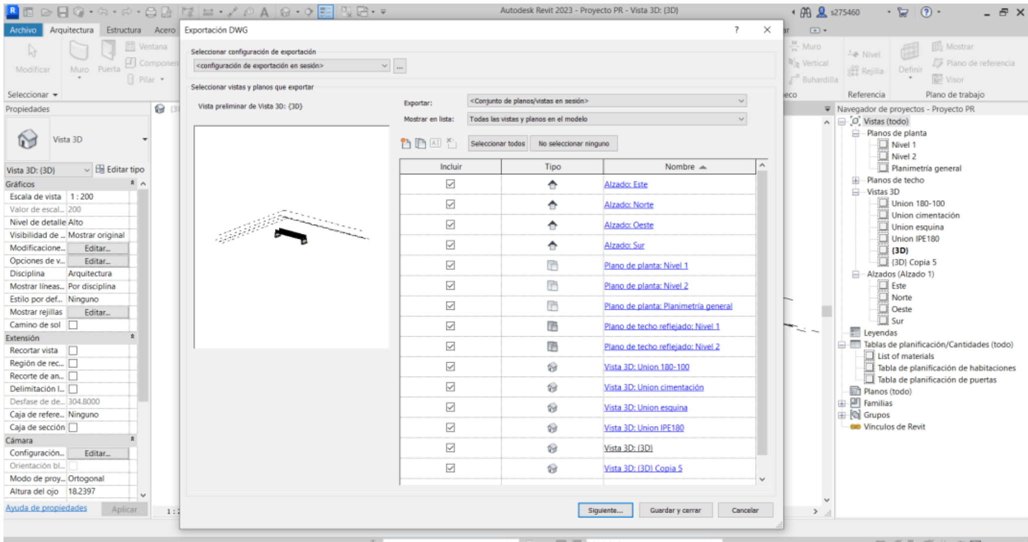


Figure 45. Export process from Revit to CAD format 2 (Revit)

As it can be seen, Revit presents a direct export function to CAD files, and more precisely to a DWG file that corresponds to an AutoCAD file. This fact, implies a good interoperability between the two different software, which is expected as both are part of the Autodesk family. In the following figure, it will be shown the exact architectural model passed to AutoCAD.

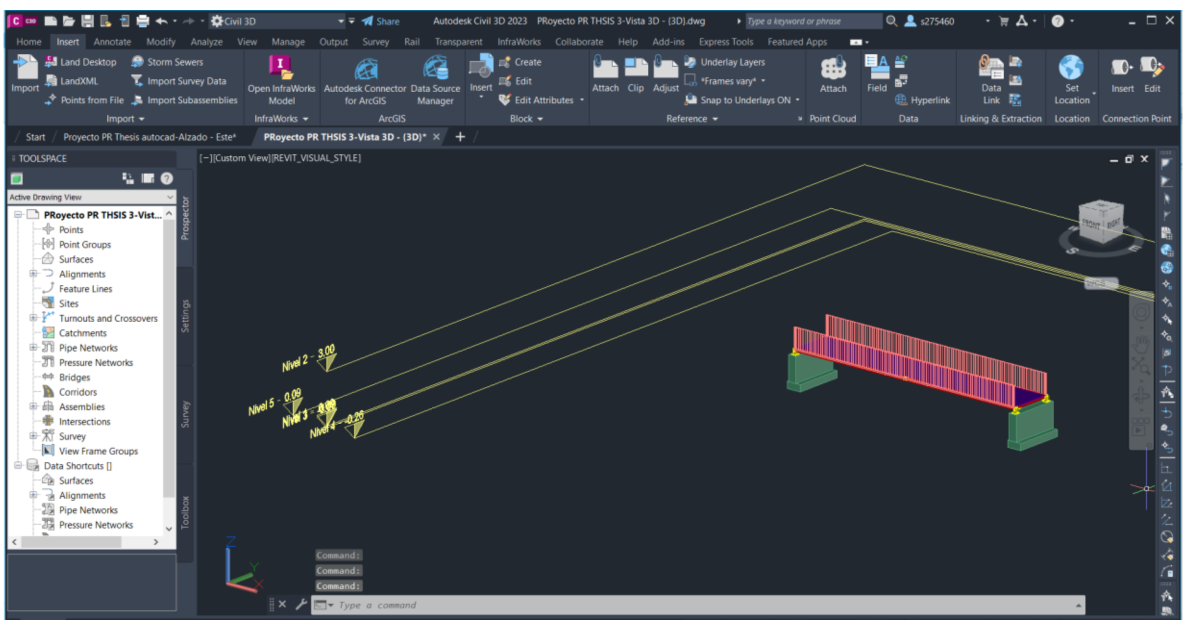


Figure 46. Architectural model 3D (AutoCAD)

Once the architectural model is completely exported to AutoCad, it can be imported from SketchUp as it's shown in the following figures.

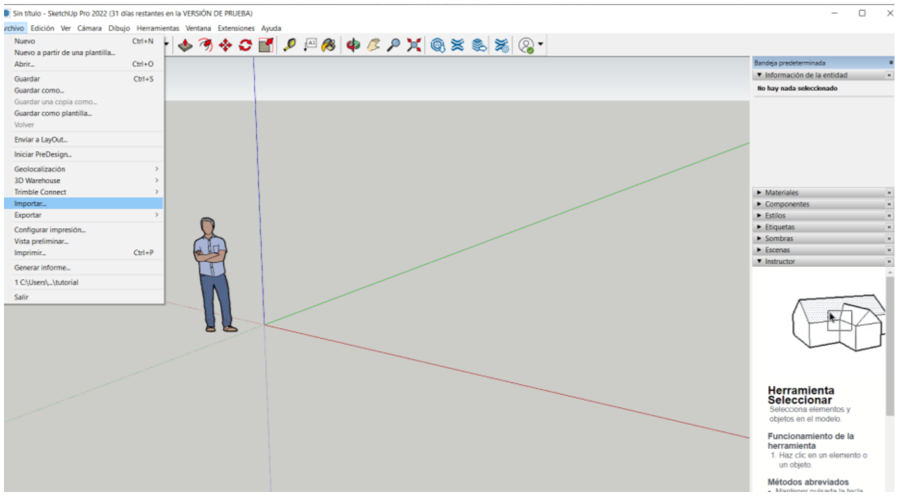


Figure 47. Import process from AutoCAD 1 (SketchUp)

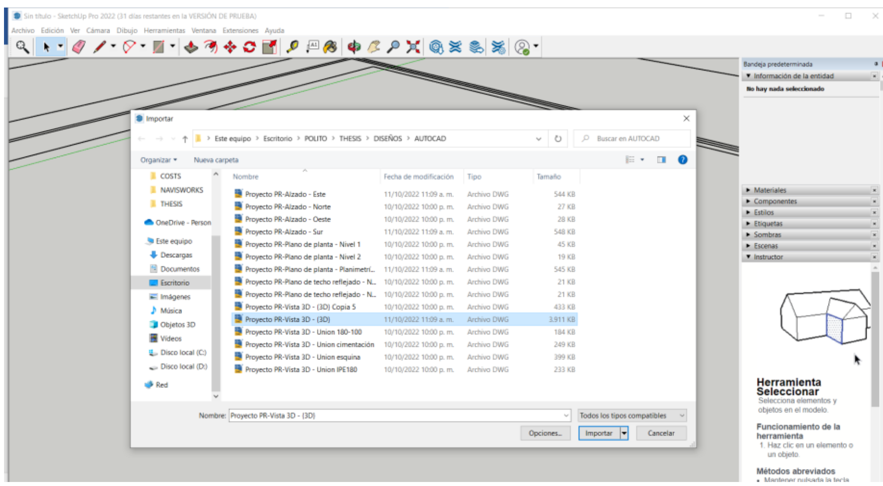


Figure 48. Import process from AutoCAD 2 (SketchUp)

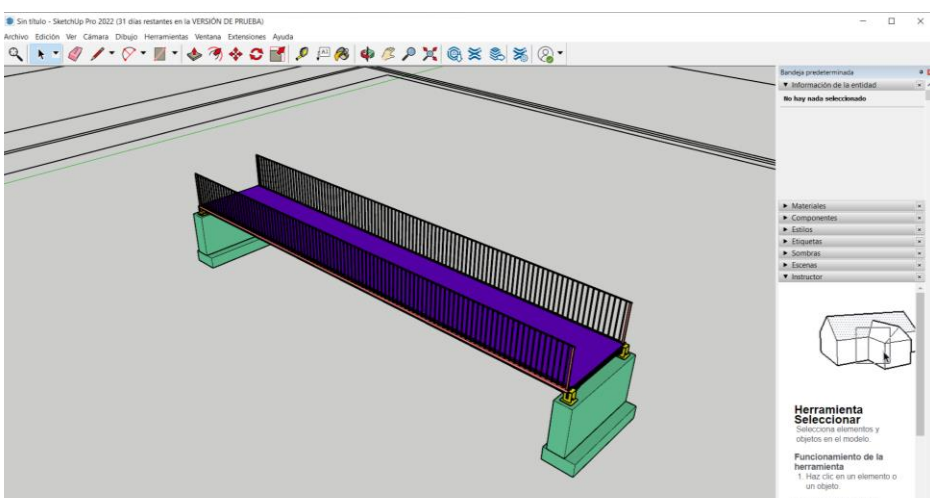


Figure 49. Imported 3D model (SketchUp)

At this point, it has been decided to continue the architectural modelling in SketchUp due to the facility and level of detail that can be achieved in this software. This level of detail is very important in further steps of the BIM process as the project management.

Figure 50. Architectural design 1 with SketchUp (3D lateral view)

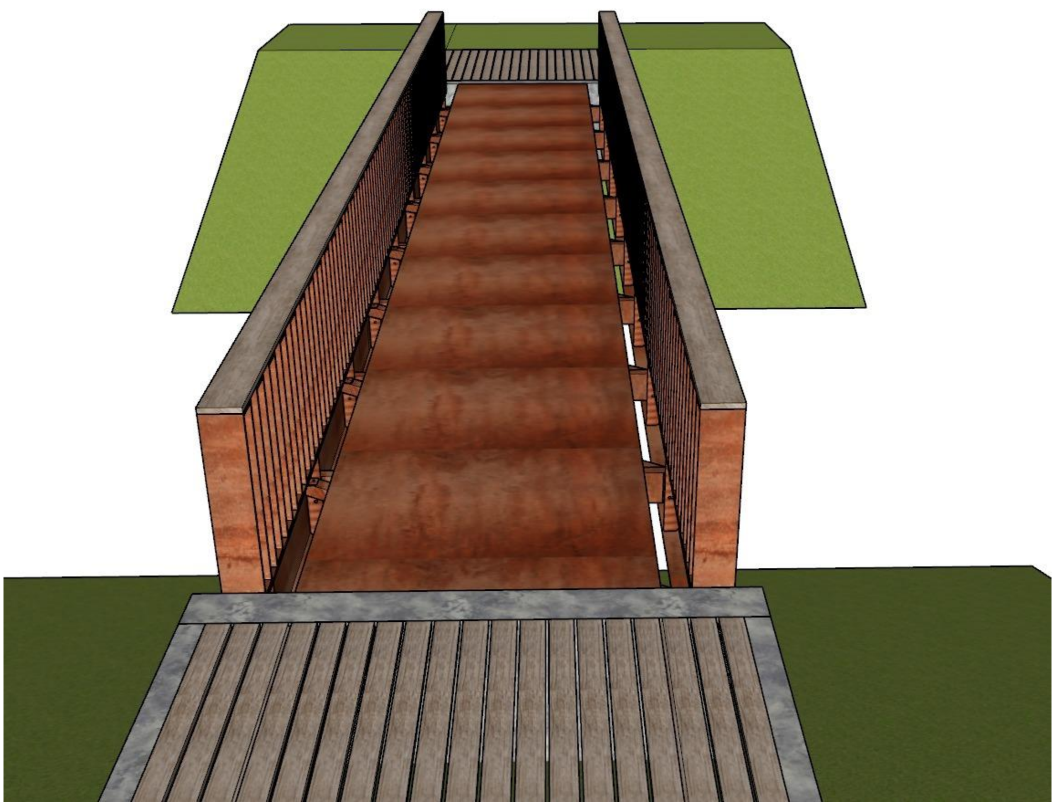


Figure 51. Architectural design 1 with SketchUp (3D horizontal view)

Once the first architectural design is presented, it must be analyzed. First, it can be said that the approach just presented meets all principal requirements determined in the case study in terms of measurements, used materials and purpose, however, as it has been already explained, one of the principal objectives of the case study is to give to the zone an added value with the architectural point of view. Then, this architectural design does not fulfill all aspects that needs to be considered.

6.2. Architectural design 2

For the second approach, a more complex architectural design has been intended. For this case, the software SketchUp was used. SketchUp is defined by Trimble (industrial technology company developer) as an intuitive 3D modeling application that allows to create and edit 2D and 3D models with a patented "Push and Pull" method. The Push and Pull tool allow designers to extrude any flat surface into 3D shapes. SketchUp is a program used for a wide range of 3D modeling projects like architectural design.

The use of this software, will allow to have a realistic architectural design with a high accuracy and high detail. The amount of detail reached by this program give a clearer view of all singular parts that must be considered on the structural design. In the following figures, is shown the reached architectural design for the second approach.

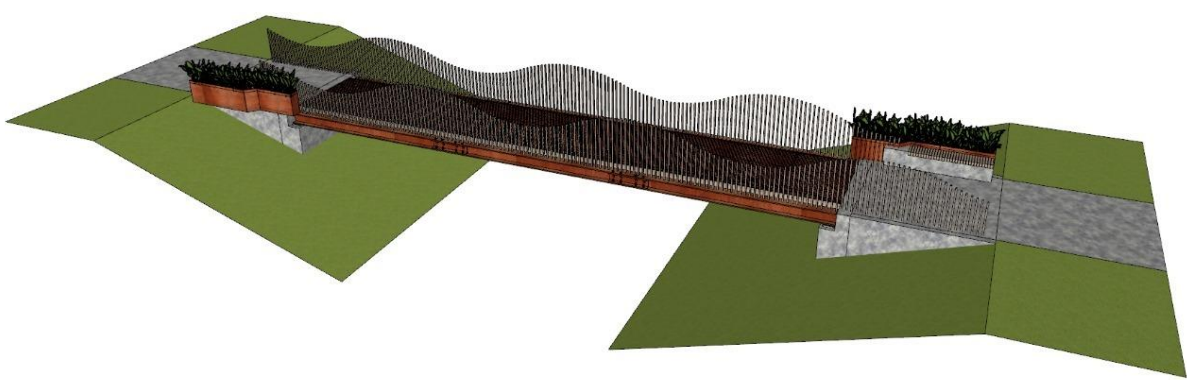


Figure 52. Architectural design 2 with SketchUp (3D lateral view)

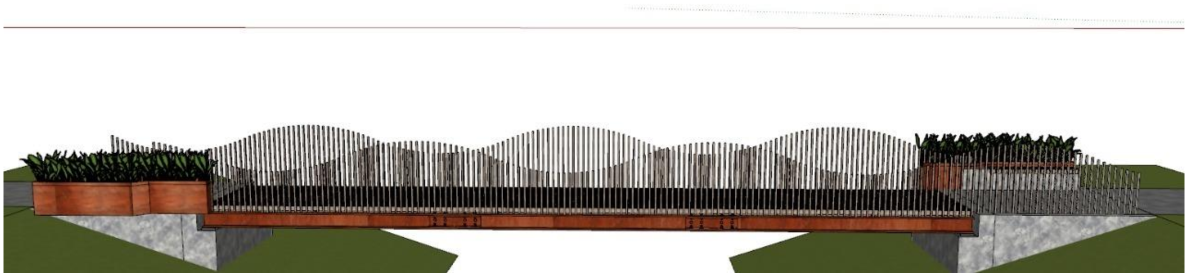


Figure 53. Architectural design 2 with SketchUp (3D horizontal view)

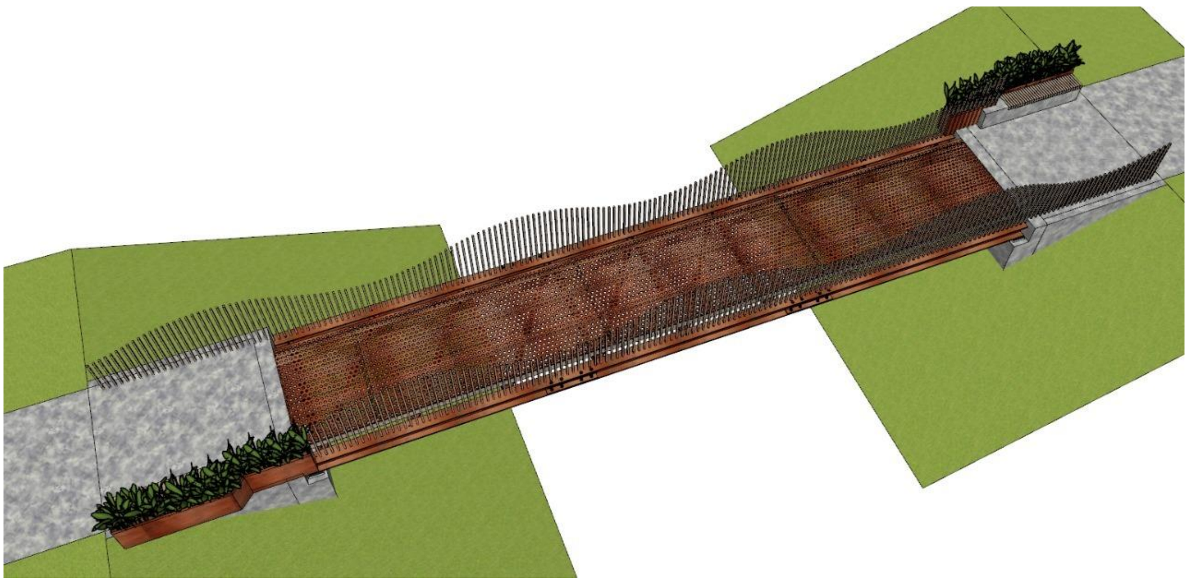


Figure 54. Architectural design 2 with SketchUp (3D upper view)

Figure 55. Architectural design 2 with SketchUp (Architectural details)

The architectural approach just presented, maintains the principal design of the first architectural approach. It is a simple beam and slab bridge in which the structure (beams and slabs) is also proposed in Corten-steel. The difference and the importance in the design, is that first, the runway is proposed as a perforated Corten steel sheet which brings an excellent congruence with the environment presented for the case study. Additionally, the railings and handrails are proposed in Glulam wood, but in this case, with a difference in height in each railing, allowing to have a sinusoidal shape, providing a design that will be possible to build taking into account the conditions of the workplace and with an architectural touch that reach an added value to the area where the pedestrian bridge is intended to be constructed.

Finally, the architectural design presents resting places at each side of the pedestrian bridge, this places with the presence also of pots convert the structure not only for passing from one side of the river to another, but to enjoy the environment and the entire zone.

The architectural design that is been proposed, presents a combination of ideas extracted from examples of pedestrian bridges that were analyzed during the bibliographical research of pedestrian bridges with combined materials such as the bridges CAN GILI from Spain, the Bayraklı Coast Pedestrian Bridge from Turkey and THE BOSTANLI PEDESTRIAN BRIDGE also from Turkey.

7. Structural Design

With the architectural design already decided and presented in last chapter, is time to proceed with the structural design. This structural design will be analyzed in two different software. One, SAP 2000, which is a structural and earthquake engineer software produced by Computers & Structures Inc, this software offers a single user interface to perform modeling, analysis, design, and reporting. On the other hand, Robot Structural Analysis will be used, this software is produced by Autodesk and it's described as an advanced BIIM-integrated structural analysis and code compliance verification tool.

The proper use of these two software will allow to achieve one of the main objectives of the entire BIM Methodology which is the possibility to use many technological tools available, in order to produce a complete project. Additionally, the software Robot as is an Autodesk tool, will have a good interoperability with other Autodesk software used for the present project as Revit, Advance steel and Navisworks, this two last software will be presented and explained later.

It's important to say that the structural analysis must contain all regulations by EUROCODE taking into account the materials, location and use of the type of structures proposed. In the following table, are shown all material properties of Corten Steel material.

S355 (EN 10025-2)		
Description	**Symbol**	**Value**
Density	p (Kg/m3)	7850
Young Modulus	E (Mpa)	210000
Shear Modulus	G (Mpa)	81000
Yield strength	fy (Mpa)	355
Ultimate strength	fu (Mpa)	470

Table 6. Structural properties of Corten-Steel S355 (EN 10025-2)

7.1. Structural design on SAP 2000

For the structural design that is about to be developed in SAP2000, the chosen architectural design will be analyzed and as it was already explained, the main structural elements of the bridge, are going to be considered in Corten steel.

As Corten steel is a wide extend used material, the software SAP2000 has the general properties of the material as input data as we can see it.

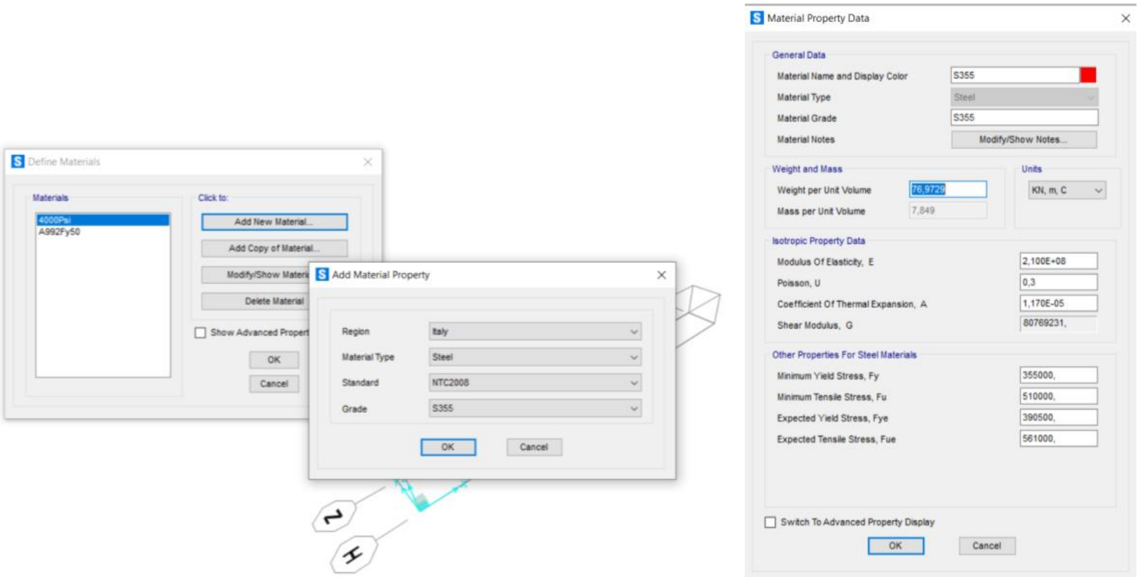


Figure 56. Structural data of Corten steel - SAP 2000

The material used is S355, a non-alloy structural steel that meets European Standard (EN 10025-2) and is most frequently utilized after S235 when extra strength is required. Let's look at more mechanical information about this steel since it has excellent weldability and machinability. S stands for structural steel, while 355 represents the minimum yield strength (N/mm2) of 355 Mpa. This type of structural steel has a density of 7850 kg/m3, and its Youngs's modulus ranges from 190 to 210 Gpa.

With the assigned properties of the material, the structural elements must be pre-defined. For the analysis of the present project, the principal beams are defined as IPE300 and the slabs are presented as IPE240.

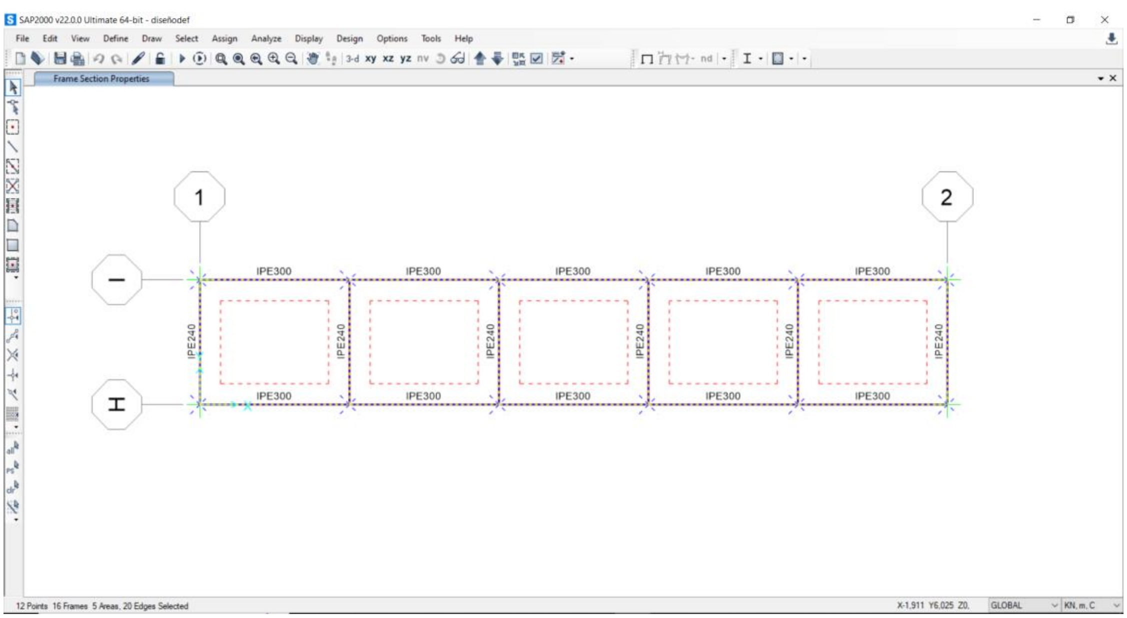


Figure 57. Section dimension of elements - SAP 2000

Now, with the properties of the material and with the section dimension of elements defined, it's possible to draw the geometry of the elements from the architectural design in order to build up the structure. In the following figure, all structural elements are shown included the position of foundation.

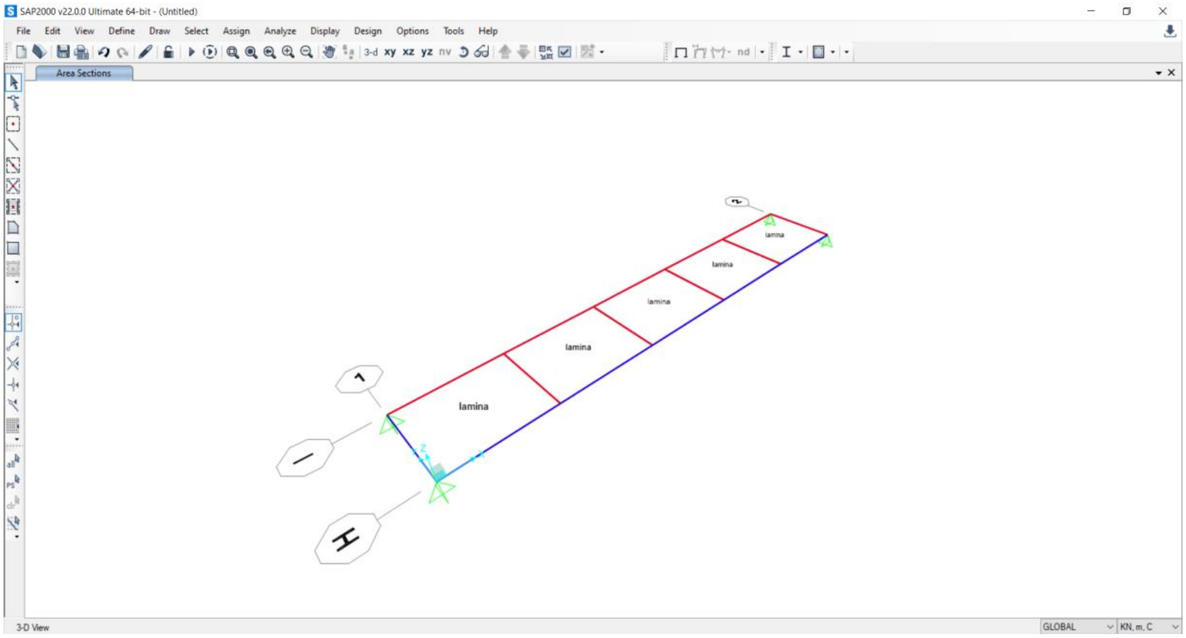


Figure 58. Geometrical model of the bridge for structural analysis - SAP 2000

Now, it's necessary to take into account the different loads that are imposed by regulations (Eurocodes). During the evaluation of the dimension and load analysis of the pedestrian bridge

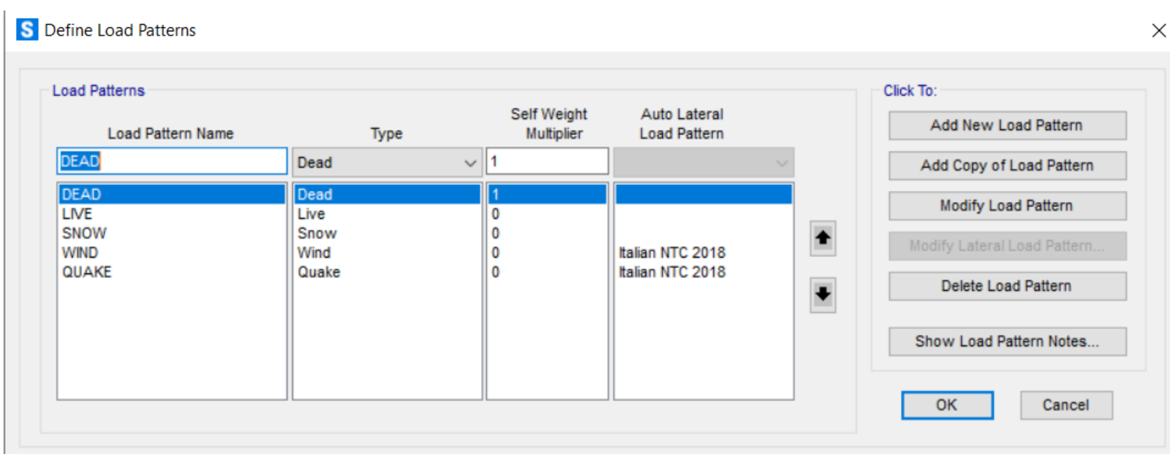


Figure 59. Evaluated loads for structural analysis - SAP 2000

- **Dead loads:** SAP2000 allows to obtain the weight of the structure (main elements). This weight is the considered dead load.

- **Live loads:** As it was already exposed during the description of the static loads, a conservative value of live loads is taking into account, preventing a remote situation of crowded use of the pedestrian bridge, 5 kN/m2 in the chosen value.

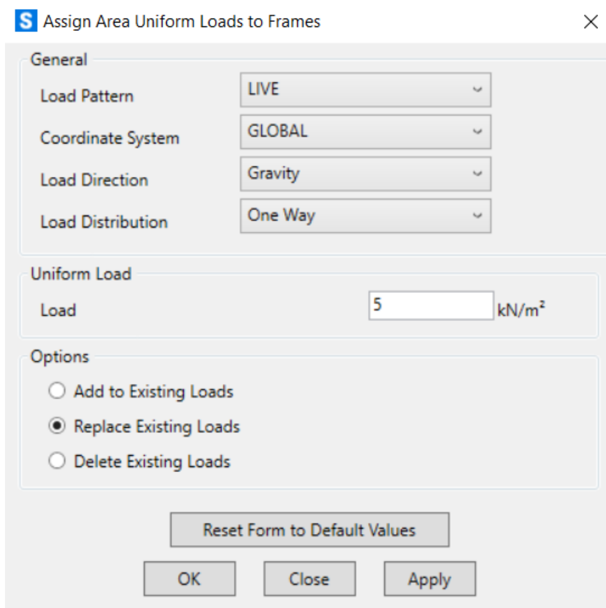


Figure 60. Live load - SAP 2000

During the definition of the static and dynamic loads, it was said that the wind loads and the snow loads depend on the location of the project, for the proper case, this location is Piedicavallo, Biella, Piedmont region, in Italy. These loads were also defined.

- **Wind loads:** The wind load analysis on SAP2000 is presented in the following figure.

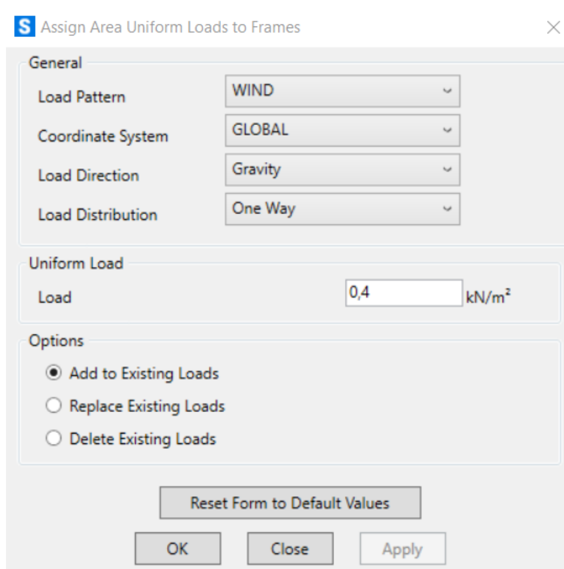


Figure 61. Wind loads - SAP 2000

- **Snow loads:** The snow loads were also found as 4.25 kN/m2.

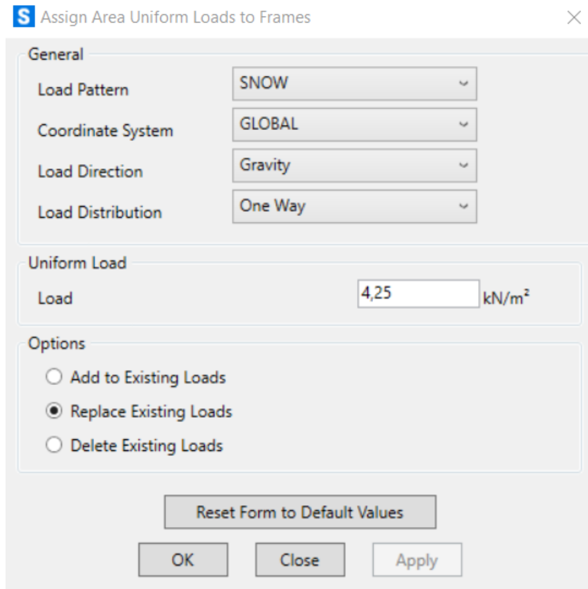


Figure 62. Snow loads - SAP 2000

- **Earthquake:** For the case of the earthquake, it was said that the present project will not enter in much detail on this topic, however, the quake will be defined in SAP2000 using a design ground acceleration for a return period of 30 years is ag = 0.422 m/s2.

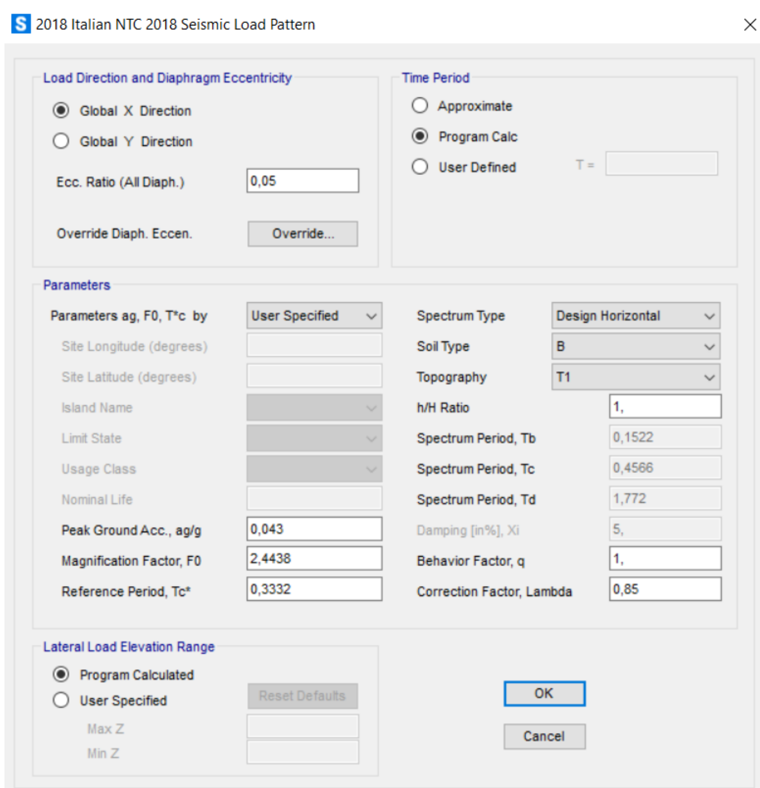


Figure 63. Earthquake - SAP 2000

Then, in the following figure it can be seen how are acting all different loads in each area of the pedestrian bridge.

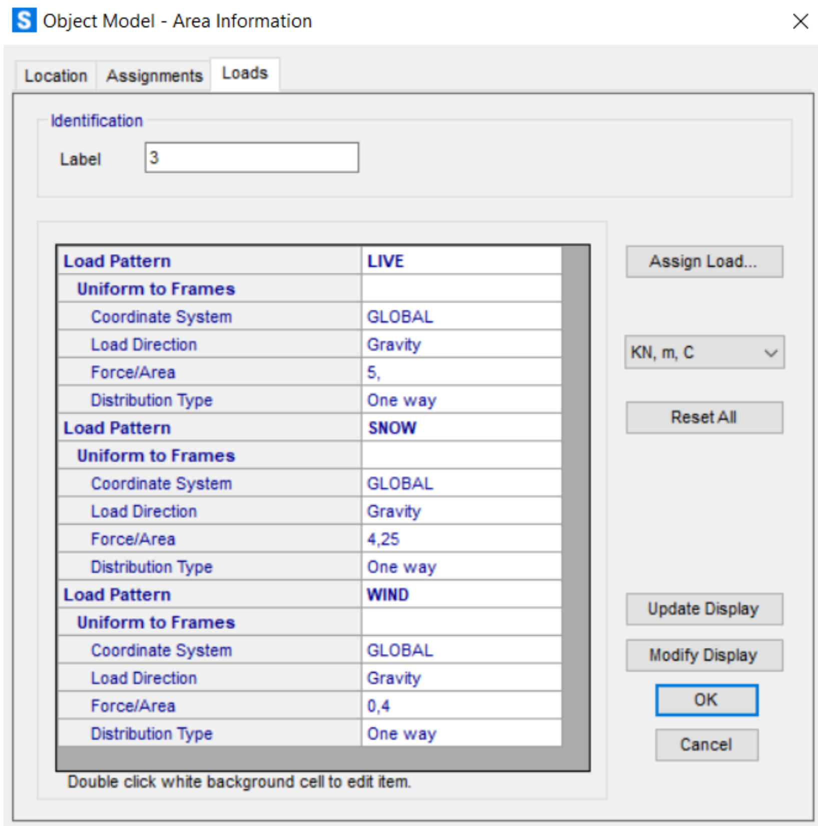


Figure 64. Loads on area - SAP 2000

- **Combination of loads:** To determine the combination of vertical loads, the ultimate limit state (ULS) must be used, this follows the next formula provided by Eurocode and NTC2018.

$$\gamma_{G1} G1 + \gamma_{G2} G2 + \gamma_P P + \gamma_{Q1} Q1 + \Sigma \gamma_{Gi} \Psi_{Qi} Qi$$

Equation 13. Determination of combination of vertical loads

For the case of the combination of loads, it will be used several combinations that follows the EUROCODE and NTC2018 for pedestrian bridges in steel structure. In the following figures are shown the different values in order to construct the combinations.

Tab. 5.1.V – *Coefficienti parziali di sicurezza per le combinazioni di carico agli SLU*

		Coefficiente	EQU(1)	A1	A2
Azioni permanenti g_1 e g_3	favorevoli sfavorevoli	γ_{G1} e γ_{G3}	0,90 1,10	1,00 1,35	1,00 1,00
Azioni permanenti non strutturali (2) g_2	favorevoli sfavorevoli	γ_{G2}	0,00 1,50	0,00 1,50	0,00 1,30
Azioni variabili da traffico	favorevoli sfavorevoli	γ_Q	0,00 1,35	0,00 1,35	0,00 1,15
Azioni variabili	favorevoli sfavorevoli	γ_{Qi}	0,00 1,50	0,00 1,50	0,00 1,30
Distorsioni e presollecita-zioni di progetto	favorevoli sfavorevoli	$\gamma_{\varepsilon 1}$	0,90 1,00(3)	1,00 1,00(4)	1,00 1,00
Ritiro e viscosità, Cedimenti vincolari	favorevoli sfavorevoli	$\gamma_{\varepsilon 2}, \gamma_{\varepsilon 3}, \gamma_{\varepsilon 4}$	0,00 1,20	0,00 1,20	0,00 1,00

Figure 65. Partial safety factors (NTC, 2018)

Tab. 5.1.VI - *Coefficienti ψ per le azioni variabili per ponti stradali e pedonali*

Azioni	Gruppo di azioni (Tab. 5.1.IV)	Coefficiente ψ_0 di combi-nazione	Coefficiente ψ_1 (valori frequenti)	Coefficiente ψ_2 (valori quasi permanenti)
Azioni da traffico (Tab. 5.1.IV)	Schema 1 (carichi tandem)	0,75	0,75	0,0
	Schemi 1, 5 e 6 (carichi distribuiti	0,40	0,40	0,0
	Schemi 3 e 4 (carichi concentrati)	0,40	0,40	0,0
	Schema 2	0,0	0,75	0,0
	2	0,0	0,0	0,0
	3	0,0	0,0	0,0
	4 (folla)	--	0,75	0,0
	5	0,0	0,0	0,0
Vento	a ponte scarico SLU e SLE	0,6	0,2	0,0
	in esecuzione	0,8	0,0	0,0
	a ponte carico SLU e SLE	0,6	0,0	0,0
Neve	SLU e SLE	0,0	0,0	0,0
	in esecuzione	0,8	0,6	0,5
Temperatura	SLU e SLE	0,6	0,6	0,5

Figure 66. Coefficients for variable action for pedestrian bridges

Once all the different coefficients are known, the combinations of actions are performed and are shown in the following figure.

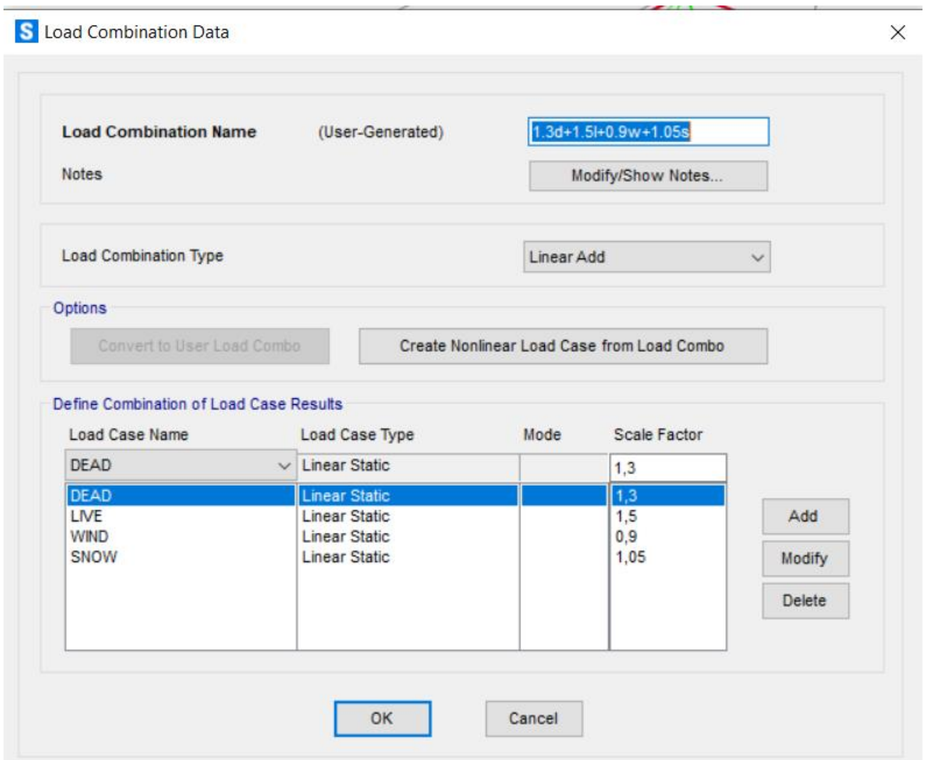


Figure 67. Example of combination of loads used - SAP 2000

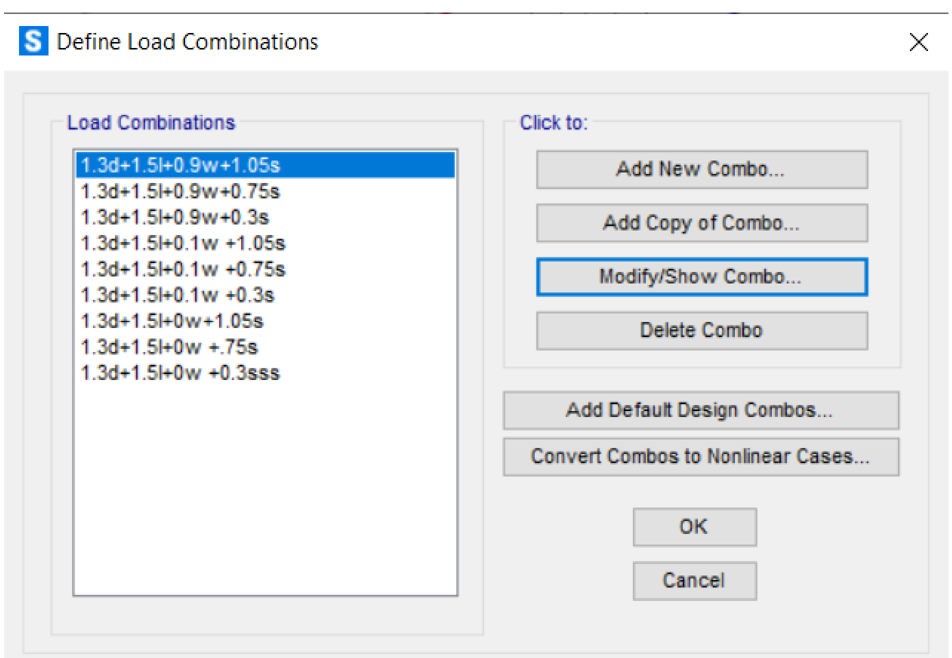
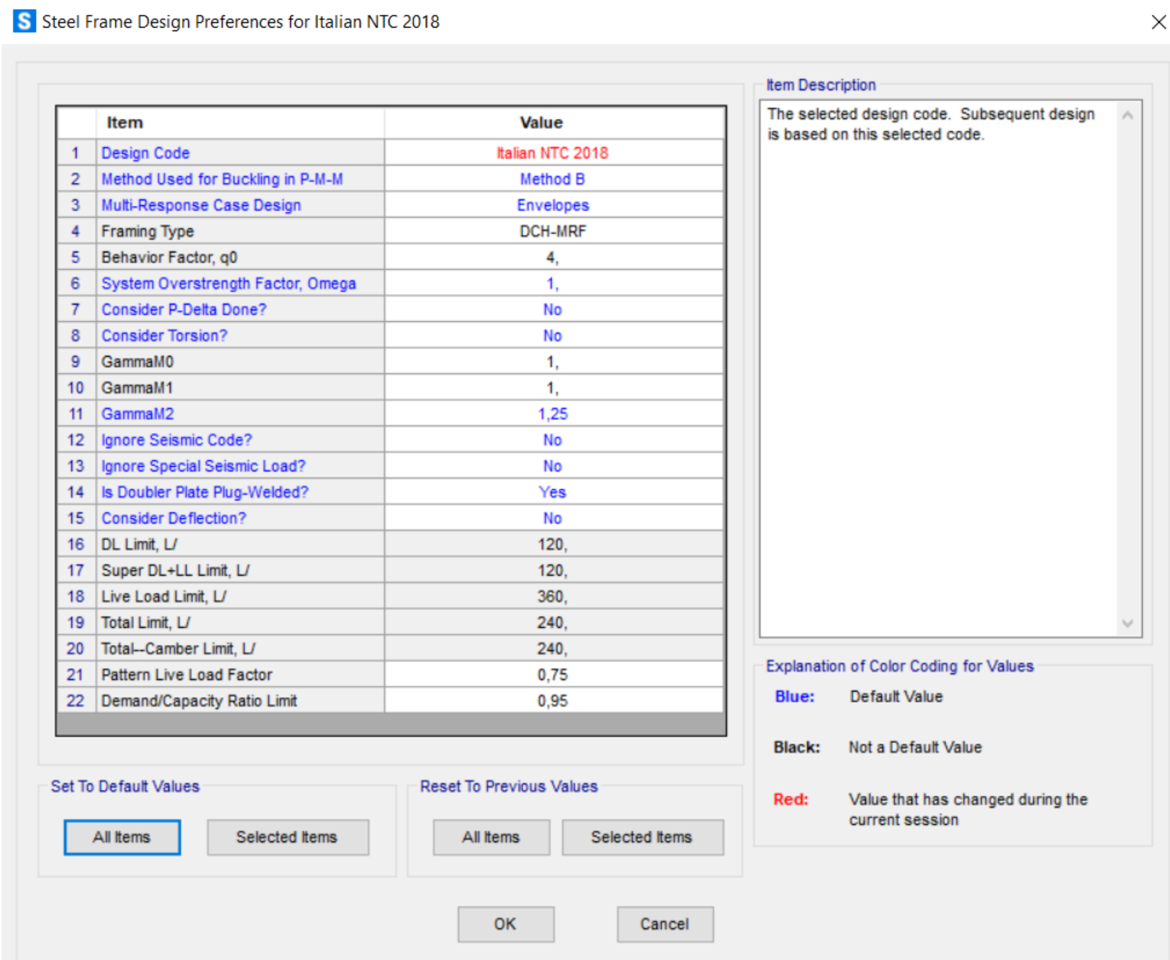


Figure 68. Combination of loads used - SAP 2000

Now, SAP 2000 allows to define the regulations that wants to be used during the structural analysis, for the case of the study, NTC 2018 (Italian regulation) was used.



	Item	Value
1	Design Code	Italian NTC 2018
2	Method Used for Buckling in P-M-M	Method B
3	Multi-Response Case Design	Envelopes
4	Framing Type	DCH-MRF
5	Behavior Factor, q0	4,
6	System Overstrength Factor, Omega	1,
7	Consider P-Delta Done?	No
8	Consider Torsion?	No
9	GammaM0	1,
10	GammaM1	1,
11	GammaM2	1,25
12	Ignore Seismic Code?	No
13	Ignore Special Seismic Load?	No
14	Is Doubler Plate Plug-Welded?	Yes
15	Consider Deflection?	No
16	DL Limit, L/	120,
17	Super DL+LL Limit, L/	120,
18	Live Load Limit, L/	360,
19	Total Limit, L/	240,
20	Total--Camber Limit, L/	240,
21	Pattern Live Load Factor	0,75
22	Demand/Capacity Ratio Limit	0,95

Figure 69. Regulation for analysis design - SAP 2000

With the geometry, material properties and also the loads defined, it’s possible to run the analysis. Once the analysis is performed, SAP2000 allows to do a design-check of the structural elements used in order to verify the behavior.

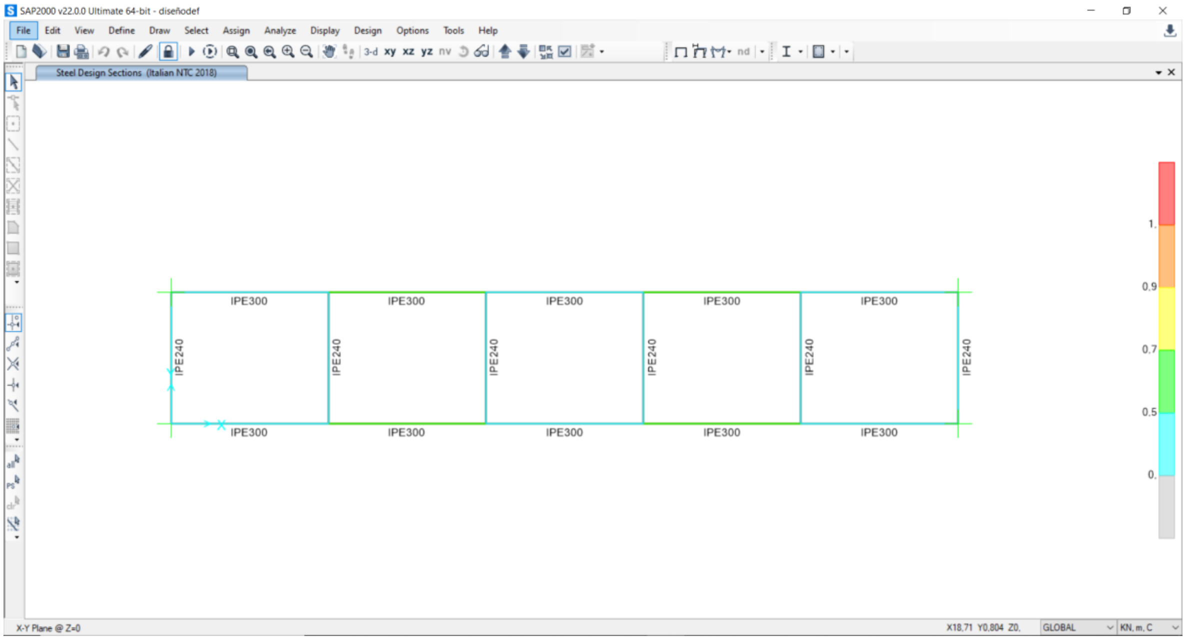


Figure 70. First design-check of structural elements - SAP 2000

As it was said at the beginning of the structural design, the elements were pre-defined, which means that the same could be changed depending the analysis. For the present case, SAP2000 is showing that the structure chosen is over dimensioned. Structurally this fact is not a problem, however, an over estimation of the structure will lead in increment of costs, then, the structure dimensions will be changed.

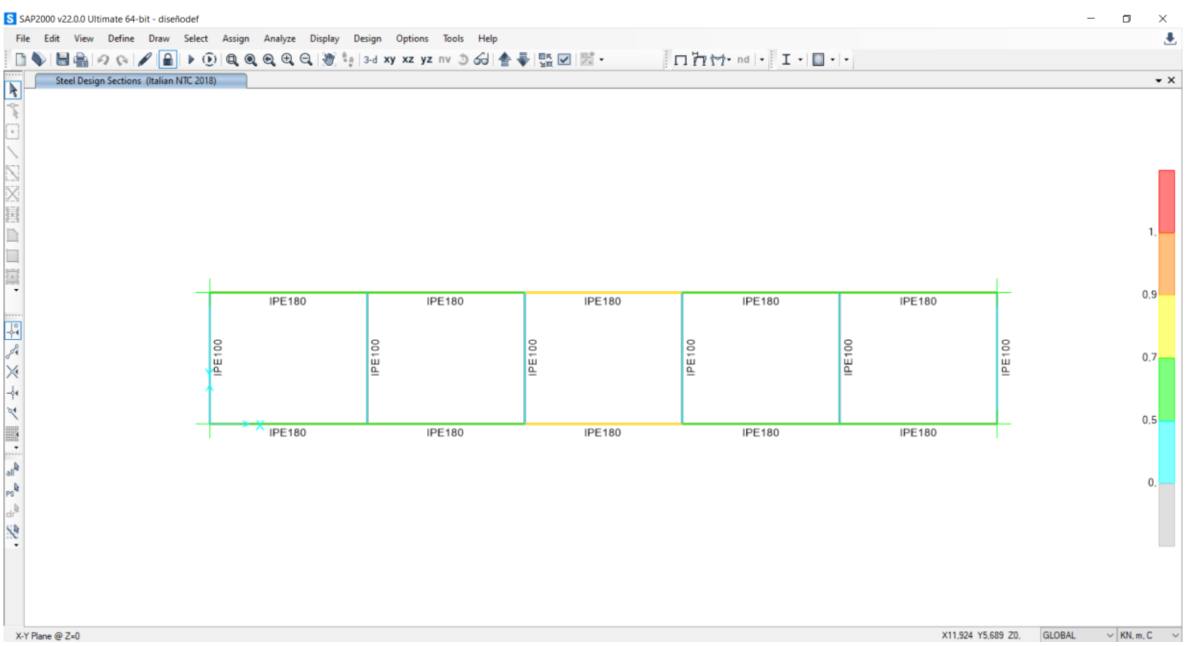


Figure 71. Final Design-check of structural elements - SAP 2000

With the new elements, the principal beams are defined as IPE180 and the slabs are presented as IPE100, it can be seen how the structure is still verified and the changes between sections are important, which will lead into cost savings.

Once all loads are defined, is possible to obtain results of deformation shape, shear, bending moments and axial forces regarding the analysis of the structure of the pedestrian bridge.

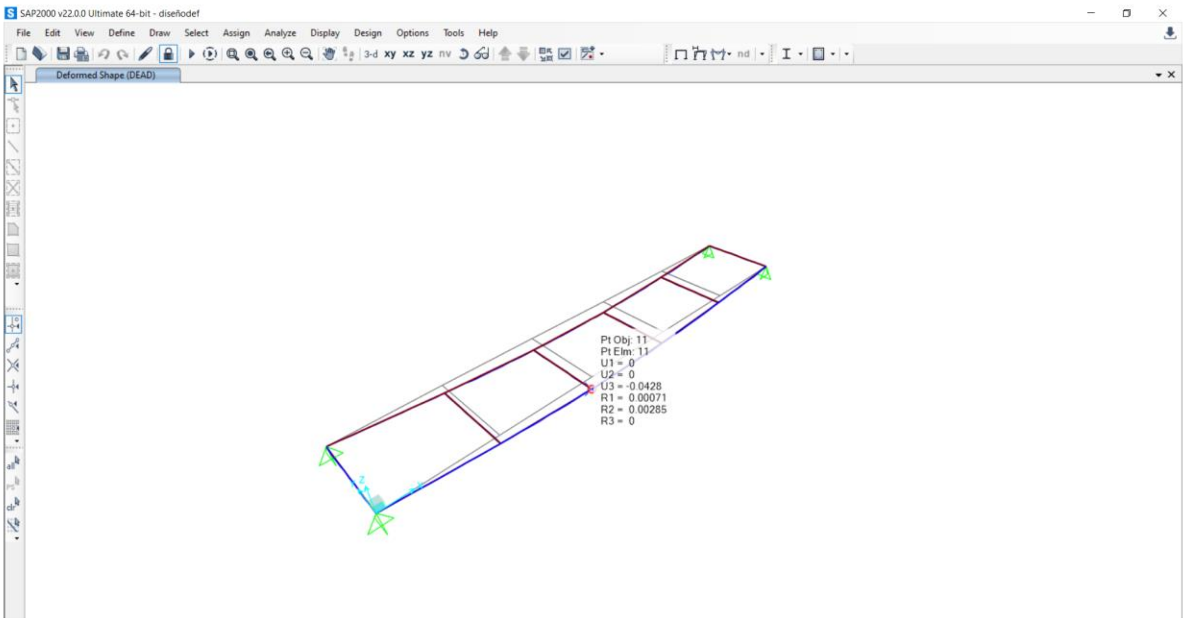


Figure 72. Deformed shape of structure - SAP 2000

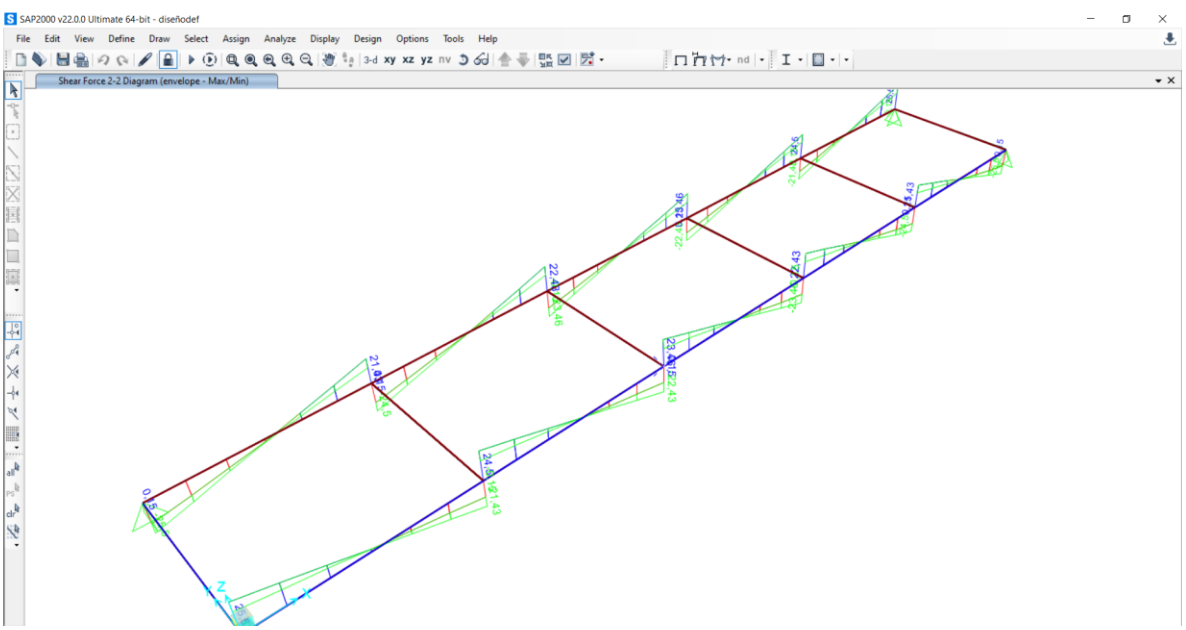


Figure 73. Shear force of structure - SAP 2000

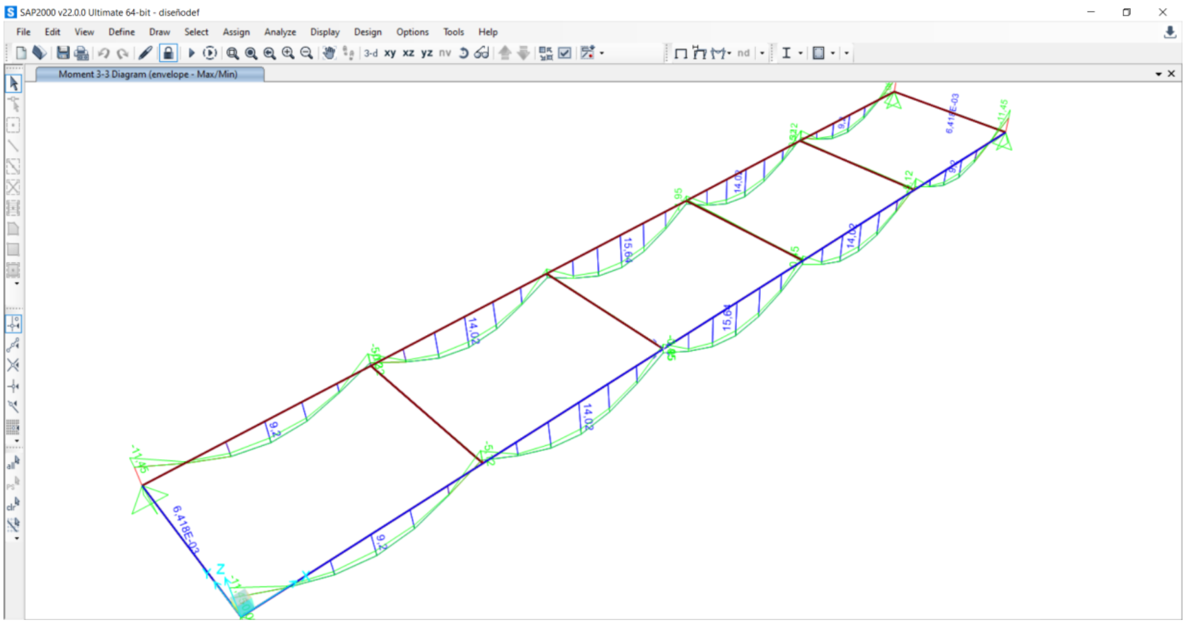


Figure 74. Bending moments - SAP 2000

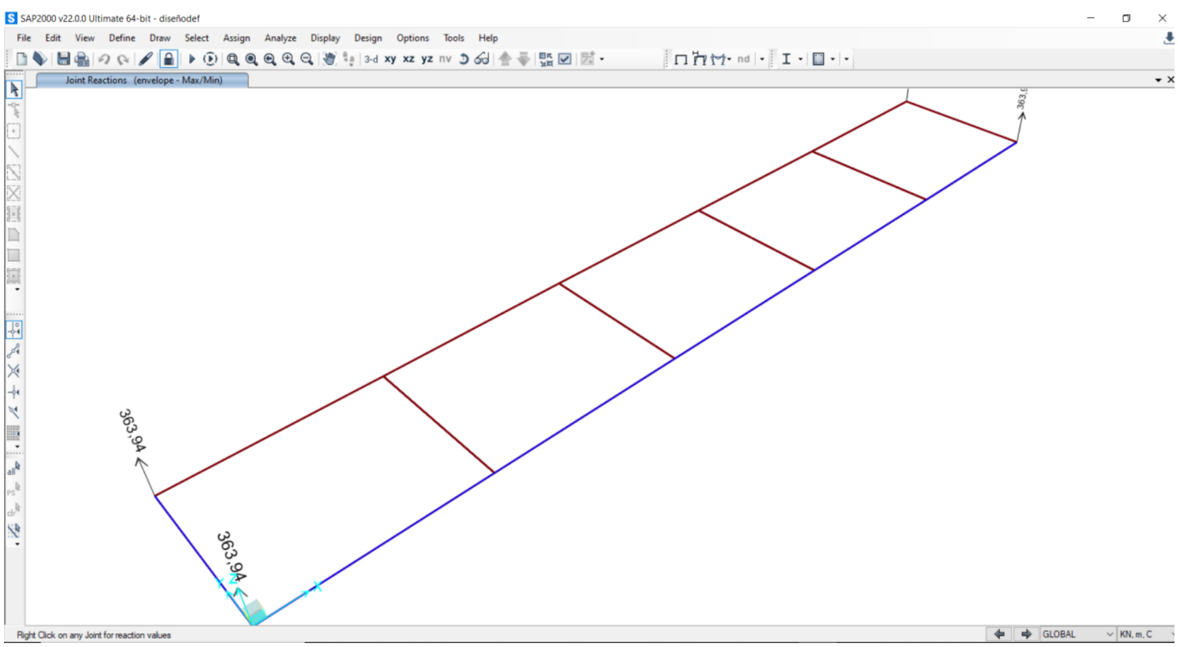


Figure 75. Reactions in supports - SAP 2000

Now, all forces are presented and the analysis is completed. It can be said that was reached an overdesign of elements taking into account the conditions and uses that will have the pedestrian bridge in real life. However, this condition will help considering the possible events that can adopt the river during an important flooding.

7.2. Pre-Design of connections

As it was presented during the development of the architectural design, in Autodesk Revit was proposed the Corten steel structure and also the correspondent connections. These connections are suggested and also checked by Revit depending on the type of elements that are part of the structure. In the following figures, are shown the Corten steel structure and also the connections that have been suggested during the development of the architectural design.

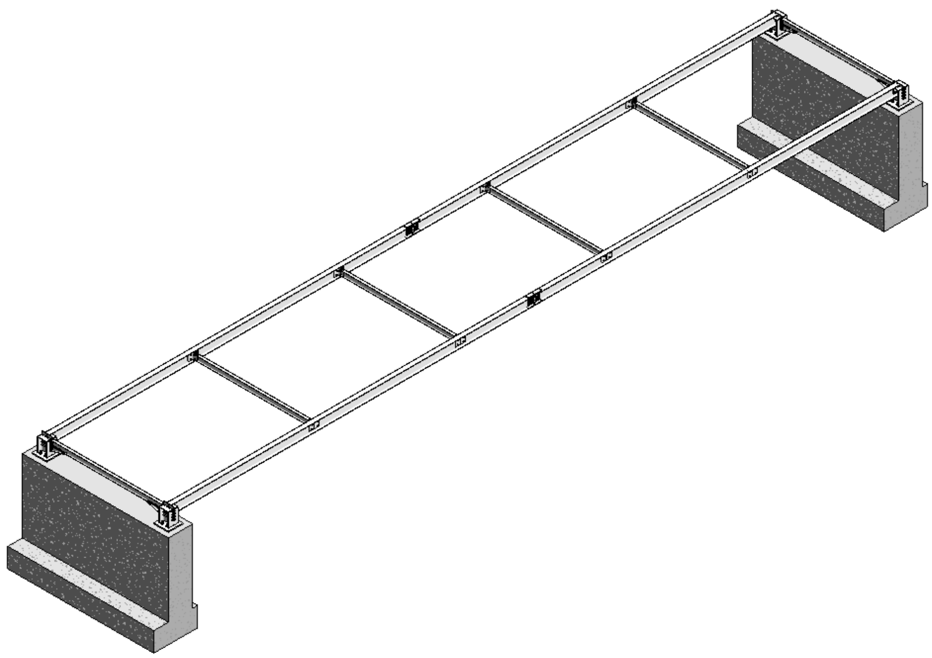


Figure 76. Corten steel structure and foundation - Revit

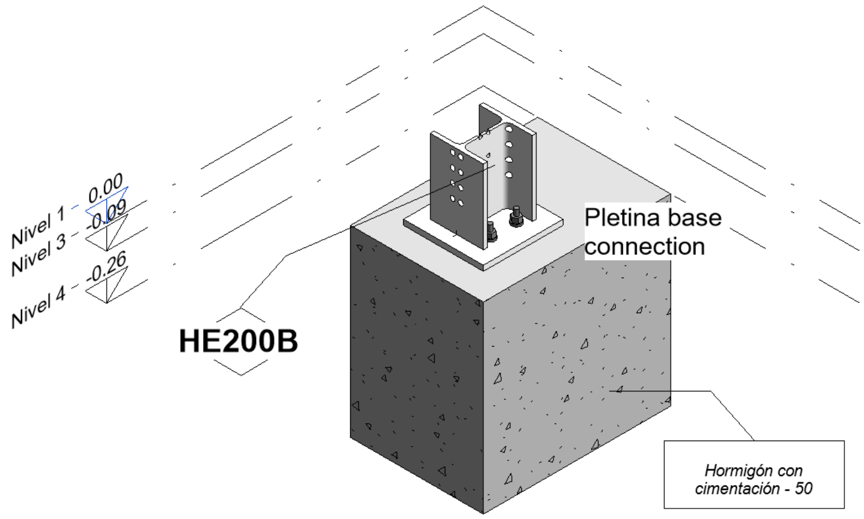


Figure 77. Pletina base connection - Revit

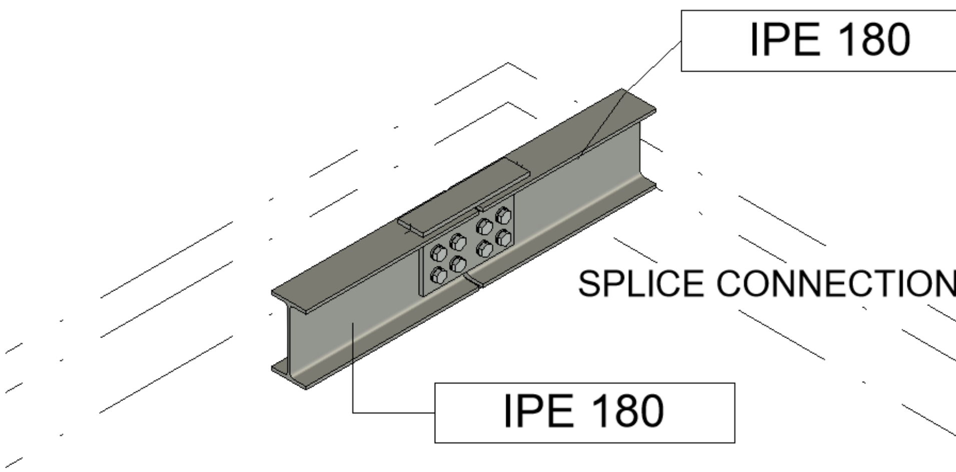


Figure 78. Main beams connection - Revit

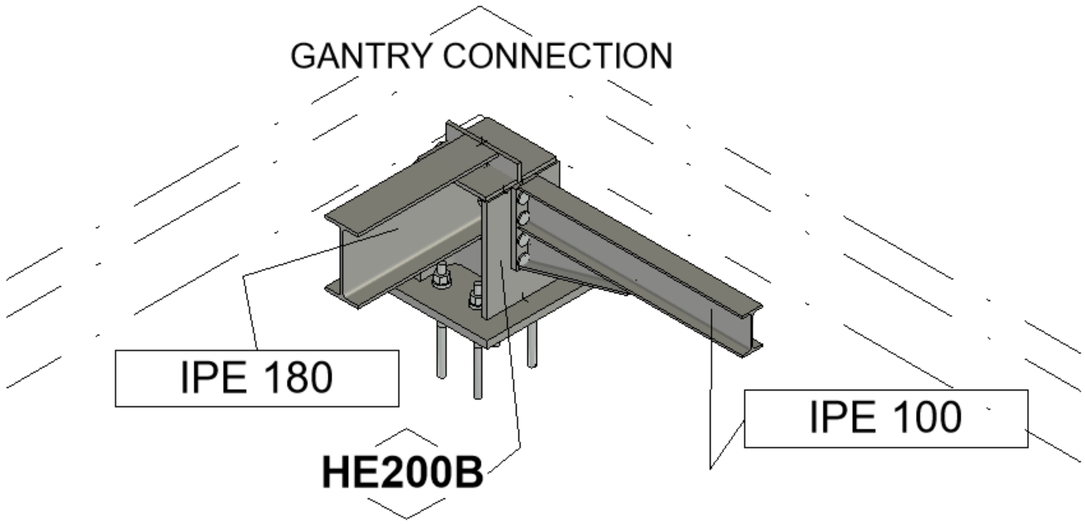


Figure 79. Gantry connection - Revit

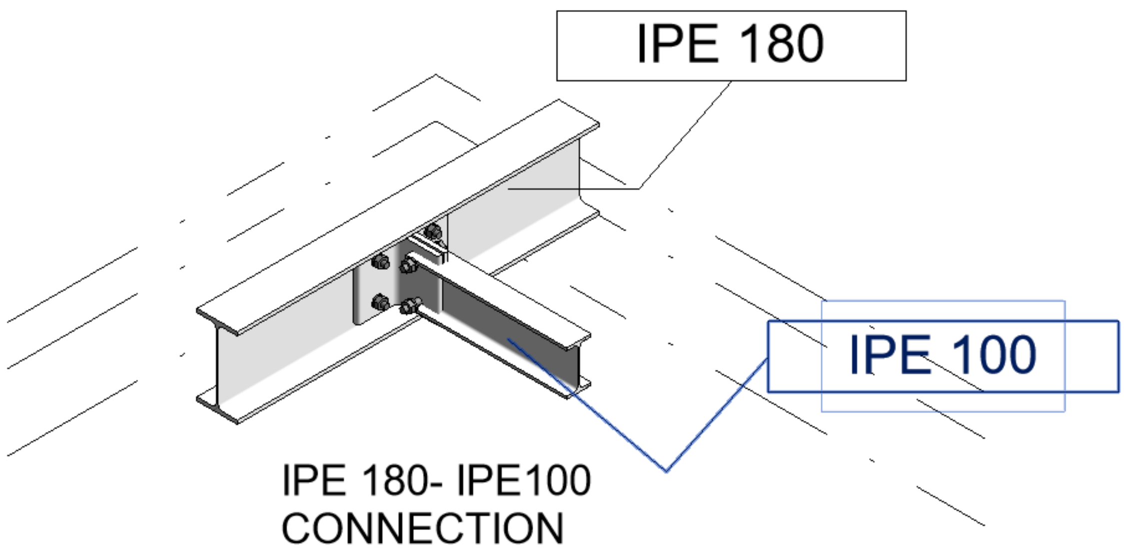


Figure 80. Main and secondary beams connection- Revit

As it was presented, different connections were suggested from Autodesk Revit for the structural design. However, it's important to notice that a correct evaluation of the connections must be done, using values of shear, bending moment and reaction of supports that were achieved during the structural design on SAP 2000. Next step involves the evaluation of the designed connections in order to verify the resistance considering the mentioned loads from structural analysis.

7.3. Design and evaluation of connections

In order to do the designing and evaluation of the connections, it has been decided to use another software named Idea Statica. This is a software for steel connection design for all types of welded and bolted structural steel connections and base plates. It fastens the connection design process, allowing to completely separate the connections and apply its correspondence loads in order to verify. Eurocode regulations can be used in Idea Statica for the proper calculations.

For the present case, as it was said, has been decided to use the architectural design developed in Revit. Then, was necessary to export the connections to Idea Statica by activating a plugin. In the following figure, will be presented the activated plugin that was used in Revit.

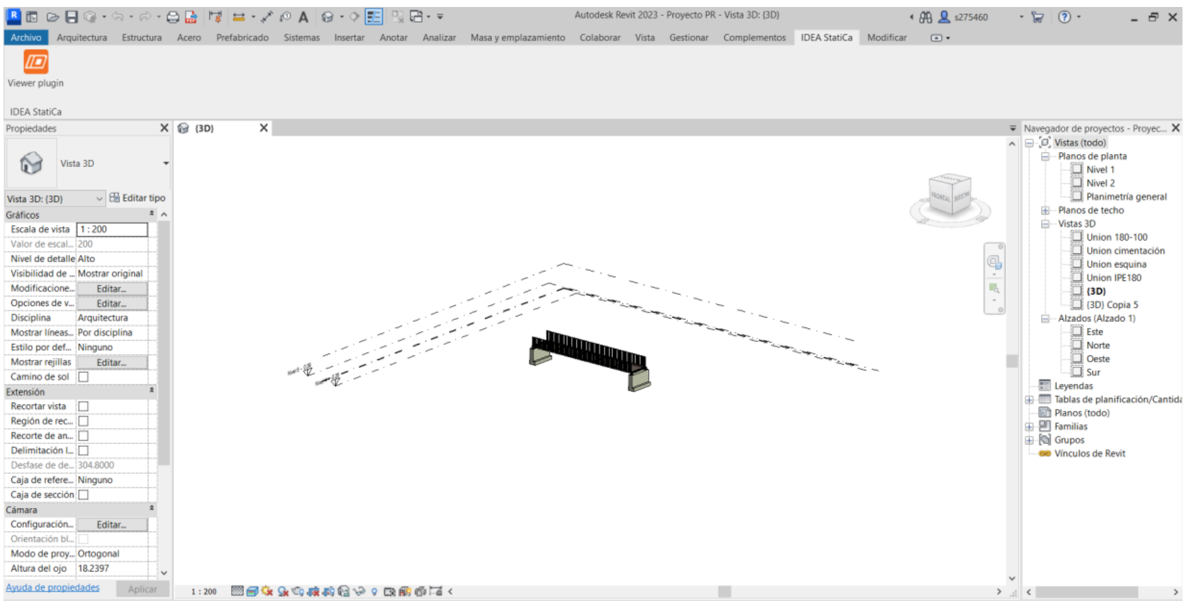


Figure 81. Interoperability between Revit and IdeaStatica

The procedure was performed; however, it was necessary to redrawn geometry of the connection due to changes in measurements and also types of elements. Now, it will be shown the designing and evaluation process of the different type of connections needed for the model. For the present case, five different types of connections were identified.

- **Platen base connection:**

  The platen base connection is the connection between the foundations and borders of the Corten steel structure. For this, it has been decided to use the HEB200 column that was suggested from architectural design. In the following figure it's shown the design of this type of connection that was developed in Idea Statica.

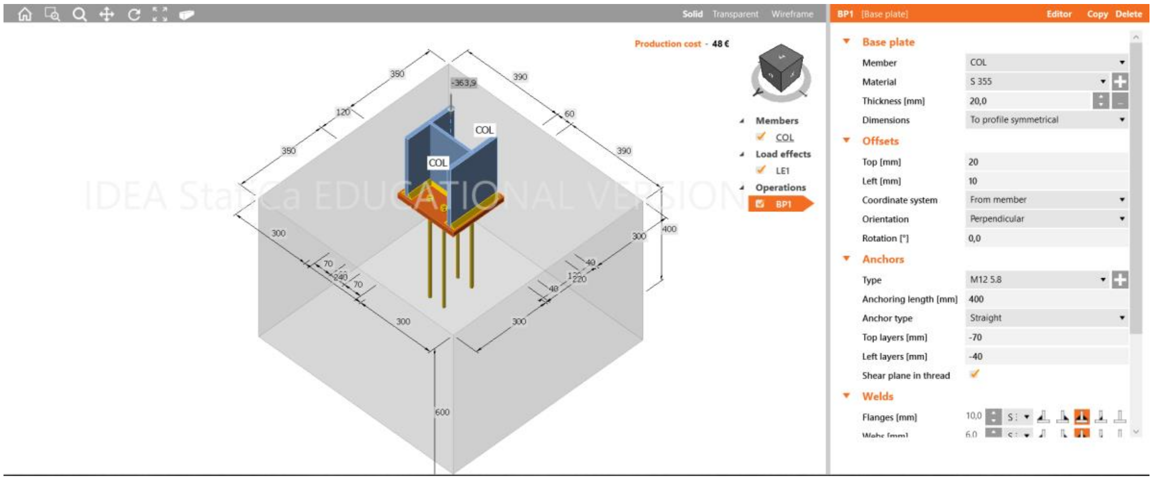


Figure 82. Design of Platen base connection (IdeaStatica)

Once the corresponding geometry and elements are properly design, it's necessary to input the loads. For this case, it will be used the reactions on supports that were presented during the structural design on SAP2000. In the following figure, it's shown the load case that is presented for the case.

LE1 [Load] **Copy** **Delete**

	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
>	COL / End	-363,9	0,0	0,0	0,0	0,0	0,0

Figure 83. Load case Platen base connection (IdeaStatica)

Once the geometry and also the loads are properly introduced on the model, it's necessary to identify the code and calculation settings that are part of the model in Idea Statica. These settings that will be presented next, are going to be used for all connections that will be designed during the evaluation of the case study.

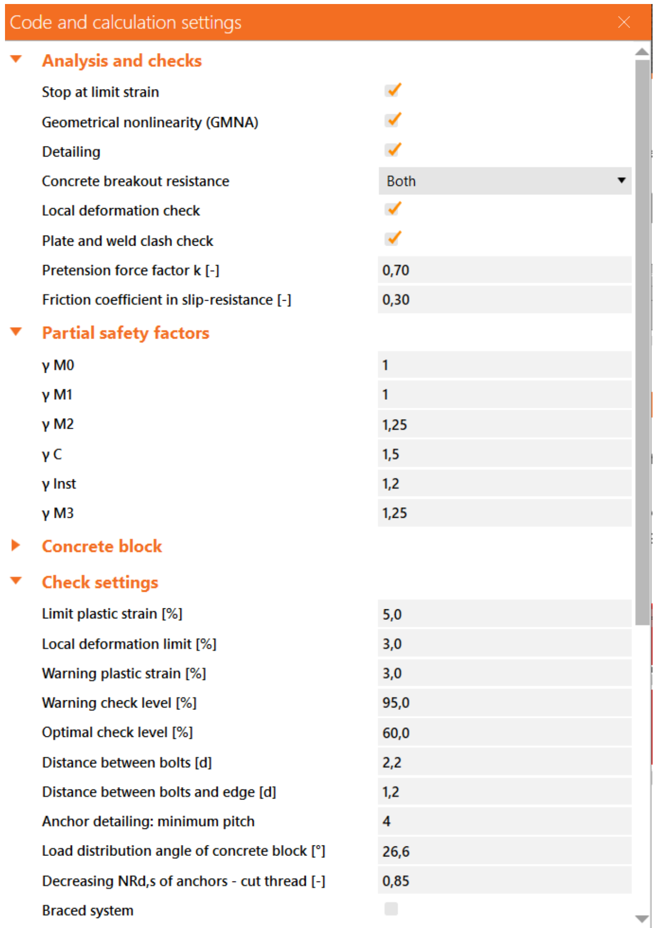


Figure 84. Code and calculation settings (IdeaStatica)

Now, it can be analyzed the connection that it's been designed.

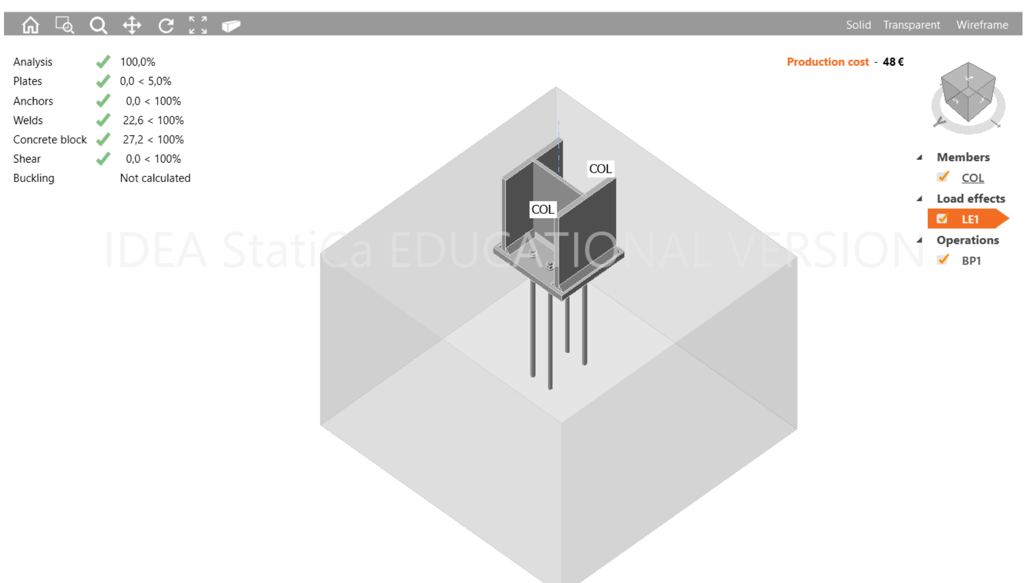


Figure 85. Check of platen base connection (IdeaStatica)

As it can be seen, the connection has been checked for the several considerations that were presented. Additionally, Idea Statica allows to identify the equivalent stresses, that for the case, corresponds to the equivalent stresses of the foundation and also the section HEB200.

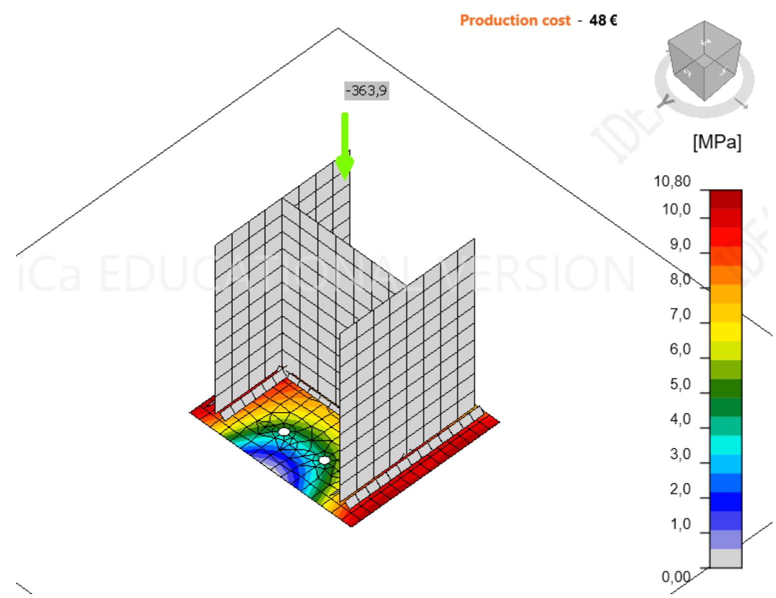


Figure 86. Equivalent stresses of foundation in platen base connection (IdeaStatica)

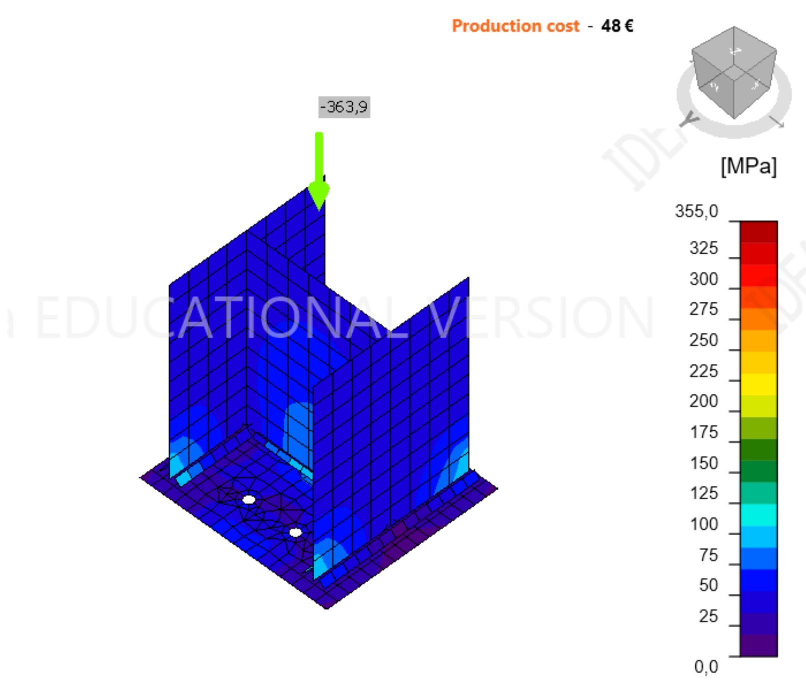


Figure 87. Equivalent stresses of element HEB200 in platen base connection (IdeaStatica)

Finally, Idea Statica present a project report for each element that has been designed and properly checked. This report for the platen base connection is presented next.

Project item Connection for foundation

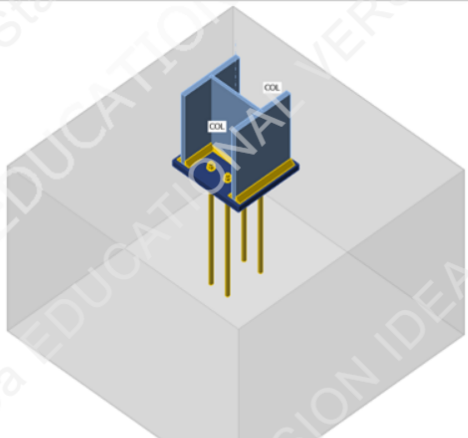
Design

Name	Connection for foundation
Description	Pletina base connection
Analysis	Stress, strain/ loads in equilibrium

Members

Geometry

Name	Cross-section	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]	Forces in
COL	1 - CON1(HEB200)	0,0	-90,0	0,0	0	0	0	Node



Cross-sections

Name	Material
1 - CON1(HEB200)	S 355

Anchors

Name	Bolt assembly	Diameter [mm]	fu [MPa]	Gross area [mm^2]
M12 5.8	M12 5.8	12	500,0	113

Load effects (forces in equilibrium)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	COL	-363,9	0,0	0,0	0,0	0,0	0,0

Foundation block

Item	Value	Unit
CB 1		
Dimensions	820 x 840	mm
Depth	600	mm
Anchor	M12 5.8	
Anchoring length	400	mm
Shear force transfer	Friction	

Check

Summary

Name	Value	Status
Analysis	100,0%	OK
Plates	0,0 < 5,0%	OK
Anchors	0,0 < 100%	OK
Welds	22,6 < 100%	OK

Figure 88. Project report for platen base connection (IdeaStatica)

- **Main beams connection:**

The main beams connection, allows to join the IPE 180 beams which are considered principal ones. As it was explained, the slab is designed so that the load is distributed over the main beams' direction. In the following figure it's shown the design that was achieved in Idea Statica software.

Figure 89. Design of main beams connection (IdeaStatica)

Once the corresponding geometry and elements are properly design, it's necessary to input the loads. For this case, it will be used the maximum values of bending moments and shear forces presented during the structural design on SAP2000. This chose of maximum values, allows to design only one type of connection, corresponding to the critical case. In the following figure, it's shown the load case that is presented for the case.

LE1 [Load] **Copy Delete**

	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
	B1 / End	0,0	0,0	-24,6	0,0	15,6	0,0
>	B2 / End	0,0	0,0	24,6	0,0	15,6	0,0

Figure 90. Load case for main beams connection (IdeaStatica)

With the geometry and also the loads properly introduced on the model, and using the code and calculation settings, it's possible to run the model.

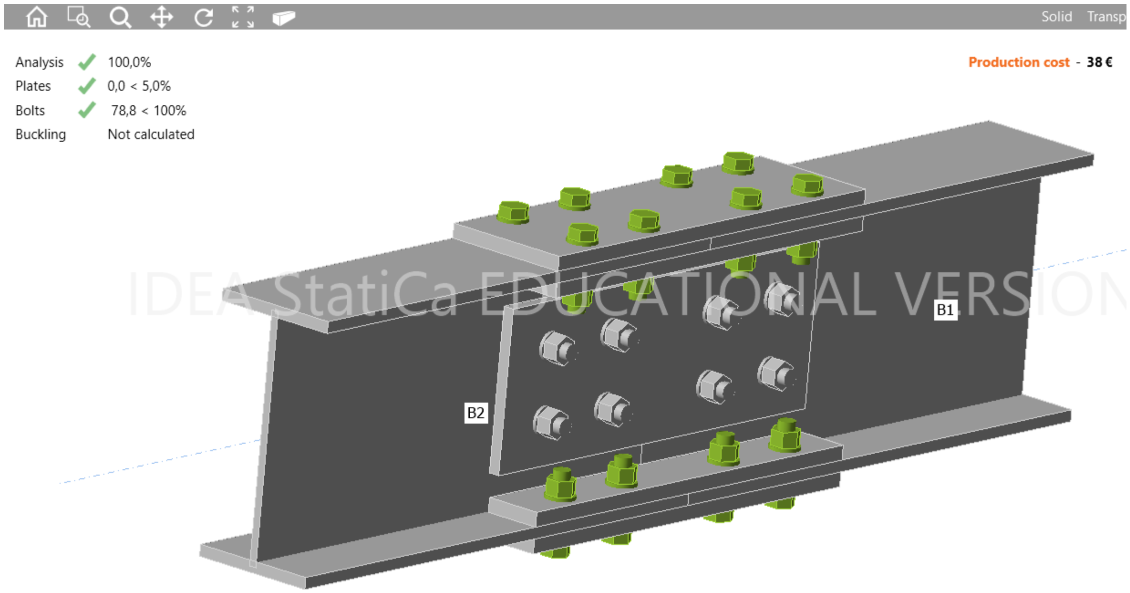


Figure 91. Check of platen base connection (IdeaStatica)

As it can be seen, the connection has been checked for the several considerations that were presented. Additionally, it will be shown the equivalent stresses and the deformed mesh of the main beam connection from Idea Statica.

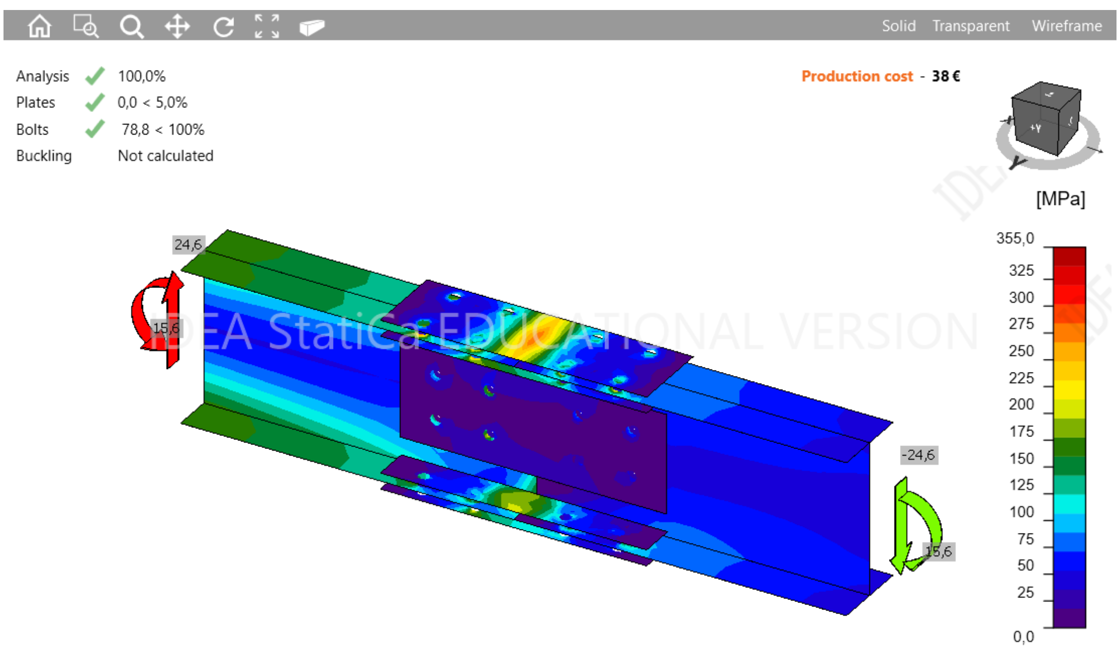


Figure 92. Equivalent stresses of main beam connection (IdeaStatica)

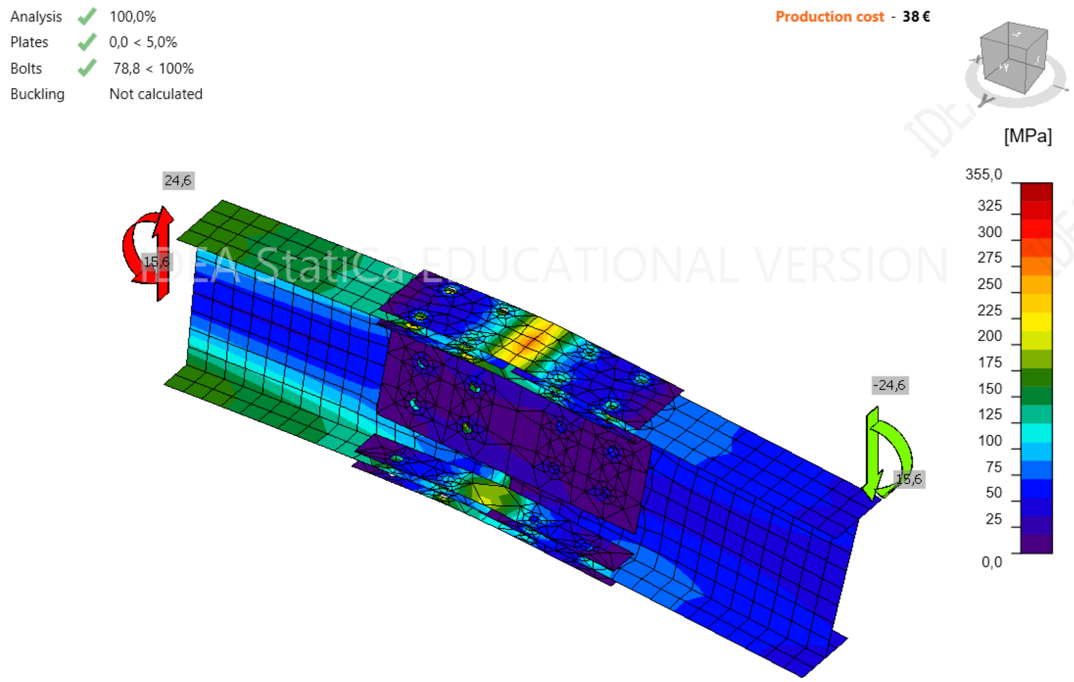


Figure 93. Deformed mesh of main beam connection (IdeaStatica)

Finally, Idea Statica presents a project report for each element that has been designed and properly checked. This report for the main beam connection is presented next.

Project item Main beam connections

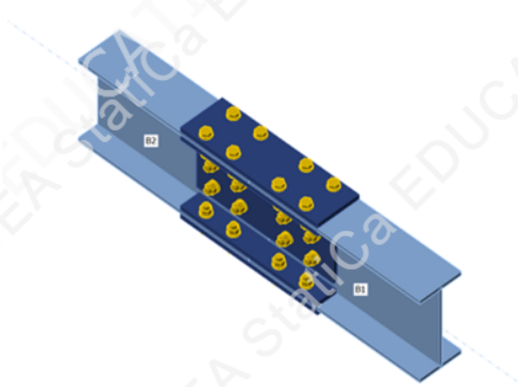
Design

Name	Main beam connections
Description	IPE180/180
Analysis	Stress, strain/ loads in equilibrium

Members

Geometry

Name	Cross-section	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]	Forces in
B1	1 - IPE180	0,0	0,0	0,0	0	0	0	Node
B2	1 - IPE180	180,0	0,0	0,0	0	0	0	Node



Cross-sections

Name	Material
1 - IPE180	S 355

Bolts

Name	Bolt assembly	Diameter [mm]	fu [MPa]	Gross area [mm^2]
M12 5.8	M12 5.8	12	500,0	113

Load effects (forces in equilibrium)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	B1	0,0	0,0	-24,6	0,0	15,6	0,0
	B2	0,0	0,0	24,6	0,0	15,6	0,0

Check

Summary

Name	Value	Status
Analysis	100,0%	OK
Plates	0,0 < 5,0%	OK
Bolts	78,8 < 100%	OK
Buckling	Not calculated	

Plates

Name	Thickness [mm]	Loads	σ_{Ed} [MPa]	ε_{Pl} [%]	$\sigma_{c,Ed}$ [MPa]	Status
B1-bfl 1	8,0	LE1	198,3	0,0	10,5	OK
B1-tfl 1	8,0	LE1	210,2	0,0	12,5	OK
B1-w 1	5,3	LE1	111,9	0,0	5,5	OK
B2-bfl 1	8,0	LE1	197,2	0,0	26,7	OK

Figure 94. Project report for main beam connection (IdeaStatica)

- **Main and secondary beams connection:**

The main and secondary beams connection, serve to join the secondary beams (IPE100) with the principal beams (IPE180). This connection will allow to transmit all loads from the slab of the pedestrian bridge to the principal beams, that as it was explained, are the ones who carry all loads. In the following figure, it's the shown the design reached in Idea Statica.

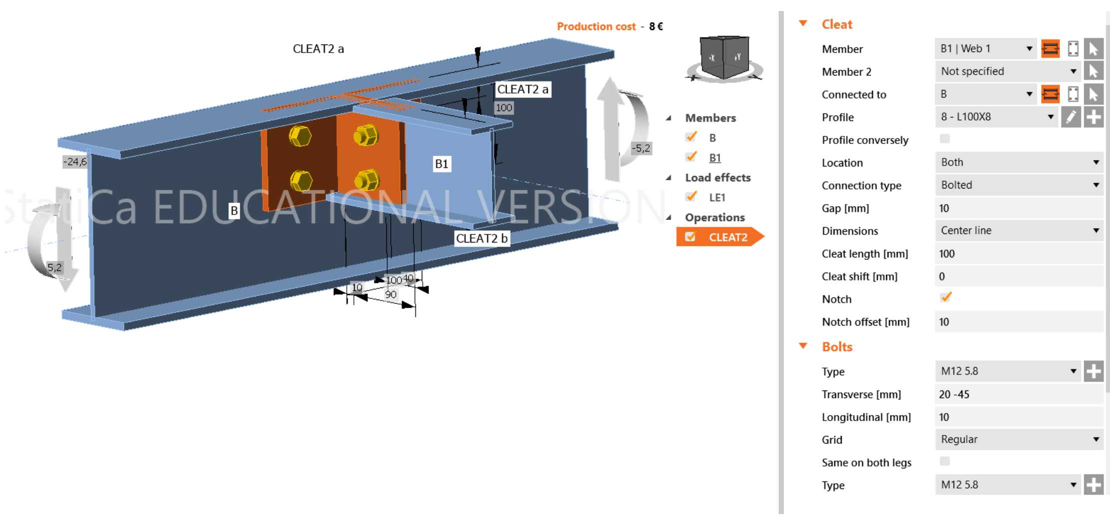


Figure 95. Design of main and secondary beams connection (IdeaStatica)

With the geometry and elements properly designed, it's necessary to input the loads. For this case, it will be used the loads presented on the sections that are connected the main and secondary beams, these values are found in the structural design on SAP2000. In the following figure, it's shown the load case that is presented for the case.

	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
	B / Begin	0,0	0,0	-24,6	0,0	5,2	0,0
	B / End	0,0	0,0	24,6	0,0	-5,2	0,0
>	B1 / End	0,0	0,0	0,0	0,0	0,0	0,0

Figure 96. Load case for main and secondary beams connection (IdeaStatica)

Once the geometry and also the loads are properly set on the model, and using the code and calculation settings, it's possible to run the model. In the following figures, it will be shown the equivalent stresses and the project report for the checked connection that has been reach in Idea Statica.

Project item Connection main-secondary beam

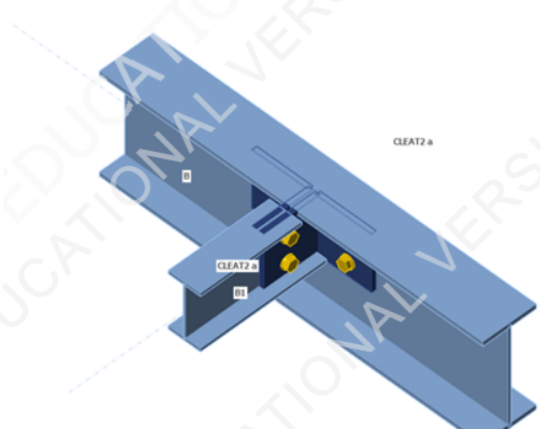
Design

Name	Connection main-secondary beam
Description	IPE180-IPE100
Analysis	Stress, strain/ loads in equilibrium

Members

Geometry

Name	Cross-section	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]	Forces in	X [mm]
B	1 - CON1(IPE180)	0,0	0,0	0,0	0	0	0	Node	0
B1	2 - CON1(IPE100)	-90,0	0,0	0,0	0	0	40	Bolts	63



Cross-sections

Name	Material
1 - CON1(IPE180)	S 355
2 - CON1(IPE100)	S 355
8 - L100X8	S 355

Bolts

Name	Bolt assembly	Diameter [mm]	fu [MPa]	Gross area [mm^2]
M12 5.8	M12 5.8	12	500,0	113

Load effects (forces in equilibrium)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	B	0,0	0,0	-24,6	0,0	5,2	0,0
	B	0,0	0,0	24,6	0,0	-5,2	0,0
	B1	0,0	0,0	0,0	0,0	0,0	0,0

Check

Summary

Name	Value	Status
Analysis	100,0%	OK
Plates	0,0 < 5,0%	OK
Bolts	1,4 < 100%	OK
Buckling	Not calculated	

Figure 97. Project report for main and secondary beam connection (IdeaStatica)

- **Gantry (HEB200-IPE180) connection:**

This connection allows to join the HEB 200 section that has been used to transfer loads to the foundation, and the principal beams (IPE 180). In the following figure, it's the shown the design reached in Idea Statica.

Figure 98. Design of Gantry (HEB200-IPE180) connection (IdeaStatica)

With the geometry and elements properly designed, it's necessary to input the loads. For this case, it will be used the loads presented on the supports points, these values are found in the structural design on SAP2000. In the following figure, it's shown the load case that is presented for the case.

LE1 [Load] **Copy** **Delete**

	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
	C / End	0,0	0,0	0,0	0,0	0,0	0,0
>	B / End	0,0	0,0	-25,5	0,0	-11,5	0,0

Figure 99. Load case of Gantry (HEB200-IPE180) connection (IdeaStatica)

Once the geometry and also the loads are properly set on the model, and using the code and calculation settings, it's possible to run the model. In the following figure. It will be shown the check of the connection in Idea Statica

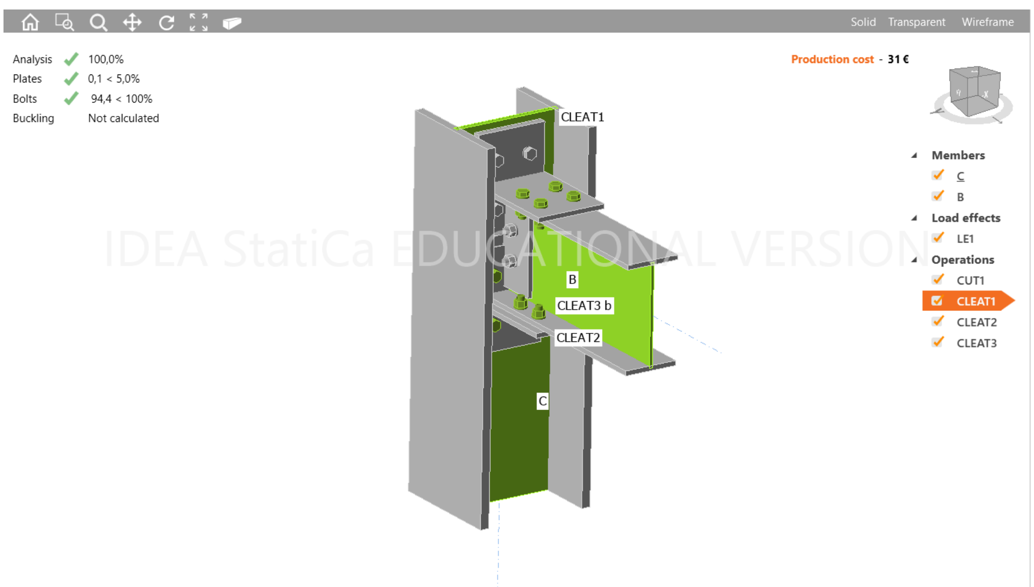


Figure 100. Check of Gantry (HEB200-IPE180) connection (IdeaStatica)

As it can be seen, the connection has been checked for the several considerations that were presented. Additionally, it will be shown the equivalent stresses and the deformed mesh of the correspondent connection in Idea Statica.

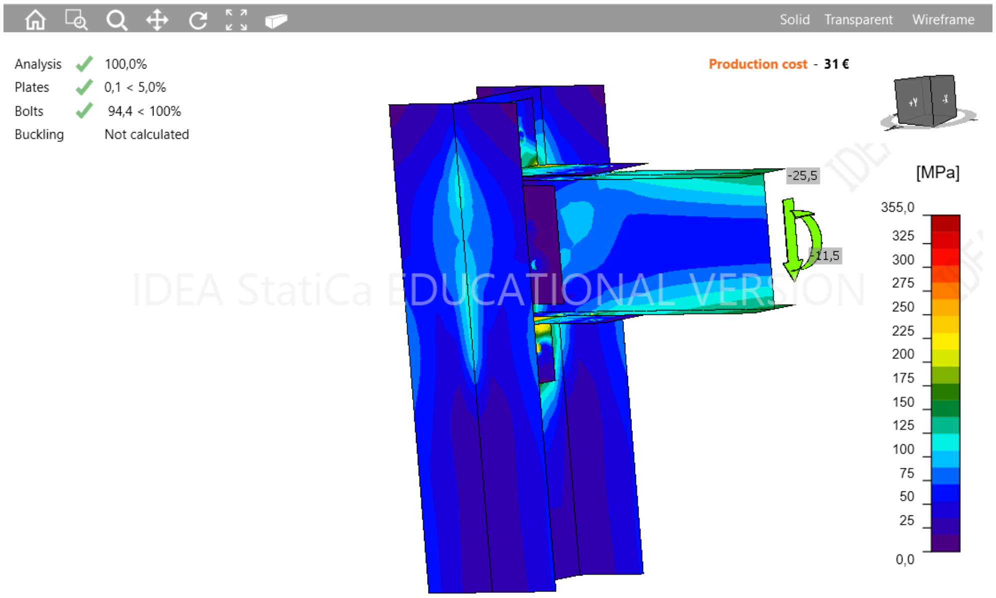


Figure 101. Equivalent stresses of Gantry (HEB200-IPE180) connection (IdeaStatica)

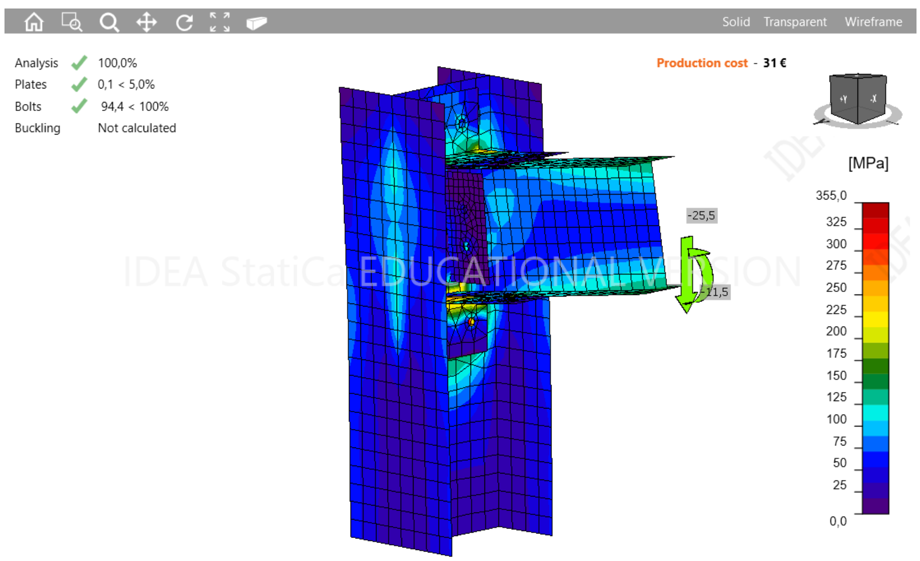


Figure 102. Deformed mesh of Gantry (HEB200-IPE180) connection (IdeaStatica)

Finally, it will be presented the project report for each element that has been designed and properly checked. This report is shown next.

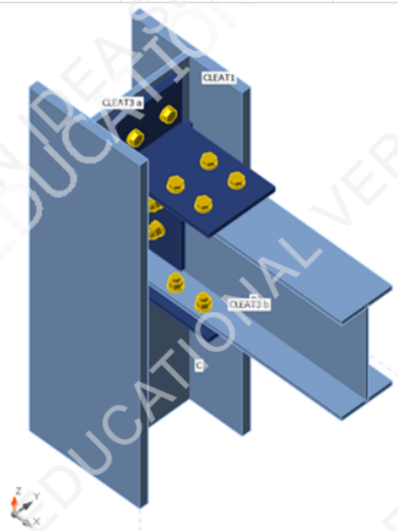
Design

Name	GANTRY CONNECTION
Description	HEB200-IPE180
Analysis	Stress, strain/ loads in equilibrium

Members

Geometry

Name	Cross-section	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]	Forces in
C	4 - HEB200	0,0	90,0	90,0	0	0	0	Node
B	5 - IPE180	0,0	0,0	0,0	0	0	0	Node



Cross-sections

Name	Material
4 - HEB200	S 355
5 - IPE180	S 355
6 - T(IPE360)	S 355
7 - L80X8	S 355

Bolts

Name	Bolt assembly	Diameter [mm]	fu [MPa]	Gross area [mm^2]
M12 5.8	M12 5.8	12	500,0	113

Load effects (forces in equilibrium)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	C	0,0	0,0	0,0	0,0	0,0	0,0
	B	0,0	0,0	-25,5	0,0	-11,5	0,0

Check

Summary

Name	Value	Status
Analysis	100,0%	OK
Plates	0,1 < 5,0%	OK
Bolts	94,4 < 100%	OK
Buckling	Not calculated	

Figure 103. Project report of Gantry (HEB200-IPE180) connection (IdeaStatica)

- **Gantry (HEB200-IPE100) connection:**

This connection corresponds to the one that will join the HEB200 section to last secondary beam (IPE100). As it was mentioned before, the design has been contemplated so that the slab transmits the loads in the direction of the main beams. Then, the secondary beam that is considered for the present connection, will not transmit any loads other than its own weight to the HEB 200 section. There is not necessity of evaluating any loads for the connection. However, the design has been performed on Idea Statica with the loads of the IPE 100 beam. In the following figures, it will be shown the design reached and the respective checked and project report by Idea Statica.

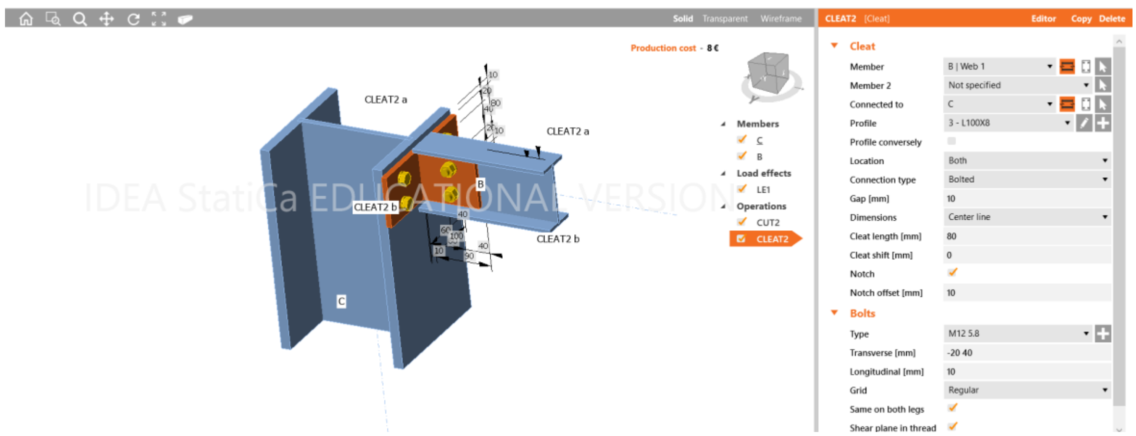


Figure 104. Design of Gantry (HEB200-IPE100) connection (IdeaStatica)

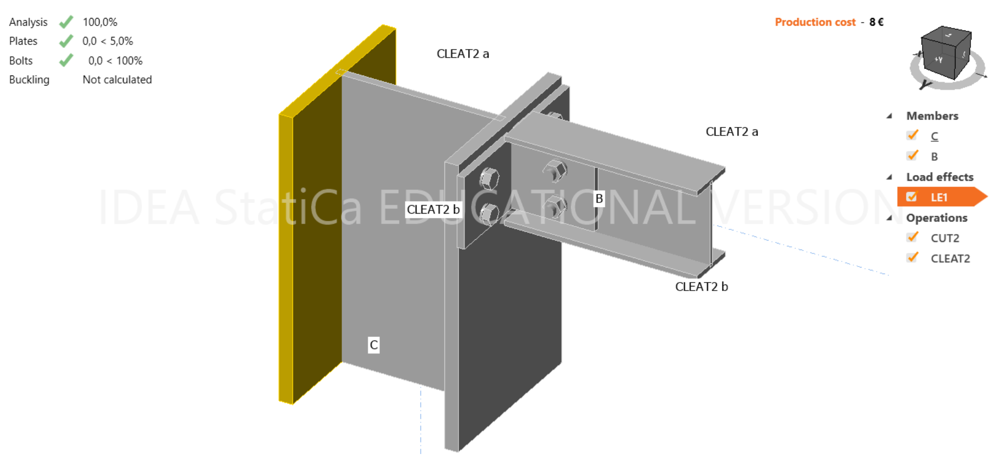


Figure 105. Check of Gantry (HEB200-IPE100) connection (IdeaStatica)

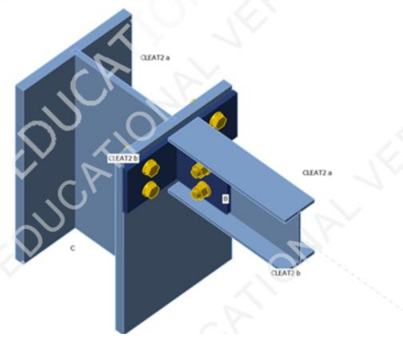
Design

Name	CON1
Description	
Analysis	Stress, strain/ loads in equilibrium

Members

Geometry

Name	Cross-section	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]	Forces in	X [mm]
C	1 - HEB200	0,0	90,0	0,0	0	0	0	Node	0
B	2 - IPE100	0,0	0,0	0,0	0	0	0	Bolts	160



Cross-sections

Name	Material
1 - HEB200	S 355
2 - IPE100	S 355
3 - L100X8	S 355

Bolts

Name	Bolt assembly	Diameter [mm]	fu [MPa]	Gross area [mm^2]
M12 5.8	M12 5.8	12	500,0	113

Load effects (forces in equilibrium)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	C	0,2	0,0	0,0	0,0	0,0	0,5
	B	0,0	0,0	0,0	0,0	0,0	0,0

Check

Summary

Name	Value	Status
Analysis	100,0%	OK
Plates	0,0 < 5,0%	OK
Bolts	0,0 < 100%	OK
Buckling	Not calculated	

Figure 106. Project report of Gantry (HEB200-IPE100) connection (IdeaStatica)

7.4. Design of foundation

The steel structure of the pedestrian bridge is completely designed, now, is necessary to design and evaluate the foundation. For this procedure, we must use all different applied loads that were already found.

Foundations are one of the essential parts of the structure. It is defined as the part that transfers all loads from structure to the soil. For the case study, it's been considered a shallow foundation taking into account that the structure of the pedestrian bridge corresponds to a lightweight structure.

The type of shallow foundation that will be designed is a wall footing or strip footing. Continuous footing is another name for wall footing. This kind is employed to disperse loads from structural or non-structural load-bearing walls to the ground without exceeding the soil's load-bearing capacity. Additionally, this type of foundation works well on sand soils, the kind of soil that will be considered as there is no further information about the soil than the reference that the foundation will be placed at sides of a river.

With the type of foundation decided, it's possible to start the designing of the wall footing which will be treated as a vertically loaded foundation on a sand soil. First, its needed to consider a section of the wall footing. In the following figure, is shown the geometry of the proposed foundation.

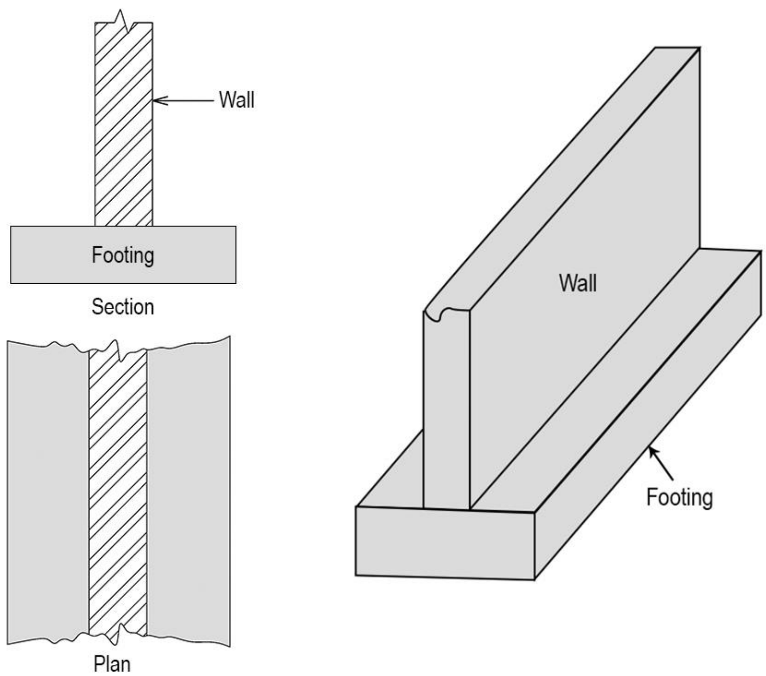


Figure 107. Wall footing

Where the width B is considered as 3,0 m, the height h is considered as 1.5 m and the length L is considered as 0.50 m.

7.4.1. Bearing capacity of foundation

Once the geometry is defined, it must be evaluated in order to verify it resistance. First, the real applied load needs to be calculated considering the weight of the structure.

$$Ptotal=P+\gamma c*B*L*h$$

Equation 14. Shallow foundations (Lancellota)

Where P is the load of the pedestrian bridge and the second portion of the equation is the load of the foundation. The γ' concrete is considered as 25 kN/m3 and the total load qof bridge and footing is 111,14 kN.

After having the design loads, we should evaluate the main parameters that have to be taken into account to develop the problem. The γ' soil is taken from the book of Lancellotta as 18 kN/m3. The cohesion is equal to zero because the soil used corresponds to a sand. The friction angle ϕp cannot be calculated due to lack of information, then a common value for this angle will be supposed as 31.5°

Next step, is to calculate the Bearing capacity of the foundation, for sands following book of Lancellota, is presented the following equation and all of the several factors involved.

$$q_{\lim} = \frac{1}{2}\gamma B N_\gamma s_\gamma i_\gamma b_\gamma g_\gamma + c' N_c s_c d_c i_c b_c g_c + q' N_q s_q d_q i_q b_q g_q$$

Equation 15. bearing capacity equation (Lancellota)

In order to solve this equation, we must find the different factors.

- Shape Factor that follows the next relation.

$$s_q = s_\gamma = 1 + 0.1\frac{1+\sin\varphi'}{1-\sin\varphi'}\frac{B}{L}; \qquad s_c = 1 + 0.2\frac{1+\sin\varphi'}{1-\sin\varphi'}\frac{B}{L}$$

Equation 16. A dimensional parameters Shallow foundations (Lancellota)

- Depth Factor

The depth of foundation is lower than 2 meters, then is taken as 1.

- Inclined Force Factor

$$i_\gamma = \left(1 - \frac{H}{N + BLc'\cot\varphi'}\right)^{m+1}; \qquad i_q = \left(1 - \frac{H}{N + BLc'\cot\varphi'}\right)^{m}$$

$$i_c = i_q - \frac{1-i_q}{N_c\tan\varphi'}; \qquad m = \frac{2+\frac{B}{L}}{1+\frac{B}{L}}$$

Equation 17. Inclined force factor (Lancellota)

- Inclined Founding Base Factor

Taken as 1 because the condition is not presented.

- Sloping Factor

Taken as 1 because the condition is not presented.

$$N_q = tg^2\left(45° + \frac{\varphi}{2}\right)\cdot e^{\pi\cdot tg\varphi}$$
$$N_c = (N_q - 1)\cot g\,\varphi$$
$$N_\gamma = 2(N_q + 1)\,tg\,\varphi$$

Equation 18. N factors (Lancellota)

Once having all different factors, the bearing capacity is shown in the following table.

	BEARING CAPACITY	
	qlim kPa	3923,208
ɣ	Nɣ	28,019
	sɣ	2,913
	iɣ	1,000
	bɣ	1,000
	gɣ	1,000
q	Nq	21,861
	sq	2,913
	dq	1,000
	iq	1,000
	bq	1,000
	gq	1,000

Table 7. qlim - Bearing capacity computacion for Wall footing foundation (kPa)

In order to define the resistance loads, it must be considered the portion of soil that was excavated.

$$q' = \gamma\text{Soil} * \text{h} = \frac{18\text{Kn}}{\text{m3}} * 1.5\text{m} = \frac{27\text{ kN}}{\text{m2}}$$

Equation 19. q' (kN/m2) (Lancellota)

Eurocode suggest a factor of safety of 2.3 to find the resistance value qRd, then we have.

Verifica	Coefficiente parziale
	(R3)
Carico limite	$\gamma_R = 2{,}3$
Scorrimento	$\gamma_R = 1{,}1$

Table 8. Partial coefficient for ULS (Eurocode)

$$qRd = \frac{qlim - q'}{FS} = 1694{,}0\ kPa$$

Equation 20. Resistance load (kN/m2) (Lancellota)

With the resistance load calculated, the acting load must be computed and follows the next equation.

$$qEd = \frac{Nd}{(B - 2e) * L}$$

Equation 21. Acting load (kN/m2) (Lancellota)

Where Nd is the vertical load applied, B and L considered the geometry of wall footing and e is the eccentricity. Then, Nd and e follows the equation:

$$Nd = P\ tot - \gamma\text{Soil} * \text{h} * \text{B} * \text{L} = 70{,}64$$

Equation 22. Axial force (kN) (Lancellota)

$$e = \frac{Mtot}{Nd} = 0.25\ m$$

Equation 23. eccentricity (m) (Lancellota)

Finally, the acting load qEd is found with a value of 55,95 kN/m2, being lower than the resistance load, then the wall footing foundations is verified.

qED net kPa	48,183
qRD net kPa	1694,003
qED<qRD	ULT

Table 9. Verification of ULS for foundation (kPa)

7.4.2. Assessment of sliding of foundation

The foundation shall be checked also against failure by sliding on the base. For the sliding resistance, Eurocode 7 suggest the following inequality:

$$Hd \ \leq Rd + Rp$$

Equation 24. Sliding resistance assessment (Eurocode 7, 2013)

Where:

- Hd is the design value of the active earth forces imposed on the foundation.
- Rd is the resistance due to friction
- Rp is the contribution to resistance due to passive thrust that may develop in front of the foundation.

In the following figure, it can be seen all different forces that will act in the foundation wall that has been considered for the case study.

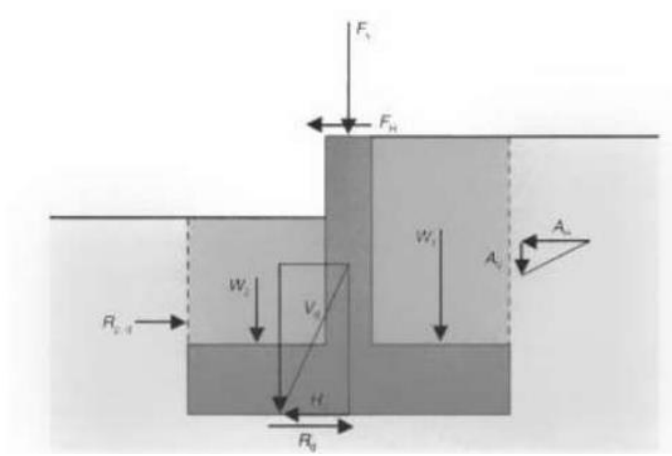


Figure 108. Actions to be included for checking against sliding (Eurocode, 2013)

For the case of the active forces, it will be evaluated the acting pressure that the soil is imposing against the foundation wall. The following figure, describes the behavior of this active force.

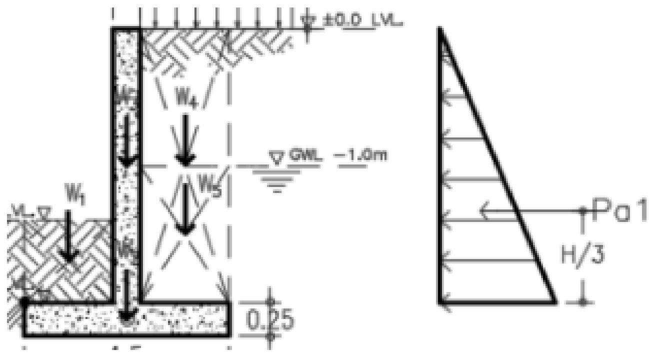


Figure 109. Representation of active force due to soil Hd

In order to evaluate the force Hd, it must be derivate the total force that is been applied by the soil and then, the active force will ve the resultant force at the distance h/3.

$$Hd = Area\Delta * ka * \gamma soil * h$$

Equation 25. Active force Hd

Ka represents the active pressure coefficient and follows the next relation.

$$ka = \frac{1 - \sin \emptyset}{1 + \sin \emptyset}$$

Equation 26. Active pressure coefficient

The resistance due to friction Rd, requires the involvement of the load caused by the wall foundation and the coefficient of friction. As there is absence of laboratory tests, literature has been followed finding that a normal value for coefficient of friction between soil and concrete is 0,6. Then, the resistance due to friction will present the following relation, taking into account the coefficient described and the weight of the foundation wall

$$Rd = \mu * Nd$$

Equation 27. Resistance due to friction Rd

Contribution resistance due to passive thrust, depends on the buried foundation height. For the case, it will be calculated a height of 0,50 meters, meaning that at one site of the foundation wall, 1,0 meters will be uncovered. The resistance due to passive thrust Rp, follows the next relation.

$$Rp = \gamma soil * kp * \frac{hp^2}{2}$$

Equation 28. Resistance due to friction Rd

As it can be seen, it appears the passive pressure coefficient, which follow the next relation.

$$kp = \frac{1 + \sin \emptyset}{1 - \sin \emptyset}$$

Equation 29. Passive pressure coefficient

Once all values are calculated, the assessment of sliding for foundation wall is presented in the following table.

ϕp degrees	31,50
ɣ' soil (kN/m3)	18
G footing (kN)	73,125
h wall (m)	1,5
ka	0,845
Hd (kN)	17,113
Coeff friction	0,600
Rd (kN)	43,875
kp	1,183
hp (m)	0,5
Rp (kN)	2,663
Rd+Rp (kN)	46,538
Hd<Rd+Rp	**ULT**
FOS	**2,7**

Table 10. Assessment of sliding for foundation wall

As it has been shown, the foundation wall is checked also against failure by sliding on the base. At the last part of the table that was presented, it can be seen the factor of safety that has been reached with the proposed foundation wall in terms of sliding.

7.4.3. Assessment of piping of foundation

Piping is a particular form of failure that occurs from a hydraulic process. The hydraulic process leads into the development of macropores and can be associated with landslides or collapse of buried structures in the ground. This phenomenon generally happens in earthen dams or water retaining embankments. In the following figure, it's shown an example of conditions that may cause piping.

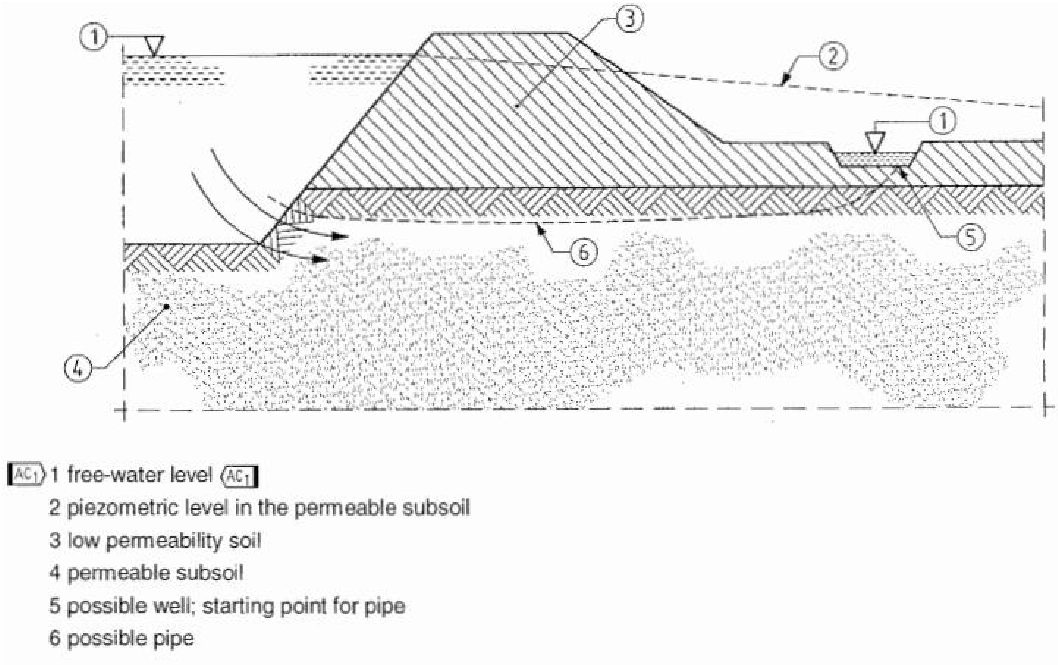


Figure 110. Example of conditions that may cause piping (Eurocode 7, 1997)

No mathematical formulation is provided in EN 1997-1 to validate the final limit state due to the complexity of failure by piping. In Eurocode 7 (Geotechnical design) 1997, different considerations are presented in order to prevent failure by piping. These considerations are presented as prescriptive measures for zones where prevailing hydraulic and soil conditions can lead to the occurrence of piping as corresponds to the case study.

- Application of berms on the land side of a retaining embankment, thus displacing the possible starting point of piping farther away from the structure and decreasing the hydraulic gradient at this point.
- Application of impermeable screens below the base of the hydraulic structure by which the ground-water flow is either blocked or the seepage path is increased, thereby decreasing the hydraulic gradient to a safe value.

During periods of extremely unfavorable hydraulic conditions such as floods, areas susceptible to piping shall be inspected regularly so that necessary mitigating measures can be taken without delay. Materials for such measures shall be stored in the vicinity (Eurocode EN7, 1997).

However, the NTC2018 (6.2.4.2) suggest a method to calculate the piping for foundations, sustaining that the geotechnical works must be checked against the possible limit states of lifting or siphoning.

Piping occurs if the upward flow of water is such as to cancel the resistance of the ground, resulting in the progressive collapse of the work. Then, if the hydraulic gradient equals the value of the critical hydraulic gradient. In order to verify this phenomenon, the following relation must be maintained.

$$ir \leq \frac{icr}{\gamma M}$$

Equation 30. Piping assessment (NTC 6.2.4.2., 2018)

The method that will be follow to do the verification of piping for the foundation, correspond to the calculation of the partial coefficient described. For the case study, several values will be assumed from the soil as the saturated unit weight of 20 kN/m3. The next figure represents he several measures needed for the assessment.

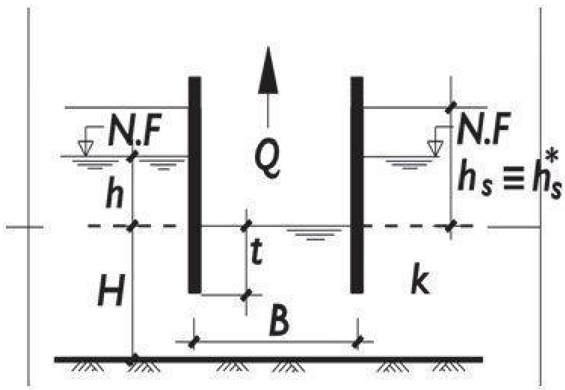


Figure 111. Piping assessment illustration

The critical hydraulic gradient is the icr and follows the next relation.

$$icr = \frac{\gamma'}{\gamma w}$$

Equation 31. Critical hydraulic gradient (NTC 6.2.4.2., 2018)

The hydraulic gradient is represented with ir and follows the next relation.

$$ir = \frac{\Delta u}{\gamma w * t}$$

Equation 32. Hydraulic gradient (NTC 6.2.4.2., 2018)

Where:

- Δu is the excess pore pressure:

$$\Delta u = \frac{\gamma w * h}{1 + \sqrt[3]{(1 + \frac{hs *}{t})}}$$

Equation 33. Excess pore pressure (NTC 6.2.4.2., 2018)

For the case of γM, NTC 2018 maintains the following considerations in predominantly vertical flow conditions:

- In the case of a free outflow border, the piping check is performed by checking that the hydraulic gradient ir is not higher than the critical hydraulic gradient ic divided by a partial coefficient. This partial coefficient will be $\gamma M=3$, if the average hydraulic gradient is taken as the effect of the actions. The partial coefficient will be $\gamma M= 2$, if it's considered the hydraulic gradient of outflow.

- In the presence of a load imposed on the outflow boundary, the check is carried out by checking that the pore pressure in excess of the hydrostatic condition is not higher than the effective vertical tension calculated in the absence of filtration, divided by a partial coefficient $\gamma M = 2$.

For the case study, it will be assumed a partial coefficient of $\gamma M= 2$, due to the conditions of the second case descripted by NTC2018.

Then, the calculations have been performed and shown in the following table.

ɣ' soil (kN/m3)	18
ɣ' water (kN/m3)	9,81
icr	1,835
hwater river (m)	1,600
t (m)	1,500
k1 (m/s)	0,010
k2 (m/s)	0,0001
hs (NF soil)	0,016
Δu (kN/m2)	7,0698611
ir	0,4504
ɣM	2,000
icr/ɣM	0,917
ir<icr/ɣM	**ULT**

Table 11. Piping assessment results

It's important to mention that even for a factor of safety of $\gamma M = 3$, the piping assessment still reach the verification.

8. Time analysis

The BIM application contains not just the designing process but also the planning, organization and scheduling of projects. For what it concerns the time scheduling 4D is the term used. The 4D refers to adding time to the 3D. This is done by linking objects from the 3D model, to a task in the construction schedule, using a 4D scheduling tool like Microsoft project or Navisworks23. Each software has the ability to visualize the whole construction project or just some phases of it, and see who timing of tasks affect the workflow.

A 4D building information modelling is a time-dependent model in which objects of the 3D digital model are intelligently linked with time or schedule information. This methodology allows to create animations and detect space-time conflicts that over ten years have proven to improve construction planning and production control as well as the onsite management of safety and workspaces (Jupp, J. 2017).

A 4D model can be used at all stages of the project. During the conceptual design, it can be used to discuss site logistics. It can be used to support subcontractor billings to the owner for finished work, demonstrate work to owners, give health and safety instructions, and validate the costs of completed work during the building phase. A 4D timetable is easy to maintain and update after it has been set up. Finally, the 4D modelling has become very popular dimension of BIM, due to its ability to give immediate clarity to all stakeholders in understanding the construction activities and space requirements on the building site (Warsaw University of Technology of Poland, 2015).

8.1. Definition of project management activities

For the project management that is about to start, it will be used the methodology Program Evaluation and Review Technique (PERT). This is a technique for examining the jobs in a schedule and figuring out a different Critical Path Method (CPM). The methodology PERT evaluates the time required to complete each task and its associated dependencies to determine the minimum time to complete a project. It estimates the shortest possible time each activity will take, the most likely length of time, and the longest time that might be taken if the activity takes longer than expected.

The methodology PERT, requires the definition of the project components that implies the construction process.

- Definition of activities and sub activities.
- Estimate of the duration of each of the individual activities.
- Estimation of the allocation of human resources for the execution of individual activities.
- Identification of the constraints and dependencies between the various activities. The relation between activities.

Before can be described the activities that will be part of the construction process, several conditions must be taken into account. This Project management will face many challenges associated with the fact the construction site corresponds to a remote area.

Remotes sites means an extreme working condition, often in isolated location, these sites are facing higher risks than average construction sites in well located areas. *"Remote projects have their unique problems that are caused mainly by the remoteness of the project itself in spite of rapid progress in the project management field. All project parties, experiences countless difficulties and cumbersome management problems, which negatively affect project quality and cause substantial delays and increases cost*". (Usman - Ibrahim, 2015).

Under normal conditions, construction sites naturally represent many complications, risks and uncertainties. However, these conditions are greatly increased when the area where a project is developed is remote. This condition is mainly due to the lack of communication with the work site, lack of qualified worker, since it is almost mandatory to have only local workers, which results in difficult management.

The construction sector council (2010), presented three global aspects that are considered challenging for the construction management in remote sites. First, there is a low-quality requirement from clients and auditors. Then, the lack of information in conditions, materials and costs in rural areas that means that the planned costs can increase significantly. Finally, also lack of qualified workers, contractors and machinery, such as the possibility of reaching the constructions sites with the tools commonly used in normal constructions. (Usman - Ibrahim, 2015).

There is a lot of research and articles dealing with the pitfalls and complexities of building a remote site and also its possible solutions. However, it is necessary to take into account that like a normal construction site, each remote site will have its own specific characteristics, which makes it impossible to draw a guide to face the challenges of each case. Then, for the case study, it is mandatory to account for all the aspects that were described during the representation of the Piedicavallo pedestrian bridge project.

For the time analysis of the project, that will be named as Pedestrian Bridge Construction, it can be identified 6 main groups of activities following a real construction process, the transportation of materials, the preliminary works, the foundation works, the assembly of the metal superstructure, the runway installations and the final works. Each of these main activities will be explained, detailing also the sub activities that are part of them.

Transportation of materials: As it was explained during the definition of the case study, the construction site contains a very complicated location, where is almost impossible to arrive at the zone with trucks, this problem leads into a necessity of transport materials such as Corten steel beams and perforated sheet, concrete materials and railings by helicopter. The helicopter must work during the several phases of the construction site due to the necessity of having all material at construction site in order to have a proper efficiency on works. Additionally, the transportation of lighter materials can be considered by car through the dirt road that exist.

Figure 112. Representation of transport of steel materials by helicopter (CTS bridges limited. (s.f.). "FRP bridges installed by helicopter – Scotland")

The previous figure, shows a construction of a two-fiber reinforced polymer (FRP) bridges at a remote site in central Scotland with the assistance of a helicopter.

Preliminary works: Preliminary works refer to all the activities that are involved in a construction site before the actual work commences, such as demolition, site clearance, site survey, soil survey, planning and construction of the camp. For the present project, the preliminary works are composed by the following activities.

- Construction of camp: The camp is important because is the place where all materials can be stored and also the place where it can be concentrated all administration and management settings.

Figure 113. Construction site camp representation

- Enclosure: A correct enclosure or delimitation of the construction area its important due to the necessity of create limits with people around, in order avoid any problems or accidents.

Figure 114. Construction site enclosure representation

- Site clearance: Site clearance is the process of removing waste as a way of making sure that an area is free from hazardous material and any other obstacles or huge mess as part of preparing the area for a construction or demolition project.

Figure 115. Site clearance representation

- Topographic delimitation: The topographic works, allows to have a graphic representation of the relief, its location, delimitation and size, through high-precision measuring instruments, processing and vectorization. Specially on a steel structure, the topographic work becomes indispensable since the precision on the location of each part of the structure is extremely important in order to have a proper assembly.

Figure 116. Topographic works representation

Foundation works: As it was explained in the correspondent chapter, a structural foundation is the part of a building that fixes it into the soil. Similar to how a tree's roots support its stem, these structures act as supports for the larger structures that are visible above the soil line.

- Excavation of foundation areas: Excavation work generally means the work that involves the removal of soil or rock from a site to form an open face, hole or cavity, using tools, machinery or explosives.

Figure 117. Excavation works representation

- Assembly of reinforcing steel for foundation: The foundation as a concrete structure, must have reinforcing steel. It's used in concrete to provide additional strength, tensile property for concrete structures is obtained by incorporating steel reinforcement. Both in tension and compression, the steel reinforcement is powerful. The tensile property provided by the steel reinforcement will prevent and minimize concrete cracks under tension loads.

Figure 118. Assembly of reinforcement steel for foundation representation

- Foundation cast in place concrete: Once the reinforcement is properly adapted in the excavation area, is possible to start the cast-in-place concrete, where the building material is poured, molded, and cured on site.

Figure 119. Foundation cast in place concrete representation

Corten steel superstructure assembly: The pedestrian bridge is considered with a Corten steel structure. These types of structures are made of essential steel parts associated with one another to convey stacks and give full rigidity. The structure is principally made out of steel shafts, steel sections, steel supports, and different segments made of steel and steel plates, and the joints, jolts, or bolts are typically associated between the layers or parts.

- Assembly of steel structure beams: Once the foundation works are done, it must have some days after in order to allow a proper curing time of concrete and reach the structural properties intended for the foundation work. Then, the Corten steel slabs can be assembly.

Figure 120. Assembly of steel structure beams representation

- Assembly of steel structure connections: During the assembly of the Corten steel structure, the connections must be also prepared and installed in order to build the entire skeleton of the structure.

Figure 121. Assembly of steel structure connections representation

Runway installations: During the architecture design, it was decided to have the runway with a perforated Corten steel sheet, additionally, the railings were decided to have a sinusoidal shape, which contains a proper behavior with the environment.

- Assembly of perforated Corten steel sheet: Once the super structure is completed, is possible to install the Corten steel perforated sheet which will be the runway for pedestrians' users.

Figure 122. Assembly of perforated Corten steel sheet representation

- Installation of railings: The installation of the railings can be done at the time that the Corten steel perforated sheet it's been assembly. It's important to notice that each bar of the railing must be proper cut and also placed in the correspondence place.

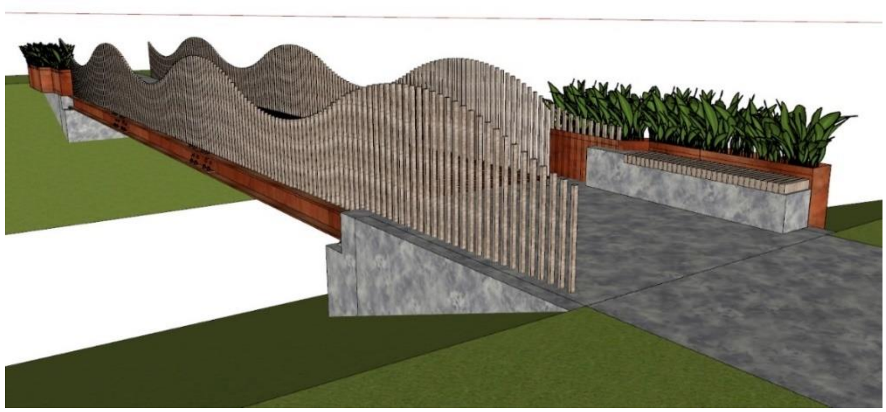


Figure 123. Installation of railings

Final works: Finally, when all pedestrian bridge structural parts and runways parts are placed, the final works can be done. These activities correspond to the decorations considered during the architectural design for the pedestrian bridge, also, the final works contend the proper cleaning and clearance from all materials for the construction process. The activities will be list next

- Installation of wood benches
- Pot planting

- Road demarcation
- Disassembly of work site

Figure 124. Final works representation

In order to start the time analysis of the present BIM project, using the PERT method, it will be described step by step the procedure that it has been decided to follow for the management of the project. This procedure intends to account all variables that needs to be faced during the complex construction of the pedestrian bridge.

First, it has been decided that the construction of the pedestrian bridge will require two different camps. The first one, will be placed in the closest town of the construction site, Piedicavallo (Biella). The second camp will be located directly in the site of the pedestrian bridge project.

The construction camp located in Piedicavallo, will be used to store and received from different suppliers all necessary materials for the entire project. This first construction camp will serve for administrative and coordination activities. Additionally, the designated camp will hold also works such as the assembly of the Corten steel beams, the assembly of the Connections for the steel sections (IPE 180 and IPE 100), the require works of the perforated Corten steel sheet, as well as the preparation of the railings for the runway. Finally, from this place will be transported to the construction site all materials by car or helicopter, depending on the case.

The second camp will be used for the store of materials and tools that are directly require for activities such as preliminary and foundations works. As the conditions of the zone where it will be constructed the pedestrian bridge are not the best, it will be intended that materials that are transported by car through the dirt road, can be used as soon as they arrive. Additionally, taking into account that will be impossible to have at site a machinery as a crane, to elevate the heavier materials (Corten steel sections), the helicopter must bring these kinds of materials placing them exactly where are needed. For the case of the structure, the helicopter must transport the assembled Corten steel structure and place it directly above the foundation.

After defining the necessity of having two different camps, the sequence of the construction process that has been decided will be listed.

- Construction of camp 1 in Piedicavallo (Biella)
- Receiving of materials in camp 1 for project that are transported by different suppliers to Piedicavallo (Biella).
- Transport of materials by car from Piedicavallo to construction zone. This first process of transport by car refers to materials for camp and enclosure, also different tools needed can be transported.
- Construction of camp 2 in site of work.

At this point, the works must be divided in the different locations (Piedicavallo and construction site). Then, as it has been explained, the assembly of principal beams of Corten structure will be held in camp 1 and may start when works in construction site are also started.

- Assembly of principal beams.
- Assembly of steel connections for principal beams (IPE180).
- Assembly of steel connections for secondary beams (IPE100).
- Assembly of secondary beams with principal beams.

For this case, it has been decided to assembly only the beams and connections of the pedestrian bridge. The railings and the Corten steel sheet need to be assembled and transported separately at construction site due to maximum load that is able to carry a helicopter in one trip. The weight of the assembled structure (Corten steel beams) is 755 kilograms. Looking into the "Prezziario di Piemonte, Edizione Straordinaria Luglio 2022" it's found the following information about the costs and types of transport by helicopter.

Sez.	Codice	Descrizione	U.M.	Euro	Manod. lorda	% Manod.	Note
18	18.P08.A05	MEZZI DI SERVIZIO Elicottero leggero per trasporto al gancio con portata operativa non superiore a 1200 kg, compresa ogni operazione di carico e scarico, consumi, personale di volo ed assistenza a terra, compreso ogni onere accessorio. Per ogni minuto di volo effettivo.					
18	18.P08.A05.005	fino a 1500 m s.l.m., con portata operativa di 600 kg, in fase di trasporto	min	27,89			
18	18.P08.A05.010	operativo fino a 2000 m s.l.m., con portata operativa da 700 a 1000 kg, in fase di trasporto	min	32,76			

Figure 125. Helicopters load capacity and costs per minute – Taken from: Prezziario di Piemonte, Edizione Straordinaria, Luglio 2022

Following with the construction process and with the materials from first process of transport completed, the preliminary works can be followed.

- Construction of camp 2.
- Enclosure of construction site.
- Site clearance.
- Topographic delimitation, where points for foundations works must be marked at locations that has been decided during different phases of design.

Up to this point, the foundation works can start, for this, a second process of transport needs to be done. As the foundation works required high quantities of material as sacks of cement and aggregates, the use of the helicopter will be required to transport from Camp 1 in Piedicavallo to Camp 2. The foundation works will follow the next steps.

- Transport of foundation materials by helicopter from camp 1 to camp 2.
- Excavation of foundation.
- Removal and transport of excavated soil (to around zones).
- Assembling of reinforcing steel for foundation.
- Cast in place concrete.
- Assembly of connections between foundation and Corten steel structure.

The foundation as a concrete structure, must require a minimum time before it achieves the intended strength, in the case of a normal concrete, the time required to achieved the maximum strength is approximately 28 days.

Once the foundation work is completed and has achieved the strength, a third process of transport from Piedicavallo to Camp 2 is required, where the Corten steel structure must be shipped by helicopter and placed above the foundation.

- Transport of Corten steel structure by helicopter from camp 1 to camp 2.
- Assembly of Corten steel structure with foundation.

Up to this point, the Corten steel structure is assembled, meaning that the runway installations followed by the final works can be performed. In order to proceed, the last transport process can be done, where the helicopter must move from camp 1 to camp 2 the different sections of perforated Corten steel sheets, as well as the Glulam wood materials (railings and benches). These works are listed next.

- Transport by helicopter from camp 1 to camp 2 of sections of perforated Corten steel sheets and well as the Glulam wood materials (railings and benches).
- Assembly of sections of perforated Corten steel sheet for floor.
- Installation of railings in Glulam wood.
- Installation of wood benches in Glulam.
- Pot planting.
- Road demarcations.
- Disassembly of construction camp 1.
- Disassembly of construction camp 1.

Once, the BIM time analysis process is defined and also the description of the activities is depicted, the software recognized as tool, will be shortly described before the analysis itself begins. In order to apply the 4D BIM methodology in this specific case study, the correct software search must guarantee the interoperability and coordination between the work done during the BIM steps presented before. Additionally, the software must help the further steps of the BIM project as the cost analysis.

8.2. Time analysis in Navisworks and Microsoft Project

Microsoft Project is a project management software that helps a manager create a schedule, allocate resources to projects, monitor progress, control costs, and assess workloads. For project management experts, it provides features like Gantt charts, Kanban boards, and project calendars.

The Microsoft Project software is able to manage the activities and sub-activities of a project, the priorities of the various activities, the organization and coordination of available resources, the deadlines and costs of the project and basically, thanks to MP it is possible to dynamically organize and control:

- Activities
- Resources
- Times
- Costs

In order to create the correspondent time analysis model in Microsoft Project, it's necessary to use the Revit 3D model from the architectural design. The use of this model, will allow to account in the time analysis process all different objects that are part of the design. Nevertheless, is not possible to export the model in Revit directly to Project. For this reason, it will be use also used a software from the Autodesk family called Navisworks. This software complements the 3D design packages of Autodesk and allows to generate planning simulations, space/time clash tests, animations and renderings to the work done. The use of Navisworks, allows a direct import of a Revit file as it's shown in the following figure.

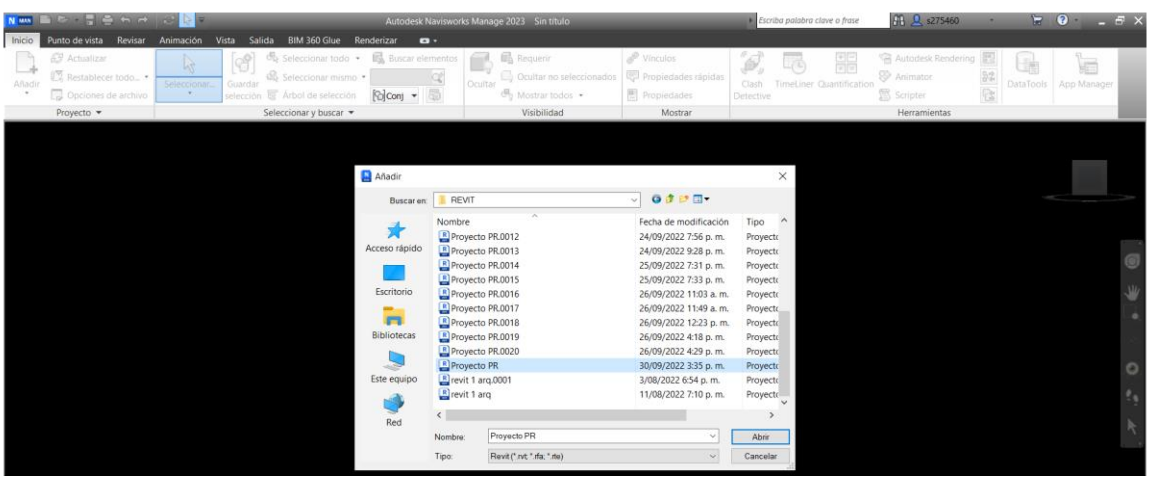


Figure 126. Import of 3D model from Revit (Navisworks)

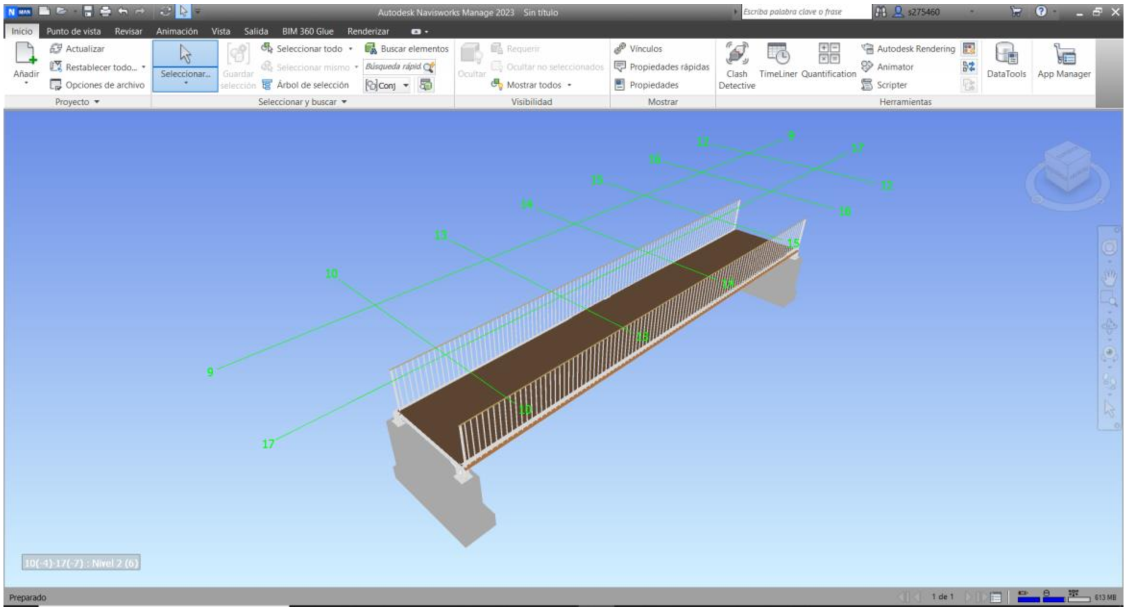


Figure 127. Import of 3D model from Revit (Navisworks)

As it can be seen, Revit and Navisworks presents a perfect interoperability. This is expected as both software are part of Autodesk family. It's important to mention that the time analysis process can be performed completely in Navisworks. However, as it will be shown during the thesis, Microsoft Project is a software that allows to consider all different aspects of the project management. Then, the process continues by recognizing from the 3D architectural model, all different elements of the structure as it's shown next.

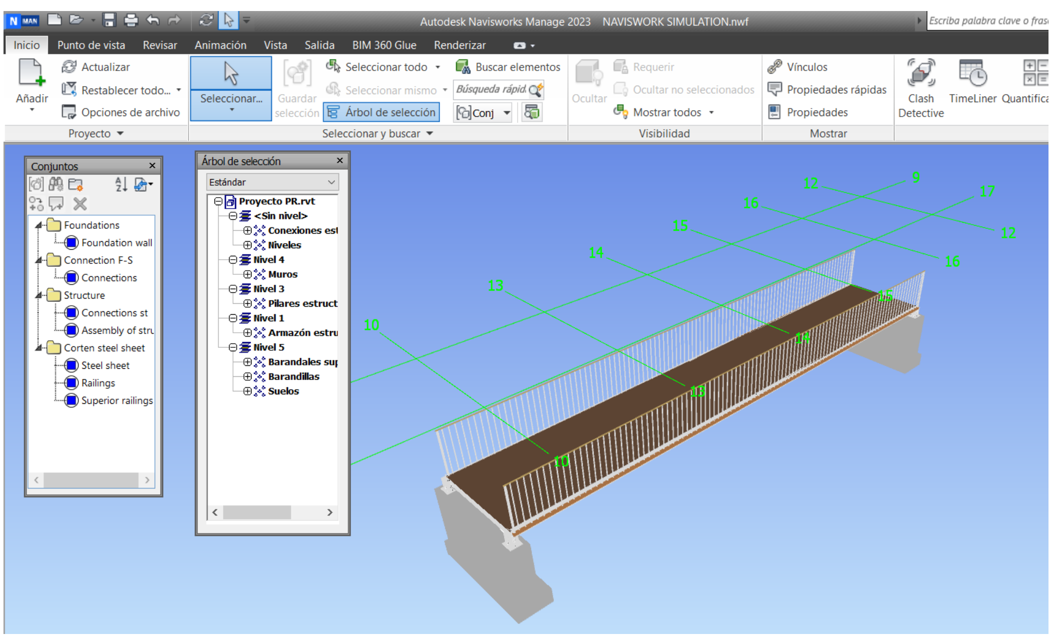


Figure 128. Elements of 3D model (Navisworks)

Once all elements are recognized and it's intended construction sequence is applied, it can be created the time liner of the project as shown in the following figure.

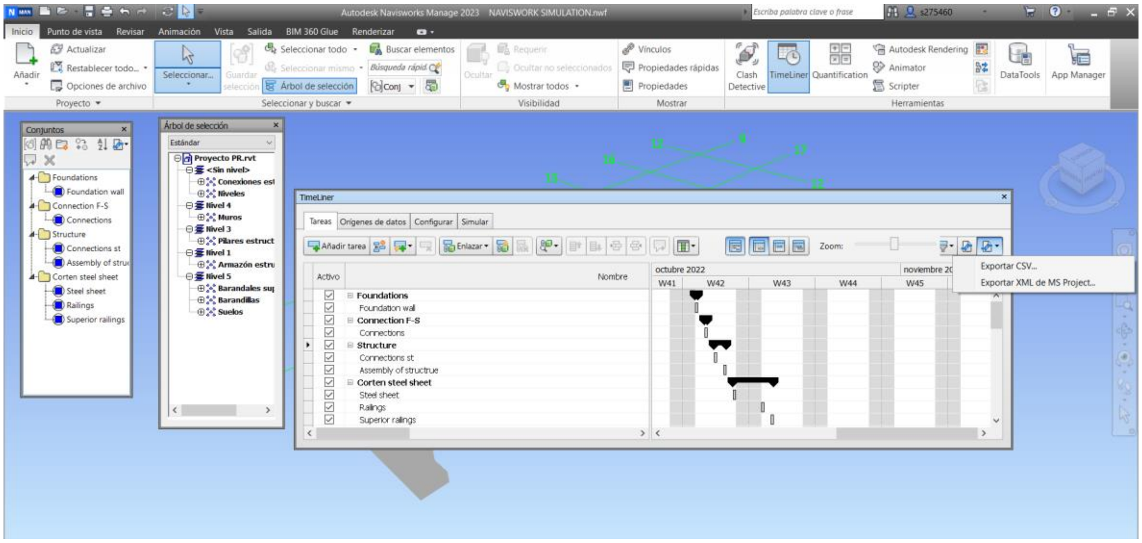


Figure 129. Time Liner of pedestrian bridge project (Navisworks)

As it can be seen, the use of Navisworks with the 3D model from Revit, allows to create almost directly a time liner of the project. Additionally, as it's shown in the upper right part of the last figure, this time liner can be exported to a MS Project file. Representing also a good interoperability between these two different tools even if they are not from the same family of software. The CSV file imported from Navisworks, is open from Microsoft Project as follows.

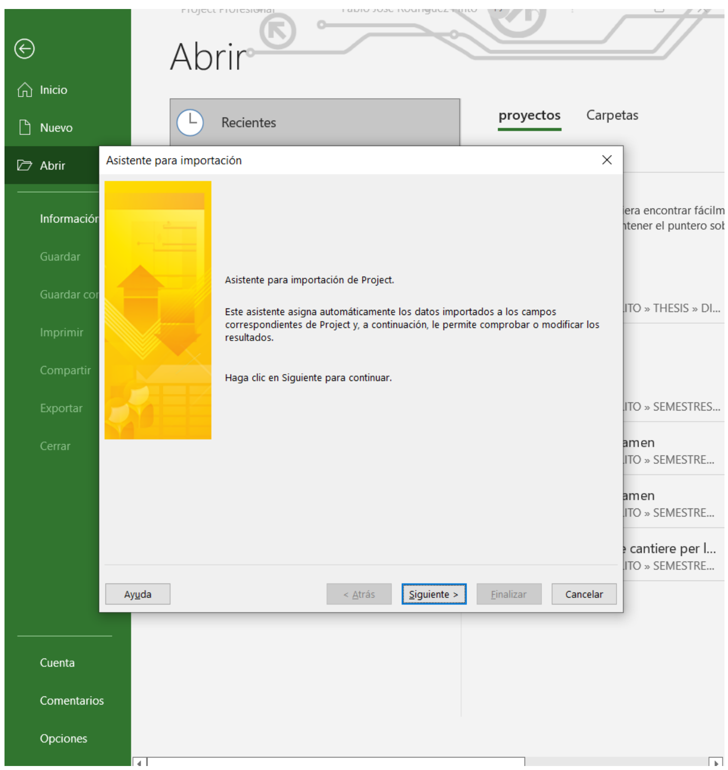


Figure 130. Import process from Navisworks (Microsoft Project)

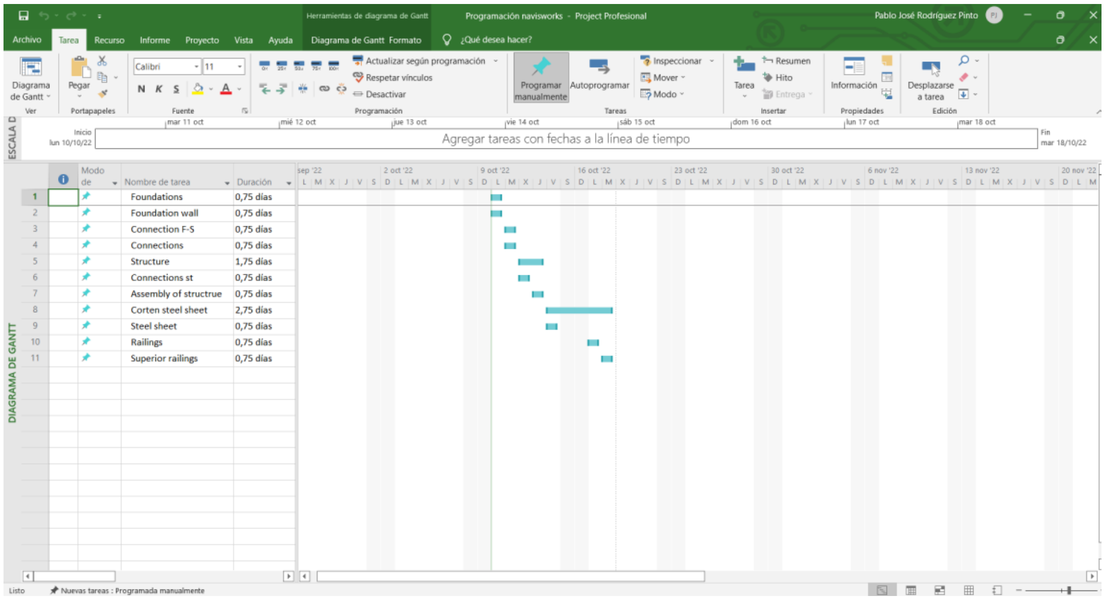


Figure 131. Activities imported from Navisworks (Microsoft Project)

As it can be seen, the activities correspond only to elements of the 3D model. However, it's important to mention that the time analysis requires a more precise information about the entire construction process. Then, in order to create a proper project management, it will be necessary to add all activities that were descripted before and are needed for the case study. Additionally, it's needed to configure the calendar that will be followed for the construction works. For the case study, is decided to follow a working calendar of 8 hours for each day of week (Monday to Friday), as is shown in the next figure.

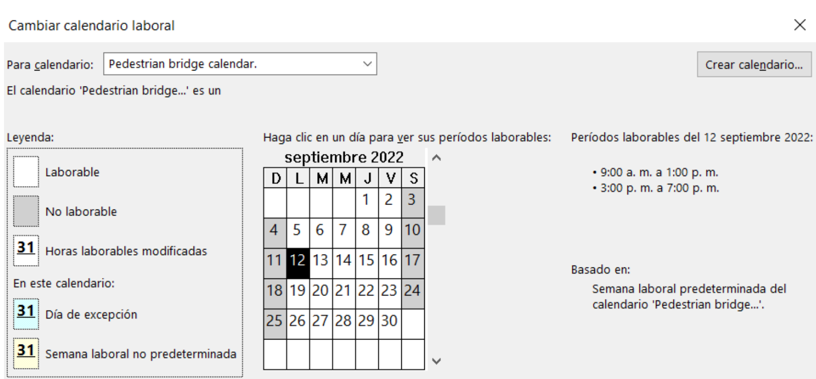


Figure 132. Working calendar for pedestrian bridge project – Microsoft project

Now, it's needed to use all activities or works for the construction of the pedestrian bridge that were previously described. Additionally, it's necessary to define the importance of each activity, this means that the activities and sub activities must be differentiated, allowing to organize the project works hierarchically. These main activities and sub activities are listed in Microsoft Project as follows.

	ℹ	Modo de	Nombre de tarea
1			**Pedestrian bridge Management**
2			**Transport of materials**
3			Transport of preliminary work materials by car from camp 1 to construction site
4			Transport of foundation materials by helicopter from camp 1 to camp 2
5			Transport of Corten steel structure by helicopter from camp 1 to camp 2
6			Transport by helicopter from camp 1 to camp 2 of sections of perforated Corten steel sheets and Glulam wood materials (railings and benches)
7			**Preliminary works**
8			Receiving of materials from suppliers
9			Construction of camp 1 in Piedicavallo (Biella)
10			Construction of camp 2 in site work
11			Enclosure of construction site
12			Site clearance
13			Topographic delimitation
14			**Foundation works**
15			Excavation of foundation
16			Removal and transport of excavated soil (to around zones)
17			Assembling of reinforcing steel for foundation
18			Cast in place concrete
19			Assembly of connections between foundation and Corten steel structure
20			**Corten steel superstructure assembly**
21			Assembly of principal beams
22			Assembly of steel connections for principal beams (IPE180) in camp 1
23			Assembly of connections for secondary beams (IPE100) in camp 1
24			Assembly of secondary beams with principal beams in camp 1
25			Assembly of Corten steel structure with foundation
26			**Runway installations**
27			Assembly of sections of perforated Corten steel sheet for floor
28			Installation of railings in Glulam wood
29			**Final Works**
30			Installation of wood benches in Glulam
31			Pot planting
32			Road demarcation
33			Disassembly of construction camp 1
34			Disassembly of construction camp 2

Figure 133. Definition of main activities and sub activities - Microsoft Project

As it can be seen, this procedure that was performed allows also to organize the project and for instance, will help to summarize the different main activities. Once the activities are completely defined and organized, it can be introduced the duration of each construction work of the pedestrian bridge. The duration of the activities is chosen considering the difficulties and lack of uses of many tools or machinery that can be used in a normal construction site, however, the durations are also chosen depending on the necessity to occupy, utilize or rent several equipment's that are necessary, then, an increment on duration of activities and especially on the ones that are considered as critical ones will increase also the costs of the entire project. This critical path will be analyzed subsequently when results from time analysis are obtained. Thus, in the following figure are shown the activities with their respective durations.

		Mod de	Nombre de tarea	Duración
1			**Pedestrian bridge Management**	**50 días**
2			**Transport of materials**	**41 días**
3			Transport of preliminary work materials by car from camp 1 to construction site	1 día
4			Transport of foundation materials by helicopter from camp 1 to camp 2	1 día
5			Transport of Corten steel structure by helicopter from camp 1 to camp 2	0,5 días
6			Transport by helicopter from camp 1 to camp 2 of sections of perforated Corten steel sheets and Glulam wood materials (railings and benches)	1 día
7			**Preliminary works**	**7 días**
8			Receiving of materials from suppliers	1 día
9			Construction of camp 1 in Piedicavallo (Biella)	1 día
10			Construction of camp 2 in site work	1 día
11			Enclosure of construction site	1 día
12			Site clearance	1 día
13			Topographic delimitation	1 día
14			**Foundation works**	**10 días**
15			Excavation of foundation	5 días
16			Removal and transport of excavated soil (to around zones)	2 días
17			Assembling of reinforcing steel for foundation	4 días
18			Cast in place concrete	1 día
19			Assembly of connections between foundation and Corten steel structure	1 día
20			**Corten steel superstructure assembly**	**41 días**
21			Assembly of principal beams	5 días
22			Assembly of steel connections for principal beams (IPE180) in camp 1	1 día
23			Assembly of connections for secondary beams (IPE100) in camp 1	1 día
24			Assembly of secondary beams with principal beams in camp 1	5 días
25			Assembly of Corten steel structure with foundation	0,5 días
26			**Runway installations**	**3 días**
27			Assembly of sections of perforated Corten steel sheet for floor	2 días
28			Installation of railings in Glulam wood	2 días
29			**Final Works**	**7 días**
30			Installation of wood benches in Glulam	1 día
31			Pot planting	1 día
32			Road demarcation	1 día
33			Disassembly of construction camp 1	1 día
34			Disassembly of construction camp 2	1 día

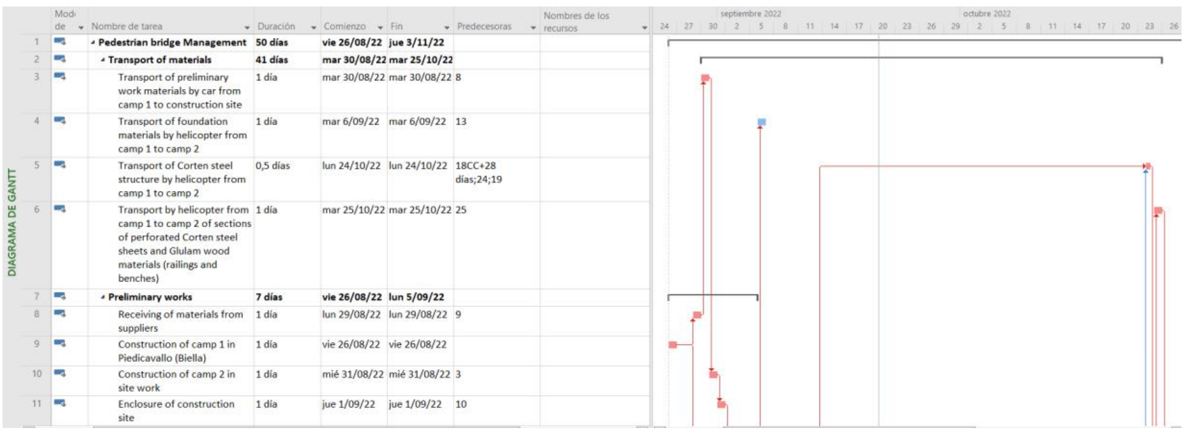
Figure 134. Duration of activities in Microsoft project

The assignment of durations to the constructions works will not bring a proper time estimate of the entire project, this is because it's needed to introduce also the path that must follow each activity, meaning that each activity must be preceded from another one. This decision is completely dependent on the criteria of the project manager. Microsoft project allows to work with a tool that is called predecessor, which works attaching a specific activity to another one and allowing to start or finish this activity depending on the command that is introduced. There are basically four types of connection to create a work schedule:

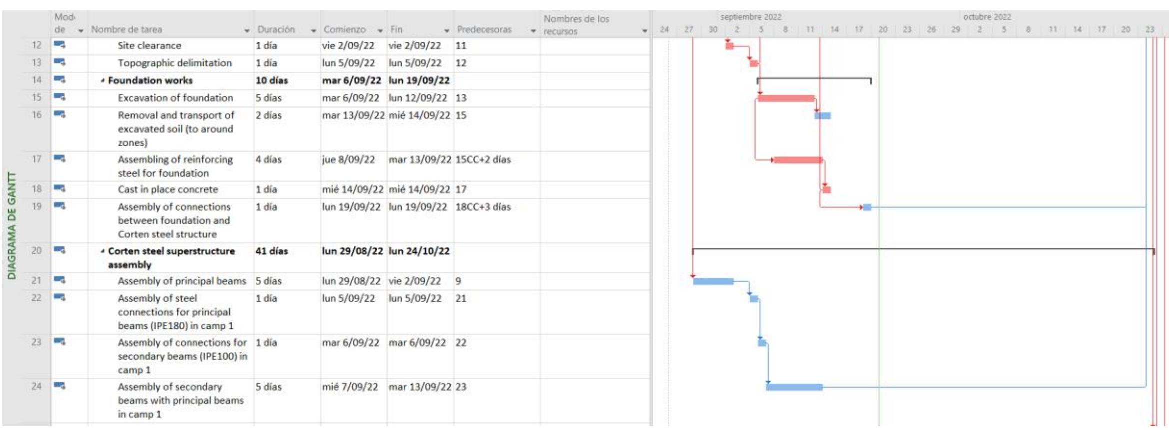
- End - Start (FC): The dependent activity cannot begin until the dependent activity does not it has been completed.

- Start – Start (CC): The dependent activity cannot begin until the dependent activity does not has begun. The dependent business can start at any time after the start of the business from which it depends on.
- End - End (FF): The dependent activity cannot be completed until the activity from which depends has not been completed or the dependent activity can be completed at any time after the completion of the activity on which it depends.
- Start - End (CF): The dependent activity cannot be completed until the activity from which it depends has not begun or the dependent activity can be completed at any time after the start of the activity on which it depends.

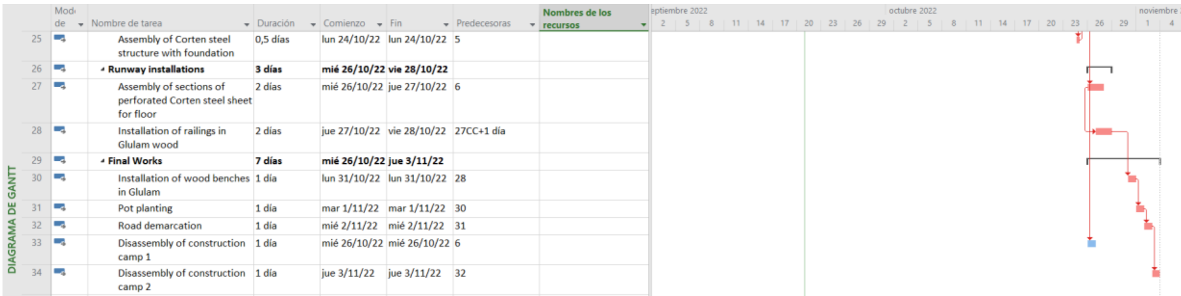
The definition of the dependency on activities will also give the Gantt Diagram which is commonly used in project management to show activities (tasks or events) displayed against time. On the left of the following figure, it will be presented the list of the activities and along the top is a suitable time scale. A bar is used to symbolize each activity, and the position and length of the bar correspond to the activity's beginning, middle, and finish dates.



	Modo de	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras	Nombres de los recursos
1		**Pedestrian bridge Management**	**50 días**	**vie 26/08/22**	**jue 3/11/22**		
2		**Transport of materials**	**41 días**	**mar 30/08/22**	**mar 25/10/22**		
3		Transport of preliminary work materials by car from camp 1 to construction site	1 día	mar 30/08/22	mar 30/08/22	8	
4		Transport of foundation materials by helicopter from camp 1 to camp 2	1 día	mar 6/09/22	mar 6/09/22	13	
5		Transport of Corten steel structure by helicopter from camp 1 to camp 2	0,5 días	lun 24/10/22	lun 24/10/22	18CC+28 días;24;19	
6		Transport by helicopter from camp 1 to camp 2 of sections of perforated Corten steel sheets and Glulam wood materials (railings and benches)	1 día	mar 25/10/22	mar 25/10/22	25	
7		**Preliminary works**	**7 días**	**vie 26/08/22**	**lun 5/09/22**		
8		Receiving of materials from suppliers	1 día	lun 29/08/22	lun 29/08/22	9	
9		Construction of camp 1 in Piedicavallo (Biella)	1 día	vie 26/08/22	vie 26/08/22		
10		Construction of camp 2 in site work	1 día	mié 31/08/22	mié 31/08/22	3	
11		Enclosure of construction site	1 día	jue 1/09/22	jue 1/09/22	10	



	Modo de	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras	Nombres de los recursos
12		Site clearance	1 día	vie 2/09/22	vie 2/09/22	11	
13		Topographic delimitation	1 día	lun 5/09/22	lun 5/09/22	12	
14		**Foundation works**	**10 días**	**mar 6/09/22**	**lun 19/09/22**		
15		Excavation of foundation	5 días	mar 6/09/22	lun 12/09/22	13	
16		Removal and transport of excavated soil (to around zones)	2 días	mar 13/09/22	mié 14/09/22	15	
17		Assembling of reinforcing steel for foundation	4 días	jue 8/09/22	mar 13/09/22	15CC+2 días	
18		Cast in place concrete	1 día	mié 14/09/22	mié 14/09/22	17	
19		Assembly of connections between foundation and Corten steel structure	1 día	lun 19/09/22	lun 19/09/22	18CC+3 días	
20		**Corten steel superstructure assembly**	**41 días**	**lun 29/08/22**	**lun 24/10/22**		
21		Assembly of principal beams	5 días	lun 29/08/22	vie 2/09/22	9	
22		Assembly of steel connections for principal beams (IPE180) in camp 1	1 día	lun 5/09/22	lun 5/09/22	21	
23		Assembly of connections for secondary beams (IPE100) in camp 1	1 día	mar 6/09/22	mar 6/09/22	22	
24		Assembly of secondary beams with principal beams in camp 1	5 días	mié 7/09/22	mar 13/09/22	23	



	Modo de	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras	Nombres de los recursos
25		Assembly of Corten steel structure with foundation	0,5 días	lun 24/10/22	lun 24/10/22	5	
26		**Runway installations**	**3 días**	**mié 26/10/22**	**vie 28/10/22**		
27		Assembly of sections of perforated Corten steel sheet for floor	2 días	mié 26/10/22	jue 27/10/22	6	
28		Installation of railings in Glulam wood	2 días	jue 27/10/22	vie 28/10/22	27CC+1 día	
29		**Final Works**	**7 días**	**mié 26/10/22**	**jue 3/11/22**		
30		Installation of wood benches in Glulam	1 día	lun 31/10/22	lun 31/10/22	28	
31		Pot planting	1 día	mar 1/11/22	mar 1/11/22	30	
32		Road demarcation	1 día	mié 2/11/22	mié 2/11/22	31	
33		Disassembly of construction camp 1	1 día	mié 26/10/22	mié 26/10/22	6	
34		Disassembly of construction camp 2	1 día	jue 3/11/22	jue 3/11/22	32	

Figure 135. Gantt diagram - Microsoft Project

The Gannt diagram allows to see what the various activities are, when each activity begins and ends, how long each activity is scheduled to last, where activities overlap with other activities and finally, the start and end date of the whole project. With this final step, the time analysis is completed and can be analyzed.

8.3. Time analysis results

Until now, the time analysis is been performed, obtaining the Gantt diagram and the total expected duration of the Piedicavallo pedestrian bridge project. For the case of the duration of works, a total of 50 working days was reached, which means that in terms of calendar, the project can be completed after 2 months and 1 week. It's important to clarify that Microsoft Project allows to specified the start day of the project, so for further analysis, the Gant diagram will be obtained without any problem.

As it was mentioned before, the fulfillment of the duration of project will allow also to reach the estimated costs during the real construction process and a delayed will bring extra costs due to the necessity of counting more time with human resources, equipment, tools and construction machinery. As a project manager, there is a necessity of accomplish this estimated duration, then it must be avoided many as possible uncertainties that can be presented during a construction work, these uncertainties are presented:

- Lack of project controls
- Issues with suppliers and subcontractors
- Environmental or weather conditions
- Unknown construction site conditions

Considering the complex situation that is presented in the construction site due to the climatic conditions and also the difficulties to reach the construction site, the project planning and the start of the project can be suggested to be scheduled for the months of the year where is not presented climate conditions as heavy rains and also snow, which means, months from April to October.

A very important result that is obtained from a time analysis of a project is the critical path. This is basically the sequence of dependent tasks or activities and the amount of time that it takes to complete them from beginning to end. All tasks are significant, but only some are critical. These critical activities are the ones that are considered and affects directly finish date. Then, if any task on the critical path is late, the whole project is late and also, when the critical path is finished, the entire project is finished.

In the following figure, it will be shown the entire project with its activities, the Gantt diagram and also the critical path of it.

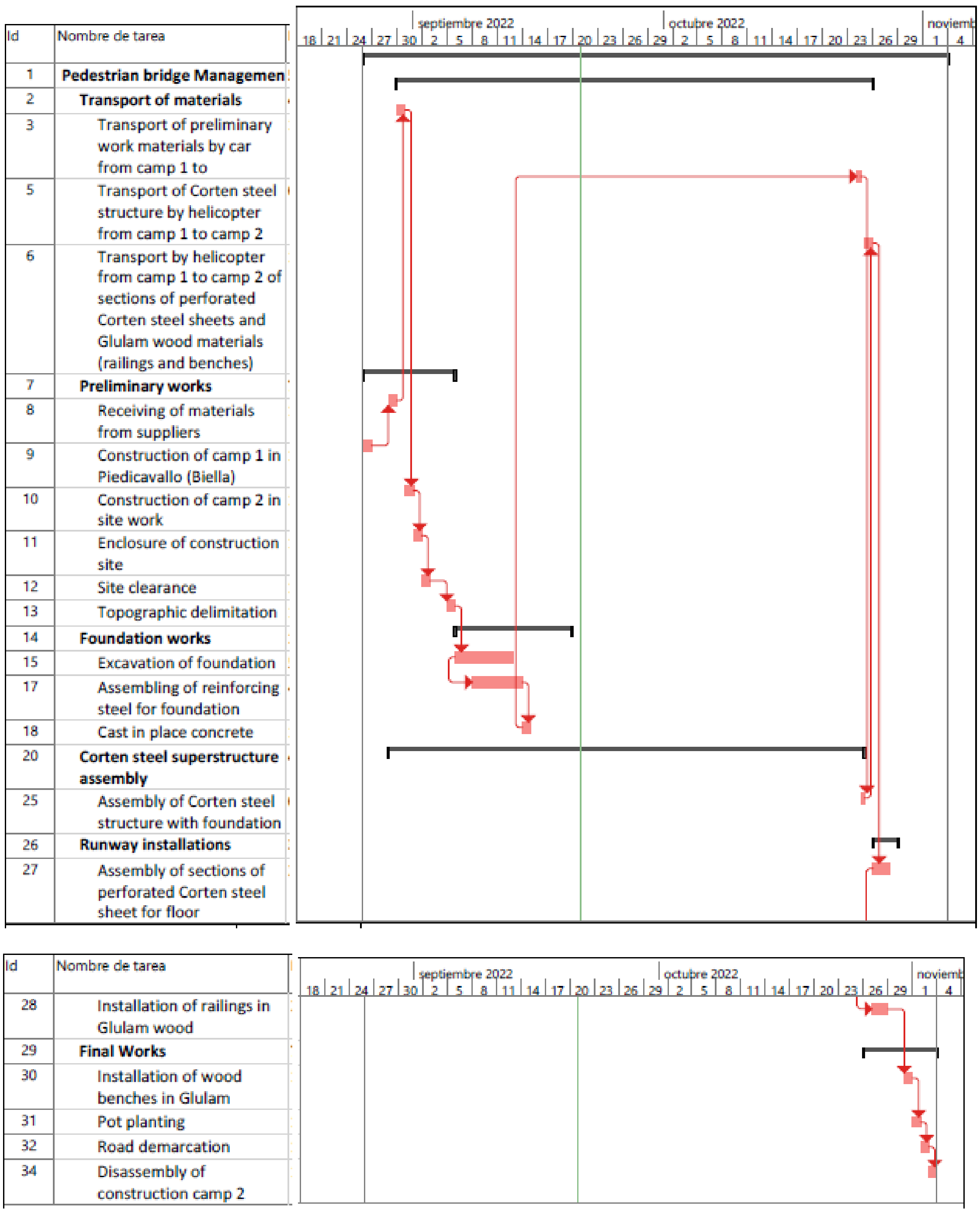


Figure 136. Gantt diagram with Critical Path - Microsoft Project

In Microsoft project, the critical path and critical activities are marked in red as it can be seen in last figure. As its shown, almost all main activities have critical sub activities, which means that during the development of the construction project, the manager must be very attentive of every single activity, because a delay on at least one of them, will induce on a delay of the entire project, then, creating an increase also in costs.

It's important to clarify that Microsoft Project is also able to manage information about resources and costs for projects. As the present thesis also aims to estimate the entire cost of the project, it will be analyzed the resources in terms of workers for each activity that must be held. For this, the workers will be divided in three different types depending on the conditions, necessities, capacities and knowledge for each activity. The resources are shown next.

HOJA DE RECURSOS

		Nombre del	Tipo	Iniciales
1		Common worker preliminary works	Trabajo	CW P
2		Qualified worker preliminary works	Trabajo	QW P
3		Common worker Foundation works	Trabajo	CW F
4		Qualified worker Foundation works	Trabajo	QW F
5		Specialized worker Foundation works	Trabajo	SW F
6		Common worker Structure aseembly	Trabajo	CW SA
7		Qualified worker Structure aseembly	Trabajo	QW SA
8		Specialized worker Structure aseembly	Trabajo	SW SA
9		Common worker Runway installations	Trabajo	CW RI
10		Qualified worker Runway installations	Trabajo	QW RI
11		Specialized worker Runway installations	Trabajo	SW RI
12		Common worker Final works	Trabajo	CW FF
13		Qualified worker Final works	Trabajo	QW FF

Table 12. List of resources - Microsoft Project

As it can be seen, some main activities have just common and qualified workers, different to others that also have specialized workers. This fact depends on the requirements in terms knowledge that represent each type of activity in the construction field.

Now, it will be assigned the resources to the different activities that are part of the construction process of the pedestrian bridge. The assignation of resources is performed following the example shown in next figure for the activity construction of camp 1 in Piedicavallo. For this case, it has been decided to use 1 qualified worker and 1 common worker.

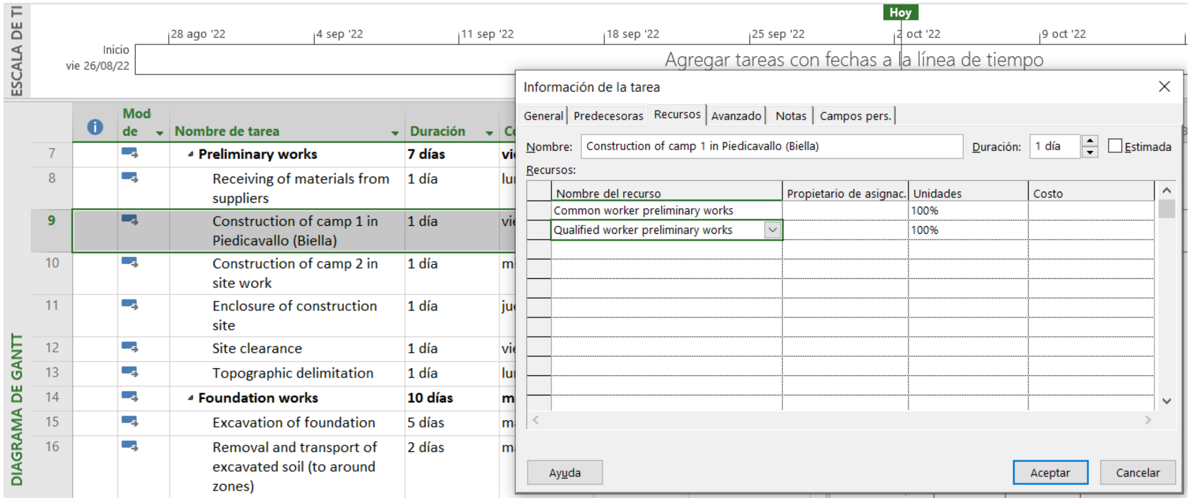


Figure 137. Resources for activity of Preliminary works - Microsoft Project

The same procedure it's performed for all different activities taking into account the specific requirements. Then, is possible to print the list of resources that are needed for the project with it corresponded required hours.

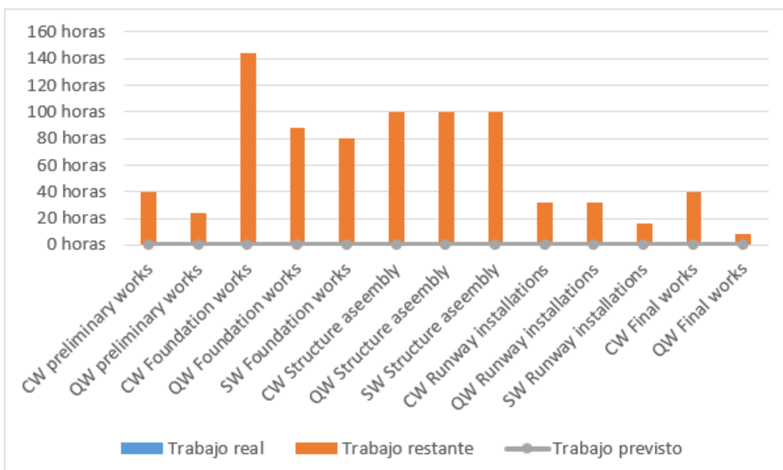


Figure 138. Work status of work resources - Microsoft Project

As it can be seen, it was obtained the total work hours of each type of worker. This information will be very useful in the determination of total costs. In the following table, it's shown the summary of work hours of each human resource and also the dates that the worker will be doing all labors.

Nombre	Comienzo	Fin	Trabajo restante
CW preliminary works	vie 26/08/22	lun 5/09/22	40 horas
QW preliminary works	vie 26/08/22	lun 5/09/22	24 horas
CW Foundation works	mar 6/09/22	mié 14/09/22	144 horas
QW Foundation works	mar 6/09/22	lun 19/09/22	88 horas
SW Foundation works	mar 6/09/22	mié 14/09/22	80 horas
CW Structure aseembly	lun 29/08/22	lun 24/10/22	100 horas
QW Structure aseembly	lun 29/08/22	lun 24/10/22	100 horas
SW Structure aseembly	lun 29/08/22	lun 24/10/22	100 horas
CW Runway installations	mié 26/10/22	vie 28/10/22	32 horas
QW Runway installations	mié 26/10/22	vie 28/10/22	32 horas
SW Runway installations	mié 26/10/22	jue 27/10/22	16 horas
CW Final works	mié 26/10/22	jue 3/11/22	40 horas
QW Final works	lun 31/10/22	lun 31/10/22	8 horas

Table 13. List of resources with work hours - Microsoft Project

Finally, it´s important to mention that Microsoft Project allows to do further analysis about cost estimate analysis such as cashflows and the budget of the project. However, the model from Microsoft Project has managed to meet all expectations regarding the present chapter, time analysis.

9. Cost estimate analysis

Cost estimating is an important aspect on building process. The process consists in digitizing or making a manually takeoff from the paper drawings and designs in order to estimate all quantities, however, the potential of errors and inaccuracies from original designs can be high. By Using a BIM instead of drawings, the process can be generated directly from the model, having a consistency with the design and leading into saving of time work and reduction of errors, therefore a reduction also in costs itself.

As it was said, one of the main steps of a BIM project is the cost management. During the development of the BIM modelling through the recent years, the quantification process increasingly becomes automated and the challenge for management profession is to increase also the level of detail of the cost modelling and the possibility to share the cost information with the project team. The automatization of processes such a quantification, will reduce highly time spent on technical work, adding efficiency and accuracy.

As prove of the importance of the development of 5D (Cost) in BIM Modelling, in 2008 The Association for the Advancement of Cost Engineering International (AACE), the American Society of Professional Estimators (ASPE), the United States Army Corps of Engineers, the General Services Administration (GSA) and the National Institute of Building Sciences (NIBS), worked together to solve cost engineering related problems in order to give facilities to the industry under the building SMART Alliance.

In terms of BIM development, John Eynon in his “Construction manager’s BIM Handbook” suggest that the output of a cost analysis can be in a form that cost planning or also an estimating software can accept, although how this actually works needs to be defined upfront to make the technical aspects feasible. As project-based data libraries are built over time, this will make it possible to obtain information quickly and effectively to create cost plans.

The function of the quantity surveyor (QS) is changing as BIM procedures take the form of standards and technologies. The old 2D costing process is rapidly being replaced by 3D measuring and information data management. In a standard BIM project, the information created by the different designers and consultant does not, contrary to common belief, only consist of a digitalized 3D model, but also comprises information regarding that model and the whole project in general (Guillemet, 2016).

With the information just presented, it can be said that the 5D in BIM Modelling is a function of construction management that must involve knowledge about several topics that concerns the AEC industry

Cost estimation is an important function of construction management that requires specific skills and knowledge. The cost engineer must have knowledge about structures, building engineering and construction engineering. A construction project's failure can result from incorrect estimates, which can also cause budget and time overruns.

Once the definition of a BIM cost analysis is determined and al also the model is completely designed (architectural and structural), it's possible to start the cost estimate analysis for the present BIM project.

First, as the case study correspond to a pedestrian bridge located in Italy, it will be followed the process that is made in the country due to regulations "Computo Metrico Estimativo". The Italian regulations Rif. DLgs 50/16 Art 59 comma 5bis says that the execution of public works is stipulated as a body (Corpo) or by measure (Misura), or partly by body (Parte a Corpo) and partly by measure (Parte a Misura). For performance to body the offered price remains fixed and cannot vary up or down, according to the quality and actual quantity of the work performed. For performance by measure, the price agreed may vary, increasing or decreasing, according to the actual quantity of work performed. For measure services, the contract sets invariable prices for the unit of measurement. This is directly defined by the "Computo Metrico Estimativo".

- **Body contract:** The contractual consideration refers to the overall performance as performed and as deduced from contract.
- **Measure contract:** The contractual consideration comes determined by applying to the units of measurement of the individual parts of the work performed the unit prices deducted in the contract.

For the case study, it will be developed a cost analysis focusing on the quantities and expenses of each work that is part of the complete project. Additionally, the design studio of the Dott. Ing. Gariazzo Pier Giorgio, who is in charge of the real construction of the project for the pedestrian bridge, followed this procedure in order to build the economic evaluation. As it was said during the evaluation of the case study, one of the goals will be also the comparison between the two projects. Thus, having the same way of evaluate the analysis of costs, it will be possible to do a better a better approach, keeping the differences of each one of the projects and in this way, getting the possibility to do the respective comparisons.

9.1. Cost analysis using Primus

For the present part of the project management of the pedestrian bridge, it has been decided to use a software from the ACCA family. This software will be Primus, which is defined as an ideal software for the construction cost estimating process. Primus, allows to estimates in a quickly and intuitively way, different aspects from construction materials in order to get the site cost management. Additionally, this software is widely used in Italy, this is due to the facility that it presents to work directly with costs documents of the different Italian regions.

The cost estimate analysis that is about to begin will be developed with information from the "Prezzario della Regione Piemonte – Edizione Straordinaria Luglio 2022". This document is disseminated by government entities and presents a list of different activities related to the construction area and their corresponding prices. The use of this document will allow to present an adequate cost estimate, taking into account real data from the region where the project will be carried out. It's important to mention that the document in mention, was updated for the second half of the year due to many political and economic factors that are affecting the costs in Europe. In the following figure, it's shown the "Prezzario della Regione Piemonte – Edizione Straordinaria Luglio 2022".

Figure 138. "Prezzario della Regione Piemonte – Edizione Straordinaria Luglio 2022".

Before the cost estimation process is started, it's necessary to define the quantities of materials used for construction. These quantities can be taken directly from the architectural design in Autodesk Revit, meaning that the information about materials can be easily imported to any other software as it will be Primus.

The process to obtain the complete project list of materials, requires the use of a tool in Revit that is called takeoff quantities. This option allows to obtain all different materials and quantities that are part of a model. In the following figure, it's how it was activated this tool.

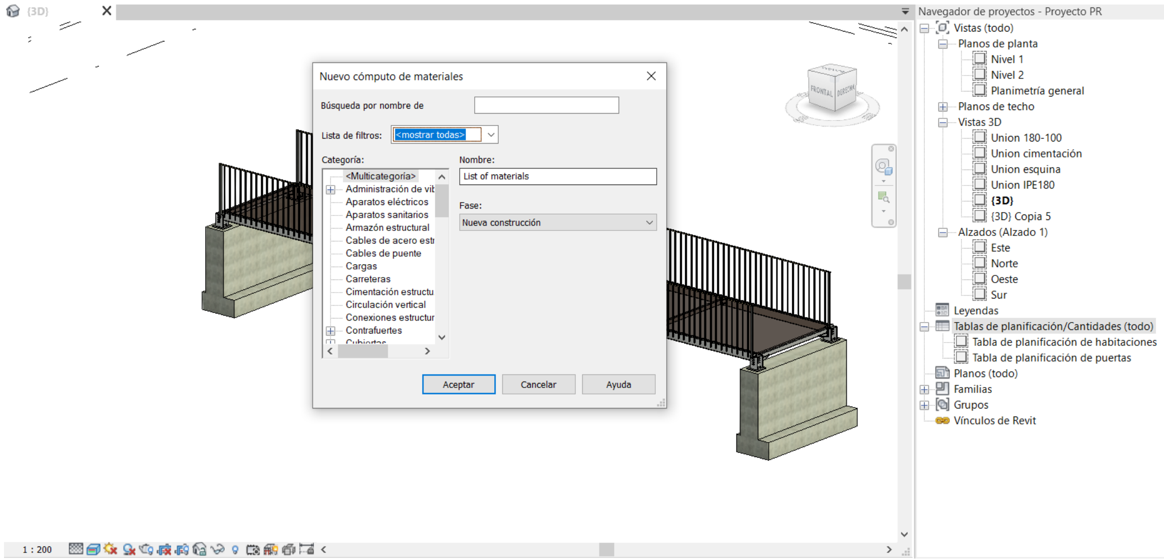


Figure 140. Materials takeoff tool – Revit.

Now, it's necessary to add all categories that are of interest for the quantification of materials. For the case study, were chosen the name of the materials, the unitary weight of materials, the volume of material and the area of the material. These last three information categories, allows to obtain total cost of activities from a unitary prices list as the present project has it.

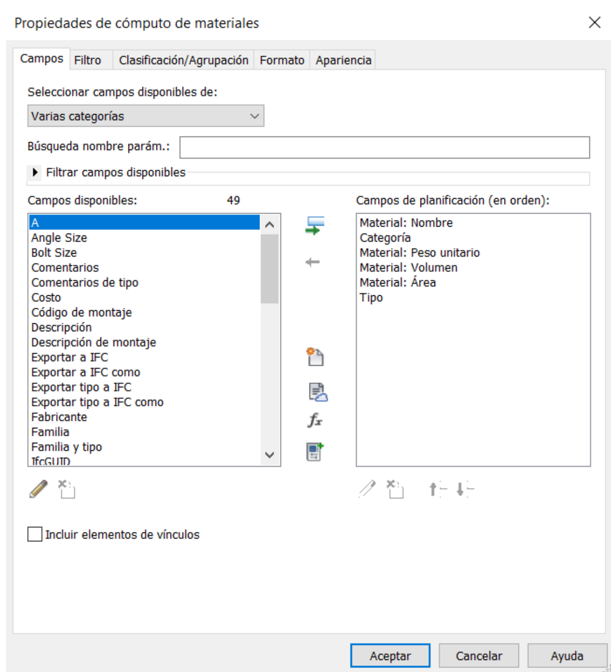


Figure 141. Categories for takeoff materials – Revit.

Now, it's possible to obtain all different materials that were used in the architectural design model in Autodesk Revit. In the following table will be shown the complete list of all materials.

<List of materials>

A	B	C	D	E	F
Material: Nombre	Categoría	Material: Peso unita	Material: Volumen	Material: Área	Tipo
Acero estructural -	Suelos	78.5 kN/m^3	0.95 m^3	37.50 m^2	steel sheet
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.22 m^2	Empalme
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.22 m^2	Empalme
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.06 m^2	Ángulo de escalera en la parte superior derecha
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.11 m^2	Ángulo de escalera en la parte superior
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.11 m^2	Ángulo de escalera en la parte superior
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.11 m^2	Ángulo de escalera en la parte superior
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.11 m^2	Ángulo de escalera en la parte superior
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.11 m^2	Ángulo de escalera en la parte superior
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.11 m^2	Ángulo de escalera en la parte superior
Acero, 45-345	Pilares estructurale	77.0 kN/m^3	0.00 m^3	0.35 m^2	HE200B
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.18 m^2	Nudo de pórtico atornillado, con cartela
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.08 m^2	Pletina de coronación de muro frontal
Acero, 45-345	Pilares estructurale	77.0 kN/m^3	0.00 m^3	0.35 m^2	HE200B
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.08 m^2	Pletina de coronación de muro frontal
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.18 m^2	Nudo de pórtico atornillado, con cartela
Acero, 45-345	Pilares estructurale	77.0 kN/m^3	0.00 m^3	0.35 m^2	HE200B
Acero, 45-345	Pilares estructurale	77.0 kN/m^3	0.00 m^3	0.35 m^2	HE200B
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.18 m^2	Nudo de pórtico atornillado, con cartela
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.18 m^2	Nudo de pórtico atornillado, con cartela
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.08 m^2	Pletina de coronación de muro frontal
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.08 m^2	Pletina de coronación de muro frontal
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.11 m^2	Ángulo de escalera en la parte superior
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.11 m^2	Ángulo de escalera en la parte superior
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.21 m^2	Pletina base
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.21 m^2	Pletina base
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.21 m^2	Pletina base
Acero, 45-345	Conexiones estruct	77.0 kN/m^3	0.00 m^3	0.21 m^2	Pletina base
Hormigón, Moldead	Muros	23.6 kN/m^3	2.25 m^3	4.50 m^2	Hormigón con cimentación - 50
Hormigón, Moldead	Muros	23.6 kN/m^3	2.25 m^3	4.50 m^2	Hormigón con cimentación - 50
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.02 m^3	5.22 m^2	IPE 180
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.02 m^3	5.22 m^2	IPE 180
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.00 m^3	0.91 m^2	IPE 100
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.00 m^3	0.97 m^2	IPE 100
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.00 m^3	0.97 m^2	IPE 100
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.00 m^3	0.97 m^2	IPE 100
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.00 m^3	0.97 m^2	IPE 100
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.00 m^3	0.91 m^2	IPE 100
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.02 m^3	5.22 m^2	IPE 180
Metal - Acero - 345	Armazón estructural	77.0 kN/m^3	0.02 m^3	5.22 m^2	IPE 180

Table 14. List of all components of architectural model – Revit.

As it can be seen, the list that was presented correspond to all different components or sections that are part of the entire model. However, it's also possible to obtain a list where the sections that correspond to the same type of category are summarize as just one component. In this way, it will be possible to add costs to categories and not to single object, making the work faster and more efficient.

Proyecto PR - Tabla de planificación: List of materials

<List of materials>

A	B	C	D	E	F
Material: Nombre	Categoría	Material: Peso unita	Material: Volumen	Material: Área	Tipo
Acero estructural -	Suelos	78.5 kN/m³	0.95 m³	37.50 m²	steel sheet
Acero, 45-345	Conexiones estruct	77.0 kN/m³	0.00 m³	0.43 m²	Empalme
Acero, 45-345	Pilares estructurale	77.0 kN/m³	0.01 m³	1.39 m²	HE200B
Acero, 45-345	Conexiones estruct	77.0 kN/m³	0.00 m³	0.73 m²	Nudo de pórtico atornillado, con cartela
Acero, 45-345	Conexiones estruct	77.0 kN/m³	0.01 m³	0.83 m²	Pletina base
Acero, 45-345	Conexiones estruct	77.0 kN/m³	0.00 m³	0.32 m²	Pletina de coronación de muro frontal
Acero, 45-345	Conexiones estruct	77.0 kN/m³	0.00 m³	0.91 m²	Ángulo de escalera en la parte superior
Acero, 45-345	Conexiones estruct	77.0 kN/m³	0.00 m³	0.06 m²	Ángulo de escalera en la parte superior derecha
Hormigón, Moldead	Muros	23.6 kN/m³	4.50 m³	9.00 m²	Hormigón con cimentación - 50
Metal - Acero - 345	Armazón estructural	77.0 kN/m³	0.01 m³	5.68 m²	IPE 100
Metal - Acero - 345	Armazón estructural	77.0 kN/m³	0.07 m³	20.90 m²	IPE 180

Table 15. List of materials of architectural model – Revit.

It's important to take into account that the takeoff materials tool of Revit didn't give information about the railings and decorations such as pots and seats. For this reason, the estimation of costs in Primus will need to add also this component that is part of the entire construction process. Additionally, it's important to mention that the cost estimate analysis will also need the information about work hours of human resources that was obtained during the time analysis in Microsoft Project.

Now, that the source of data about costs for the case study is defined, and also the quantities of materials were properly imported from Revit, the estimation of costs in the software Primus may start.

As mentioned, the cost analysis will be performed using unit price data from the Piedmont region. Primus allows to directly link this data to the model, making it quick and easy to input all the different activities that are part of the build process. The unitary price list for the Piedmont region can be easily found on the Internet. However, on the ACCA website, this list can be downloaded as a Primus file as shown in the figure below.

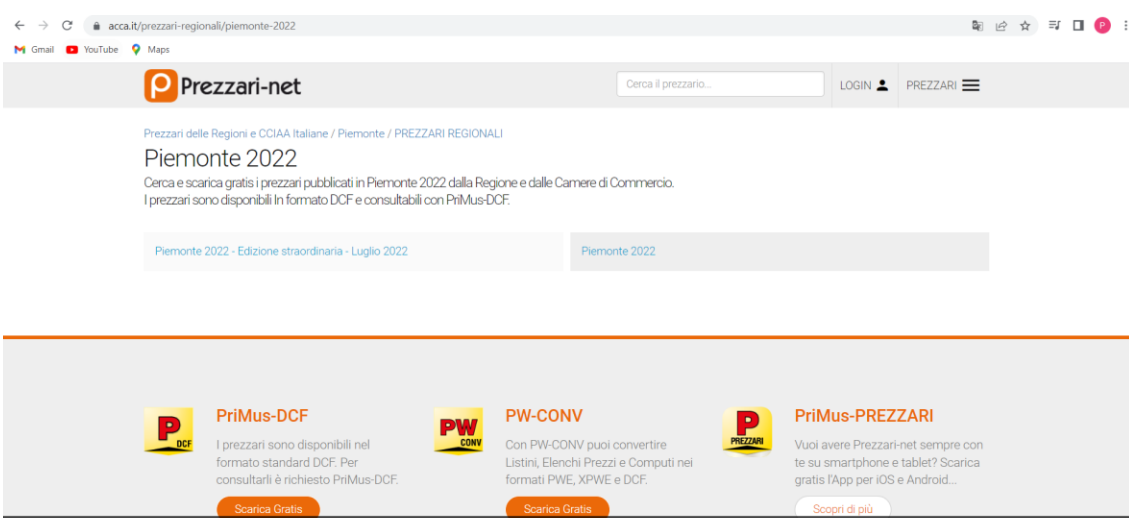


Figure 142. Prezzari regionali from ACCA family

Once the Piedmont region unitary prices file is downloaded as a Primus file, all the different activities of the construction process can be seen as shown in the figure below. Then, following a simple dragging process, the activity that matches the necessary description for the case study can be inserted into the cost analysis model.

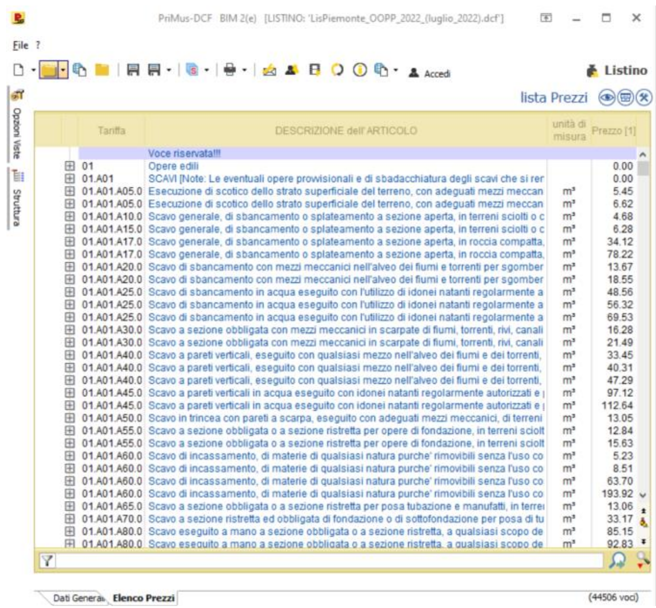


Figure 143. List of activities taken from Prezzario di Piemonte (Primus).

At this moment, all information of interest for the case study cost analysis is completely gathered, then, the model can be started. As first step, Primus allows to input all general data of the project that is aim to be evaluated. In the following figure it's shown the information that was introduced for the model.

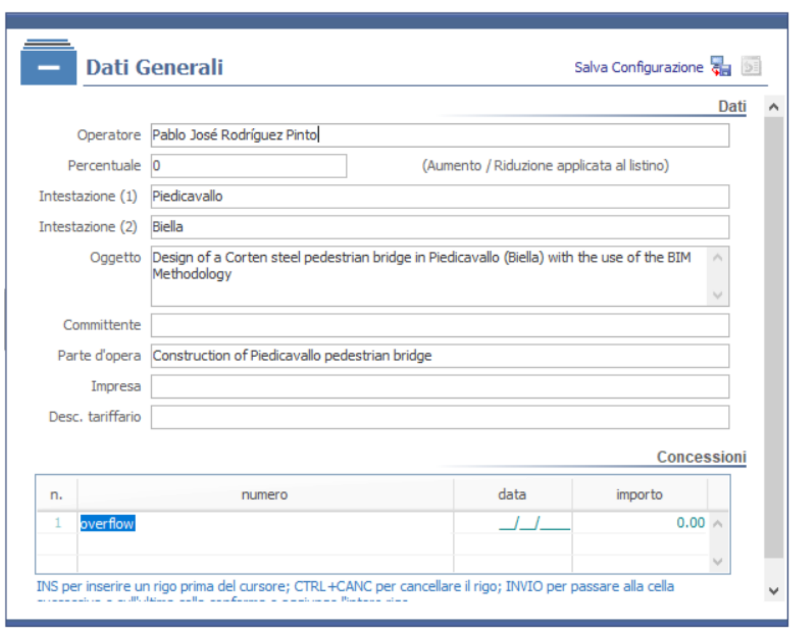


Figure 144. General data for estimation of cost model - Primus.

The software Primus allows to obtain the totality of costs of a project. However, it's also important to organize the activities that are part of the construction process in categories. This determination, will allow a deeper analysis in terms of costs of the main activities for the construction of the pedestrian bridge. For this, it has been decided to use the same main activities defined for the time analysis, being also the categories in Primus.

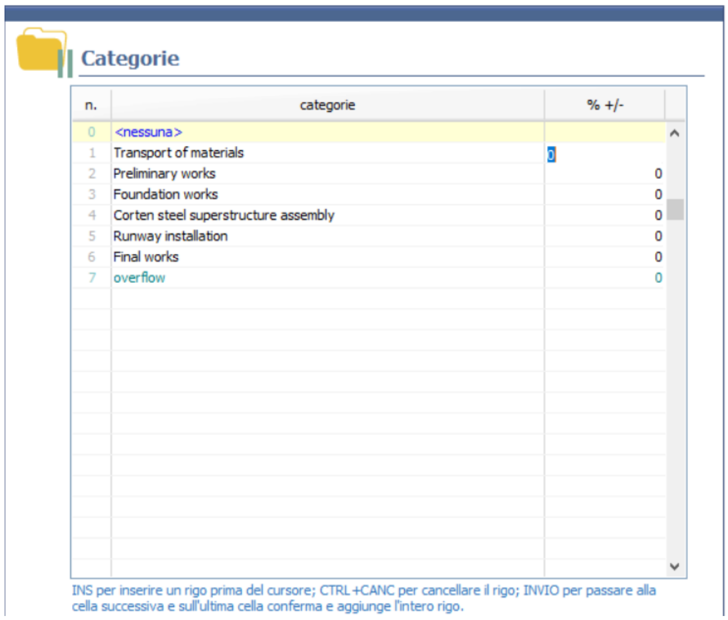


Figure 145. List of categories for Cost analysis (Primus).

Following with the cost analysis process, it must be used the construction activities that were declared during the time analysis. Nonetheless, it must be clear that the estimation of costs may include more singular activities than the list given by the time analysis process. This is due to a need to have a more extensive detail in the different activities, in order to obtain a budget that is much closer to reality. For example, in the main activity that was named as Foundation works, it must be added an item that is required for the casting of concrete, the formworks.

The project management it's a very important work, that requires not only technical knowledge but also experience to been capable of account all different aspects that form an entire construction process. Additionally, it's required to know how the "Prezzario di Piemonte" is made up, in order been able of add the adequate data to the model in Primus. In the following figure, it will be shown an example of an activity that is needed for the cost analysis model off the case study.

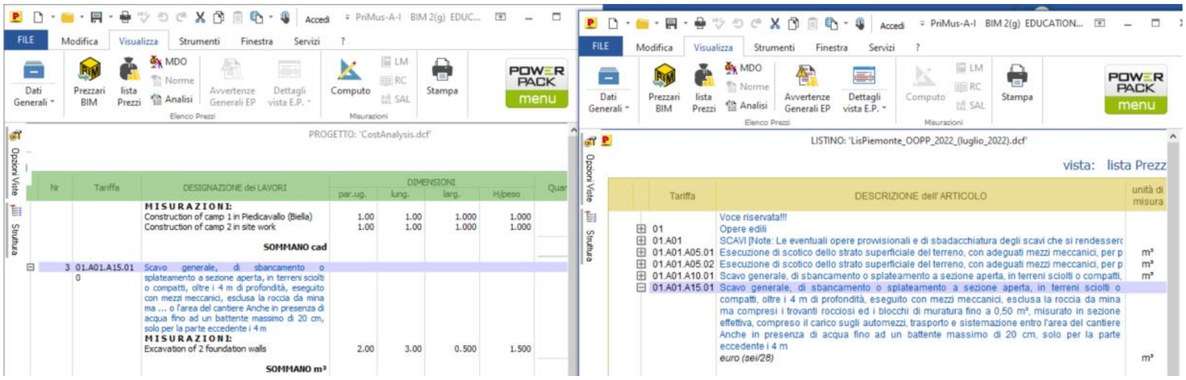


Figure 146. Excavation for foundation work (Primus).

The case presented corresponds to an activity that is necessary for the foundation works. Excavation for foundations is presented in the "Prezzario di Piemonte" with a unit of measurement of m3. Then, it is important that when this activity is dragged into the cost analysis model, the quantity of excavated material to be entered is also thought of as m3. Each activity can have a different unit of measure, depending on the type of category it corresponds to. Thereby, the cost analysis model has been performed in Primus giving the following results.

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	IMPORTI TOTALE	incid. %
	RIPORTO		
	Riepilogo Strutturale CATEGORIE		
M	**LAVORI A MISURA euro**	55´574,00	63,585-(100,000)
M:001	Construction of Piedicavallo Pedestrian Bridge euro	55´574,00	63,585-(100,000)
M:001.003	Foundation works euro	4´695,92	5,373-(8,450)
M:001.004	Corten steel superstructure assembly euro	14´204,19	16,252-(25,559)
M:001.005	Runway installations euro	34´031,65	38,937-(61,237)
M:001.006	Final works euro	2´642,24	3,023-(4,754)
C	**LAVORI A CORPO euro**	31´827,57	36,415-(100,000)
C:001	Construction of Piedicavallo Pedestrian Bridge euro	31´827,57	36,415-(100,000)
C:001.001	Transport of materials euro	16´381,50	18,743-(51,470)
C:001.002	Preliminary works euro	6´405,60	7,329-(20,126)
C:001.003	Foundation works euro	9´040,47	10,344-(28,405)
	TOTALE euro	87´401,57	100,000
	Data, 13/10/2022		

Figure 147. Summary of costs analysis for pedestrian bridge (Primus).

As it can be seen in the summary of costs analysis presented in Primus, the work activities had been divided in its different categories and also in type of works (a misura o a corpo). The organization of the cost process in these sections, allows to analyze better how the costs are divided through the several activities of the construction process. Additionally, is important to divide activities in type of work (a corpo o misura) for the project management process. Depending on the type, each activity must be managed and contracted individually if it's the case. In the following figure, it will be shown the list of cost only by categories and finally the total cost of the construction of the Piedicavallo Pedestrian Bridge.

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	IMPORTI TOTALE	incid. %
	RIPORTO		
	Riepilogo CATEGORIE		
001	Transport of materials	16´381,50	18,743
002	Preliminary works	6´405,60	7,329
003	Foundation works	13´736,39	15,716
004	Corten steel superstructure assembly	14´204,19	16,252
005	Runway installations	34´031,65	38,937
006	Final works	2´642,24	3,023
007		0,00	0,000
	Totale CATEGORIE euro	87´401,57	100,000

Figure 148. Costs analysis for pedestrian bridge (Primus).

The cost analysis for the present project was made taking into account every detail that was explained during the time analysis of the project. Once all construction activities and costs were accounted, the cost analysis yielded a result of €87.401,57 as its shown in the figure presented before. This cost is divided by the several categories chosen for the time analysis of the project. For the case, it can be seen that the principal costs correspond to activities of transport and of the structure (Superstructure and foundation).

In the following figures, it will be shown the complete list of activities that were considered for the cost analysis. These activities were mainly extracted from the "Prezzario della Regione Piemonte – Edizione Straordinaria Luglio 2022".

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	DIMENSIONI par.ug.	lung.	larg.	H/peso	Quantità	IMPORTI unitario	TOTALE
	RIPORTO							
	LAVORI A CORPO							
	Construction of Piedicavallo Pedestrian Bridge (SpCat 1) **Transport of materials (Cat 1)**							
1 07.A02.B10.015	Carico, trasporto di saracinesche, pezzi speciali, chiusini e materiali vari; compreso il carico nei magazzini o depositi dell'Amministrazione Appaltante, lo scarico a pie d'opera; (per q)							
	Trasnport of preliminary work materials by car from camp 1 to camp 2				40,000	40,00		
	SOMMANO min					40,00	4,80	192,00
2 18.P08.A05.005	MEZZI DI SERVIZIO Elicottero leggero per trasporto al gancio con portata operativa non superiore a 1200 kg, compresa ogni operazione di carico e scarico, consumi, personale di volo ... cessorio. Per ogni minuto di volo effettivo. fino a 1500 m s.l.m., con portata operativa di 600 kg, in fase di trasporto							
	Transport of foundation materials by helicopter from camp 1 to camp 2				330,000	330,00		
	SOMMANO min					330,00	27,89	9´203,70
3 18.P08.A05.010	MEZZI DI SERVIZIO Elicottero leggero per trasporto al gancio con portata operativa non superiore a 1200 kg, compresa ogni operazione di carico e scarico, consumi, personale di volo ... i minuto di volo effettivo. operativo fino a 2000 m s.l.m., con portata operativa da 700 a 1000 kg, in fase di trasporto							
	Transport of corten steel super structure from camp 1 to camp 2				60,000	60,00		
	SOMMANO min					60,00	32,76	1´965,60
4 18.P08.A05.005	MEZZI DI SERVIZIO Elicottero leggero per trasporto al gancio con portata operativa non superiore a 1200 kg, compresa ogni operazione di carico e scarico, consumi, personale di volo ... cessorio. Per ogni minuto di volo effettivo. fino a 1500 m s.l.m., con portata operativa di 600 kg, in fase di trasporto							
	Transport of corten steel perforated sheets				150,000	150,00		
	Transport of glulam wood materials				30,000	30,00		
	SOMMANO min					180,00	27,89	5´020,20
	Parziale Transport of materials (Cat 1) euro							16´381,50

	Preliminary works (Cat 2)							
5 28.A05.E05. 015	RECINZIONE perimetrale di protezione in rete estrusa in polietilene ad alta densità HDPE peso 240 g/m2, di vari colori a maglia ovoidale, resistente ai raggi ultravioletti, indefor ... o riparando le parti non più idonee; lo smantellamento, l'accatastamento e l'allontanamento a fine opera. altezza 1,80 m							
	Enclosure of construction site				30,000	30,00		
	SOMMANO m					30,00	7,15	214,50
6 25.A01.A30. 005	Cantiere prefabbricazione conci impalcati ponte (luce cantiere di prefabbricazione conci per impalcato da ponti (luce m 35-55), costituito da un impianto di prefabbricazione compre ... di conci ad altezza variabile ,compreso pure la manodopera e le attrezzature di servizio. Per ogni concio prefabbricato.							
	Construction of camp 1 in Piedicavallo (Biella)				1,000	1,00		
	Construction of camp 2 in site				1,000	1,00		
	SOMMANO cad					2,00	2´013,18	4´026,36
7 23.P10.A10.0	Utilizzo di decespugliatore professionale leggero: con cinghia a tracolla, cilindrata 30-35 cc, potenza 1,5 kW, testina a filo o lame, impugnatura							
	A RIPORTARE							20´622,36

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	DIMENSIONI				Quantità	IMPORTI	
		par.ug.	lung.	larg.	H/peso		unitario	TOTALE
	RIPORTO							20´622,36
05	semplice o doppia							
	Site clearance				8,000	8,00		
	SOMMANO h					8,00	2,85	22,80
8 22.P01.A70.0 05	Rilievo magnetometrico, comprensivo di sopralluogo nella zona di intervento, trasporto strumentazione, progettazione ed esecuzione delle misure (anche topografiche), elaborazione, ... si ed interpretazione dei dati, in funzione della maglia di acquisizione dati Per ogni punto di misura, con maglia 2x2 m							
	Topographic delimitation				50,000	50,00		
	SOMMANO cad					50,00	1,85	92,50
9 01.P01.A30.0 05	Operaio comune Ore normali							
	CW for preliminary works				40,000	40,00		
	SOMMANO h					40,00	30,71	1´228,40
10 01.P01.A20.0 05	Operaio qualificato Ore normali							
	QW for preliminary works				24,000	24,00		
	SOMMANO h					24,00	34,21	821,04
	Parziale Preliminary works (Cat 2) euro							6´405,60
	Foundation works (Cat 3)							
11 01.A01.A90. 035	Scavo in trincea a pareti verticali di materie di qualunque natura purche' rimovibili senza l'uso di mazze e scalpelli, compresa ogni armatura occorrente per assicurare la stabilit ... terie scavate ed il loro deposito a lato dello scavo A mano, fino alla profondita' di m 3 e per un volume di almeno m³ 1							
	Excavation of foundation wall 1	1,00	3,00	0,500	1,500	2,25		
	Excavation of foundation wall 2	1,00	3,00	0,500	1,500	2,25		
	SOMMANO m³					4,50	156,14	702,63
	Parziale Foundation works (Cat 3) euro							702,63
	Parziale LAVORI A CORPO euro							23´489,73

	LAVORI A MISURA							
	Construction of Piedicavallo Pedestrian Bridge (SpCat 1) **Foundation works (Cat 3)**							
12 01.P26.A40.0 05	Trasporto entro cantiere con carriola a mano, compreso il carico a mano del materiale da trasportare Removal and transport of excavated soil (to around areas)				8,000	8,00		
	SOMMANO h					8,00	34,21	273,68
	Parziale Foundation works (Cat 3) euro							273,68
	Parziale LAVORI A MISURA euro							273,68
	LAVORI A CORPO							
	Construction of Piedicavallo Pedestrian Bridge (SpCat 1) **Foundation works (Cat 3)**							
	A RIPORTARE							23'763,41

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	DIMENSIONI				Quantità	IMPORTI	
		par.ug.	lung.	larg.	H/peso		unitario	TOTALE
	RIPORTO							23'763,41
13 01.A04.H40. 005	Armatura per sostegno pareti di scavo per fondazioni di opere idrauliche, anche in presenza di acqua, compreso il puntellamento ed ogni onere occorrente A cassero continuo							
	Support for excavation of foundation 1	2,00	3,50	1,500	1,000	10,50		
	Support for excavation of foundation 2	2,00	3,50	1,500	1,000	10,50		
	SOMMANO m²					21,00	28,05	589,05
14 25.A12.A15. 015	Acciaio in barre per lavori in sotterraneo Tipo B450C con controllo in stabilimento							
	Reinforcing steel for fondation 1 *(H/peso=2,25*75)				168,750	168,75		
	Reinforcing steel for fondation 2 *(H/peso=2,25*75)				168,750	168,75		
	SOMMANO kg					337,50	2,34	789,75
15 01.A04.B20. 005	Calcestruzzo a prestazione garantita in accordo alla UNI EN 206, per strutture di fondazione (plinti con altezza < 1.5 m. platee di fondazione e muri di spessore < 80 cm. cordoli, ... gati 32 mm. Cl 0.4. Fornitura a piè d'opera, escluso ogni altro onere. Classe di resistenza a compressione minima C25/30							
	Concrete for foundation 1				2,250	2,25		
	Concrete for foundation 2				2,250	2,25		
	SOMMANO m³					4,50	137,28	617,76
16 01.A04.C00. 005	Getto in opera di calcestruzzo cementizio eseguito a mano In struttura di fondazione							
	Cast in place concrete for foundation 1				2,250	2,25		
	Cast in place concrete for foundation 2				2,250	2,25		
	SOMMANO m³					4,50	84,00	378,00
17 01.P01.A10.0 05	Operaio specializzato Ore normali Specialized worker for foundation works				80,000	80,00		
	SOMMANO h					80,00	36,91	2'952,80
18 01.P01.A20.0 05	Operaio qualificato Ore normali Qualified worker for foundation				88,000	88,00		
	SOMMANO h					88,00	34,21	3'010,48
	Parziale Foundation works (Cat 3) euro							8'337,84
	Parziale LAVORI A CORPO euro							8'337,84

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	par.ug.	lung.	larg.	H/peso	Quantità	unitario	TOTALE
	LAVORI A MISURA							
	Construction of Piedicavallo Pedestrian Bridge (SpCat 1)							
	Foundation works (Cat 3)							
19 01.P01.A30.0 05	Operaio comune Ore normali Common worker for foundation works				144,000	144,00		
	SOMMANO h					144,00	30,71	4'422,24
	Parziale Foundation works (Cat 3) euro							4'422,24
	Corten steel superstructure assembly (Cat 4)							
20 25.A08.A00. 005	Strutture in acciaio CORTEN tipo S355 a doppio T - Luci m25-40. Fornitura e posa di strutture portanti a doppio T in acciaio "Corten" - Luci m 25-40, varate dal basso con autogru o di punta, come da norme tecniche art.24							
	A RIPORTARE							36'523,49

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	DIMENSIONI				Quantità	IMPORTI	
		par.ug.	lung.	larg.	H/peso		unitario	TOTALE
	RIPORTO							36'523,49
	seconda parte. Varo di punta							
	Corten steel HE200B				102,366	102,37		
	Corten steel IPE100				147,015	147,02		
	Corten steel IPE180				682,440	682,44		
	Connections of corten steel structure				78,518	78,52		
	SOMMANO kg					1'010,35	3,98	4'021,19
21 01.P01.A30.0 05	Operaio comune Ore normali Assembly of Corten steel structure				100,000	100,00		
	SOMMANO h					100,00	30,71	3'071,00
22 01.P01.A20.0 05	Operaio qualificato Ore normali Assembly of corten steel structure				100,000	100,00		
	SOMMANO h					100,00	34,21	3'421,00
23 01.P01.A10.0 05	Operaio specializzato Ore normali Assembly of corten steel structure				100,000	100,00		
	SOMMANO h					100,00	36,91	3'691,00
	Parziale Corten steel superstructure assembly (Cat 4) euro							14'204,19
	Runway installations (Cat 5)							
24 25.A09.B90. 005	Fornitura e posa in opera di manufatti in ferro lavorato e/o profilato Compreso trattamento antiossidante e verniciatura a 4 mani come indicato dalle norme tecniche ed ogni altro onere. Perforatted corten steel sheet *(H/peso=2460,63*0,8)				1968,504	1'968,50		
	SOMMANO kg					1'968,50	11,82	23'267,67
25 01.P16.G00.0 05	Fornitura di travi, travetti e simili per strutture in legno lamellare GL24H con marchiatura CE per la realizzazione di travature dritte In abete (Picea abies, Abies alba) Railings in Glulam wood *(H/peso=6,800*1,1)				7,480	7,48		
	SOMMANO m³					7,48	1'082,35	8'095,98
26 01.P01.A30.0 05	Operaio comune Ore normali Common work for Runway installations				32,000	32,00		
	SOMMANO h					32,00	30,71	982,72
27 01.P01.A20.0 05	Operaio qualificato Ore normali Qualified worker for Runway installations				32,000	32,00		
	SOMMANO h					32,00	34,21	1'094,72
28 01.P01.A10.0 05	Operaio specializzato Ore normali Specialized worker for Runway installations				16,000	16,00		
	SOMMANO h					16,00	36,91	590,56
	Parziale Runway installations (Cat 5) euro							34'031,65
	Final works (Cat 6)							
29 01.P16.G00.0	Fornitura di travi, travetti e simili per strutture in legno lamellare GL24H con marchiatura CE per la realizzazione di travature dritte In abete (Picea							
	A RIPORTARE							84'759,33

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	DIMENSIONI				Quantità	IMPORTI	
		par.ug.	lung.	larg.	H/peso		unitario	TOTALE
	RIPORTO							84'759,33
05	abies, Abies alba) Installation of wood benches				0,500	0,50		
	SOMMANO m³					0,50	1'082,35	541,18
30 20.A27.A68. 005	Messa a dimora di arbusti comprendente scavo della buca, carico e trasporto ad impianto di trattamento autorizzato del materiale di risulta, provvista e distribuzione di g. 50 di c ... di letame maturo nonche' della terra vegetale necessaria, piantagione dei soggetti e due bagnamenti Buca di cm 30x30x30 Pot planting				8,000	8,00		
	SOMMANO cad					8,00	6,96	55,68
31 23.A15.A00. 015	Fornitura e posa in opera di palo di dimensioni 8x8 cm., h 300 cm., in legno scortecciato e trattato con materiali impregnati per renderlo imputrescibile, ancorato al suolo, compre ... te analoghe caratteristiche e collocazione di tappo sommitale zincato per palo in legno. condizioni difficili di accesso Road demarcation				2,000	2,00		
	SOMMANO cad					2,00	271,65	543,30
32 01.P01.A30.0 05	Operaio comune Ore normali Common worker for final works				40,000	40,00		
	SOMMANO h					40,00	30,71	1'228,40
33 01.P01.A20.0 05	Operaio qualificato Ore normali Qualified worker for final works				8,000	8,00		
	SOMMANO h					8,00	34,21	273,68
	Parziale Final works (Cat 6) euro							2'642,24
	Parziale LAVORI A MISURA euro							55'300,32
	TOTALE euro							87'401,57

Figure 149. Complete Cost analysis model (Primus).

9.2. Interoperability considerations in cost estimate analysis

Cost analysis is a fundamental part of project management. As explained during the time analysis chapter, a remote construction site presents challenges in cost estimation. This, due to many uncertainties of materials, capacity to use machinery and tools, lack of communication and qualified workers that can cause delays and errors in construction, increasing costs.

An important activity that must be carried out for cases such as the one under study in order to reduce uncertainties is to use the BIM methodology. In this way, all the different objects in the 3D model must be fully understood and taken into account in the cost analysis. For the present project the Primus software was used, which presented a low level of interoperability with other software used for the entire project such as Microsoft Project and the software from the Autodesk family. This low level of interoperability caused an increment in time for the process, as it was necessary to input one by one the objects that were took off from the Revit 3D model.

For this reason, it can be recommended for this type of work the use of an architecture design software from ACCA family called Edificius. It is a BIM software that allows the 2D and 3D architectural design and also the rendering virtual reality. Additionally, this software allows the integration with other 3D architecture software as Revit, where the entire 3D design of the pedestrian bridge was carried out.

The 3D model in Revit could have been exported to Edificius and then the entire model could also have been exported to Primus, increasing the level of interoperability. However, the 3D model does not take into account all the different activities required for cost estimation such as transportation, preliminary work, etc., activities that need to be entered manually. Especially, if it is necessary to work with a cost document where all the different construction activities are described in detail such as the Prezzario della Regione di Piemonte. So, it can be said that the cost estimation process represents a critical step in the entire BIM process.

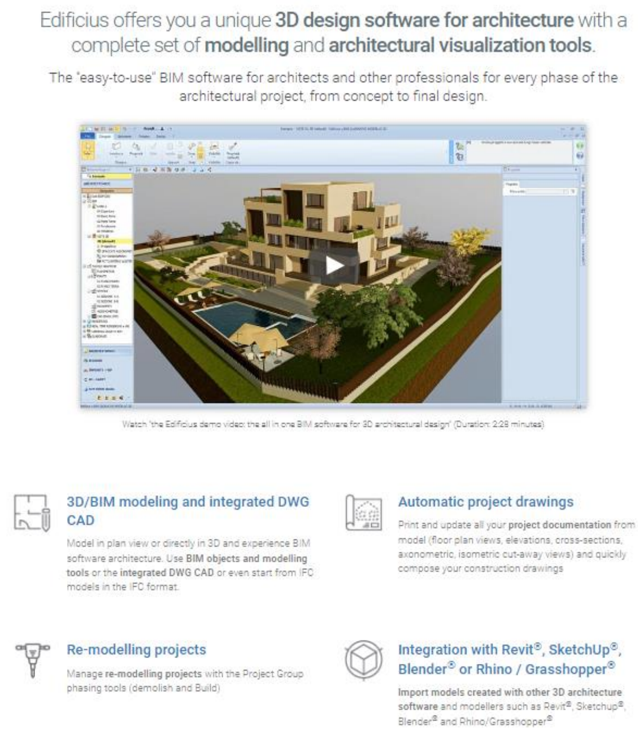


Figure 150. Edificius overview – taken from ACCAsoftware

9.3. Introduction of lighting system for the pedestrian bridge project

For the cost analysis has been decided to consider separately a category that is called lighting system. This category intends to account costs about the lighting of the pedestrian bridge with a solar system as it was designed during the architectural process. However, it's important to clarify that a proper design of lighting should be held as a future work in the BIM process. Additionally, this possibility of future work will be mentioned during the chapter called future developments for the pedestrian bridge. Where, the 6D dimension of the BIM process corresponding to the sustainability and possible software to held the process will be explained.

The development of the estimation of costs for the lighting system has been also made using Primus software. In the following figure it will be shown the cost analysis reached for this consideration.

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	DIMENSIONI				Quantità	IMPORTI	
		par.ug.	lung.	larg.	H/peso		unitario	TOTALE
	RIPORTO							
	LAVORI A MISURA							
1 03.A13.A01.005	Posa in opera di moduli fotovoltaici a struttura rigida in silicio cristallino o amorfo, su struttura di sostegno modulare costituita da profilati in alluminio o acciaio, incluso c ... o altra attrezzatura per il trasporto su copertura Su coperture piane o su terreno, superficie installata fino a m² 100 Assembly of solar system				30,000	30,00		
	SOMMANO m²					30,00	82,93	2´487,90
2 03.P14.A09.005	Kit per l'illuminazione stradale: sistema autonomo costituito da moduli fotovoltaici, plafoniera, lampada ai vapori di sodio a bassa pressione, batteria di accumulo, regolatore di ... fissaggio dei moduli, cavi, viti e morsetti. Lampione stradale con lampada da 26 W e 3600 lm, potenza dei moduli 170 Wp Lighting system				12,000	12,00		
	SOMMANO cad					12,00	825,74	9´908,88
3 085019b	Sistema per l'integrazione solare composto da collettori solari piani Integration system for solar assembly					1,00		
	SOMMANO cadauno					1,00	5´268,10	5´268,10
4 01.P01.A30.005	Operaio comune Ore normali CW lightyn system				80,000	80,00		
	SOMMANO h					80,00	30,71	2´456,80
5 01.P01.A20.005	Operaio qualificato Ore normali QW lighting system				80,000	80,00		
	SOMMANO h					80,00	34,21	2´736,80
6 01.P01.A10.005	Operaio specializzato Ore normali SW lighting system				40,000	40,00		
	SOMMANO h					40,00	36,91	1´476,40
	Parziale LAVORI A MISURA euro							24´334,88
	T O T A L E euro							24´334,88
	Data, 13/10/2022							
	Il Tecnico							

Figure 151. Cost estimate analysis for lighting system (Primus)

As it can be seen, the estimated costs of the lighting system for the pedestrian bridge are €24.335. Meaning that if there is a decision to add this system to the pedestrian bridge project, the costs will be increased almost a 28%, then, the cost of the entire project will change from €87.401,57 to €117.736,45. For this reason, it has been decided to perform this estimation in a separate way, where it will be possible for stakeholders to take into account many factors and decide if it is worth the increased costs.

However, the decision of include also this activity costs can be very prudent with respect the architectural design. Especially, taking into account that the lighting of the pedestrian bridge in considered an important aspect for the architectural design in the aim of presenting an added value for the pedestrian bridge and as well as for the zone. In the chapter of the present thesis that is called Tracking and controlling advancement of project, will be shown the rendering of the pedestrian bridge with the lighting system.

10. Tracking and controlling advancement of project

The tracking and controlling of a construction project are one the most essential parts of an entire project. During this phase, the different designs held for the project must be followed precisely and the construction needs to be done in accordance with specifications developed.

The construction phase also requires a detailed monitoring due to the high level of activity that occur during construction in terms of quantity of people working and also the costs that are involved per day. The construction phase also has the most opportunities for cost overruns due to changes and delays, disputes with contractors, and the resulting contract changes and claims (FTA, 2012).

The Federal transit administration research (FTA), sustains in its Construction Project Management Handbook that during construction phase is imperative to do timely and critic decisions. Additionally, it recommends to use in a precise way the project management plan (PMP) that was created for the project. For this, is important to create the proper lines of communication and delegated authorities through the several work teams that are part of a construction project.

In order to accomplish a good development of the construction phase, it has been decided to consider different aspects during this chapter. First, it's necessary to consider that during a construction, the work teams usually are more familiar with planes in 2D instead of 3D as it's been offered during the present thesis. For this reason, AutoCAD software from Autodesk will be used for detailing and 2D plans. For the case of management of costs during the construction, it will be proposed to use Microsoft Project, that allows to manage in a complete way all considerations from costs. Additionally, it has been decided to present in Navisworks, a detailed simulation of the intended construction of the pedestrian bridge. Finally, it will be presented the render of the project in Sketchup in order to have a complete understanding on the details demanded by the architectural design.

10.1 CAD representation 2D – AutoCAD planes

As it was mentioned, the CAD representation that corresponds to the 2D planes, it's still necessary for the construction work teams. For this, it has been decided to use AutoCAD software, from the Autodesk family. AutoCAD it's a software that allows to designs and annotate 2D geometry and 3D models. In order to present the planes, it can be using the architectural model that was presented in Revit and exported directly to AutoCAD as it was performed during the architectural design. It's important to remember that Revit presents a direct export function to CAD files, and more precisely to a DWG file that corresponds to an AutoCAD file. This fact, implies a good interoperability between the two different software. In the following figure, is shown the 3D architectural model that was exported to AutoCAD.

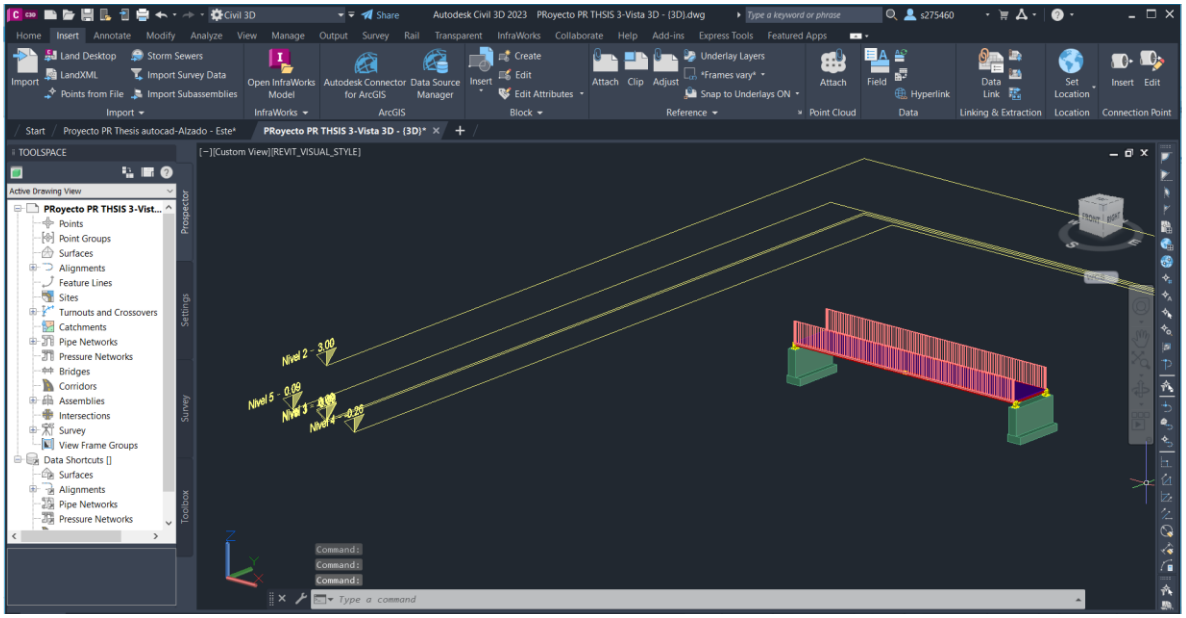


Figure 152. Architectural model 3D (AutoCAD)

Once the architectural model is completely exported to AutoCad, the 2D planes can be easily made by doing the annotation process of different views that can be require from the construction team. For the case, it has been decided to present a lateral view, a frontal view and a Top view. These planes, are presented in the following figures.

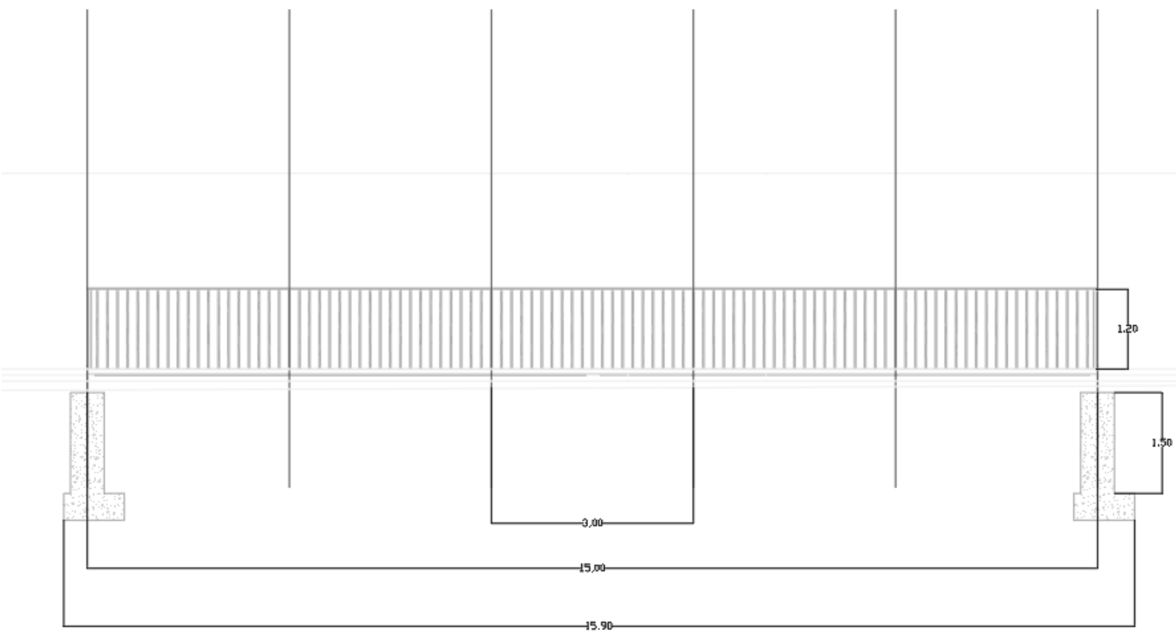


Figure 153. Lateral view (AutoCAD)

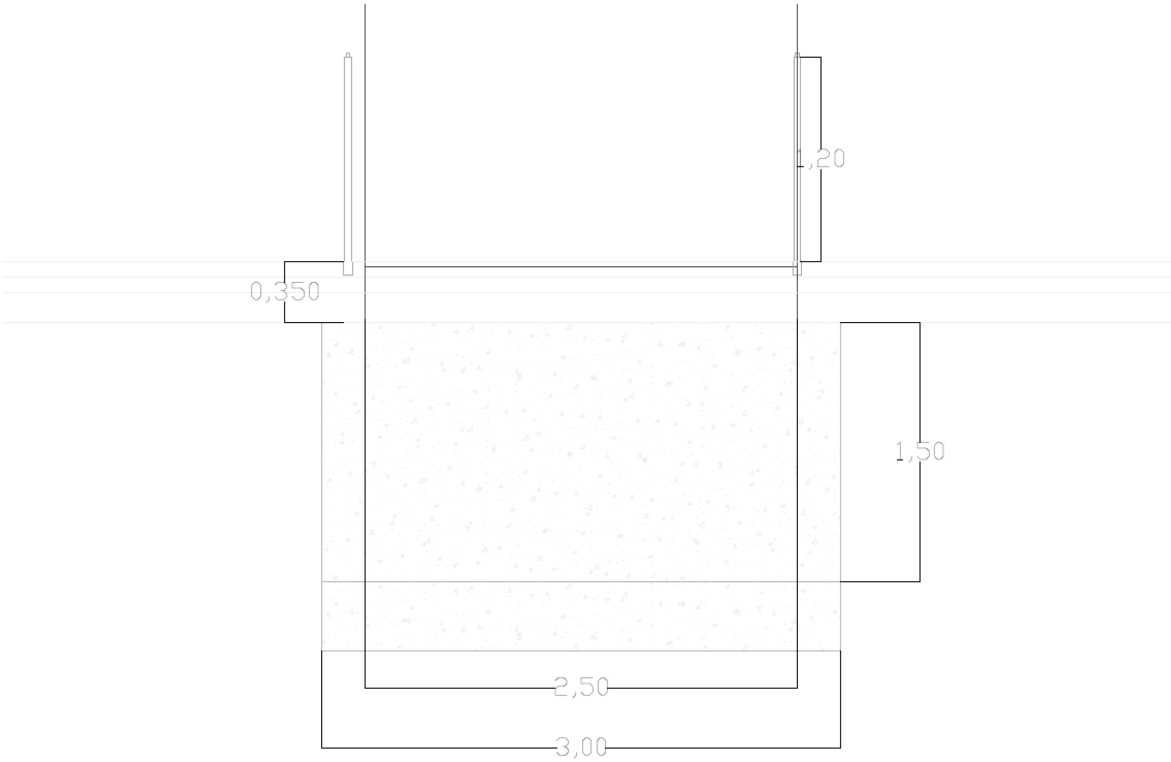


Figure 154. Frontal view (AutoCAD)

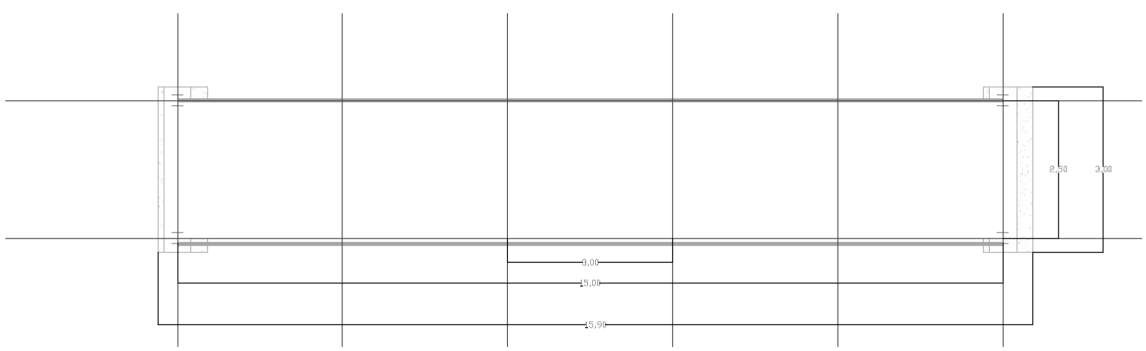


Figure 155. Top view (AutoCAD)

10.2. Construction management

The principal goal of the construction management is to control the time schedule during the progress of the construction process and also to complete the project within budget. Most construction contracts have a fixed price, as the one that can be presented in the case study.

Then, as a contractor, it will be necessary to complete the pedestrian bridge at a fixed prince, unless a change in contract is made between the parties involved.

The most effective approach to controlling the cost of changes is a management culture that resolves contractor RFCs in a timely, decisive, and equitable manner. Experience has taught project managers that it is expensive to let a backlog of unresolved changes build. A backlog creates contention and diverts management attention to the backlog and away from productive project activities. (FTA Research, 2012).

For the construction management of the pedestrian bridge project, it's suggested the use of Microsoft Project. Apart of being the software used for the planning phase, Project allows to analyze in real time the advancement of construction and also the budget information of the project. This budget or cost information, it's represented by project in terms of graphs showing how the different resources are being used at the time that the construction is advancing.

In the case of the progress of the schedule, Microsoft Project allows to directly draw a graph showing how the work should evolve during the time of the construction phase. In the following figure it will be shown, how work hours are distributed through the estimated time of construction.

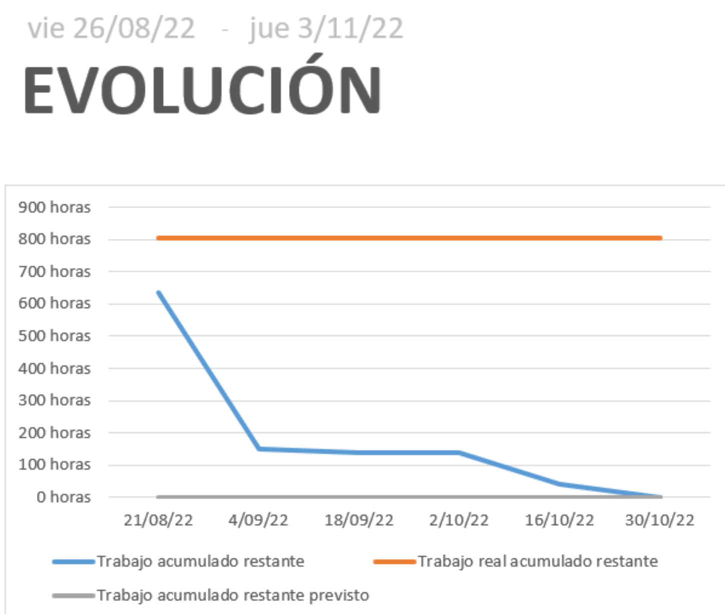


Figure 156. Distribution of construction work during time (Microsoft Project)

For the construction managements considerations regarding to costs and budge, it's necessary to add to the Project model the costs that were estimated during the analysis on Primus. For this case, it must be completely filled a column in Project model that contains the costs of each single activity that is part of the construction process. These costs are shown in the following table.

Modo de	Nombre de tarea	Costo
	Pedestrian bridge Management	**€110.190,62**
	Transport of materials	**€16.381,50**
	Transport of preliminary work materials by car from camp 1 to construction site	€192,00
	Transport of foundation materials by helicopter from camp 1 to camp 2	€9.203,70
	Transport of Corten steel structure by helicopter from camp 1 to camp 2	€1.965,60
	Transport by helicopter from camp 1 to camp 2 of sections of perforated Corten steel sheets and Glulam wood materials (railings and benches)	€5.020,20
	Preliminary works	**€6.405,60**
	Receiving of materials from suppliers	€2.049,44
	Construction of camp 1 in Piedicavallo (Biella)	€2.013,18
	Construction of camp 2 in site work	€2.013,18
	Enclosure of construction site	€214,50
	Site clearance	€22,80
	Topographic delimitation	€92,50

Modo de	Nombre de tarea	Costo
	Foundation works	**€13.736,38**
	Excavation of foundation	€2.779,67
	Removal and transport of excavated soil (to around zones)	€2.350,85
	Assembling of reinforcing steel for foundation	€2.875,85
	Cast in place concrete	€3.661,91
	Assembly of connections between foundation and Corten steel structure	€2.068,10
	Corten steel superstructure assembly	**€12.658,35**
	Assembly of principal beams	€3.708,58
	Assembly of steel connections for principal beams (IPE180) in camp 1	€2.228,96
	Assembly of connections for secondary beams (IPE100) in camp 1	€2.036,60
	Assembly of secondary beams with principal beams in camp 1	€2.396,80
	Assembly of Corten steel structure with foundation	€2.287,41

Modo de	Nombre de tarea	Costo
	Runway installations	**€34.031,65**
	Assembly of sections of perforated Corten steel sheet for floor	€24.601,67
	Installation of railings in Glulam wood	€9.429,98
	Final Works	**€26.977,14**
	Installation of wood benches in Glulam	€841,60
	Pot planting	€356,10
	Road demarcation	€843,72
	Disassembly of construction camp 1	€300,42
	Disassembly of construction camp 2	€300,42
	Lighting system	€24.334,88

Table 16. List of costs of activities of pedestrian bridge construction (Microsoft Project)

Once the costs of activities are completely input to the model in Microsoft Project, it's possible to obtain several reports about the executive management of the project as cash flows, budget and cost of activities. In the following figure it will be shown reports from Project about the costs of the Pedestrian bridge construction.

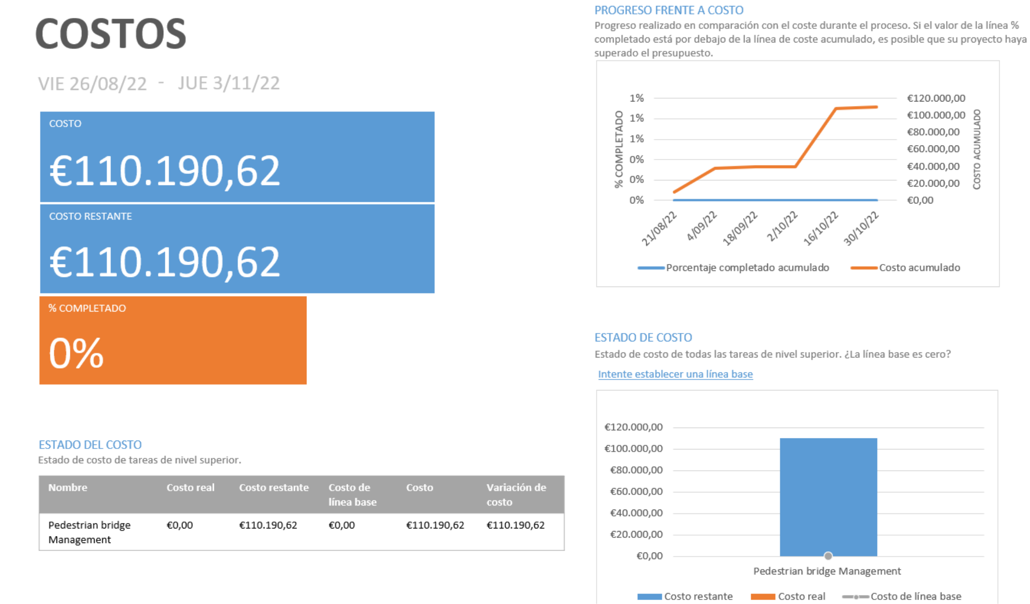


Figure 157. Distribution of construction costs during time (Microsoft Project)

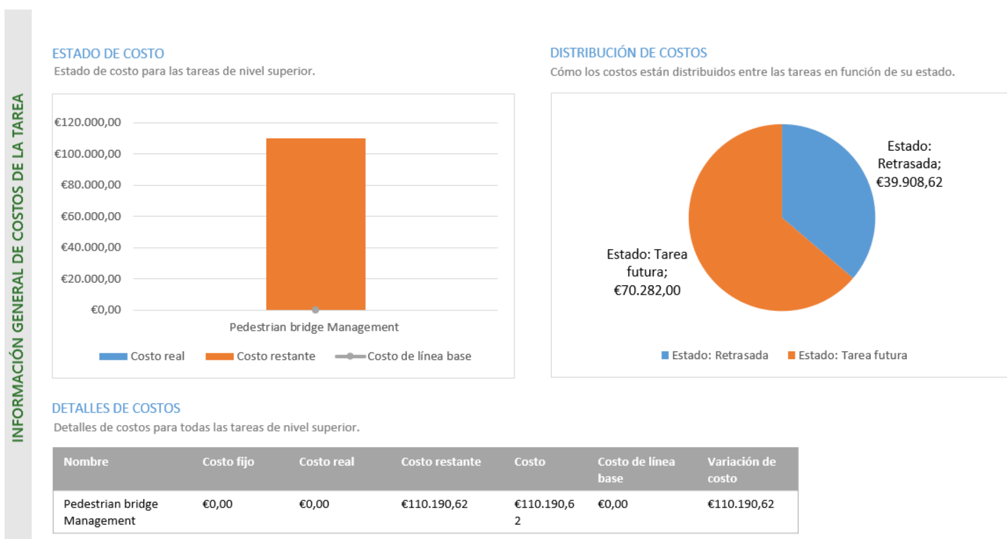


Figure 158. Financial statements (Microsoft Project)

Finally, it's important to mention that Microsoft Project allows also to track cost overruns of a project. Then, it can be said that this software is considered a fundamental part of one of the most important aspects of this thesis, which is project management.

10.3. Execution phase – Simulation and rendering

The construction phase can be supported also with simulations and renderings of the project. This models, allows to have a better understanding from the construction work teams of what the design team intends to happen during the construction process. For this, Autodesk Navisworks and Sketchup software will be used.

10.3.1. Simulation in Autodesk Navisworks

For the simulation process of the construction phase, it will be use Navisworks, which is an Autodesk software. This software complements the 3D design packages of Autodesk and allows to generate planning simulations, space/time clash tests, animations and renderings to the work done. It is important to note that Navisworks is not designed to modify the 3D model, then, it will need to be linked to the model where the 3D design was performed, in this case Revit. As it was explained during the time analysis chapter of the present thesis, Navisworks have a perfect interoperability with Revit as both are from Autodesk family. For this case, in Navisworks is possible to open directly a file from Revit as it will be shown next.

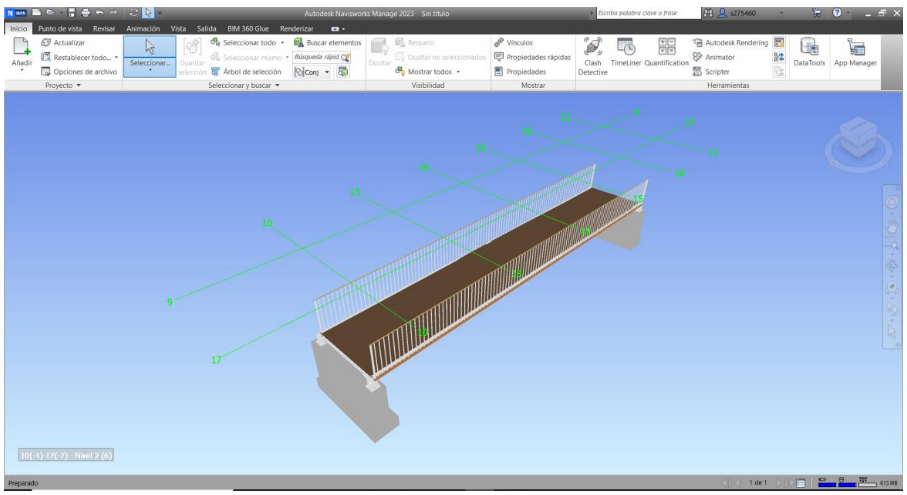


Figure 159. Pedestrian bridge 3D model (Navisworks)

It's important mention that even if Navisworks has a TimeLiner tool that allows the software to create tasks and schedules, according to many manuals one of the fastest and most efficient ways to use this tool is to import schedules from a software purely dedicated to work planning. (Dodds, J. and Johnson, S. 2012. The time analysis process embraced use of Microsoft Project, where different activities were considered and must be used for the simulation of the construction phase. Then, it's necessary to import the Microsoft Project schedule to Navisworks by following the steps that will be presented.

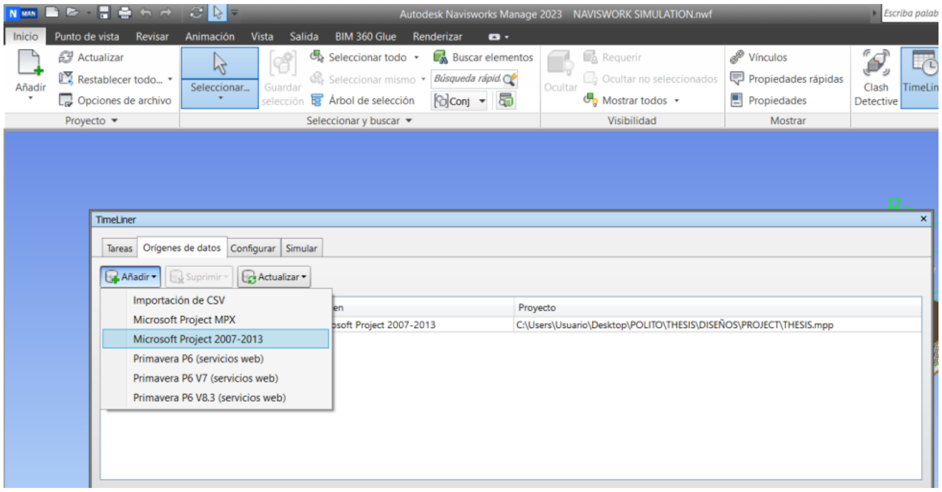


Figure 160. Data import process from Microsoft Project (Navisworks)

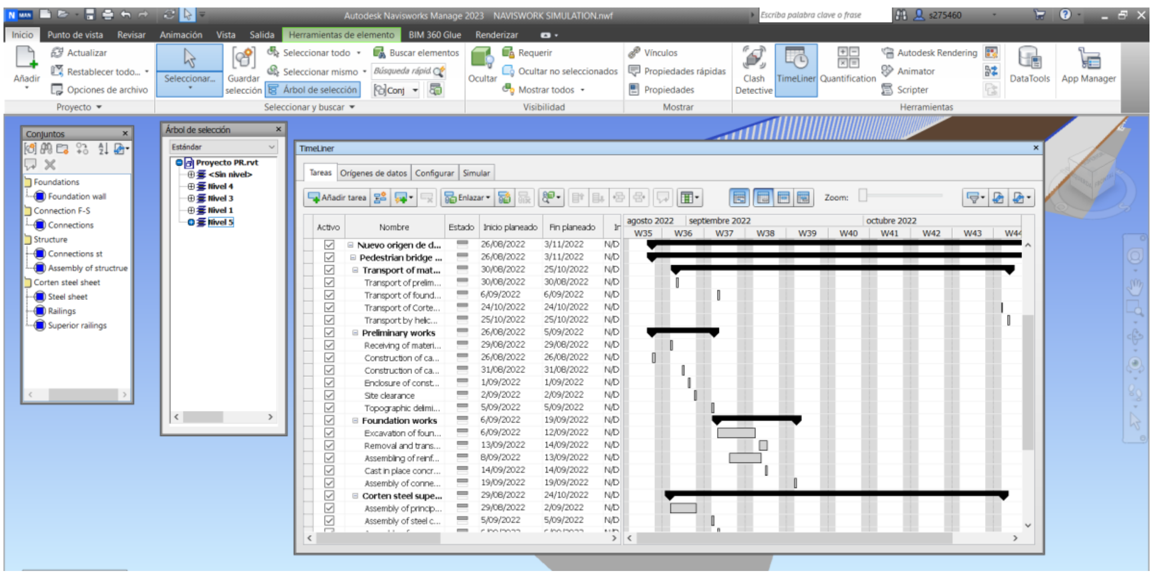


Figure 161. Imported data from Microsoft Project to Navisworks (Navisworks)

As it's shown, the schedule process that was designed on Microsoft Project it's completely exported to Navisworks. Then, by linking the schedule to the 3D model, it's possible to run the simulation of the construction process as it's intended to be performed. This simulation is presented as a video file, however, in the following figures it will be represented the process.

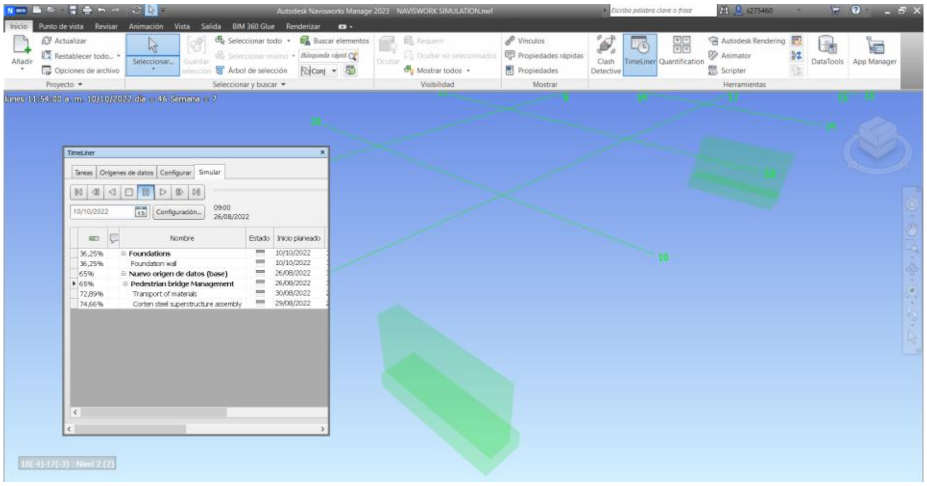


Figure 162. Simulation of construction phase - Foundations (Navisworks)

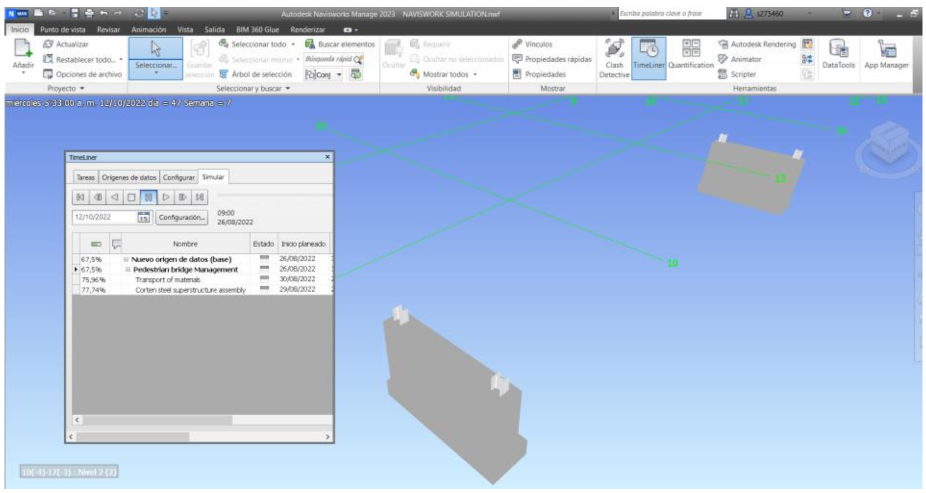


Figure 163. Simulation of construction phase – Connections between foundation and structure (Navisworks)

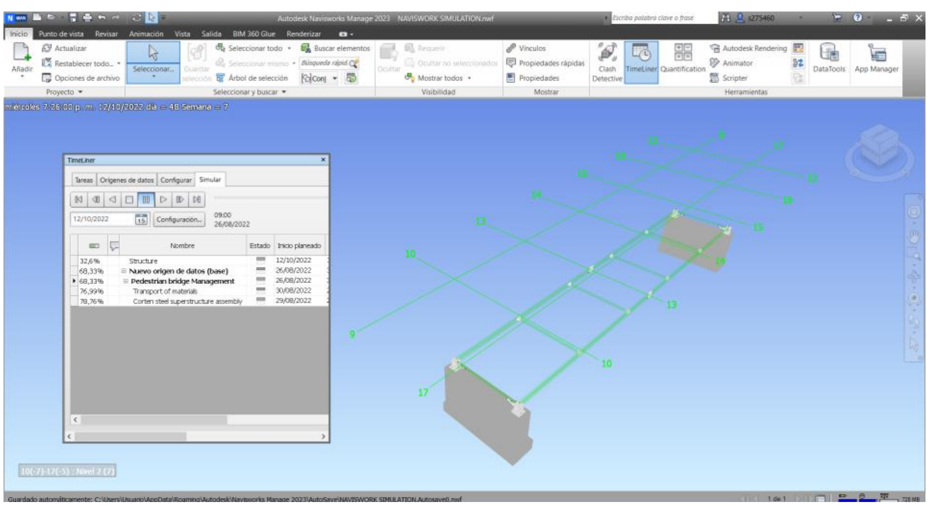


Figure 164. Simulation of construction phase – Assembly of Corten steel structure (Navisworks)

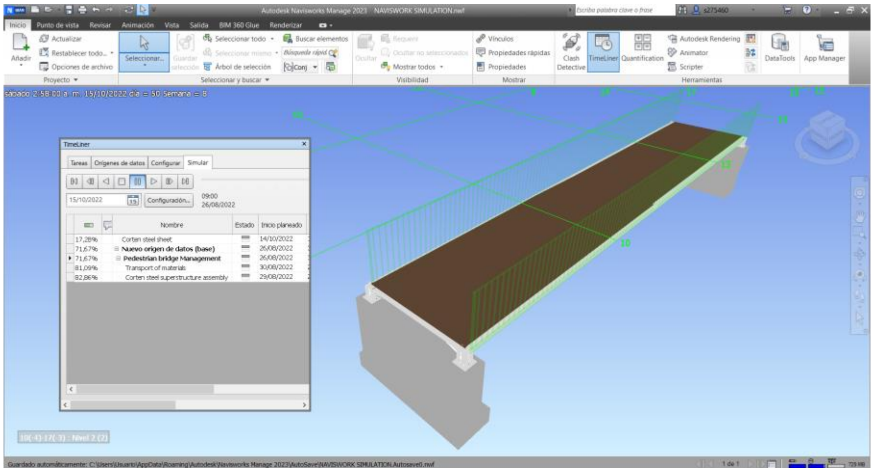


Figure 165. Simulation of construction phase – Assembly of Corten steel sheet (Navisworks)

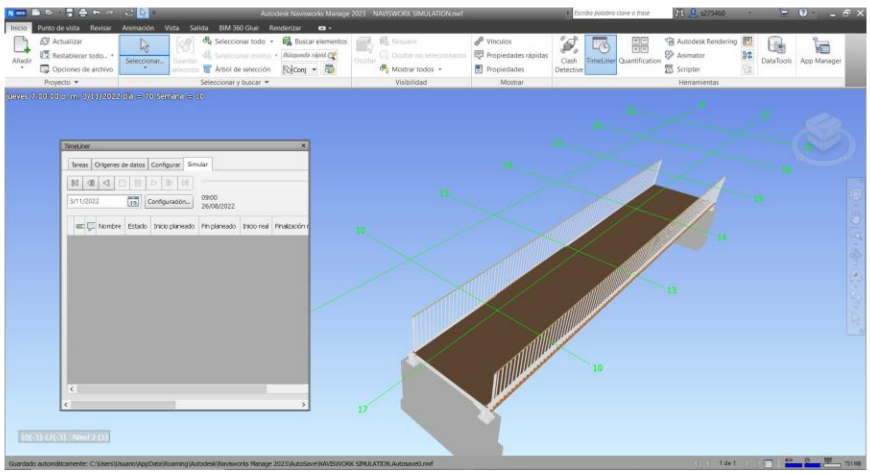


Figure 166. Simulation of construction phase – Final representation of construction phase (Navisworks)

10.3.2. Rendering in Lumion

The architectural model was partly performed using Sketchup, this software allows to have a better detail on architectural aspects. For the present part of the work, it has been decided to add to the architectural design the rendering. This process is a generation of 2D or 3D image from a model. The rendering allows to have a better representation and help the understanding of construction work teams on the final steps of the construction process (benches, pot planting and lighting). For this, the software Lumion was used, which present a good level of interoperability with SketchUp. From this software is possible to export the file as a DAE format, then, in Lumion it's possible to import directly the DAE format file. This procedure will be shown in the following figures.

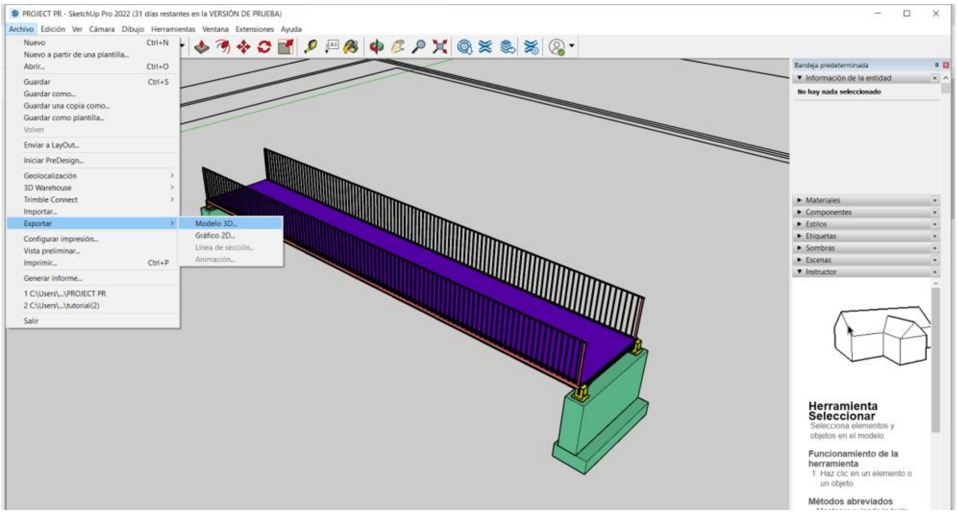


Figure 167. Export of 3D model in SketchUp to Lumion (SketchUp)

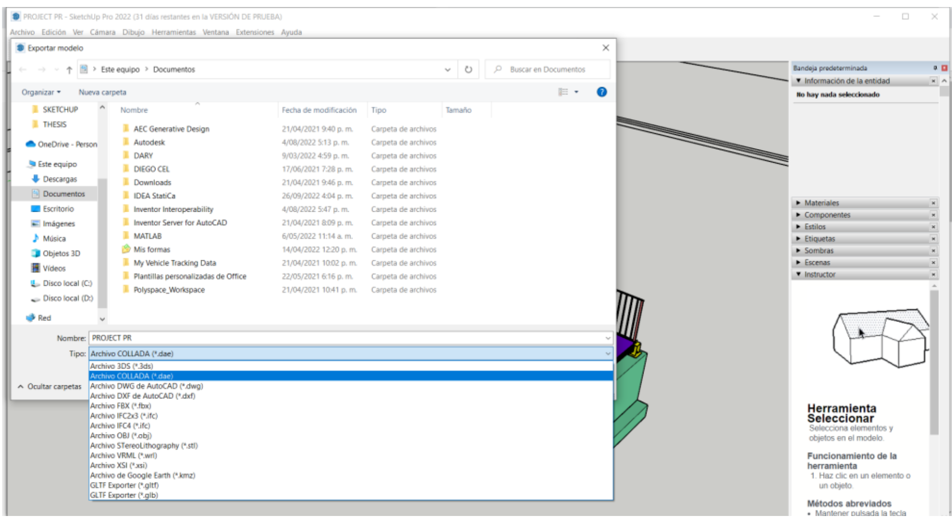


Figure 168. Export of 3D model in SketchUp to Lumion (SketchUp)

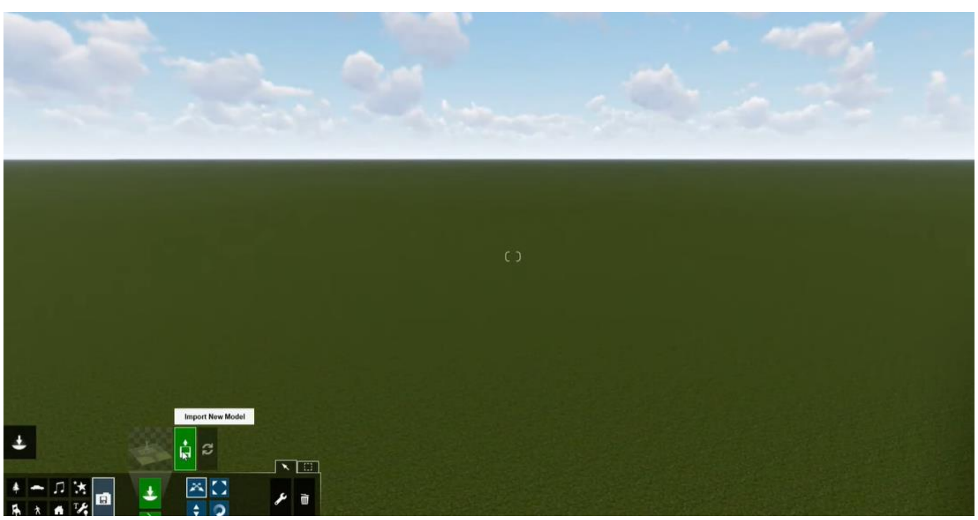


Figure 169. Import of 3D model in Lumion from SketchUp 1 (Lumion)

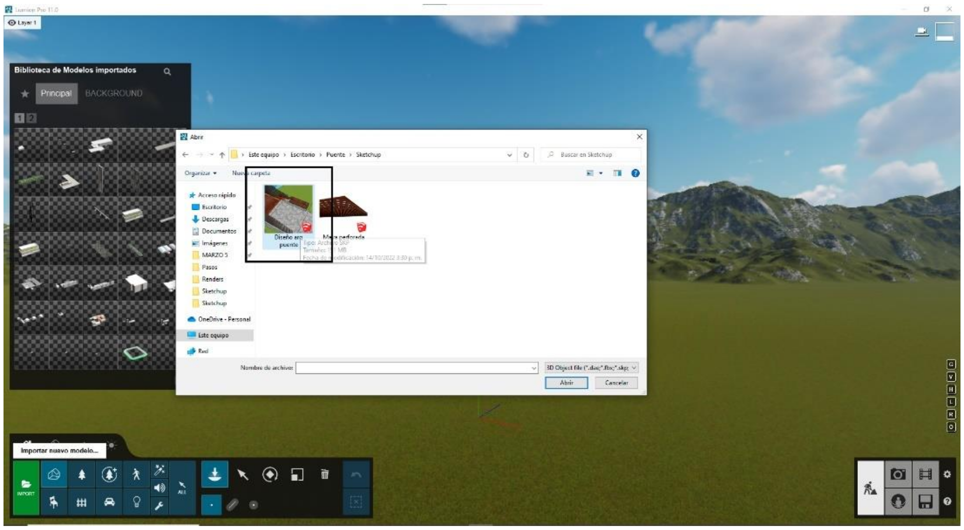


Figure 170. Import of 3D model in Lumion from SketchUp 2 (Lumion)

It's important to mention also, that a rendering is very important and it’s used for a better understanding from the stake holders and every party that are involved in a construction project. The rendering for the present project it’s shown in the following figures.

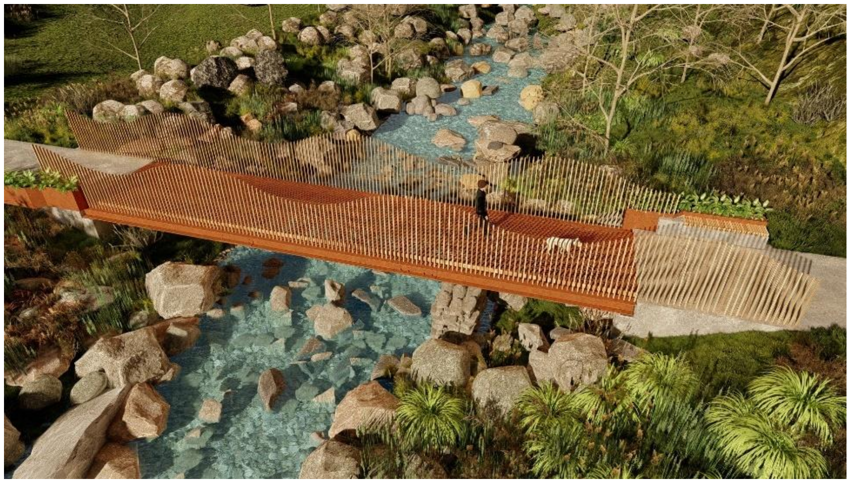


Figure 171. Rendering of Piedicavallo Pedestrian Bridge (Lumion)

As it was mentioned during the estimation of costs for the project, a lighting system has been suggested for the pedestrian bridge. This lighting system has been also included during the rendering in Lumion as its shown in figures below.

Figure 172. Rendering of Piedicavallo Pedestrian Bridge with Lighting system (Lumion)

11. Interoperability between software

The architecture, engineering and construction (AEC) industry, it's an industry that needs the collaboration between many work groups in order to achieve the correspondence activities and goals. However, there is not a single software or computer application that can contain all different needed designs and considerations, leading into a problem and inefficiency in design processes of projects.

As it was introduced before, a Building Information Model (BIM) is a methodology that combines digital tools, processes and technologies that allows the coordinated handling of all the information corresponding to a construction project. This is where an important term as interoperability appears. BIM is a shared digital representation based on open standards for interoperability. For this reason, it has been rapidly introduced in recent decades in different countries, especially in Europe and in countries with a high development in infrastructure.

Interoperability identifies the need to pass data between applications, and for multiple applications to jointly contribute to the work at hand (Osello, 2012). In a general context interoperability is defined as the ability of software and hardware, on multiple computing platforms from multiple vendors, to exchange information in a useful and meaningful manner. The capacity to use, manage, and exchange electronic product and project data amongst project participants in the design, engineering, construction, maintenance, and related business processes is known as interoperability in the construction environment. Technically, interoperability in BIM parlance can be achieved by using an open and publicly managed schema (dictionary) using a standard schema language. A schema is a description of the formal organization of a certain collection of data. This is generally defined using a schema language (Sawhney, 2014).

The interoperability of each project defers and depend on the design, each design process contains the necessity to involve different software, then the facility and efficiency between software may change. Then, the interoperability on BIM project depends on the software used, for design, architectural design, structural design, construction management and detailing purposes. Additionally, the interoperability also changes depending on the company that owns the correspondent software. Usually, the software that are fabricated by the same company have very good interoperability between them, such as, Autodesk and Acca.

For the present chapter, the evaluation of the interoperability requires the list of the software that were used in order to achieve all goals that were settle as objectives for the case study. During the present project, software from Autodesk, ACCA family, Trimble and CSI were mainly used, such as AutoCad (Drawing and 2D planes), Revit (Architectural and Executive design), SketchUp (Architectural design and rendering), SAP 2000 (Structural Analysis), IdeaStatica (Connection design), Microsoft Project (Project management), Navisworks (Time depending modelling and simulation), Primus (Costing Analysis), SketchUp (Rendering and VR) and Cloud Compare (Common cloud in site).

The software were chosen and used for the present work for many reasons. First, the prior knowledge of each tool, then, the many opportunities that the software brings in its used such as correctness on designs, facilities and the most importantly, efficiency in the work process. The list of used software are shown in the following table.

Software used	Function
Revit	Architectural and Executive design
SketchUp	Architectural design and 3D Modelling
Sap 2000	Structural analysis
IdeaStatica	Analysis of connections
Excel	Calculation of fundation
Microsoft Project	Project management, scheduling and budget
Navisworks	Time depending modelling and simulation
Primus	Cost analysis
Autocad Civil 3D	Drawing and 2D planes
Lumion	Rendering and VR
Dropbox	Common cloud in site

Table 17. List of software used – Interoperability

Once all software used during the BIM project are listed, it can be seen how there are differences between the present list and the one proposed on the evaluation of the BIM methodology for the case study. These differences respond to necessities presented during the development of the BIM project. For instances, in the beginning of process, a software as Advance steel was thought to respond a function as the drawing and detailing of the connections. However, on Revit was possible to draw and design the connections and export it directly to IdeaStatica, where the analysis was performed, leaving apart the use of Advance steel.

Now, it will be described the interoperability process reached between all different used software. It's important to underline that the interoperability between the software that are by the same company, such Autodesk software, have a higher level. For the interoperability evaluation, it will be summarizing all different activities and works that were developed during the present BIM project.

11.1. Analysis of interoperability between software used

The evaluation of the interoperability of each software will be perform by comparing each case where the work process involved the interaction between two different tools. For this, the different steps that the BIM methodology contemplates during the development of the pedestrian bridge project will be described.

- **Revit 2021 to AutoCAD:** The architectural design and the 3D model were created in Autodesk Revit. Then, the 3D model in Revit was directly exported to AutoCAD by converting the file as a DWG one. From AutoCad, it was possible to manage different operations as the creation of the different 2D planes.

- **AutoCAD to SketchUp:** From AutoCAD, the model was exported to SketchUp. SketchUp, allows to directly import a DWG file without necessity of any plugin or add. In this software, the 3D modelling was improved and a higher level of detailed was reached.

- **Revit 2021 to SAP2000:** Once the architectural design was completed, the structural analysis was performed using SAP2000. For this point, it was not possible to find a high level of interoperability between Revit or SketchUp and SAP2000. For this reason, the geometry of the 3D model was redrawn in SAP2000 and structural analysis was performed.

- **SAP2000 to Revit 2021:** With the structural analysis performed, the sections for the structure were redrawn in Revit and also the connections were added to the model. As the contrary process, it was not possible to export the new model to Revit, meaning a low level of interoperability between these two software.

- **Revit 2021 to IdeaStatica:** The Revit model was exported to IdeaStatica, where all connections were evaluated with the values obtained from the structural analysis in SAP2000. For this case, it was used a plug-in that is called Code check manager, allowing to export the pre-designed connection in Revit 3D model to IdeaStatica. However, it's important to mention that some connections were not completely identified by IdeaStatica. Thus, was necessary to create these connections.

- **Excel to Revit 2021:** For the case of the foundations, all different assessments were evaluated in Excel. In this way, it was possible to determine exactly the geometry of the foundation that met all the requirements. However, it was necessary correctly drawn the geometry in the Revit model. Then, it was not possible any level of interoperability between the different tools.

- **Revit 2021 to Navisworks:** Once the structure was completely design, the project management was carried out. First, the evaluation of the time analysis was performed by exporting the Revit model to Navisworks where a time depending modelling was linked to the 3D model. Navisworks as an Autodesk software, allows to directly open a file in Revit format, meaning a 100% of interoperability level.

- **Navisworks to Microsoft Project:** The time depending modelling of Navisworks was exported directly to Microsoft Project, where the time analysis was completely performed by adding all activities that were decided for the case study. Additionally, the Project model contained the resources in terms of workers that will be necessary for the estimation of costs. For this case, there is a Plug-in in Navisworks that allows to export the model as a CSV or XML file, meaning that it can be opened by Microsoft Project. This operation means a good interoperability between these two software, even if they are not from the same family. Additionally, it's important to mention that the Plug-in that was used for the case it's part of Navisworks, then, it was not necessary to download it.

- **Revit 2021 to Primus:** For the estimation of costs, it was used Primus software. In this part, the Revit model was used only to use the takeoff materials tool. As it was explained during the cost analysis chapter, it represented the most critical part for interoperability of the BIM methodology as it was not possible to link the two models. In this chapter it was also mentioned that a procedure could have been done in which using other ACCA family software such as Edificius, the Revit model could have been linked. For this, it is possible by means of a plugin to export the Revit model to Edificius. Afterwards, the building model can be exported to Primus to directly take off the quantities of materials. However, the cost estimation procedure must be done individually for each activity that is part of the construction process.

- **Microsoft Project to Navisworks:** With all project management completely described, the Microsoft Project model was exported to Navisworks. Now, in Navisworks the time liner with all activities was created and the simulation of the construction process was done. As the interoperability between Navisworks to Microsoft Project, this interoperability has also a good level. This, due to a possibility in Navisworks to directly import a Microsoft Project file or time schedule to the Time Liner of the software.

- **SketchUp to Lumion:** As a final step, Lumion software was used to rendering the pedestrian bridge model and also to add a VR to the project. For this case, it was necessary to add to the SketchUp 3D model, different colors for each type of object contained in the structure. From this software it was possible to export the file as a DAE format. Then, in Lumion it's possible to import directly the DAE format file. The colors mentioned, allows Lumion to directly change textures and materials of the objects as are recognized as colors.

Finally, it can be said that Dropbox was used as a common cloud in site, where all different models from different software were stored.

11.2. Evaluation of interoperability between software used

Once all different levels of interoperability between used software were analyzed, it's possible to evaluate it by adding a value or grade for each case. For this, 4 different grades will be considered as shown in the next table.

Good (green cross)	80-100% Good
Fair (yellow cross)	30-79% Fair
Poor (red x)	0-29% Poor
—	Not considered

Table 18. Interoperability evaluation grades

As it can be seen, the interoperability will be evaluated with 4 different ways. First a good interoperability between two software will be marked with a green cross. Then, a medium level of interoperability will be marked with a yellow cross. For the case of software that didn't have any level of interoperability or it was very low, a red x will be graded. Finally, there are software that didn't interact during the BIM methodology, for these, it will not be considered any grade, just a line as it's shown in last table.

Now, the interoperability of the BIM project will be evaluated in the table shown next, where it will be analyzing each relation between the different software.

	AUTODESK REVIT	SketchUp	SAP2000	IDEA StatiCa	Excel	Project	AUTODESK Navisworks Manage	PriMus Computo e Contabilità	AUTOCAD CIVIL 3D	LUMION
AUTODESK REVIT	Good	Good	Poor	Fair	Poor	Fair	Good	Fair	Good	Fair
SketchUp	Good	Good	—	Poor	—	Poor	Poor	Poor	Good	Good
SAP2000	Poor	—	Good	Poor	—	—	—	—	—	—
IDEA StatiCa	Fair	Poor	Poor	Good	—	—	—	—	Fair	—
Excel	Poor	—	—	—	Good	Fair	Good	Good	—	—
Project	Fair	Poor	—	—	Fair	Good	Good	Poor	—	—
AUTODESK Navisworks Manage	Good	Poor	—	—	Good	Good	Good	Poor	—	—
PriMus Computo e Contabilità	Fair	Poor	—	—	Good	Poor	Poor	Good	—	—
AUTOCAD CIVIL 3D	Good	Good	—	Fair	—	—	—	—	Good	—
LUMION	Fair	Good	—	—	—	—	—	—	—	Good

Table 19. Interoperability between software

The table just presented contains the evaluation of level of interoperability between the several software that were used during the BIM methodology of the present pedestrian bridge project. In this evaluation it's represented graphically the description made before about the relation between the couple of software. As it was expected, the software that are from the same family (Autodesk or ACCA) have a perfect level of interoperability, specially, compared with the relation between those who don't.

It can be said that Revit was the central software of the BIM methodology, as in there were managed the architectural and the executive design. For this case, it can be seen how the model in Revit had a good level of interoperability with the other Autodesk software as Navisworks and AutoCAD and also with other software from different families. This condition, may indicate that as Revit has the potential of being a good software to manage central models of the BIM methodology, other companies have been trying to create a good links to import the models or information from it.

SketchUp is a good example of what it was just explained. During the development of the model in this software, it could be seen how the model could be exported easily to other software as Revit, AutoCAD and Lumion. However, it's important to mention that for this case, the software only had a good level of interoperability with design or model software and not with software that manage structural models or the project management.

For the case of SAP2000, it needs to be clear that this is a software dedicated purely to the structural design and algo the earthquake considerations. Then, the interoperability with other software from different families was not good. As it was mentioned several times, once the structural design was completely performed, the elements (IPE sections) had to be changed. For this, it was necessary to redrawn manually in the Revit model and exported again to other models as SketchUp, representing a bad efficiency in the BIM methodology process.

Continuing with the software used for the structural analysis, it can be said that IdeaStatica didn't reach a good level of interoperability with other software. For the case of Revit, it was explained that the connections created in the model were not completely recognized by IdeaStatica. However, it's important to mention that the existence of Plugins helped to make an efficient work between the 3D model and the evaluation of connections that was performed. This evaluation of connection needed also the use of SAP2000 results from the structural analysis. As explained before, also this work wasn't efficient as was necessary to take manually the values of bending moment, shear and axial forces, meaning a increase of time spent in the model.

Microsoft Project and Navisworks are software dedicated entirely to the project management phase of the BIM methodology, as it's known, both tools are from different families of software. However, they present a good level of interoperability, where also is possible to import and export the models without any plugins or extensions. This level of interoperability was not expected; however, it means that this two software are commonly used together in the architecture, engineering and construction (AEC) industry for project management phase of buildings and constructions.

For the case of the estimation of costs, Primus didn't present a good level of interoperability with other software. As it was mentioned before, the model in Revit can be exported to Primus but first it must be exported to other ACCA family software called Edificius. Then, even by doing this process, the estimation of cost it's not an efficiency step of the BIM methodology, taking into account that it's needed to input manually several cost of activities that are not present in a 3D model as the one from Revit.

After some research, it wasn't possible to find any good examples of tools that allows a good level of interoperability for the estimation of cost of the BIM methodology. For instance, between Navisworks and Microsoft Project can be managed the cost estimation process of a project. However, it's important to mention that still many costs of activities will need to input manually the data about costs. In this part, Primus presents an advantage comparing with other software, as it was possible to directly link the data from the Prezzario della Regione di Piemonte. This possibility allowed an efficiency in the estimation of costs process, as it was possible to assign the descriptions and costs directly to all different activities that were part of the construction of the pedestrian bridge.

Finally, it could be seen how the 3D model, render and VR software as Revit, SketchUp and Lumion had a good level of interoperability. As the example of project management, for this point of the thesis, it was possible to import and export the files directly without the necessity of any plugins. This means also that the software used in thesis are commonly used together in the architecture, engineering and construction (AEC) industry.

12. Future developments and other considerations

Building information modelling is not just the creation of a 3D model for a project with it correspondent project management, but it means also the addition of information relating to sustainability and maintenance. Until this point, it was reached the 5D first dimensions of a BIM model, reaching the 3D modelling, the 4D time-related info and the 5D cost analysis. During this chapter, it will be presented some considerations for the future of the Piedicavallo pedestrian bridge project that can be taking into account in order to develop an entire BIM cycle. These considerations are the dimensions 6D that corresponds to the sustainability for the project and finally the 7D which contains the life cycle and maintenance aspects.

12.1. 6D BIM: Sustainability

The 6D dimension of a BIM project corresponds to the studies of the environmental, economic and social sustainability. It helps to analyze the energy consumption of a project and the estimating of the energy required in design stages.

The data that can be managed in this stage of a BIM includes information about manufacturer of different components, dates of installation, the required maintenance and many details about the configuration and operation of all used components. With the 6D, is possible to have a complete map of the operating, performance and lifecycle for the components of a project. Then, this approach helps to have an idea of the entire cost to achieve sustainability and also cost efficiency, allowing decision-making during the design process.

6D BIM model offers an easily-accessible and understood way of extrapolating information. With the use of graphics, many details that would have been overlooked in paper files can now be easily questioned. This strategy really shines when it enables facilities managers to plan maintenance tasks years in ahead and create spending profiles throughout the course of a built asset's lifetime, determining when repairs become unaffordable or existing systems become inefficient. This approach of planned and proactive planning offers significant benefits over a more reactive one – not least in terms of costs (Tesla OS, 2018).

The present project that corresponds to a pedestrian bridge in Piedicavallo doesn´t contain any devices that present the necessity of energy consumption, however, as it was explain during the case study and also in the architectural design, one of the main ideas of the present BIM project is to create not just a pedestrian bridge but also an added value for the region. Then, it can be proposed as a future work the use of lighting devices in order to accomplish an improvement and embellishment of the zone, additionally, it can be said that we can refer as example to one of the pedestrian bridges analyzed during the bibliographical research of pedestrian bridges with combined materials such as The Bayraki Coast Pedestrian Bridge from Turkey.

Figure 173. Bayrakli Coast Pedestrian Bridge at night (Taken from Archdaily.com)

For the proposed improvement of the Pedestrian bridge, the BIM 6D can be used in order to account the energetic consumptions and the management of the system, for this purpose a tool as Autodesk Green Building Studio can be used.

This software is a flexible cloud-based service that allows to run building performance simulations to optimize energy efficiency and to work toward carbon neutrality earlier in the design process. The capacity to design high performance buildings at a fraction of the time and expense of conventional approaches will be increased with the aid of Green Building Studio (Autodesk).

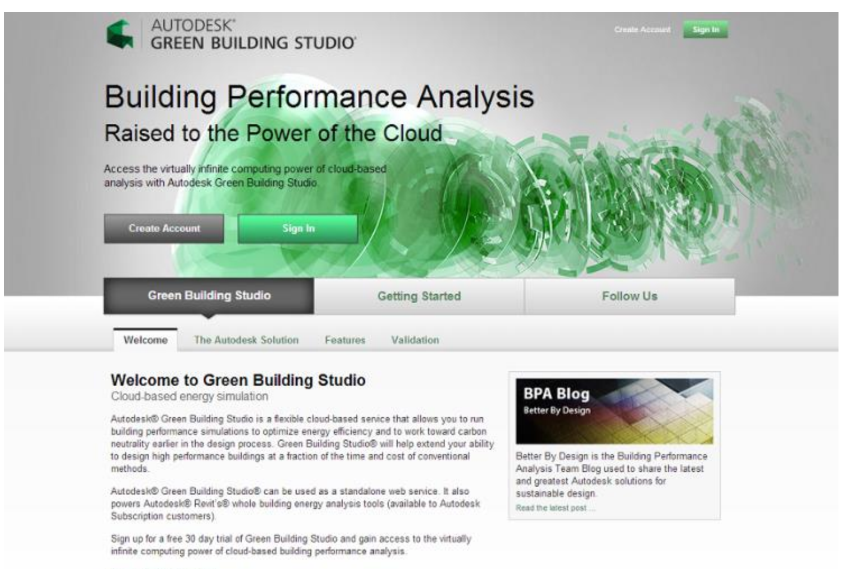


Figure 174. Autodesk Green Building Studio (Taken from Autodesk.com)

The possible development of the lighting design for the pedestrian bridge must take into account all conditions that are presented for the case study. For instance, the use of a solar technology for the energy consumption of the illumination can be recommended considering the difficulties of connections to regular energy system providers. However, a proper design must be performed where it needs to be included all economical and maintaining aspects.

12.2. 7D BIM: Maintenance plans

The 7D BIM dimension correspond to the operation and facility of management of a building or a project. The main idea of the dimension is to track important asset data such as its status, maintenance/operation manuals, warranty information and technical specifications to be used at a future stage.

In this approach is possible to collect on a single place everything that is related to facility management, in order to improve the quality-of-service delivery during the entire lifecycle of a project, finally, allowing to maintain everything in best way from day 1 of the structure until the end of the lifecycle.

As it was explained, the present project doesn't have as an objective to reach the 6D and 7D dimensions, however, it will be shortly presented some considerations for the maintenance of the pedestrian bridge during its life cycle.

For the case of the Corten steel structure, an effective inspection and maintenance will be essential to have a proper behave through the years. Unlike other steel structures, Corten steel can be more difficult to inspect due to the rust that covered the sections, reason why the following aspects are recommended by the U.S. Department of Transportation/Federal Highway Administration (1989) on a maintenance plan.

- Implement maintenance and inspection procedures designed to detect and minimize corrosion. Identify the structural components that need to be inspected and create inspection standards that show the distinction between the desired oxide coating and excessive rust scaling.
- Manage drainage to reroute runoff away from the building.
- Regularly clear the structure of all dirt, debris, and other buildups that could trap moisture against the surface.
- Regularly remove any plants that could obstruct the steel surfaces' ability to naturally dry off after being wet.
- Keep coverings and screens over access holes to keep out animals and birds that could build nests that would trap moisture against the surface of the steel.

Usually, the Glulam wood, which will be used for the railings, benches and other design aspects, doesn't require preservative treatments. However, as the conditions that will be exposed are to those with all-weather cycles, including prolonged wetting, some common agents of deterioration can appear such as decay fungi and insects (The American wood protection association AWAP, 2013). In order to extend shelf life of Glulam wood, preservative treatments are registered by the U.S. Environmental Protection Agency (EPA) depending on the specific use. The guidelines stay that for the conditions that are presented in the case study, the use of creosote as a pressure-treated wood may be use to ensure safe handling and avoid environmental or health hazards.

Finally, it can be said that it's recommended to continue the BIM process and reach the 7D dimension as a future work, due to benefits that can bring such as an optimized asset and facility management from design stage to demolition, simplified and easy replacement of parts and repairs anytime during the entire life of a building and streamlined maintenance process for contractors and subcontractors.

Figure 175. BIM Dimensions (Taken from: utilizandobim.com)

13. Comparison of design with project from Dott. Ing. GARIZZO Pier Giorgio

As previously presented, the Piedicavallo pedestrian bridge has been designed and will be built by the design studio of Dott. Ing. GARIZZO Pier Giorgio. This work is part of a set of projects that have been carried out in the province of Biella, as a result of the events that occurred in October 2018. Where the rising river caused severe damage to structures such as bridges and different buildings. As it's public project, the design studio of Dott. Ing. GARIZZO Pier Giorgio has the restriction of having a maximum budget determined by the different entities, limiting the design and creating the need to manage it efficiently. Of course, within the framework of the specifications in terms of structural design for this type of building.

On other hand, the design that was reached during the present thesis did not have any limitations in terms of budget or specification on the bridge dimensions. However, the conditions of the case study made those different decisions that were taken from both designs similar such as the election of material and dimensions for the structure. Additionally, these similarities created the possibility of doing a comparison between the two different designs.

13.1. Analysis of project design from Dott. Ing. GARIZZO Pier Giorgio

The designed that has been made by the Dott. Ing. GARIZZO Pier Giorgio has been partly provided for the realization of this thesis as mentioned during the development of the case study. This design will be featured in the figures shown below.

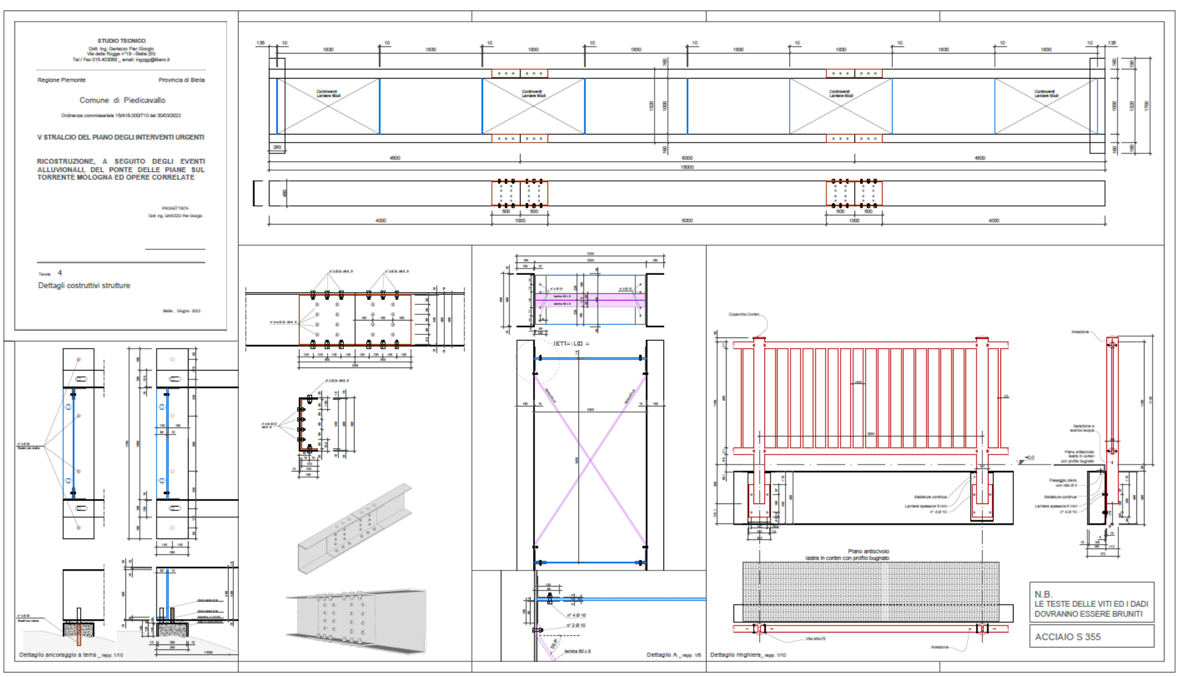


Figure 176. Structural design of Pedestrian bridge project (Taken from: Dott. Ing. GARIZZO, 2022)

In addition to the structural design, there is reference to the hydraulic relationships that were taken into account in making decisions such as the height and width of the bridge. In this way, renderings of the steel profiles and the design that is expected to be built have also been presented. It is important to bear in mind that the structure has been conceived in Corten steel material (S355). These rendered figures are presented below.

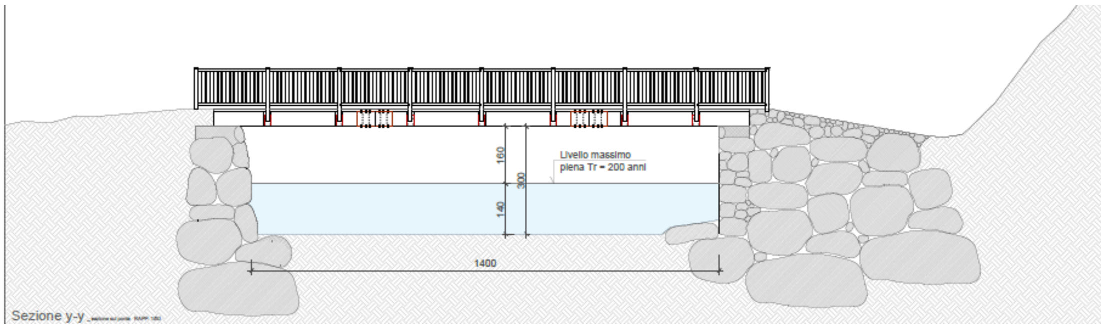


Figure 177. Dimensions of pedestrian bridge design (Taken from: Dott. Ing. GARIZZO, 2022)

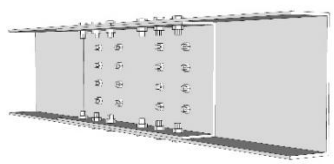


Figure 178. Connection of principal section of structure (Taken from: Dott. Ing. GARIZZO, 2022)

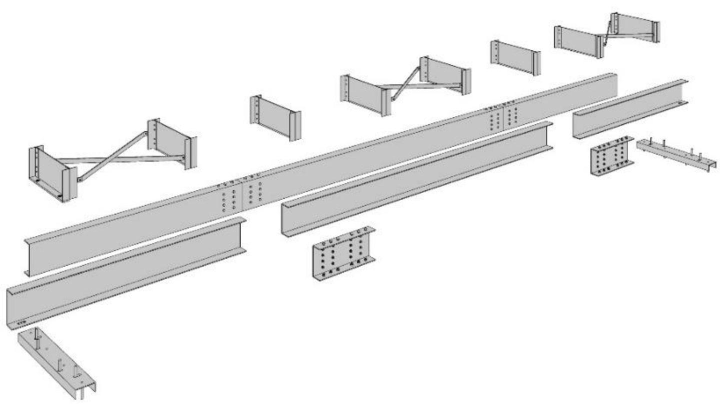


Figure 179. Different sections of Corten steel material (Taken from: Dott. Ing. GARIZZO, 2022)

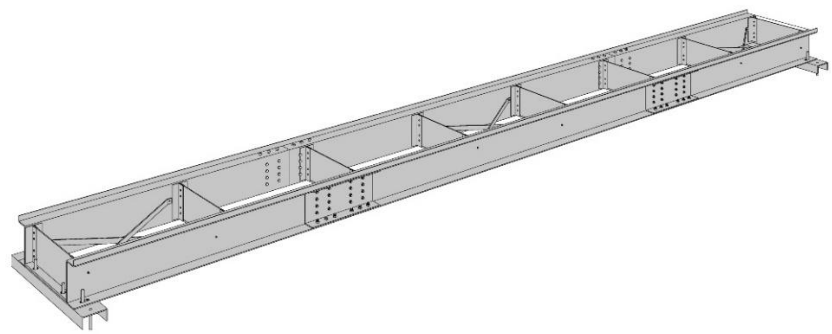


Figure 180. Ensembled structure of pedestrian bridge design from studio (Taken from: Dott. Ing. GARIZZO, 2022)

Figure 181. Render of pedestrian bridge structure design from studio (Taken from: Dott. Ing. GARIZZO, 2022)

As it can be seen, the design that was proposed by Dott, Ing. Garizzo, presents a structure with channel section or C-section. This type of section consists in two flanges that are connected in both ends, representing a typical used section in steel framed structures. Additionally, it can be seen that the connections between the C-sections have been designed with bolts instead of welded. This, due to the Corten steel material, which has limitations on weldability for temperature.

The architectural design presented is a bridge that can be found perfectly in any environment. The choice of Corten steel material is due to the need to avoid maintenance work as much as possible, considering the conditions of the area and the difficulty in reaching it.

Appart from the architectural and the structural design, the cost analysis from Dott. Ing. GARIZZO Pier Giorgio for the Piedicavallo pedestrian bridge project was also presented and it's shown in the table below.

COMPUTO METRICO ESTIMATIVO							
TOTALI PER CATEGORIA							
CODICE	DESCRIZIONE CATEGORIE DI LAVORO	IMPORTO CATEGORIE	IMPORTO MISURE	IMPORTO LORDO	IMPORTO NETTO	% CORPO	%
	Altro	€ 77.500,00	€ 77.500,00	€ 77.500,00	€ 77.500,00		100,00%
	TOTALE	€ 77.500,00	€ 77.500,00	€ 77.500,00	€ 77.500,00		100,00%

Table 20. Cost analysis of pedestrian bridge project design from studio (Taken from: Dott. Ing. GARIZZO, 2022)

The cost reached for the design of the pedestrian bridge by the Dott. Ing. GARIZZO is €77.500. However, it's important to mention that this cost does not correspond to the final contract between the design studio and the public entity. Then, changes on designs and also costs may happen during the development of the final contract and the construction of the Piedicavallo pedestrian bridge.

13.2. Analysis of pedestrian bridge project of the present thesis

In the case of the bridge designed in this thesis, it is intended to focus on the landscape and the environment. Its architectural design has been conceived so that the structure can blend in with nature. Materials such as Corten steel have been chosen for the structural sections seeking to avoid maintenance work. In addition, wood has been chosen as a complementary material for architectural details. In the following figures, it will be shown the structure sections of the pedestrian bridge.

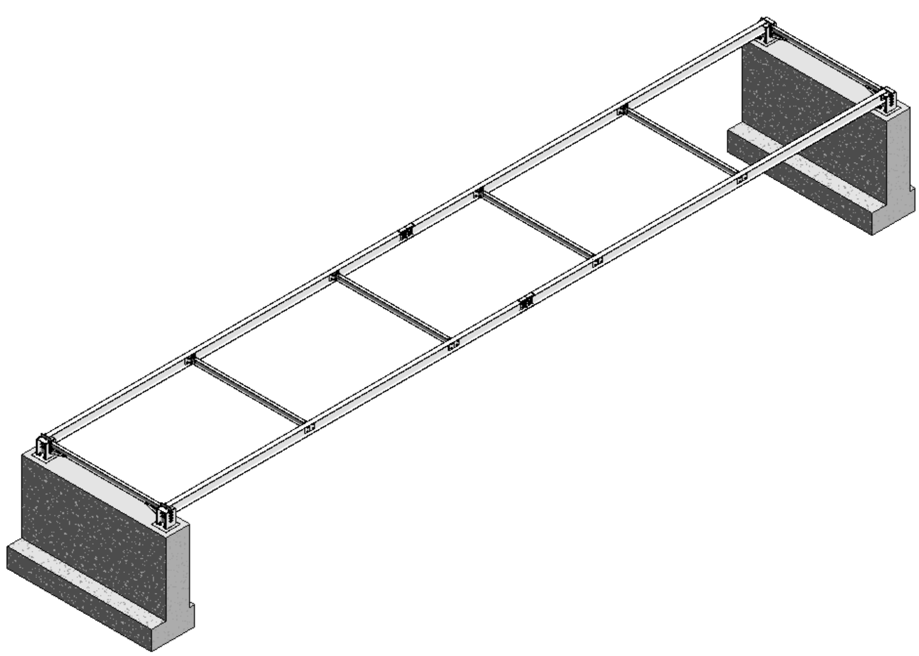


Figure 181. Structural design of pedestrian bridge (thesis)

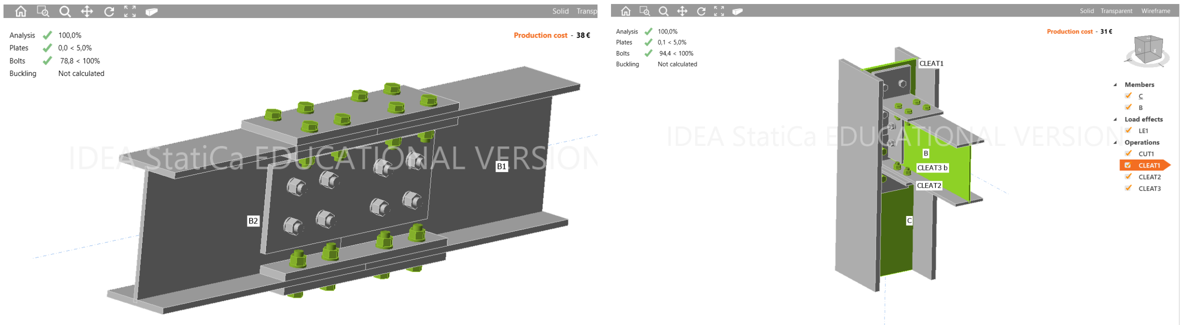


Figure 182. Connections of Corten steel structure of pedestrian bridge (thesis)

The structural design of this thesis has been developed considering I or double T sections. For the main beams a section called IPE180 was used and for the case of the secondary beams IPE100 sections were used. This design has also been proposed in Corten steel material of the type S355. Finally, it can be seen in the last figure that the connections are also considered bolted due to the impossibility of welding the sections in the case of Corten steel. Once the structural design of the pedestrian bridge was described, the architectural design will be presented in the following figures.

Figure 183. Architectural design of pedestrian bridge 1 (thesis)

Figure 184. Architectural design of pedestrian bridge 2 (thesis)

For the architectural design of the pedestrian bridge of the thesis, the floor has been considered with a perforated sheet of Corten steel material, which will allow to see the passage of the river while crossing it. On the other hand, the railings have been designed in square wooden tubes that give a sinusoidal shape. Their curves are intended to give importance to the mountains of the Mologna Valley that are part of the landscape of the study case area. Finally, the design has rest areas at the ends of the bridge, where benches have been located. This, together with the pots, give the pedestrian bridge the possibility of being used as a place of integration and rest.

With the structure completely designed, the cost analysis of the thesis was performed using Primus software. This analysis was based on the Prezzario Della Regione di Piemonte, which presents local information about the prices of construction activities. The summary of reached costs for the design is shown below.

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	IMPORTI TOTALE	incid. %
	RIPORTO		
	Riepilogo CATEGORIE		
001	Transport of materials	16´381,50	18,743
002	Preliminary works	6´405,60	7,329
003	Foundation works	13´736,39	15,716
004	Corten steel superstructure assembly	14´204,19	16,252
005	Runway installations	34´031,65	38,937
006	Final works	2´642,24	3,023
007		0,00	0,000
	Totale CATEGORIE euro	87´401,57	100,000

Figure 185. Costs analysis for the thesis pedestrian bridge design

The cost reached for the design of the pedestrian bridge of the present thesis was €87.402. Which represents an increment of almost €10.000 with respect to the one from the design studio. Also, it's important to mention that has been suggested from the architectural design the use of the lighting system, which may bring added value to the pedestrian bridge as it was shown during the rendering of the pedestrian bridge. The inclusion of the lighting for the pedestrian bridge will represent an increment in costs of €24.335, increasing also the difference with respect the design from the studio in €34.000. In the following figure, it's shown the rendering of the pedestrian bridge with the suggested lighting system.

Figure 186. Architectural design of pedestrian bridge with lighting system (thesis)

Finally, it can be said that both designs meet the main objective for which the pedestrian bridge project is being carried out. These are functional designs that comply with local specifications and regulations at the structural level. However, it can be seen how in the design carried out for the thesis an attempt has been made to give added value to the region and to the population that inhabits the area.

14. Conclusions

The definition of the case study and methodology is extremely important for the development of any work or project. For this occasion, it was essential to know all the aspects that surround the study area, in order to be able to make decisions about dimensions, materials and construction processes for the designs and considerations of the pedestrian bridge.

Bibliographical research of pedestrian bridges with combined materials was presented. During this research, it was considered different cases of pedestrian bridges around the world that use at least two different materials. Then, considering all aspects of the case study, it was decided to use Corten steel as main material for the structure, and also use Glulam wood for many architectural purposes.

The project was managed following the Building Information Modelling methodology. The development of this methodology covered all different dimension of the BIM process, reaching a solution that intends to respond the necessity of pedestrian users and also to give an added value to the case study zone.

During the architectural design, two different solutions were proposed, being chosen the one with the highest level of detail. This solution that was mainly reached in Revit and Sketchup software, contemplates an architectural design with the use of Corten steel as main material for the structure and also the runway. Additionally, Glulam wood was used for railings and details that beautify the pedestrian bridge.

The structural analysis is a very important step of any building project. During this design, different structural regulations that are particularly considered in Europe and Italy were followed, such as Eurocode and NTC2018. For the structural design were used many software as Autodesk Revit for drawings and detailing, SAP2000 for structural analysis, Idea Statica for design of connections and Excel for design of foundations.

The principal objective of the present thesis corresponded to the construction management of the pedestrian bridge, which presents many challenges due to the difficult conditions that are part of the case study. Then, the 4D dimension of the BIM methodology that corresponds to the time analysis, was performed. For this part, it was detailed every step that must be followed during the construction phase. Navisworks and Microsoft Project were used, following the methodology Program Evaluation and Review Technique (PERT). Where, by means of the Gantt Chart, the time schedule and also the duration of the entire construction phase of the project was presented with a total duration of 50 working days (10 weeks).

To continue with the project management of the pedestrian bridge, the cost analysis that correspond to the 5D dimension of the BIM methodology was developed. For this analysis, the data of “Prezzario di Piemonte, edizione Luglio 2022” was used on the software Primus. These evaluations of costs, correspond to an evaluation of estimated metric computation, where it was assigned costs to all different activities that are part of the construction process. The use of the Prezzario di Piemonte corresponded to a necessity of having real values of costs of construction activities for the area where it will be located the pedestrian bridge. The analysis of costs yielded a result of €87.401,57.

As it was intended to use the BIM methodology during this thesis, all the software used was identified and its interoperability was analyzed. For this, an evaluation form was created, where all the different software that had some relationship during the design process were verified. It is important to mention that even if some software did not belong to the same family, good interoperability was achieved. Then, a project should verify, prior to its start, the possible connection that will be needed between various designs to choose the software with the best interoperability for the project. However, this decision is also limited by the previous knowledge of the design team in terms of the BIM methodology and each of the different software.

A comparison has been made between the approach reached by the Dott. Ing. GARIZZO Pier Giorgio that is in charge of the construction of the pedestrian bridge and the present approach reached during this thesis. This comparison, evaluated the structure in terms of design and costs. For this, both designs reached the functional purpose of the pedestrian bridge following all specifications for this type of buildings. However, the design of this thesis also intended to have an architectural design that would give added value to the region, importantly considering some architectural details that were taken into account.

It has been proposed as future developments to continue with the BIM Methodology considering the 6D dimension that corresponds to sustainability and the 7D dimension that corresponds to the maintenance plans for the pedestrian bridge. For the consideration of the 6D dimension, it was suggested to add a lighting system for the pedestrian. This lighting system was also considered during the architectural design, being part of the search for added value for the region. However, this system was not accounted for in the cost analysis due to an important increase in the total prices of €24.335.

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