POLITECNICO DI TORINO

Collegio di Ingenieria Civile

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

Master of science degree Thesis

BIM methodology for design of a pedestrian bridge in Piedicavallo (Biella) – Wood as main construction material.

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Abstract

The objective of this Thesis is to define a working method for the design and construction of a pedestrian hiking bridge in Piedicavallo, Biella. This bridge will be constructed in a remote area with difficult terrestrial access to site, using as main construction material wood. The challenge is the construction of this bridge in a non-conventional way, as it will be used helicopter as the main transportation mean, for the optimization of resources and construction of bridges, it will be proposed the design and construction of the bridge.

For the bridge construction it will be performed all the design phases of the bridge for the real case scenario, but the focus of the work project will be in the construction management of the bridge, such as the transportation of the materials to site, times of construction and a complete cost analysis.

For this planning phase of the bridge construction, the works were performed in the following way:

- Architectural design (Wood was used as part of the analysis – Truss structure chosen).
- Structural Analysis (Check the architectural design is OK in terms of a global structural analysis)
- New architectural analysis with corrected sections of elements
- Local design of structure connections
- Local structural Analysis of structure connections
- Quantities takeoff of the pedestrian bridge structure
- Cost analysis based on quantities takeoff (Materials and tasks to do)
- Times analysis – Schedule (Based in tasks durations, dependencies, and resources).
- Simulation of execution – Final planning of the execution phase.

Additional to the pedestrian bridge construction, given the site conditions, the possibility of an increase in the water level of the Cervo stream that could overcome the bridge (Long realistic Return Period of the stream). A synchronous hydraulic jacking system was proposed for lifting the superstructure, the cost analysis of this possible solution has been included, but a final jacking system proposal must depend on a hydrological study of this section of the Cervo stream.

Contents

Index of figures

Index of tables

Index of equations

1. Introduction

The objective of this thesis is to develop a possible solution of a pedestrian bridge in a remote area with difficult access, by using the BIM methodology. This model integrates all the architectonic and structural components with a possible real solution taking into consideration the actual costs and the management of the materials that are going to be used to build this bridge, in a safe and easy way.

The bridge is a pedestrian hiking bridge located in Piedicavallo, Biella. Last year, in the second and third day of October of 2020 a big flood took place in this area and destroyed this bridge and many others that were located around the same area. The event that occurred, has low probability of occurring, a long return period. In the location of the bridge the only remaining part are the left side foundations, which after analyzing this project solution will not be used but instead it will be created new foundations at each side of the bridge.

Figure 1: "Ponte della coda" after flood Cervo Valley (PidCaInfo, 2020)

During the study of the whole project, it was necessary to go and visit the actual state of the bridge and the position, during this visit it was performed a point cloud (.las file) using photogrammetry techniques, from an airplane some proper photos were taken and using this superposition it was possible to construct this point cloud, to be able to recognize the optimal position of the bridge and the coordinates present in this mountain.

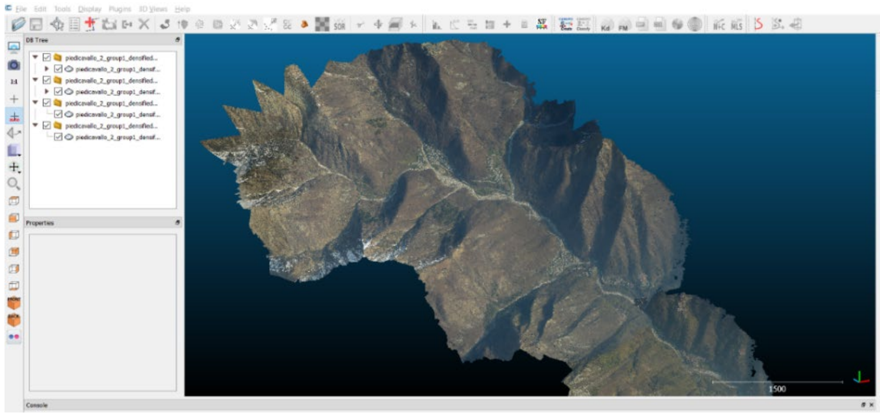


Figure 2: Point cloud Piedicavallo in Cloud Compare Software

This point cloud has been analyzed using the software cloud compare, in which we also found the real position for the bridge.

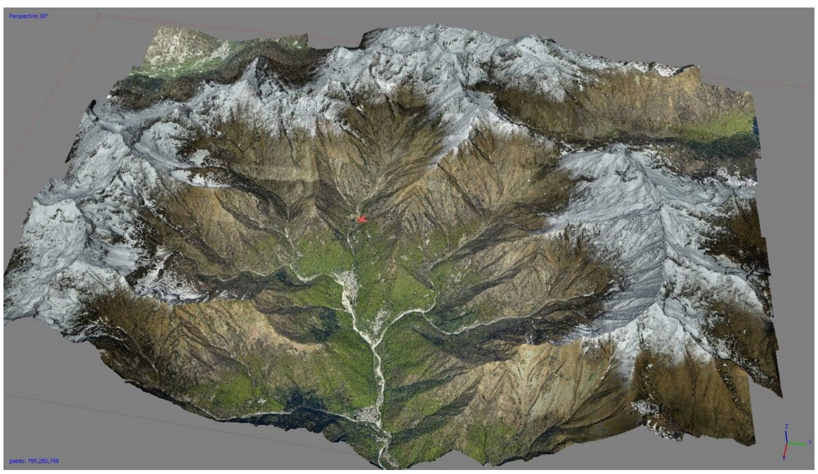


Figure 3: Actual position case of study.

In the survey performed on site it also included some pictures of the actual aspect of the pedestrian bridge and where the new pedestrian bridge will be in the Cervo stream.

Figure 4: Pictures of the actual aspect of pedestrian bridge - Cervo stream.

The objective of this thesis is to focus on this case of study and propose a possible solution for the rebuilding of this bridge, taking into consideration mainly wood as the construction material, using the BIM methodology, and proposing a solution for the construction materials and the transportation of this, considering that it will be built in a remote area, with difficult land access to the site.

This solution will be focused using different approaches and architectonic/structural designs for the same material, but at the same time there will be other thesis that will work on this same project in different materials to identify the best possible solution for the construction of this bridge.

For the solution, it was taken into consideration the construction management of the bridge, the construction and transportation of the materials, it was decided Glued Laminated timber as a main construction material, which is a thin and resistant material which makes it very efficient for construction purposes.

In this matter, as the bridge is in a remote place with difficult access, the construction idea for the project management and how the bridge will be constructed will be planned mainly using as a main transportation a helicopter. Saying, that it is essential to be efficient in the planning while using the helicopter to try to avoid extra costs in the transportation.

The main steps for the construction of the bridge will be divided in these main works, this will be divided in practical detailed tasks/activities that need to be performed for the completion of the project. This Work Breakdown Structure (WBS) are a division of the work breaking in simpler tasks with a finite duration and a dependency between each other to complete the whole project.

1) The design of the superstructure of the bridge will be passed to a manufacturer company in charge of the construction of prefabricated bridges. To all the considered companies will be sent a formal request of cost and this result will make part of the final evaluation for selecting this subcontractor. The possible subcontractor will be evaluated based in a rule of proximity, reputation, experience with similar projects, price, and construction times.

   For the construction and design of the prefabricated superstructure, the most probable company to be selected before the formal cost response will be “Barbirato Srl”, as the location is optimal, for arriving to the bridge and they have great experience with similar projects using the same materials. In any case the costs do not differ in a significant way to the costs already determined in the cost analysis, as for this analysis it was used a list of average prices and an investigation of the subcontractors.

   In the construction of the project the lead construction time and the payments ways will be agreed with the subcontractor. – Start of the construction of the prefabricated superstructure. Estimated time: 10 days.

2) Before the superstructure is built, at the site, we must be ready for receiving and installing the superstructure. So, 2 days before the superstructure is finalized, we will start the excavation for the wall foundation.

   Activity: Excavation of the wall foundations – Estimated time: 12 hours – Resources: 4 qualified workers + 1 specialized worker in site.

3) Installation of reinforcement and pouring of concrete inside the excavated foundations. For this to have a better adhesion with the connections the plate will be adhered to the concrete before curing, so when it cures the bolts are properly fixing the steel plate, that will be used for these four main external connections.

   The resources used will be the same 4 qualified workers, two per foundation wall and one specialized worker, that will make sure the correct mixing of materials for the concrete pouring and the in-situ tests.

4) Transportation of prefabricated superstructure, due to the difficult access conditions the best proposed solution is to transport the complete bridge using a helicopter. The prices for the time of the helicopter are given by the average price per minute of renting a helicopter in the region of Piemonte.

   The prefabricated bridge will descent slowly and will be received by these workers in site. They will adjust the bridge to put it in the proper place where it is located the joint plates that will connect the bridge. For this it is needed specially a well-qualified operator in the helicopter and the proper direction of the specialized worker.

   After this we have the prefabricated bridge (superstructure) connected to the substructure (Foundation walls) by means of the 4 connections.

5) Now we have the bridge almost finished, but it must be necessary to adjust some safety details, such as the fence at the sides of the bridges. For this, just after finishing the construction of the bridge, it will be developed a fence at the sides of the bridge for the operation of the pedestrian bridge to avoid accidents of the users.

For the complete approach to this project, it was used this softwares, for the phases of the construction of the bridge:

Software used	**Function**
Revit	Executive design
Edificius	Executive (Architectural) design
Sap 2000	Structural design
Robot Structural Analysis	Structural design

Tekla structures	Executive design
Microsoft Project	Project management - Schedule, resources to tasks, progress, budget and analyzing workloads
Navisworks model	4D modelling - Time depending, 3D elements linked with time
Advance Steel	Drawing and detailing
IdeaStatica	Local structural analysis
Primus	Costing analysis
Autocad	Classical use - Planes and views.
Cloud Compare	Point clouds

Table 1: List of software used (Interoperability)

To conclude, for this case of study, it will be aimed to propose a wood bridge solution, estimating the final cost of this solution, considering different designs and the complete approach from project to construction site management. It will also be evaluated a solution for the possible future floods due to future increments in the water level of Cervo stream. All this considering for the construction of the bridge as a main transportation medium the helicopter, as the project is in a location with difficult terrestrial access.

2. Literature review for bridge design

To have a complete idea for the best way for designing this pedestrian bridge solution case of study, the prior investigation for the construction site management was focused on the following aspects:

- Pedestrian bridges: Design according to regulations (Typical measurements, traffic, loads, dynamics).
- BIM methodology: General approach to the methodology that will be used for the whole design.
- Wood: Advantages and disadvantages for construction.
- Jacking bridges: Use of sensors as a possible solution for future floods of the Cervo stream.

2.1. Pedestrian Bridges – Loads analysis

Pedestrian bridges are widely constructed all over the world, for individuals to be able to cross an obstacle, from one side to the other, this means that is important that the bridge to be functional and carry this function in a safe way for which it was built for, but also in this context of a hiking bridge it must engage with the site unique features.

The wood material in this case of study structure was chosen for the bridge to engage with a bridge context, proposing a natural aspect solution, which will make hikers feel more comfortable from an architectonic point of view.

The construction of this case of study will require at all levels the interdisciplinary collaboration between the architectural designs and engineers for structural design and construction, as well as economical and time management, for this whole project will be integrated the BIM methodology considering interdisciplinary techniques during planning phase.

For design calculations it was mainly used a book called "Pedestrian bridges: Ramps, walkways and structures" by Andreas Keil in which it was presented the main features of pedestrian bridges depending on the use, description of individual materials, various types of bridges structures and some considerations of economic aspects. (Keil, 2013).

The primary function of the bridge is to allow people to pass freely over obstacles, in our case the obstacle will be the Cervo stream, for design the total cost of the bridge depends directly on the clearance gauge, width and length of the bridge. For this case of study, it was fixed a clearance gauge and length of the bridge to pass the Cervo stream from one side to the other.

For the calculation of the width in pedestrian bridges, the recommended values vary too much on the place of construction, In Great Britain are accepted values from 1.8 m to 2 m, in contrast, in Australia they have big widths up to 3m. From European regulations it was identified recommended widths depending on the usage; Footpaths only (1.8 m), Cycle paths (2.0 m) and mixed (2.5 m). (Keil, 2013).

Considering this European considerations this bridge will have these final dimensions: Length: 6.0 m and Width: 1.8 m.

The load bearing capacity of pedestrian bridges are calculated in the following way:

$$Q = v * d \quad (I)$$

Equation 1: Load bearing capacity Pedestrian bridge, Taken from (Keil, 2013).

Having that: Q: Flow rate [P/m*s]; v: Traffic velocity [m/s]; d: Traffic density [P/m^2].

For the calculation of the traffic velocity, it was studied a group of events, such as panic events, shopping events, rush hour, it was identified a linear relation between traffic density and speed.

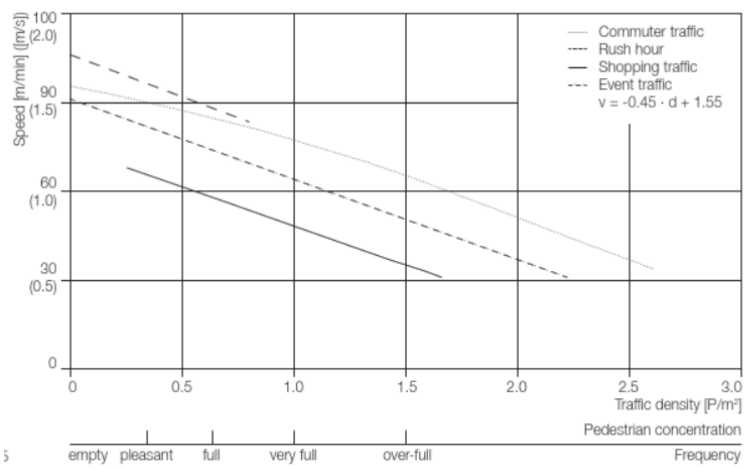


Figure 5: Graph - Linear relationship between traffic density and speed taken from (Keil, 2013)

$$v = -0.45 * d + 1.55 \quad \left[\frac{m}{s}\right] \quad (II)$$

Equation 2: Traffic speed linear relationship. Taken from (Keil, 2013).

Using (II) in (I), we obtain a quadratic function for event traffic, which is the maximum flow capacity.

$$Q = -0.45 * d^2 + 1.55 * d \quad \left[\frac{P}{m * s}\right]$$

Equation 3: Maximum flow capacity. Taken from (Keil, 2013).

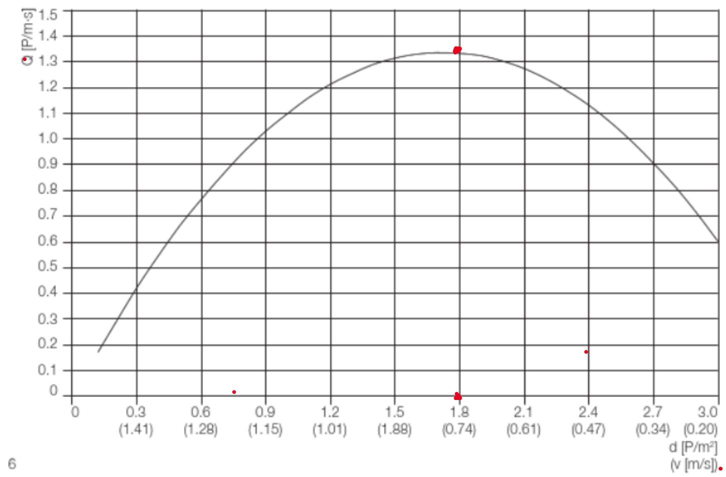


Figure 6: Quadratic function Maximum flow taken from (Keil, 2013)

Then it will be chosen by seeing this graph that shows the quadratic distribution of the flow in a pedestrian bridge then it will be chosen the maximum flow. For this we also need to consider the usage, comfort classes and traffic classes.

For all the mentioned considerations is going to be used:

Usage: Weekly (Max traffic); Comfort class: CC2 (medium) – As it is a hiking bridge we can allow vibrations; Traffic class: TC2 light (0.2 P/m^2) – As we have few traffic.

Pedestrian bridges are used to withstand both static and dynamic, the statics specifies load of the own bridge, traffic, snow, impact, temperature, and wind loads.

2.1.1. Vertical loads

Considers the bridge own weight and main vertical loads.

The vertical traffic load for a pedestrian bridge is estimated at 5 kN/m^2 with spans greater than 10 m. In this bridge is considered a span of 6m. which is the actual span of the bridge. Using the next formula: With I_{sj} as the individual span of the bridge in [m], which is of 6m.

$$2.5 \leq q_{fk} = 2.0 + \frac{120}{I_{sj} + 30} \leq 5.0 \left[\frac{kN}{m^2}\right]$$

$$\boldsymbol{q_{fk} = 5kN}$$

Equation 4: Vertical traffic load in pedestrian bridges. Taken from (Keil, 2013).

This estimated maximum traffic is being considered for design is very unusual as it represents over 6 persons per meter squared, which a usual dense pedestrian traffic considers over 1.5 persons per meter squared, but is the maximum value used for design.

2.1.2. Horizontal, wind and snow loads

As pedestrian bridges have low width to length ratio, horizontal loads can influence its sectional dimensions.

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

For the wind effects is a minor load compared to the same horizontal and vertical loads, but it comes from the bridge location (Piedicavallo, Biella), which will give us the load zone of the bridge depending on the location.

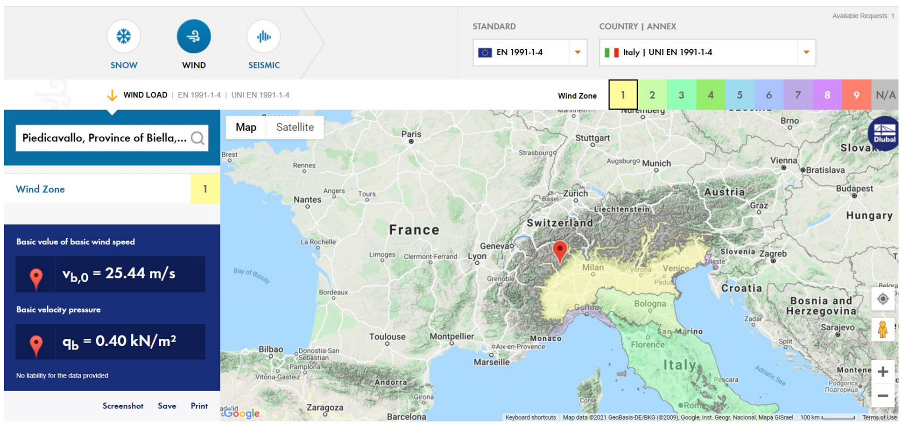


Figure 7: Wind zone Piedicavallo, Biella - Taken from (Dlubal Structural analysis and design software, 2021)

For wind load it will be added this consideration in the structural analysis.

Snow loads, act only on surfaces in contact with the external environment, this depends on the local conditions of climate and exposure of the bridge.

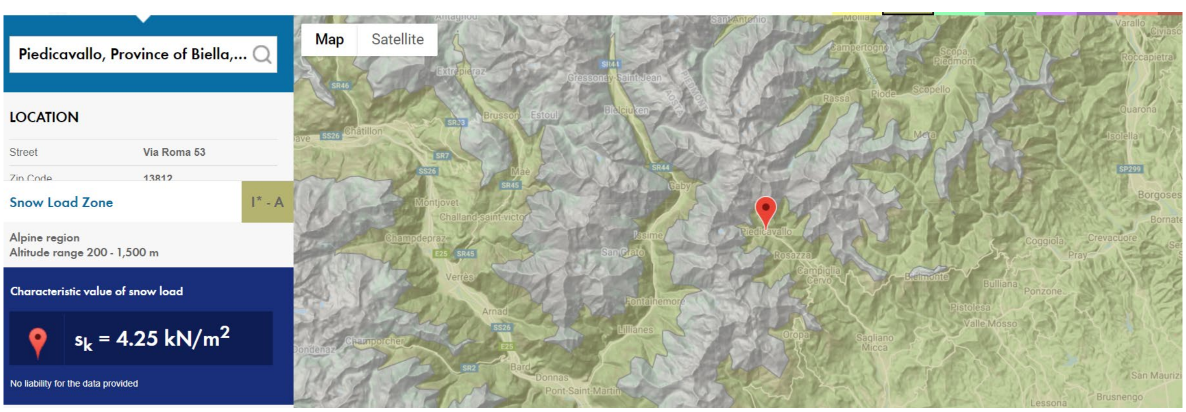


Figure 8: Snow load Piedicavallo, Biella - Taken from (Dlubal Structural analysis and design software, 2021)

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

Equation 5: Snow load equation. Taken from (European Committee for Standardization, 2004)

q_s: Snow load; μ_i: Coefficient of form = 1; q_{sk}: Reference value of ground snow load [kN/m^2] = 4.25; Ce: Exposure coefficient = 1; Ct: Thermal coefficient = 1.

2.1.3. Dynamics

For this specific project it will not be considered in detail the effects of this dynamic excitations, but they will generally be described in a general way for hiking pedestrian bridges.

In pedestrian bridges we often find two types of dynamic excitations.

- Human induced vibrations, including deliberate excitation.
- Wind induced vibrations.

The installation of dampers is a newfangled solution, that will overcome this problem.

The system is capable of vibration. Every bridge has its own vibration pattern, which are the natural modes and normal modes. Damping deflects the vibrations, reducing their amplitude and vibrations subside, also the vibrating kinetic energy.

The following options are used as damping for vibration control:

- Devices that use active forces to counteract vibrations and reduce its amplitudes.
- Additional damping elements.
- Reinforce bridge to change frequencies.
- Installing damping elements.

During the development of this project as it exceeds the scope it will not be evaluated in the design the use of dampers, but this solution will be mentioned and proposed as they could permit a better response of the structure during difficult conditions or in an extreme case of an increment in the level of the Cervo stream. This possible solution may include Damping system and a piston system to move up the bridge.

Possible damping systems that could be used in this bridge design may be: (Keil, 2013)

- Tuned mass dampers
- Liquid dampers
- Tuned pendulum dampers
- Tuned liquid column dampers
- Viscous dampers

2.2. BIM methodology

Building information modelling is a set of processes applied to create, manage, derive, and communicate information among stakeholders, at different times and for different purposes to ensure efficiency throughout building lifecycle. This methodology will not only give us complete information of a detailed working model but will permit the stakeholders share information during the lifecycle of the building, cooperating as a teamwork all the individual skills with constructive feedbacks.

This modelling way of working can be described by the following equation.

$$Building\ Information\ Modelling = Building\ Information\ Model + Interoperability$$

Equation 6: Equation of Building Information Modelling

B. I. Model: Refers to the model, a precise geometry, and relevant data (Information), which will include inside the model not only the 3D but the specifications, building elements, economy, programs, support construction, fabrication, and procurement activities to realize the building.

Interoperability: Data exchange without losing information among tools and people. Refers to the collaboration by different stakeholders in different phases of lifecycle. Sharing the digital representation. Describes an activity rather than an object.

For working with BIM in which the main objective is the teamwork and to share data, we can recognize some ways to share data and the collaboration. This collaboration must include a correct governance (Organizational framework), modelling (workflows and guidelines to model), data management (Sharing documents) and integration among models.

The information can be managed as work-sharing by:

Work sets: Each user share the information of the project synchronizing the local file to the central file database.

Links: Each user share data every time with each other without updating any central file.

Shared area, refer to the common platform where each professional will upload the new version of its work. CDE (Common data environment) is the environment professional use for this purpose, it could be Dropbox, BIM 360, etc. but refers to a place to share information.

For the case of this specific case of study, as we are not using multiple stakeholders working in this same project, the writer of this Thesis is at the same time architectural designer, structural designer, detailing and will oversee the management of costs and construction. Also, it will not be used a Common data environment for exchanging information, but just the collection of the information all by the same person, using a central database feed by the same person. For construction projects is suggested to have different engineers in charge of each of the works to use the best of the formation background for each local model and in this way being effectively retrofitting the central database according to the newest design. (Osello, 2010)

This idea of teamworking and the individual contribution to the whole project and efficiently sharing the information into a common environment is an important advantage in the construction world and is opening big opportunities for achieving better projects, with less delivery times in an optimal way. Represent an evident advantage for designing, constructing, sustaining a facility, and anticipating to problems, but it opens the door to a risk which is in finding the responsible of a wrong design to know who introduced the mistake. (Del Giudice M., 2019)

For this case of study, it will be used a wide number of different software, in which according to the advantages of the software it will be used for the case of study purposes. To all this softwares that will be used, it will be carried an interoperability test between them, in order to see how efficiently can the information manage to change between the different specialized software.

Software used	**Function**
Revit	Executive design
Edificius	Executive (Architectural) design
Sap 2000	Structural design
Robot Structural Analysis	Structural design
Tekla structures	Executive design
Microsoft Project	Project management - Schedule, resources to tasks, progress, budget and analyzing workloads
Navisworks model	4D modelling - Time depending, 3D elements linked with time
Advance Steel	Drawing and detailing
IdeaStatica	Local structural analysis
Primus	Costing analysis
Autocad	Classical use - Planes and views.
Cloud Compare	Point clouds

Table 2: List of software used (Interoperability)

During the development of this Thesis, it will be explained in detail each software results, with graphic content numerical results.

The level of detail is essentially the amount of detail that is included in the model element. The level of development is the degree to which the element´s geometry and attached information has been thought through. The degree to which project team members may rely on the information by using the model. In essence, Level of Detail is an input to the element, while Level of Development is a reliable output.

As-built BIM refers to a representation of the ¨As – is¨ conditions of the built heritage at the time of the survey. Determining the Level of Development (LoD) is important for model effects. By performing Building Information Model there is a tendency to over model, understanding this, is important to recognize what to include in the model and what to leave out of the model, depending on the aim of this specific model.

As an example of what to include in the model, for the case of a structural design to evaluate the elements, it is considered a lower LoD as we do not get into the detail of the number of bolts and welds of the connection, after doing the general structural design, for the design of the connections it must be performed a more detailed model that includes the number of bolts and welds.

For this it is considered some Levels of Development (Degree to which elements´geometry and attached information has been thought through.

- LoD100: Concept.
- LoD200: Simple geometry; Specific system.
- LoD300: Complex geometry; Specific system.
- LoD400: Complex geometry; Includes fabrication, assembly, and installation information.
- LoD500 (As – Built): Field verified representation.

This Level of Development (LoD) is composed by the Level of Geometry (LoG) and the Level of Information (LoI).

During the development of the project, for each phase it was used different Levels of Development, which are mentioned during the phase, this with the only purpose to integrate the needed information in each case, for example in a global structural design, we have a lower LOD as we are not needing to focus in each connection, but in the elements itself, then we refer to higher levels of detail when we want to calculate in detail and how the works about the individual connection will be performed in site, for this it will be needed a higher LOD.

$$LoD = LoG + LoI$$

Equation 7: Level of Development

The level of information need should be determined according to its purpose, including the appropriate determination of quality, quantity and granularity of information needed which can vary. Level of information need should be determined by the minimum amount of information needed to answer each relevant requirement. For BIM models the granularity of alphanumerical information is very important. (Osello, BIM and LoD, 2020)

Software	**Level of Development**
Revit	LoD300
Edificius	LoD300
Sap 2000	LoD200
Robot Structural Analysis	LoD200
Tekla Structures	LoD300
Microsoft Project	LoD400
Navisworks model	LoD400

Advance Steel	LoD400
IdeaStatica	LoD400
Primus	LoD400
Autocad	LoD200
Cloud compare	LoD200

Tabla 1: LoD used for different stages of project

Digital transition is not to just pass from material support to a digital one but the processing of data to improve understanding of the phenomena by generating better decision – making processes. In this BIM methodology plays a key role; phases of construction will use:

- Project phase: Use sketches and devices to recreate the idea into reality.
- Construction phase: Mixed reality and virtual reality.
- Management phase: As built augmented reality model available in site for inspection.

During this work, it will not be used virtual or augmented reality for representing any process but is important to mention as this is a new trend that is now in the AEC sector and is showing very positive results in the results of the projects.

In terms of AEC industry, what has changed mainly is the possibility to know, in advance, some situations that might be a problem in the construction site without being there. This means that digital construction site is the main expression of innovation for construction sector.

During this case of study, the attention will be focused not only in evaluating this material optimal solution, but also in the construction management to have the materials in the difficult place conditions in the best way and using the least possible resources.

Construction management is the part that is considered from the cost of the facility to the operating phase. Professionals, specialists, and workers are involved for physically building the bridge. The modelling must consider all the actors involved and orthogonal projections should be provided to the understanding of each of the actors involved in this construction. Is a management discipline that allows to plan and monitor the entire construction process. It includes the optimization of construction costs, respecting construction times, and safeguarding the quality. (Erba, Manzone, & Osello, 2015)

Dimensions of BIM:

- 3D: LoD = LoG + LoI
- 4D: Times + LoD
- 5D: Costs + Times + LoD
- 6D: Sustainability + Costs + Times + LoD
- 7D: Facility management + Sustainability + Costs + Times + LoD.

For this case of study, the focus will be in the 4D and 5D dimensions, including in this way time and costs for the project.

Quantities take off must be extracted in a precise way for planning and scheduling the construction times and costs, it is important to extract detailed information of the materials used qualitatively (Types and properties of material) and quantitatively (Precise quantities). This quantities takeoff will be described in better detail for the results of the Piedicavallo bridge.

4D: Timetable. Includes the management of project times and realization of activities and related workloads, both in preliminary phase and in the detailed one as well, and the execution phase of the individual processes, requires the definition of an appropriate project planning system.

5D: Cost estimate. Analysis of unitary prices of all the materials and activities considering the costs in terms of units.

Once the costing estimates are completed, the main phases for development of scheduling model are:

- Estimation of the duration of each of the individual activities.
- Estimation and allocation of human resources for execution of individual activities.
- Identify the constrains and dependencies of the various activities.

All these activities will be performed for this case of study using a project management software called Microsoft Project. After performing this it will be obtained a Gantt chart.

The construction project management refer to all the activities that are required to achieve the goals of the construction project. This includes Initiation, planning, executing, monitoring, and controlling as well as finishing the project, which are common in any type of project. Depending on the project other activities will also be included as design, financing, or operations. (Brockmann, 2020)

During this case of study, it will not be executed the project, but this will include a complete design plan for executing the Piedicavallo bridge considering all the constrains of using wood, so it will be performed the construction planning plan of how to manage the future construction.

2.3. Wood as construction material

As a scope of this whole case of study is to find the optimal solution for the development of this bridge project in Piedicavallo, Biella, some analyses will be performed for the same bridge, in which the main material will be changed, and at the end compare the construction management of all the possible materials to have a possible "best" solution by referring to price of the best solution for the construction of this bridge. In this case it will be analysed for the development of this project using only wood as main material of the superstructure.

The best solution is not as easy as saying the most economical design from all the aspects but is important to include nowadays which is the most convenient environmentally solution, and the design that fits best with the location in architectural terms.

Nowadays this environmental convenience is quite importance for the project as this can give the project a higher standard of environmentally friendly and at the same time is imminent that for future construction, future generations start being conscious about the environment. Wooden constructions (Glulam) in a controlled way represent a construction material in an almost renewable resource, which is good for environmental issues.

Wooden bridges are a superior technical and economic potential, as they can be prefabricated, transported, and installed on site in sections that are practically complete. Modern wood construction systems are based on our only construction material, with well managed forests wood is an infinite resource.

Prefabrication in a factory reduces the work on site to a single installation lift, reduces the dependency on access to labor on site, the actual installation of the deck is much faster than for other construction alternatives (Swedish wood, 2021).

Wood has excellent strength properties as it is a light material that can handle considerable compression and tension stresses. This wood material will be combined with other materials and with more appropriated connections. The bridge is considered as a wooden bridge if it has a superstructure made of wood, with main load – bearing function taken up by beams or slabs, made of wood. This wooden bridge will also include steel elements and fixings for joining the wooden components. These may include concrete foundations and other supplementary supports. (Swedish wood, 2021)

The bridge will be designed and fabricated using pressure treated glued – laminated wood (Glulam).

Figure 9: Bridge constructed/Taken from (Western wood structures, 2021) - Peterkort Bridge

Wood is a construction material that has a high variability between the types of wood, not only in the strength but also in durability (Ranges from very strength types of wood to very weak ones).

Resistance classes				
1 very durable	2 durable	3 fairly durable	4 not very durable	5 not durable
Afzelia Maobi Bilinga Greenheart Padauk Asiatic teak Makore	Oak/Sessile oak Chestnut Western red cedar Bangkirai Bubinga Merbau Bongossi Mahagony	Pitch pine	Fir Spruce Elm Northern red oak Yellow meranti	Birch Beech Ash European lime White meranti
Black locust		Pine, larch, Douglas fir		
	Yellow Cedar (Alaska cedar) American white oak			

Table 3: Table that show the variability between the Resistance classes of different woods

It will be used wood in both for subsidiary structural element (Surface planks), this is decisive for the chosen type of wood. Joining techniques plays a decisive role in wooden structural elements subject to high stress level. Wood tensile strength is twice as high as its compressive strength. (Keil, 2013)

For this bridge made up of wood will be important for the material to undergo some processes for the material to have better functional and structural properties. They are pressure – treated lumber, glued laminated timber (Glulam), paint types for exterior painting and other surface treatment methods.

Figure 10: Bridge constructed/Taken from (Western wood structures, 2021) - Bridge made of Glulam

2.3.1. Glued laminated timber

Glued laminated timber is an engineered wood product, manufactured from layers of parallel timber laminations, normally spruce or pine. For structural purposes Glulam in relation to its weight is one of the strongest construction materials and a lasting aesthetic value.

This material has a wide diversity of tones or colors, this depends in the type of material used for this process, in most cases it is used pine wood, as in this case of study. This material can be used at any type of weather, but it must also be performed an additional protective treatment against humidity. (Migliani, 2019)

Some additional advantages are:

- Could hold long spans and unique dimensions.
- Resistant to chemicals, torsions, and deformations.
- Flexibility, the structural material could produce different arches and curves.
- Good resistance to fire, slows the combustion of material.
- Sustainability: well managed these types of wood used they are considered renewable resources.

Cross – laminated timber (CLT):

Cross laminated timber is another processed type of wood like Glulam, which has several advantages that must be analyzed. As it was mentioned glued – laminated timber is the result of joining tables or laminated wood together, this will have as a result more linear element. In the other hand, CLT is the union of this tables in perpendicular slices, which will be very helpful for the fabrication of big dimensions, such as walls as it could reach big dimensions, static load, and stability of this elements in CLT increase.

CLT compared with reinforced concrete has very similar load bearing capacity for the compared same volume and the material itself is thinner than RC. Has good isolation properties and fire resistance. (Franco, 2019)

Furthermore, the Piedicavallo bridge case of study, will be analyzed in Glulam made of pine wood, as we are using smaller dimensions and more linear structural elements. In which in advance is an interesting construction material for future construction, and there is plenty information about the structural capacity in terms of bearing capacity and the different tests for estimating the resisting properties. (Wei, y otros, 2019)

2.3.2. Pressure treated lumber

The pressure - treating process consists in adding treatment into the cell structure of the lumber. The treatment becomes leach resistant once it reaches the cell structure of the lumber, is one of the best things it could be done to preserve this wood resource.

The idea is to put in the specified factory the chemical treatment into the cell structure of the wood, having in this way the better wood properties, by using a big pressure to drive the chemical into the cell structure of wood. (Dunn Lumber - Building success together, 2021).

Figure 11: Pressure treated wood process for Glulam - Taken from (Dunn Lumber - Building success together, 2021)

2.3.3. Surface treatment for exterior wood

Untreated wood surfaces will age over time. Treated wood surfaces age differently depending on the surface treatment ability to protect the wood against decay. Coating has a big impact in the need for future maintenance. The various recognized paint types can be divided as:

- Film formation: Measure of how well the decay of the underlying wood is prevented and how well the wood structure shows through the paint layer. (Oils and clear varnishes, wood stains, solid wood stain, finishing paint).
- Binders: The most common binders for on-site painting of wood are acrylate, alkyd oil, linseed oil, rye flour and wheat flour, which give the properties for each application.
- Paint diluent: Give the paint the right painting properties. Environmental requirements have led to organic diluents being replaced by water in most paint types. (Swedish wood, 2021)

Paint systems are based in several stages of treatment. The following are appropriate treatments used:

- Priming: Priming oil should be applied over the entire surface that is to be painted.
- Undercoating: After priming, in all surfaces before the installation. The purpose is to ensure good adhesion for the topcoat, and to further reduce moisture absorption.
- Sanding: Reduces the risk of discoloration due to dirt and mold growth.
- Finishing with a topcoat. (Swedish wood, 2021).

2.4. Jacking technology for bridges and monitoring systems

For this construction project, it is proposed to consider as a future possible solution the implementation of jacking technology for bridges, using a jacking (Lifting) system and sensors for use and to monitor the utilization of it.

Is proposed to use sensors in some places of the stream, to monitor and control any possible new floods, for in case of an important increase in the water level, use this automatic jacking system to automatically lift in a vertical way the bridge, by some centimeters. This Jacking technology is being used widely around the world, especially in China.

The details about the sensors costs and jacking system will be proposed at the end of the project, in this point it will just be mentioned some literature about this jacking systems.

Bridges in many cases will have to be lifted to meet increased navigation capacity, however, no relevant technical standard is available for the jack – up technique. The idea is to propose based on various investigations, papers and concepts a possible solution for a jacking system to raise the level of the bridge in case of a new increase in the water level of Cervo stream, to protect the bridge from collapsing.

Stress concentration is evident near the support points of the lifting process. Stress monitoring is also necessary. These points should be near the bridge web. Beam span and the rigidity of the section should be considered.

Jacking up a bridge is safer when section rigidity is large enough and beam span is not extremely long. (Xu, Wang, & Xu, 2013).

Based on the last comments is possible to conclude that it could be used a jacking system technology in a safe way, as our sections are rigid sections and the bridge span is only of 6 m, compared to the section of the bridge is a rigid section.

The possible solution for jacking technology in this bridge was inspired in the existing problematic that many bridges cannot provide enough clearance for passing large ships.

The synchronous jack – up technique has some advantages, such as low engineering cost, short construction period and shortened time of transportation interruption. Jack up technique has been applied in the integral lifting project of the Qifeng bridge in Huzhou, which is a perfect example of how to lift a bridge by using jacking technology.

This technology of lifting bridges has been widely adopted as it permits us to save investment budgets and construction time. It could be developed a bridge lifting and monitoring system for uniformly raising continuous – span RC bridges (Zhao, Wang, & Pang, 2012). Is needed a modular set of jack support and lift hardware, a hydraulic system, and a displacement monitoring system.

In the last years, several new technologies, such as programmable logic controllers (PLC) and closed - loop control has been incorporated in the hydraulic lifting system. (Zhao, Wang, & Pang, 2012).

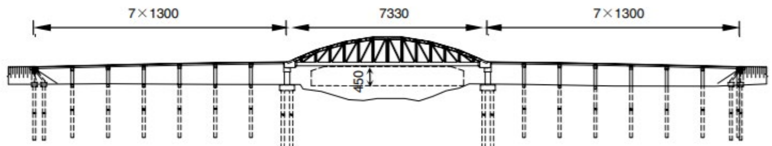


Fig. 1. Elevation view of Qifeng Bridge (unit: cm)

(a) (b)

Fig. 2. Profiles of Qifeng Bridge before lifting operation

Figure 12: Profile and elevation of Qifeng bridge before lifting operation using jacking technology. Taken from (Zhao, Wang, & Pang, 2012)

In the case of this case of study in Piedicavallo, Biella. This possible solution sounds interesting as it could lift big heavy bridges dividing in unit spans. For our case is much easier, as we are developing a wooden bridge, which is very thin, compared to other possible solutions, and we also have a rigid section and a small span of 6 meters, needing very simple jacking systems compared to the mentioned bridges.

This solution will permit us lift the bridge in such a way that if we have a considerable increase in the Cervo stream the bridge will lift a certain programmed distance, maintaining a safe distance of 50 cm between the water level and the level of the bridge, avoiding in this way any possible collapse. This jack – up systems could lift the structure up to few meters.

As we mentioned this jacking solution, is essential to have a well-developed monitoring system in the bridge for this lifting operation, some sensors must be used in the bridge structure (Stress monitoring in the members), also a monitoring system in the water level, to maintain at least this safety distance between water table and level of the bridge to avoid any possible collapse in the bridge structure.

This integrated with an Early Warning System, that will close the hiking bridge and alert the people in the mountain to be aware of a dangerous increase in the level of the Cervo stream.

3. Architectural design

For the architectural design, there were developed 4 different solutions, which were then removed based on the optimization of the structural design and on costs, so it was at the end chosen the best solution that was structurally stable with least construction cost.

As it is mentioned the solution proposed during this work is based in wood, for the construction purpose of the bridge it will be used a construction wood that is called glued laminated timber (Glulam) made of pine wood, which was connected using steel joints, that were also calculated during the development of this project.

For this predesign the aim was to use a wood structure for the architecture to be able to connect the user with the hiking mountain, also was used the point cloud obtained by a laser scanner on site, and in this way have a better understanding of the real situation on site.

Given the conditions of the mountain and the access it was considered that the new bridge must be constructed in the same place of the past bridge. Using the position of the past bridge, the new bridge will have 6 meters of length, 1.8 meters of width, and a maximum altitude of 2.5 meters as it is a pedestrian bridge. Considering all this information we can start designing some preliminary models. The design was based in trusses for considering optimal solutions.

A truss is a structure that consist of members organized in connected triangles with the purpose to have the overall assembly behaving as a single object. A web of triangles that are connected to enable the even distribution of weight and the handling of changing tension and compression without bending or shearing. The nodes can carry significant loads transferring them to supporting structures (Designing buildings Wiki, 2021). Some advantages of trusses are:

- Minimize the weight of the structure.
- Reduce deflection.

In general, since long time ago is a very typical type of construction which at the same time gives a great structural characteristic, this design has been decided to be done by using truss systems. It will be described 3 types of trusses.

- Simple truss: Consist of one single triangle, this interesting shape is described as later it will be the chosen type of structure for the bridge due to the simpleness of Piedicavallo bridge.
- Warren truss: The members form a series of equilateral triangles.
- Pratt truss: Uses vertical members for compression and diagonal members for tension. (Designing buildings Wiki, 2021).

For the design of this 6 m span bridge in Piedicavallo, Biella that aims to cross the Cervo stream, it will be consider this type of architectural design, not only in the positive aspect it could have, but specially in the optimization of resources knowing the structural advantages of trusses systems.

The proposed designs developed were created using two different software of two different companies, Revit (Autodesk) and an Italian software called Edificius (Acca). With the same design were modelled, is important to underline that the interoperability between these two programs is difficult as they are from different companies, but it can be well achieved using IFC, both works very good for design of the model 3D.

Project architectural design 1

The height of the bridge in this case is 2.5 m. The distance between transversal beams is of 1.5 m. This design is a little bit complex for this simple case but is an interesting solution to evaluate.

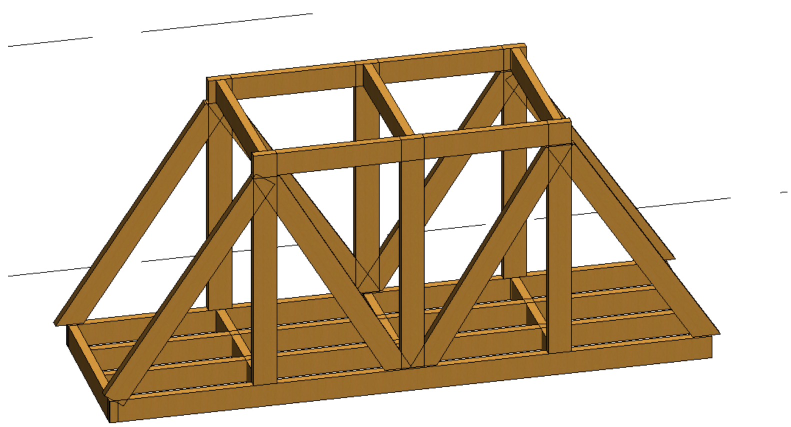
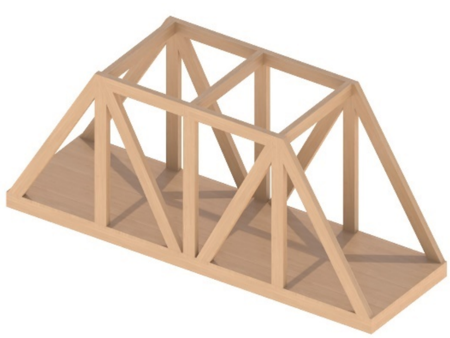


Figure 13: Architectural design 1 (Revit)



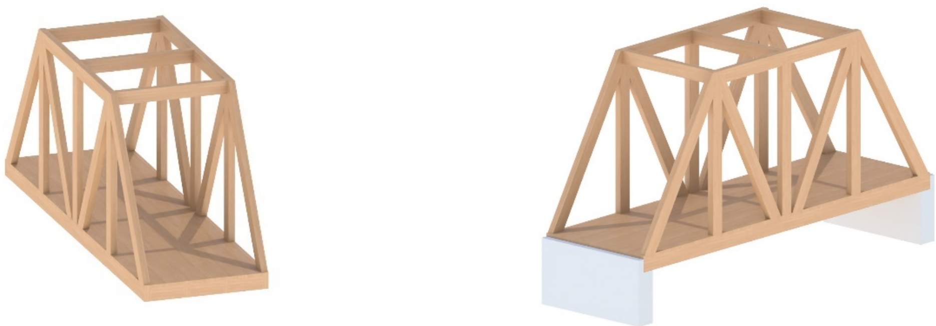


Figure 14: Architectural render 1 using Edificius

Project architectural design 2

The height of the bridge in this case is 2.5 m. The distance between transversal beams is of 1.5 m. This design is simpler than the last one, it will not be a proper structural design, due to the lack of triangles (Truss).

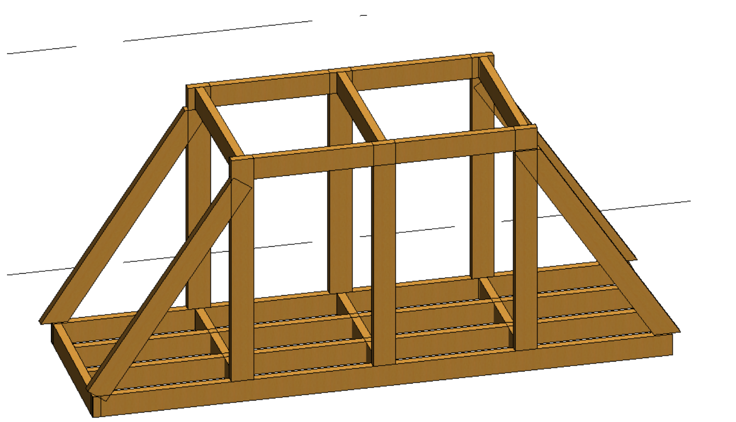
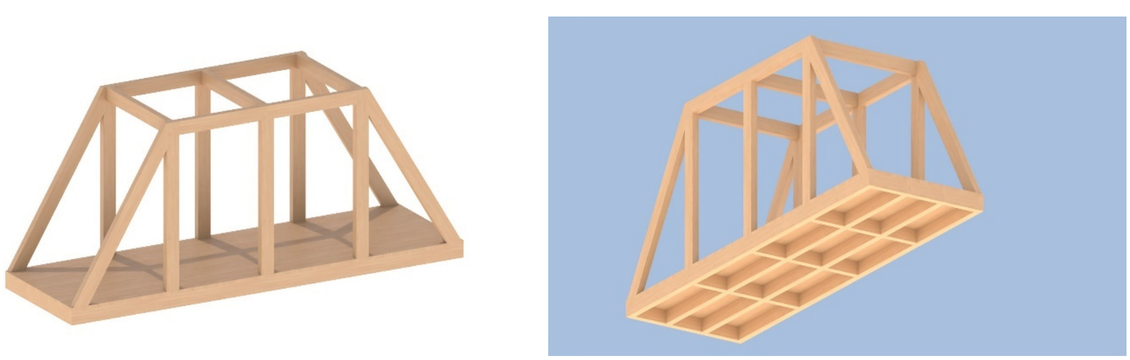


Figure 15: Architectural design 2 (Revit)



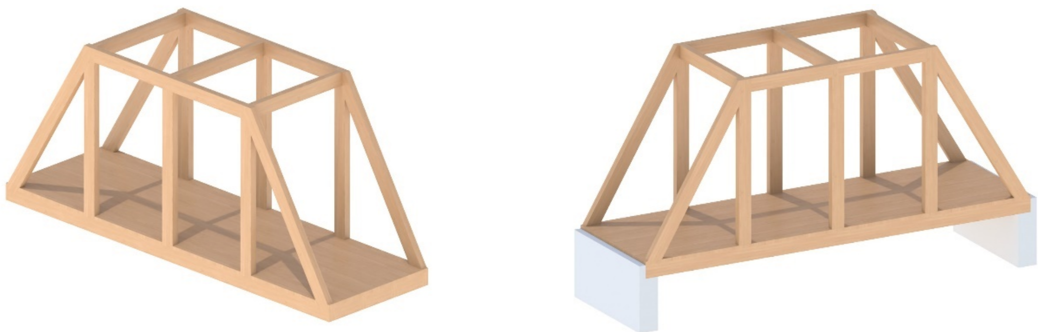


Figure 16: Architectural render 2 using Edificius

Project architectural design 3

The height of the bridge in this case is 2.5 m. The distance between transversal beams is of 2 m. This design is simpler than the others, but it may not be as simple as referring to a small bridge of 6m, but it could be considered an interesting solution.

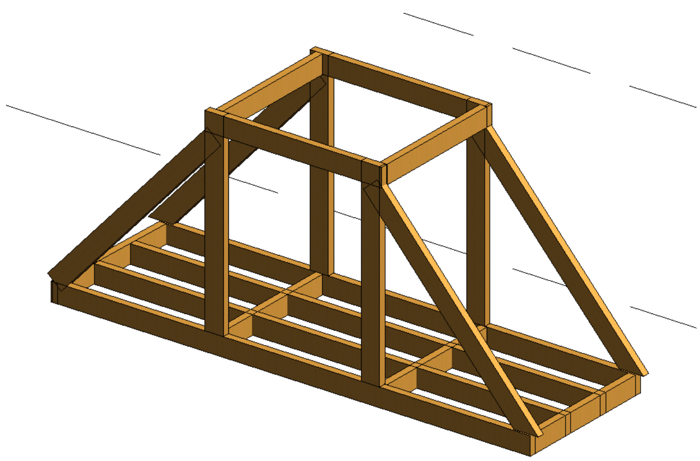


Figure 17: Architectural design 3 (Revit)

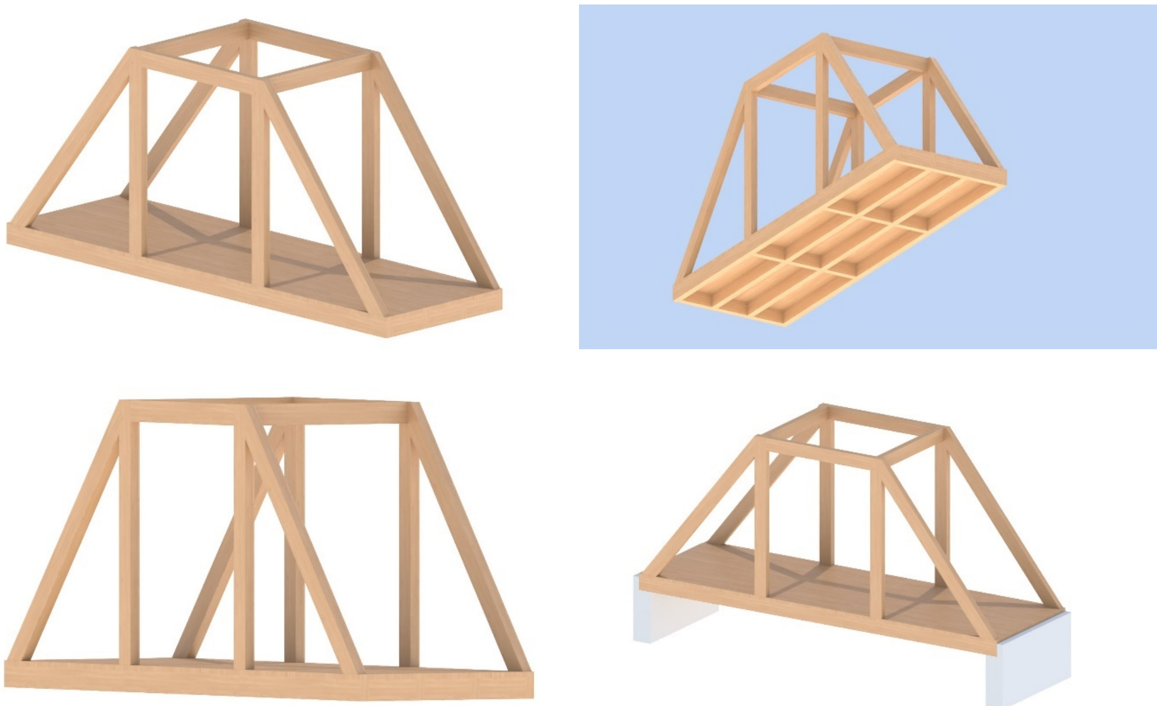


Figure 18: Architectural Render 3 using Edificius

Project architectural design 4

The height of the bridge in this case is 2.5 m. The distance between transversal beams is of 3 m. This design is simple, by a structural point of view considering the low complexity of the project, this design will be evaluated in detail as it is a simple and economical solution, that could uphold the loads in a proper way.

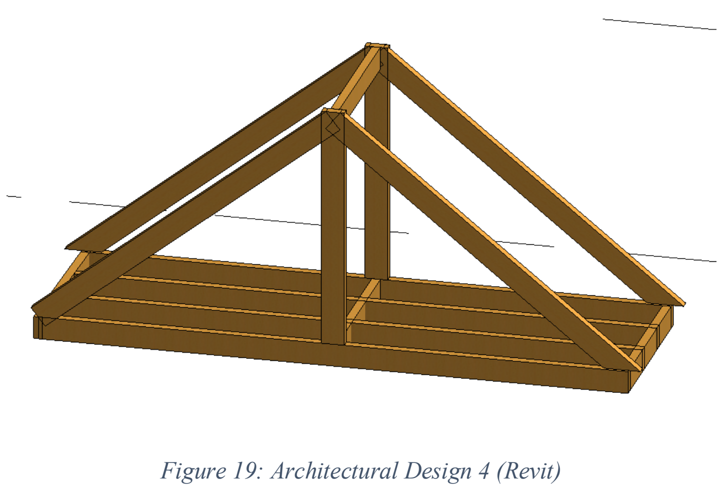


Figure 19: Architectural Design 4 (Revit)

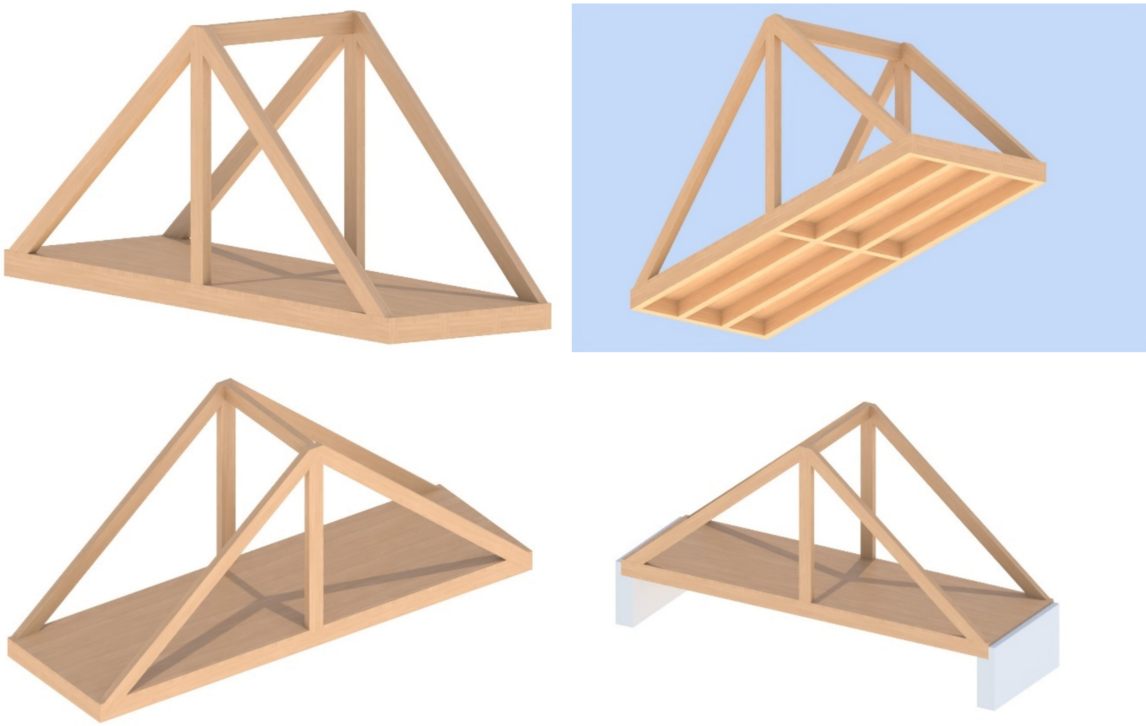


Figure 20: Architectural Render 4 using Edificius

By reviewing all the past architectural designs, considering the quantities of materials and the low complexity of construction, it was chosen the last solution, the architectural design 4. Also, the other cases were reviewed and even if in this last cases it will be possible to reduce the dimensions of the wood sections, the best option is to consider this last approach with the appropriate connections in the joints that will be calculated in further steps of the structural analysis.

The bridge material will be glued laminated timber (Glulam), as it could be observed in the aspect of the picture, this specific glulam derives from pine wood, which will give the tone of the bridge. As mentioned, Glulam is a powerful wood construction material, which will be more important in the short future of construction, as it is light, has good structural behavior and is easily prefabricated for fast constructions.

It will also be used a concrete pile in the edges of the bridge.

The bridge designed for this has a similar appearance to a wooden bridge in Sweden, more exactly in Virserum, Sweden.

Figure 21: Wooden bridge in Virserum - Image taken from (Swedish wood, 2021)

The bridge will also have this triangular shape, with glulam (pine wood) elements, a glulam slab of 5 cm on top of the beams and proper connections for the considered loads.

Figure 22: Architectural design Piedicavallo bridge

4. Structural design

For the structural design of this bridge, as another of the main objectives of this complete project is to interoperate between different fields, and working with as many software as possible, the final structural design for the bridge was developed using two structural software: SAP 2000 and Robot structures.

The main reason of using Robot structures is because of the good interoperability this software has with other used software such as Navisworks, as they are all programs of Autodesk.

4.1. Structural results using SAP 2000.

For this analysis with SAP 2000, the results were also calculated for the Architectural design 1, just for reviewing the results, in this first case as it was predicted it could be afforded to use smaller sections, but these sections will not change much if we refer to safe section values.

Going to the structural design done in SAP 2000, for the design of the dimensions of the members, it was considered a typical member of 20 cm x 10 cm of section.

For the structural calculation of the bridge, it will be considered that the main structural elements of the bridge are made up of Glulam (from pine wood). To comply the general characteristic structure, which is that the reduced structural elements of the bridge can sustain the increased loads applied to the same.

For the structural properties of Glued laminated timber, it was necessary to get information of this material from different papers and material information in which this material was correctly tested and the corresponding properties were estimated. (Xu, Guo, & Zhang, 2019)

The commercial values about Glulam properties for design were taken from a well-known European company called “James Jones & sons Ltd”.

The bridge design will be done using the material GL24h, which is taken from the strength class GL24 of a species of European spruce (Pine), using this material, we have the following structural properties:

GL24c Design Values

Width (mm)	Depth (mm)	Area (mm^2)	Section Modulus Z ($x10^5 mm^3$)	Inertia I ($x10^7 mm^4$)	EI ($x10^9$ Nmm^2)	GA ($x10^6$ N)	d/w (-)	EC5 k_h	Moment Capacity (kNm)	Shear Capacity (kN)
60	120	7200	1.44	0.86	100	6.12	2.0	1.10	1.62	5.53
	160	9600	2.56	2.05	238	8.16	2.7	1.10	2.88	7.37
80	140	11200	2.61	1.83	212	9.52	1.8	1.10	2.94	8.60
	160	12800	3.41	2.73	317	10.88	2.0	1.10	3.84	9.83
	180	14400	4.32	3.89	451	12.24	2.3	1.10	4.87	11.06
100	100	10000	1.67	0.83	97	8.50	1.0	1.10	1.88	7.68
	120	12000	2.40	1.44	167	10.20	1.2	1.10	2.70	9.22
	140	14000	3.27	2.29	265	11.90	1.4	1.10	3.68	10.75
	160	16000	4.27	3.41	396	13.60	1.6	1.10	4.81	12.29
	180	18000	5.40	4.86	564	15.30	1.8	1.10	6.08	13.82
	200	20000	6.67	6.67	773	17.00	2.0	1.10	7.51	15.36
	220	22000	8.07	8.87	1029	18.70	2.2	1.10	9.09	16.90
	240	24000	9.60	11.52	1336	20.40	2.4	1.10	10.77	18.43
120	120	14400	2.88	1.73	200	12.24	1.0	1.10	3.24	11.06
	160	19200	5.12	4.10	475	16.32	1.3	1.10	5.77	14.75
	200	24000	8.00	8.00	928	20.40	1.7	1.10	9.01	18.43
	240	28800	11.52	13.82	1604	24.48	2.0	1.10	12.93	22.12
	280	33600	15.68	21.95	2546	28.56	2.3	1.08	17.33	25.80
140	140	19600	4.57	3.20	371	16.66	1.0	1.10	5.15	15.05
	200	28000	9.33	9.33	1083	23.80	1.4	1.10	10.51	21.50
	240	33600	13.44	16.13	1871	28.56	1.7	1.10	15.08	25.80
160	160	25600	6.83	5.46	634	21.76	1.0	1.10	7.69	19.66
	200	32000	10.67	10.67	1237	27.20	1.3	1.10	12.01	24.58
	240	38400	15.36	18.43	2138	32.64	1.5	1.10	17.24	29.49
180	180	32400	9.72	8.75	1015	27.54	1.0	1.10	10.95	24.88
	240	43200	17.28	20.74	2405	36.72	1.3	1.10	19.39	33.18
200	200	40000	13.33	13.33	1547	34.00	1.0	1.10	15.02	30.72
	240	48000	19.20	23.04	2673	40.80	1.2	1.10	21.55	36.86

Table 6. GL24c Design Values

Figure 23: Resisting properties of GL24c for design

In this way we have a section of 20 cm x 10 cm, also using these estimated values for E and G.

$$EI = 773 \times 10^9 \, {}^{N}/_{mm^2} = 6.67 \times 10^7 mm^4 \times E$$

$$E = 11589.2 \, MPa$$

Equation 8: Young Modulus (E) of GL24c (Glulam)

$$GA = 17 * 10^6 N = 4.636 * 10^{12} * A$$

$$A = 3.667 * 10^{-6}$$

Equation 9: Coefficient of thermal expansion (A) of GL24c (Glulam)

The weight per unit volume was taken from a paper in a scientific journal that evaluate in detail the glued laminated timber production. (Puettmann & Wilson, 2005)

$$\gamma_{Glulam} = 4733.4 \, {}^{N}/_{m^3}$$

Equation 10: Weight per unit volume (GL24c)

In SAP 2000, these structural characteristics of this material will be inserted, for the program to evaluate the elements of the structure based on this resisting values.

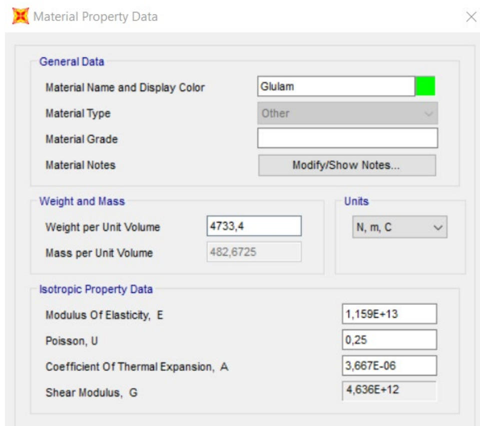
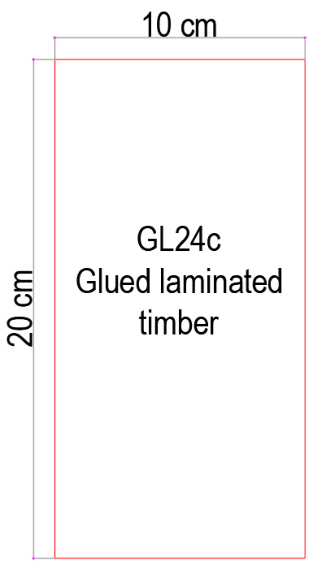


Figure 24: Structural data of GL24c

Using this material, we create the section of the elements that will be used, in this case in form of beams and columns it will only be used one simple rectangular section, and for the slab a 12 cm thickness slab also of this laminated timber.



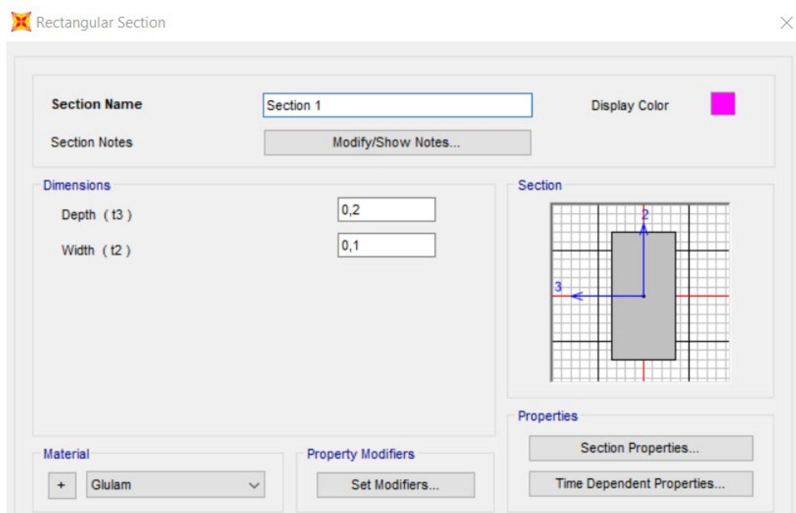


Figure 25: Section dimension of all elements (Columns and beams)

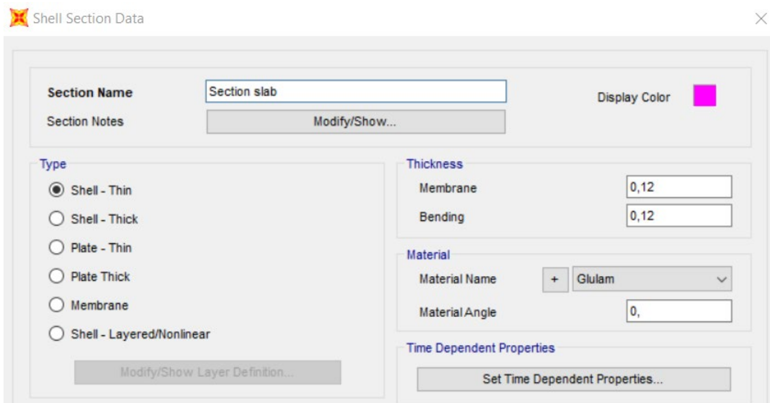


Figure 26: Section dimension of the floor (Glulam Slab)

Then in the SAP 2000 it must be drawn the geometry of the elements that will made up the structure, with the corresponding restraints in the points where we have the foundation.

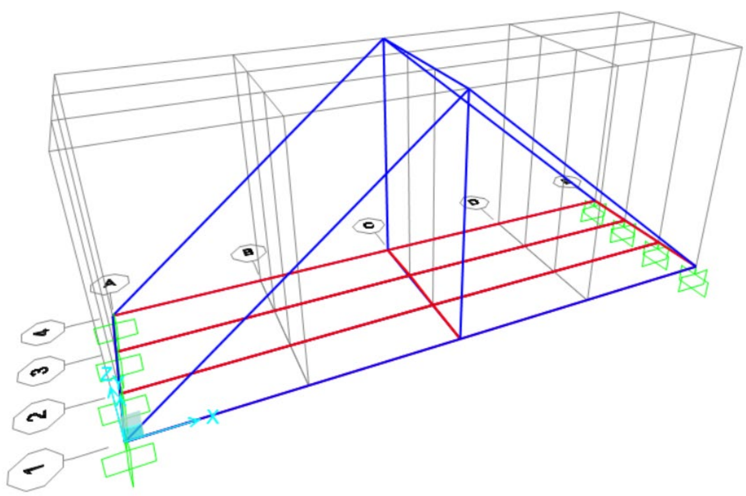


Figure 27: Geometrical model of the bridge for structural analysis

Now it must be considered the loads applied to the structure. These loads were already explained in detail in this same project.

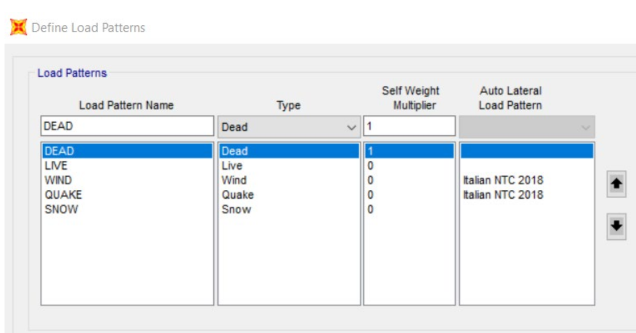


Figure 28: Loads evaluated for project

Dead loads: Structure self-weight – SAP 2000 will consider this same load in the evaluation based on the weight per unit weight given and the volume used in the structure.

Live loads: For this type of loads it will include a overestimation due to the fact that even we have a hiking pedestrian bridge and we can accept some dynamics in the bridge, there are impact loads due to the walking of the people at different speeds, it will be considered 5 kN/m2, this also contemplates in the regulation a possible event of panic in the bridge and many people crossing the bridge.

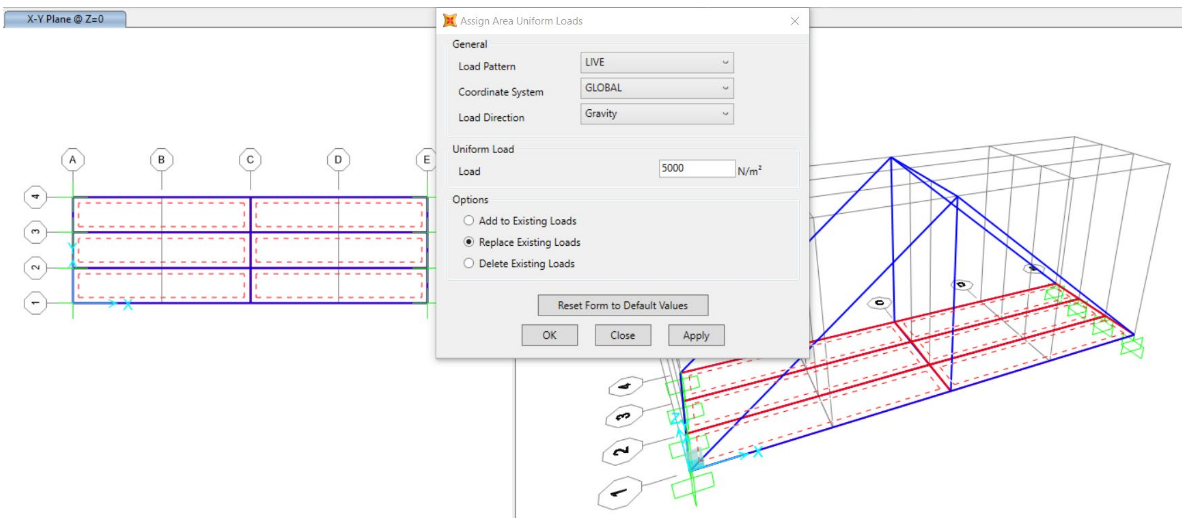


Figure 29: Live loads included in the floor of the bridge

Wind loads: As it was mentioned before during this thesis, it will be considered the following conditions due to the location of the Bridge (Piedicavallo, Biella).

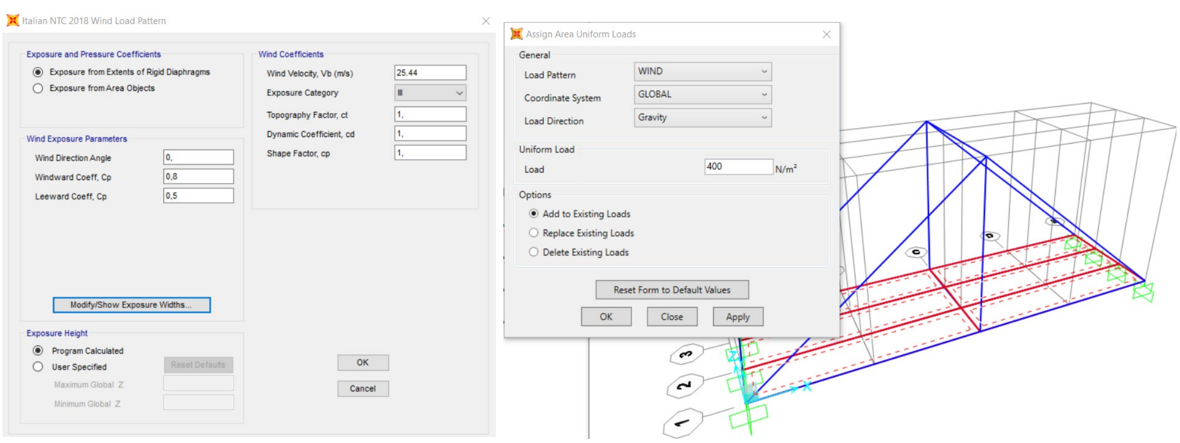


Figure 30: Wind loads – SAP 2000

Snow loads: The snow load depend on the location of the bridge; these parameters were explained before in this thesis. This load is in weight per meter squared.

Equation 11: Equation Snow loads. Taken from (Dlubal Structural analysis and design software, 2021)

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

$$q_s = 4.25 \ {kN}/{m^2}$$

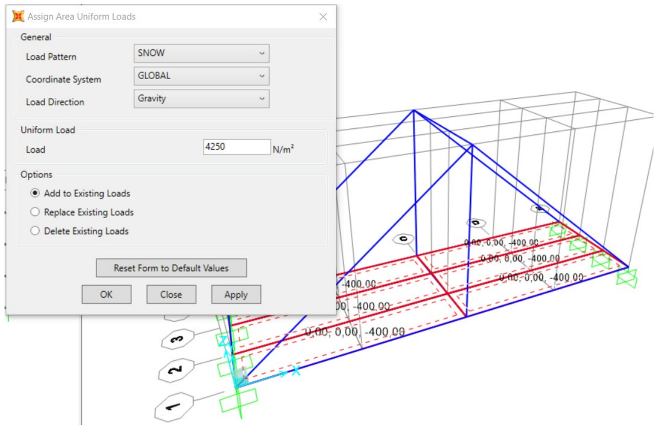


Figure 31: Snow loads – SAP 2000

Quake: For the quake, as it is not part of the approach of this project, it will be considered in a very simple way, just using the design ground acceleration for a return period of 30 years, for this we do not have the type of soil, so it will be considered a soil type B.

$$a_{g,30} = 0.422 \ {m}/{s^2}$$

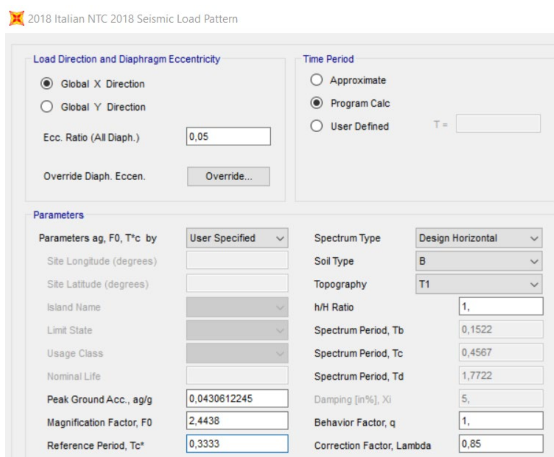


Figure 32: Quake - SAP 2000

Combination of loads: All the scenarios will be evaluated, but it will be considered special attention for design to the combination 1.2 DL + 1.6 LL, as the Dead loads are very low compared to live loads thanks to the advantages of this wooden structure, that has low weight and can uphold high loads. Contrary to typical structures that are usually heavier.

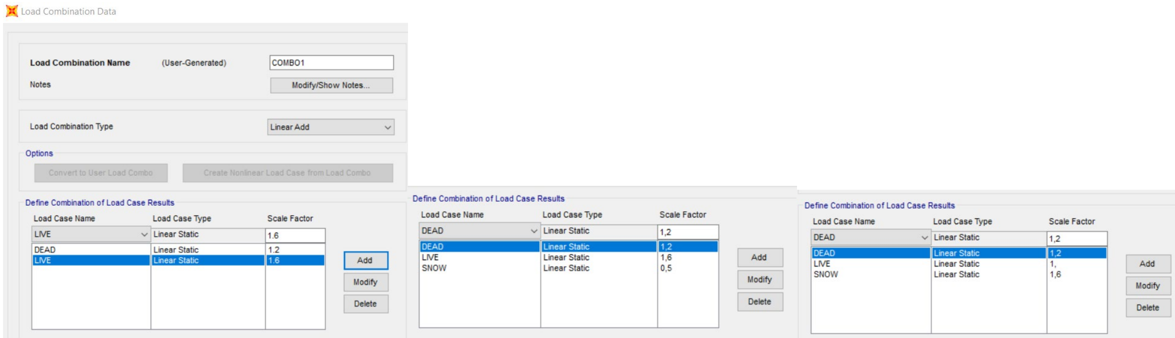


Figure 33: Some typical combination of loads used

This are some combination of loads; it was considered in total 13 combinations of loads typically used in reinforced concrete structures that evaluates different scenarios. After this, is possible to see the results.

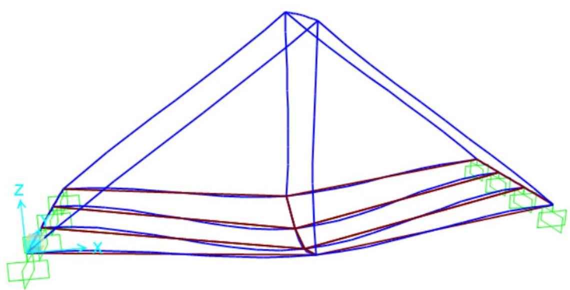


Figure 34: Deformed shape after simulation

As it is expected it could be observed some deformations, in the floor of the bridge where we expect to have most of the variable loads.

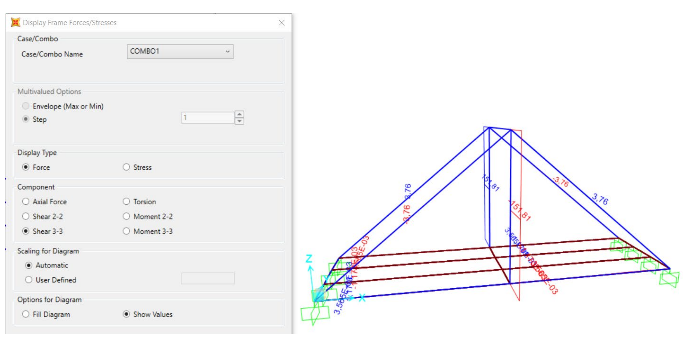


Figure 35: Shear in Y - Results SAP 2000

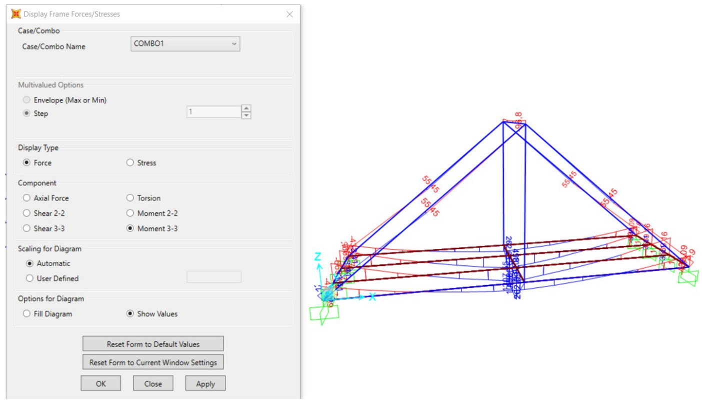


Figure 36: Bending moments - Results SAP 2000

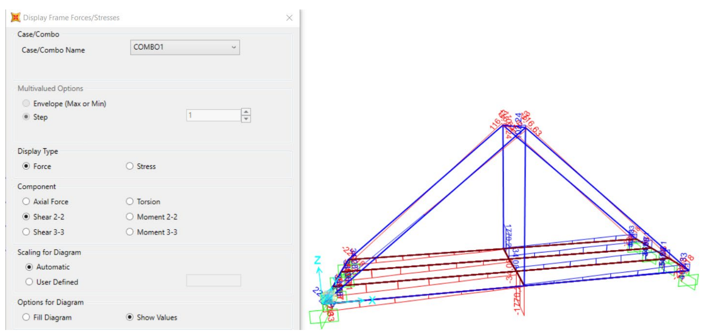


Figure 37: Shear in X - Results SAP 2000

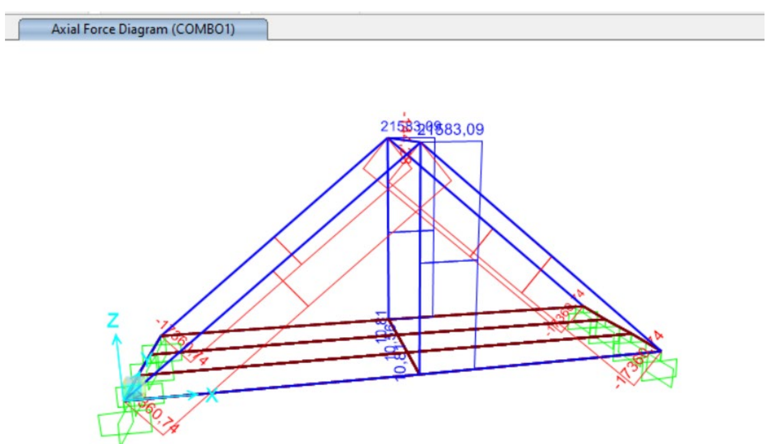


Figure 38: Axial forces - Results SAP 2000

Evaluating the possible failures, the bridge could present for all the elements, this maximum forces along the members of the structure were evaluated, comparing with the properties of GL24h, and the different values provided from design by manufacturers testing, all elements have a proper dimension to resist the loads.

In any case there is a possible overdesign for this structure, but it was considered in this way as in a real scenario behavior there could also be the lateral force of water by an increase in the Cervo stream, which for a further design will be prevented by considering the mentioned jacking technology in the bridge that will lift the structure using the proper monitoring systems. Another reason for this overdesign is due to the market dimensions of this structural Glulam, for this reason the other architectural designs that were constructed were not considered, as in those cases it will give us even smaller sections.

So, we have successfully evaluated using SAP 2000 the sections of the bridge.

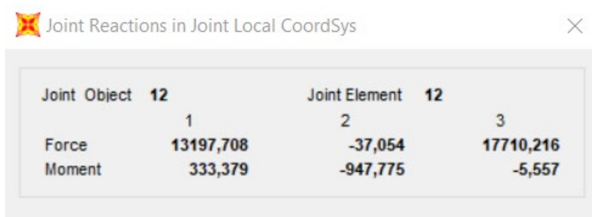


Figure 39: Joint forces and moments - Critical joint

This are the joint node forces and moments of the most critical joint in the bridge, which are going to be used to calculate the foundation.

4.2. Structural results using Robot Structural Analysis professional 2021

The structural analysis has been performed using SAP 2000, now it will be done the same analysis of each member but using Robot Structural Analysis professional. This to use a software of the Autodesk family, which will have a better interoperability between them, this considering the architectural design in Revit and further works that will be done in Advance steel and Navisworks.

The procedure is very similar to the one of SAP 2000, as both are structural analysis software.

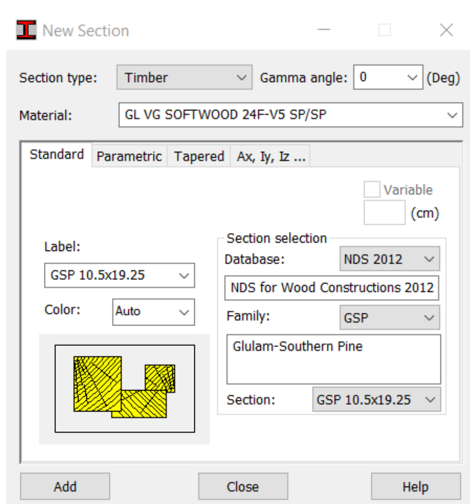


Figure 40: Section and material used for Piedicavallo bridge.

After having the Glulam section, in which it was considered with the proper characteristics, as Glued laminated, Softwood and Glulam – Southern Pine, which has very similar characteristics to the GL24h described in SAP 2000.

Then it was drawn the complete geometry of the bridge, considering all the members.

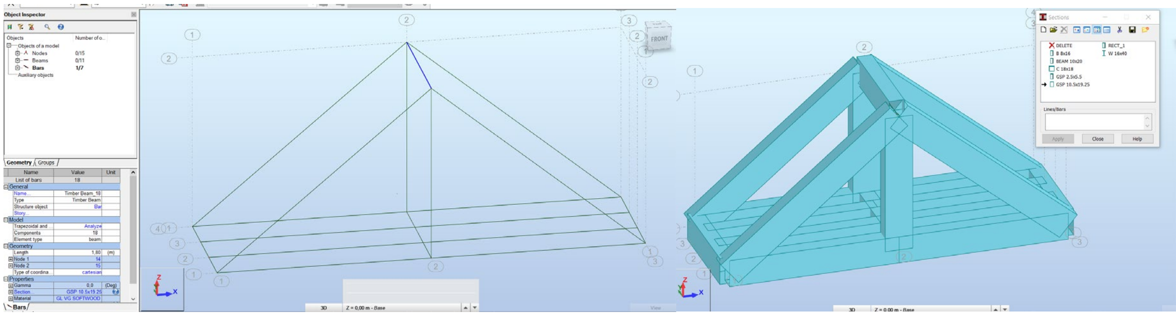


Figure 41: Geometry of Piedicavallo bridge - Robot

After having the new geometry with the correct sections, we recognize and calculate the considered load types. The same load types are considered for this project. Then the load combinations are considered for the results.

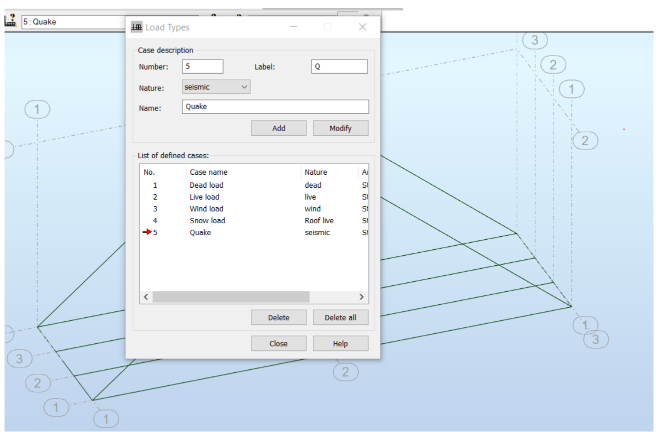


Figure 42: Types of loads – Robot

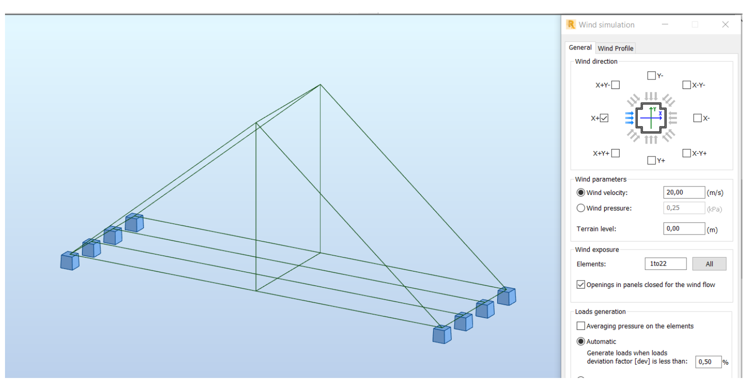


Figure 43: Wind load cases – Robot

Fixed supports are considered in the place where we have the foundation, with this we can estimate the depth of foundation.

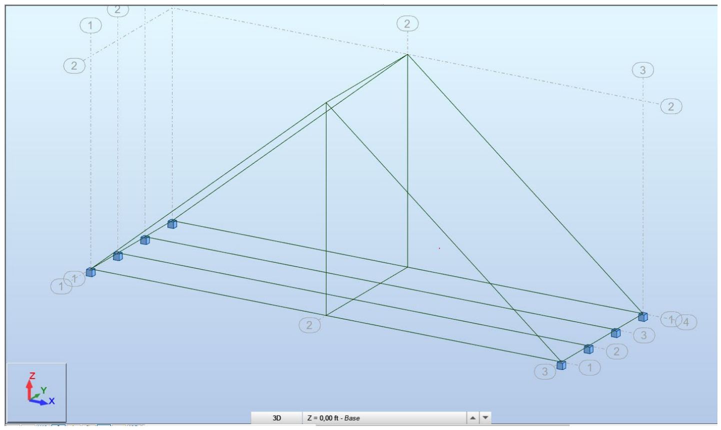


Figure 44: Fixed supports structure - Robot

After having everything in the model, we proceed to calculate the structure and verify the results.

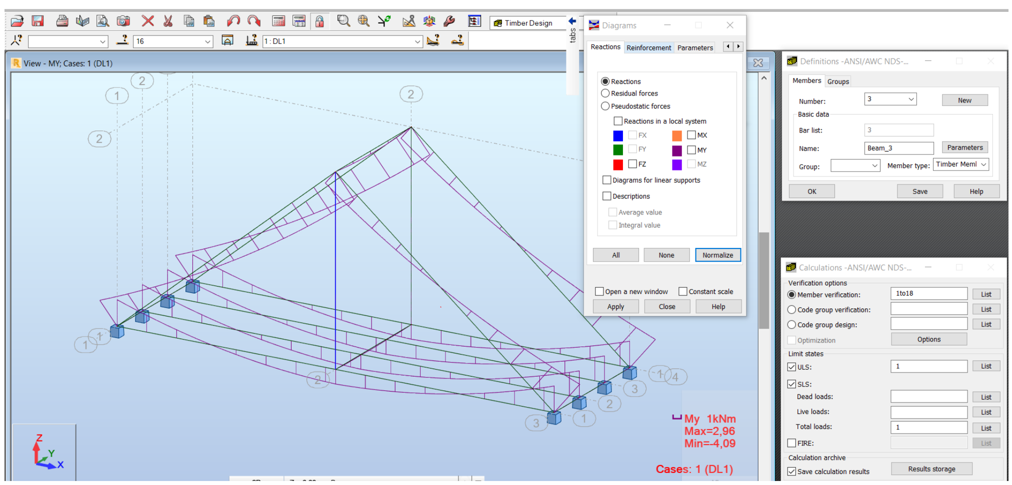


Figure 45: Forces and Moments in elements (Design in timber) – Robot

The displacements are also verified as they must not exceed 1% of the height of the bridge with the effect of the service loads as a measure of serviceability limit state.

Displacements - Case: 1 (DL1)

Node/Case	UZ (cm)	RX (Rad)	RY (Rad)
1/ 1	0,0	0,0	0,0
2/ 1	-0,0095	-0,000	0,0
3/ 1	0,0	0,0	0,0
4/ 1	0,0	0,0	0,0
5/ 1	0,0	0,0	0,0
6/ 1	-0,0096	-0,000	0,0
7/ 1	0,0	0,0	0,0
8/ 1	0,0	0,0	0,0
9/ 1	-0,0096	0,000	0,0
10/ 1	0,0	0,0	0,0
11/ 1	0,0	0,0	0,0
12/ 1	-0,0095	0,000	0,0
13/ 1	0,0	0,0	0,0
14/ 1	-0,0108	-0,000	0,0
15/ 1	-0,0108	0,000	0,0

Values / Envelope / Global

Figure 46: List of displacements - Robot

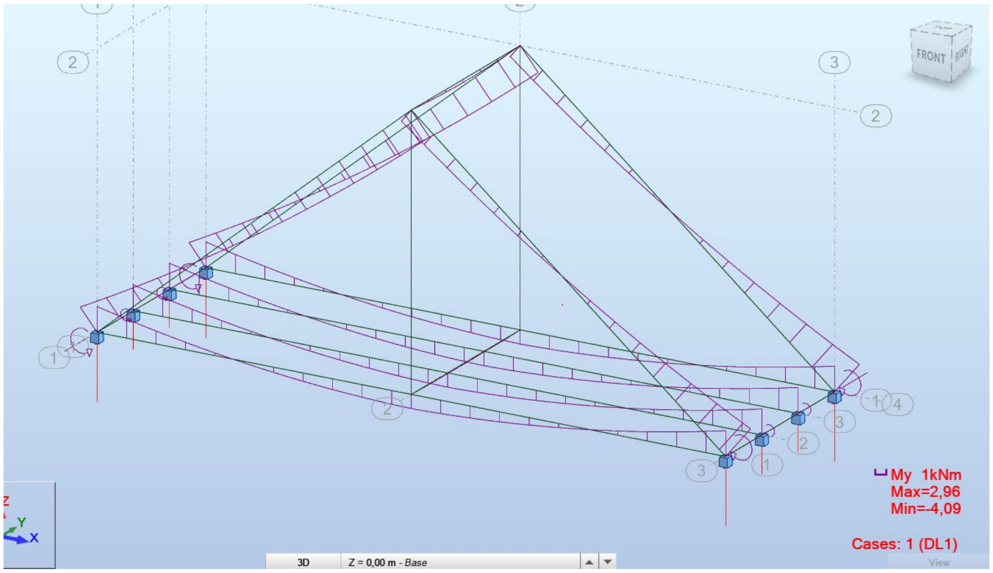


Figure 47: Final structure (Loads and reactions) – Robot

Now the structure is also verified using Robot and is concluded that the geometry and the sections considered for the bridge will uphold the loads of this pedestrian bridge, all this just for the structural members, it must also be satisfied that the bridge has a sufficient foundation and that the elements are well connected.

5. Design of connections and foundation.

For the design of the connections, it will be used an Autodesk software called Advance steel, which will provide good support for the design of the possible different types of connections that the members could have.

This software is beneficial as we are working in a greater level of development, the work will focus on the detailing of each connection of the bridge, which will include number of bolts, plates, and type of connections between the members.

As in this case the work is done using an Autodesk software the work developed in the architectural design in Revit, and the structural design in Robot could be transported in a proper way to Advance steel.

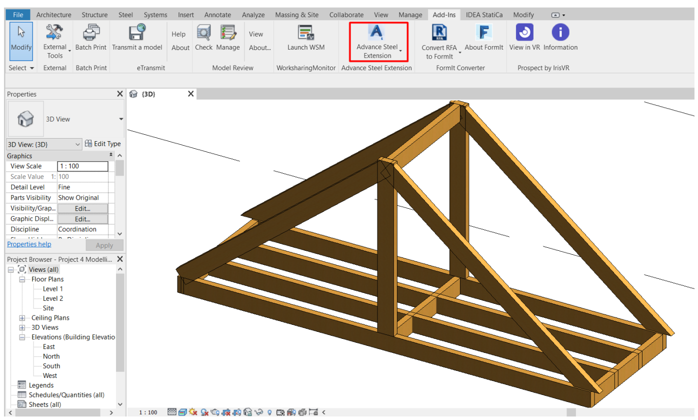


Figure 48: Interoperability - Add in to pass from Revit to Advance steel

There are several interoperability ways to pass one file in one format that is compatible with certain software, to another format compatible with a different software. In this case for checking the interoperability, it was used an ad in that transformed the file into ". smlx" which is compatible to Advance steel.

After opening this new file, the compatibility is not complete, the sections are not detected by Advance steel, but the geometry is ok. For this analysis all the elements were redrawn in this software, now aiming to use the benefits of advance steel for designing connections.

First, the section was again modified, by selecting the proper glued laminated timber option as the main section. Also, the corresponding dimensions that are used for all the members. (100 mm x 200 mm) and the concrete C25/30 typical for a simple wall foundation.

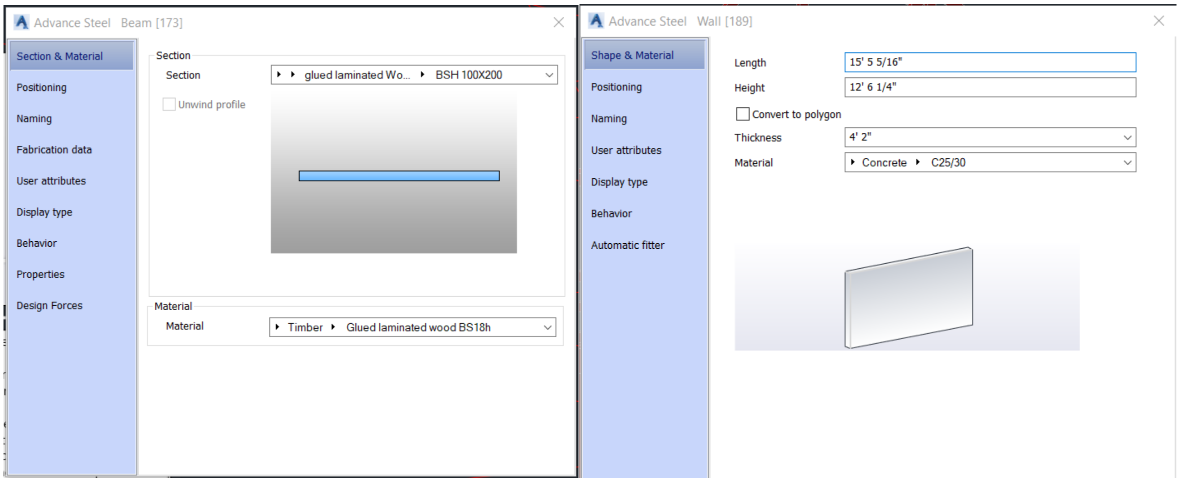


Figure 49: Materials and dimensions for elements in Piedicavallo bridge.

Section of glued laminated timber members: Length: 10 cm. Height: 20 cm.

Concrete pile wall: Thickness: 50 cm. Height: 150 cm. Length: 180 cm.

Now, using this software "Advance steel", the geometry is drawn with the proper corresponding sections.

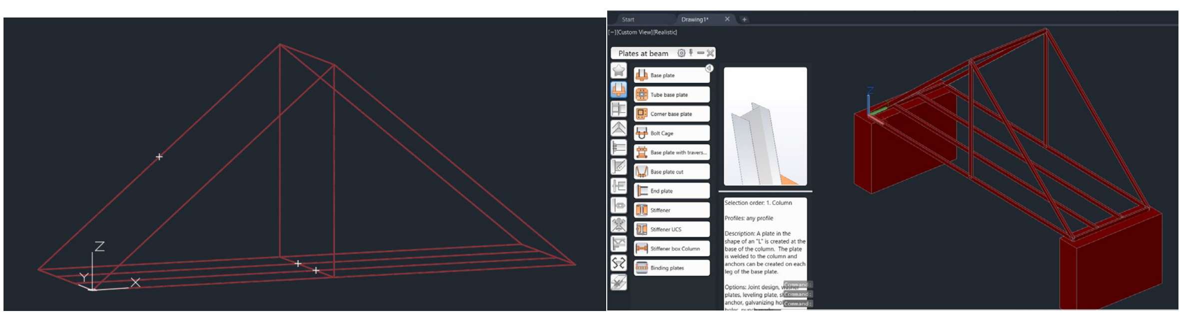


Figure 50: Process of drawing using Advance steel.

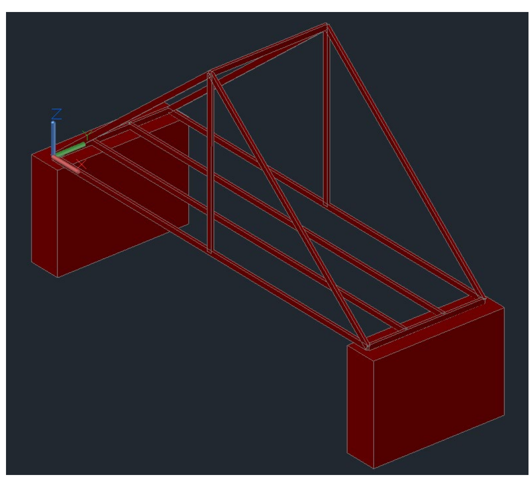


Figure 51: Piedicavallo bridge before design of connections.

5.1. Design of the type of connection

Using Advance steel software, all the connections of the bridge are going to be designed, for this structure we identify 3 types of connection. A border connection that connects with the foundation at the edges, a perpendicular column connection that connects with the column in the middle of the bridge, and finally the top connection which connects multiple members.

5.1.1. Border base plate connections:

For this border connection it is going to be considered the diagonal element, which is the one that will have this type of connection to the concrete. The other two perpendicular elements that will arrive to this point will be connected to the concrete after the concrete curing in site. Also, this plate is going to be installed in top of the concrete, before pouring the concrete, for when the concrete dries there is a better adhesion to the bolts.

This is the thickness of the plate and anchors diameter chosen for design. This same dimension of plate and bolts will be used in all the connections.

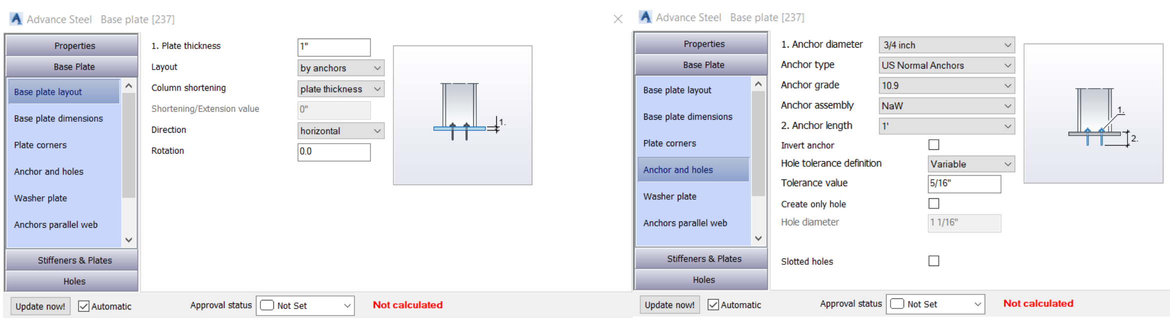


Figure 52: Dimension of plates and bolts

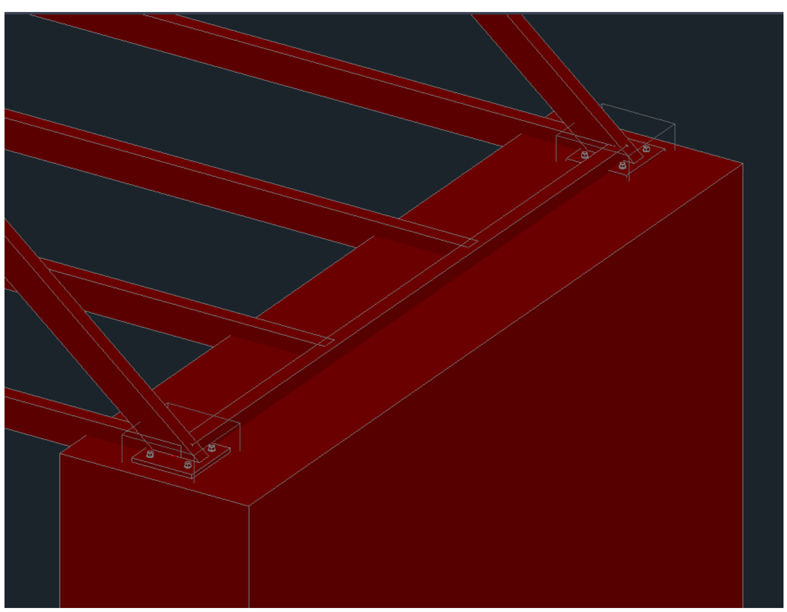


Figure 53: Border Base plate connection - Type 1

5.1.2. Connection beam perpendicular to column

For the design of this type of connection, we must consider that the members are made up of wood, so the connection will not be as simple as a welding connection, but it will require plates and bolts.

In this case we consider a knee plate (Perpendicular) that has two bolts and will fix the related members. The distance between bolts is of 2 inches.

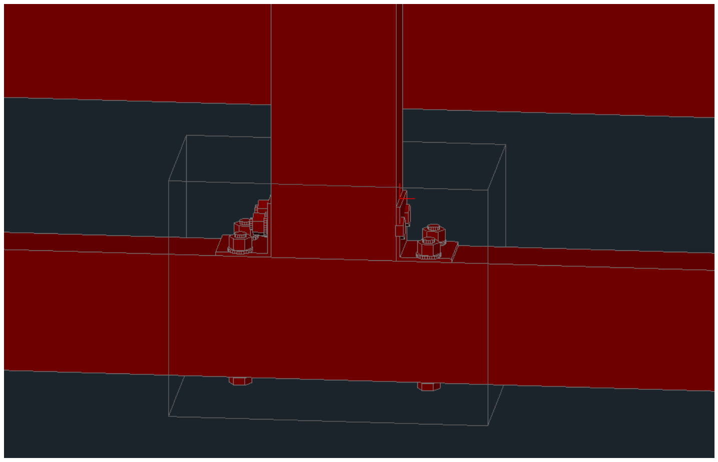


Figure 54: Connection beam perpendicular to column - Type 2

5.1.3. Connection for perpendicular column and beam with diagonal members. - Top connection.

In this case the connection will be between the vertical column and the top beam, but in addition to this connection there will be an additional connection that will fix the two diagonal members.

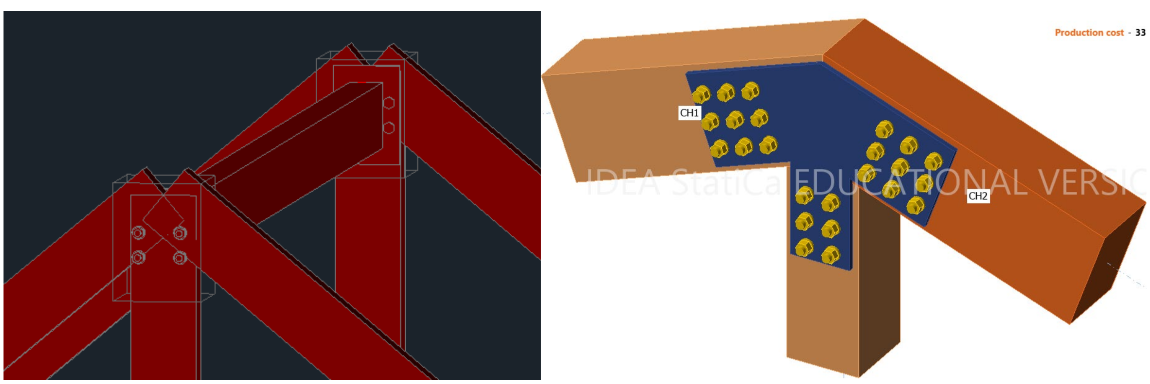


Figure 55: Top connection bridge - Type 3

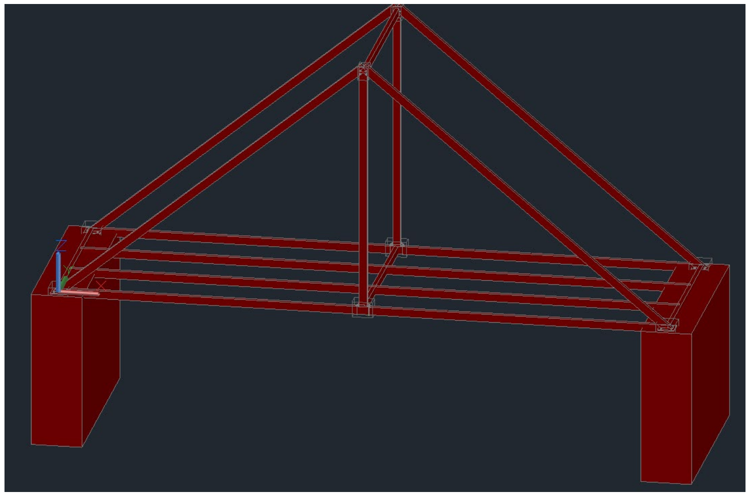


Figure 56: Final design Piedicavallo bridge - Advance steel

Now, this is the final design of the glued laminated timber bridge (Piedicavallo bridge) with concrete foundation with all the possible connections.

5.2. Evaluation of the types of connections

After having the complete design of all the connections, the next step is to evaluate these connections to make sure that the design proposed for each connection can withstand the load from the structural analysis.

For this process, in these connections it was used another specialized software called IdeaStatica. In this software we will be able to separate the connection applying the loads achieved from the structural analysis, and from this according to Eurocode regulations, the software will calculate if the connection is able to uphold these loads.

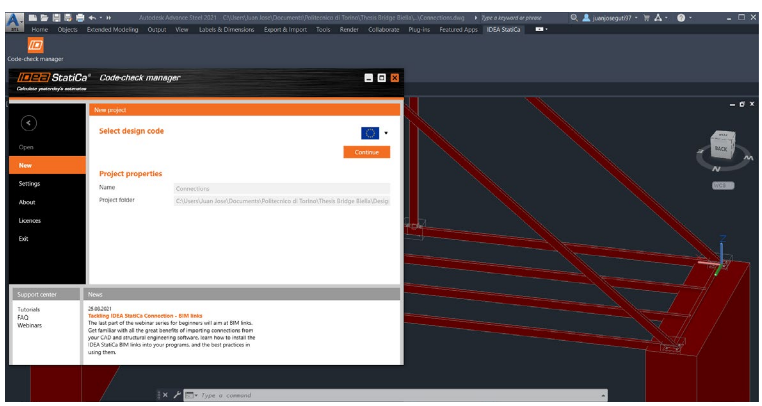


Figure 57: Ideastatica from Advance steel - Design code: Eurocode

5.2.1. Border base plate connections results

For this type of connection (Type 1 for design purposes). It will be used a rectangular tubular metallic support, that will be welded to the plate as well as bolted to concrete the plate. This wooden diagonal section will be surrounded by this support which is welded to the plate.

In this software it was also included the forces acting in the members achieved from the structural analysis.

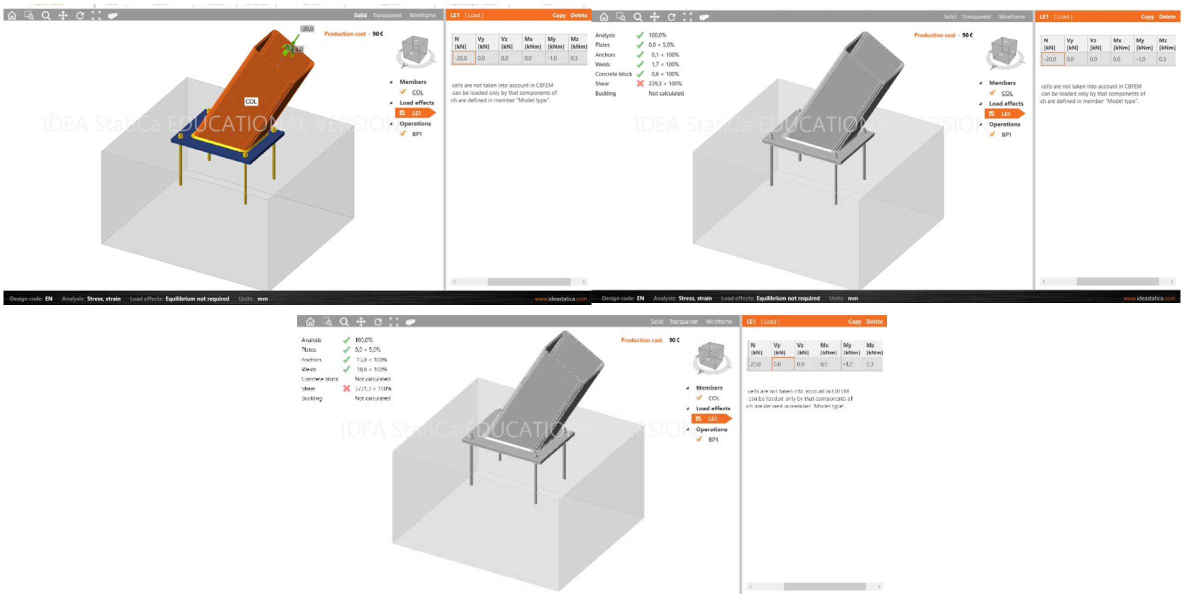


Figure 58: Evaluation of Type 1 connection

IdeaStatica gives us a estimate of the price of this connection, which will then be estimated with better detail during all the construction management phase.

5.2.2. Beam perpendicular to column results

For this type of connection, it was evaluated the design drawn using Advance steel and the dimension and number of bolts were good, but it was also considered a second design done, which results to be more beneficial from an economical point of view, in a later stage this evaluation will be done, in any case the price does not change in a significant way.

For the analysis in this software the loads in these members are inserted as an input to know if the connection is proper or no.

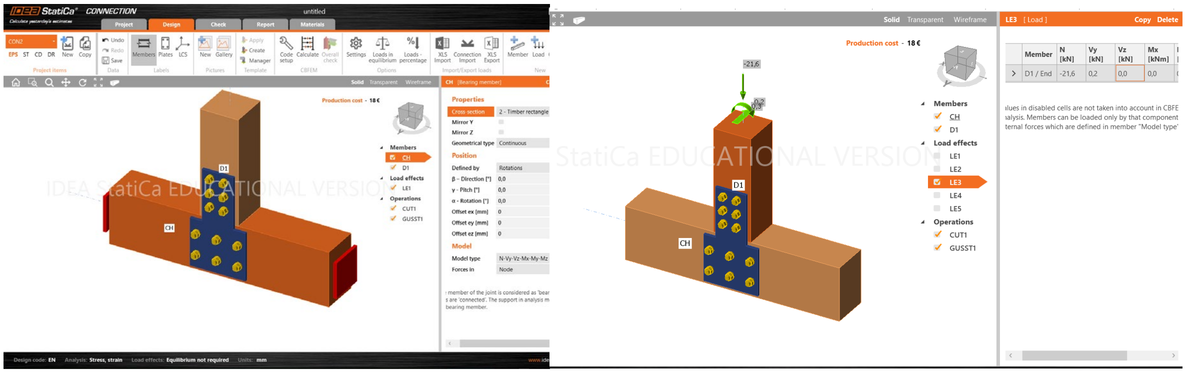


Figure 59: Evaluation of Type 2 connection

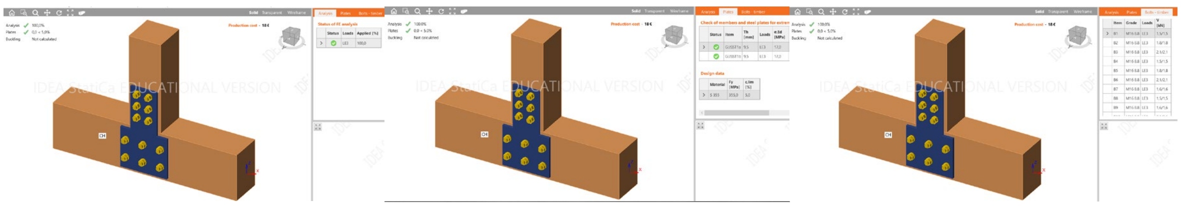


Figure 60: Type of bolts and plates for connection Type 2

5.2.3. Perpendicular column and beam with diagonal members. - Top connection.

For this top connection as it was mentioned, it will be added two different connection designs, the first one is this one drawn here between the timber members using IdeaStatica, and the second one that will fix the top beam as it was designed in Advance steel.

Both designs fit the structural design of the connection according to Eurocode.

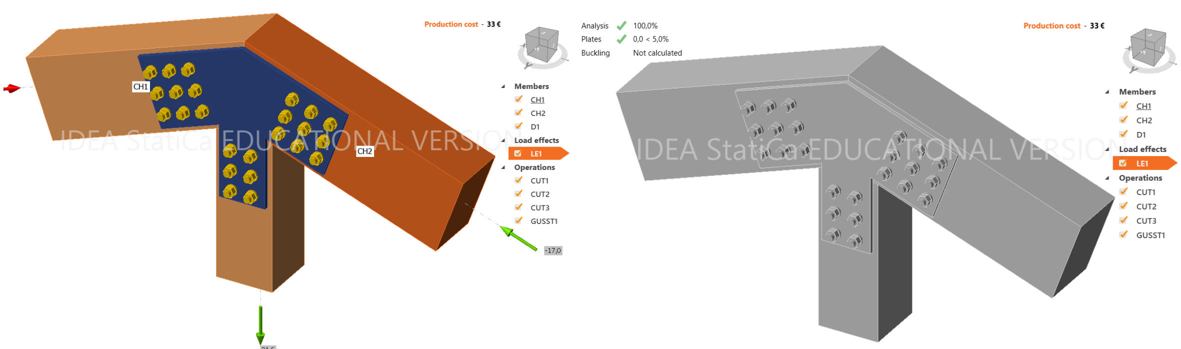
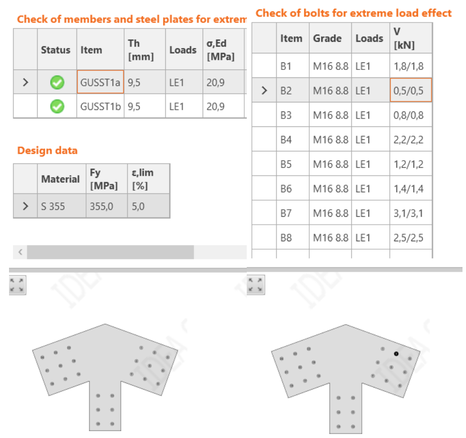


Figure 61: Evaluation of Top connection type 3.



Check of members and steel plates for extrem

	Status	Item	Th [mm]	Loads	σ,Ed [MPa]
>	✓	GUSST1a	9,5	LE1	20,9
	✓	GUSST1b	9,5	LE1	20,9

Design data

	Material	Fy [MPa]	ε,lim [%]
>	S 355	355,0	5,0

Check of bolts for extreme load effect

	Item	Grade	Loads	V [kN]
	B1	M16 8.8	LE1	1,8/1,8
>	B2	M16 8.8	LE1	0,5/0,5
	B3	M16 8.8	LE1	0,8/0,8
	B4	M16 8.8	LE1	2,2/2,2
	B5	M16 8.8	LE1	1,2/1,2
	B6	M16 8.8	LE1	1,4/1,4
	B7	M16 8.8	LE1	3,1/3,1
	B8	M16 8.8	LE1	2,5/2,5

Figure 62: Type of plates and bolts type 3 connection

IdeaStatica is a powerful software for evaluation the connections that the bridge will have during the construction and the operation phase.

5.3. Design and evaluation of the foundation

Having the loads applied to the foundation it could be estimated if the foundation wall we have as a foundation for both ends of the bridge is sufficient to contain the loads applied at this point. For doing so, some equations will be used for estimating the resistance of the foundation.

For this some soil parameters were supposed considering a typical case scenario for the soil at this stream.

For foundation it must be considered as an additional load the weight of the foundation itself and multiply it by a proper conservative safety factor.

$$\gamma_{Concrete} = 23.6\, {}^{kN}/_{m^3}$$

$$\gamma_{Soil} = 18\, {}^{kN}/_{m^3}$$

Equation 12: Weight per unit volume of concrete and medium sand

For this type of soil, it will be used a scenario for the soil in which the angle will be equal to the angle of friction of this sand. The sand is a medium sand with an angle of friction of 31.5 degrees.

As it is known the loads are extremely small compared to real construction scenarios, this is due to the fact we are considering the individual load over one joint and this joint carries a very light bridge. This is the reason why is even heavier the weight of the foundation than the load applied to this joint by this small and light bridge.

$$\emptyset_p = \emptyset_{cv} = 31.5°$$

$$P_{Footing} = SF * \gamma_{Concrete} * B * L * H = 1.3 * 23.6 * 0.5 * 1 * 1.5 = 23.01\ kN$$

Equation 13: Shallow foundations - Lancellota

$$P_{Bridge} = 17.71\ kN$$

$$P_{Total} = P_{Footing} + P_{Bridge} = 40.72\ kN$$

$$M_{Total} = 0.948\ kN * m$$

$$q = \gamma * D = 18 * 1.4 = 25.2\ kPa$$

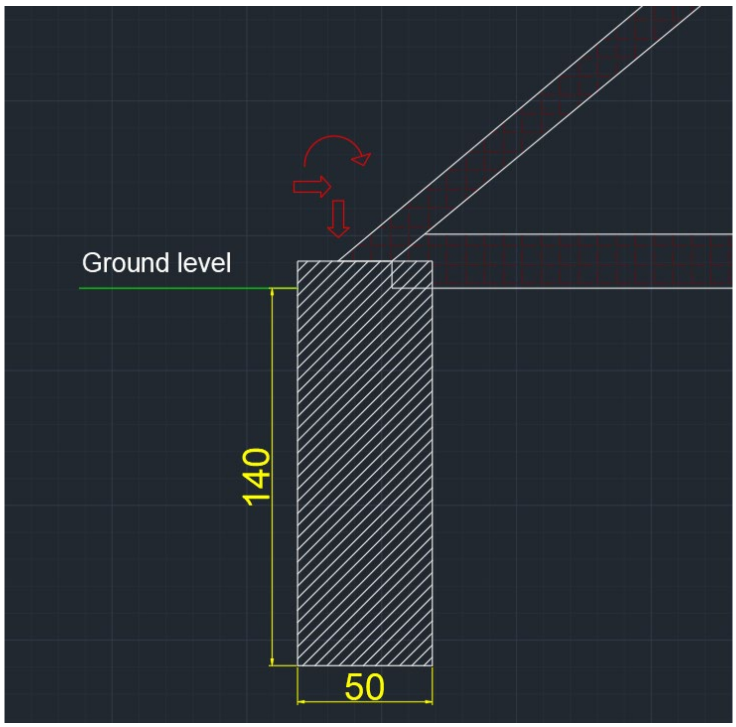


Figure 63: Dimensions of foundation using Autocad

$$N_d = P_{Tot} - \gamma_{soil} * 1.4 * 0.5 * 1$$

$$N_d = 40.72 - 18 * 1.4 * 0.5 * 1 = 28.12\ kN.$$

Equation 14: Vertical load

As there is also a moment, this moment will be considered as a vertical load with a certain eccentricity from the center of the foundation, where is ideally applied the force. For this total force applied it must also be subtracted the weight of the volume of soil that was removed.

$$e_{cc} = {M_{Tot}}/{N_d} = \frac{0.948}{28.12} = 0.034\ m.$$

Equation 15: Calculation of Eccentricity

In addition, it could also be calculated the strength of this sand. Using the following equation.

$$q_{lim} = \frac{1}{2} * \gamma * B * N_\gamma * S_\gamma + q * N_q * S_q + c * N_c$$

Equation 16: Shallow foundations equation - Lancellota

Having that:

$$N_q = e^{\pi * \tan \emptyset_p} * (\tan\left(45° + \frac{\emptyset_p}{2}\right))^2 = 21.86$$

$$N_\gamma = 2 * (N_q + 1) \tan \emptyset_p = 28.02$$

$$S_\gamma = S_q = 1 + 0.1 * \frac{1 + \sin \emptyset_p}{1 - \sin \emptyset_p} * \frac{B}{L} = 1.16$$

Equation 17: Adimensional parameters Shallow foundations - Lancellota

In this case for this sand, it will be considered the sand as cohesionless. So $c = 0$.

$$q_{lim} = 785.28\ kPa$$

Equation 18: Limit strength resisted by sand

Using the Eurocode for design of foundations, it must be considered a big factor of safety of 2.3, due to the uncertainty. So, in this way we have:

$$q_{Rd} = \frac{q_{lim} - q}{FS} = \frac{785.28 - 25.2}{2.3} = 330.47\ kPa.$$

Now we have the resisting loads due to the foundation, the next step is to compare this result with the acting load strength in the structure. For being stable the resisting strength must be greater than the acting strength.

$$q_{ED} = \frac{N_d}{(B - 2e) * L} = \frac{28.12}{0.432} = 65.09\ kPa.$$

The dimensions of the foundation chosen are good, as the loads for the foundation that were obtained from the structural analysis represent a lower acting strength than the resisting strength provided by the foundation.

6. Cost estimate analysis (5D)

As one of the main objectives of this Thesis is to develop a complete and detailed construction management analysis of the Piedicavallo bridge. This includes a precise cost estimation of the materials used and all the working for the final construction of the bridge. This bridge is in a remote place, with null access by land so is necessary a good planning for the transportation of the materials to avoid a big increase in the cost of the bridge construction.

All this is going to be analyzed during this next chapters, as well as the cost of the materials considered for the design of this bridge.

In this whole analysis the main objective is to evaluate this solution costs by using this material, and then this solution could be compared with another proposed solution in a different material with different architectural design.

For this initial cost estimation, it will be developed an analytic estimation of the costs of construction. In Italian "Computo metrico estimativo" as this project takes place in Italian territory.

In Italy there are two main types of retributions for the work developed during the project that are included in this analytic estimation of the costs. They are:

- Contract works (Opere a corpo): Is the economical compensation for each work done or for all the work as a total, this is fixed and invariable and must be estimated with precision in the design phase. The company is recognized as a percentage of the physical advance of the project, independently of the quantities developed.
- Contract – Sized works (Opere a misura): The economical compensation is a function of the real quantities done during construction, based on a list of unitary prices agreed in the contract.

Is important to mention that there are more types of contracts for retributions to the companies for the work developed, and this also can vary in bonifications agreed during the contract or any modification.

In this report we will not focus on the types of contracts for construction, but for this initial cost estimation, it will be done a cost estimation by the measure of the actual quantity of each work that will be developed, this will be done organized in a different way for the total retribution at the end of the project.

For this case it will be considered the first type of contract works, it must be developed an estimation cost considering the quantities and all costs and expenses for each work that will be done and paid. For this project it will be considered a unique contract work, so the total retribution will be based after the construction of the complete bridge. This will be a formal proposition for the construction of the bridge, in how the bridge will be constructed, the times of construction and the total cost for the construction of it.

The computation of the estimation of costs is an analytic procedure for estimating the costs of construction. Using this main equation.

$$CME = \sum_{i=1}^{n} (Q_i * P_i)$$

Equation 19: Equation for "Computo metrico estimativo". Taken from (DEI - Tipografia del genio civile, 2020)

So, the final estimation represents the sum of all the different quantities of each specific work with the corresponding quality that must be done multiplied by the unitary price for each unit of this specific work.

This estimation of costs has some advantages such as:

- For the client, the program for the dates to do the investments, depending in the real need of resources and for a better valuation of the offer that is presented by the company interested in doing this work.
- For designer, to control the project (Control of the budget) and for a better redacting of the working program.
- For the director of the project, to control the development of the work and the accountability of the project.
- For the contractor, a preventive analysis of the processes and related costs to define the offer, planning the supplies and resources needed and to control costs, to compare these costs during the construction, comparing in this way the predicted costs with the real costs. (Lioce, 2005)

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. Incorrect estimates can lead to budget and time runoffs and to failure of a construction project.

This construction estimate sums up building materials, workforces, and equipment for all units of construction works. Is also used to plan project investment budget and to control costs. The main cost estimating methods depending on the phase of construction are:

- Cost estimation based on analogue existing buildings o projects as a total.
- Detailed cost estimation after completing the design phase: This is the case we are working now. It is used detailed cost estimates using unit cost method based on regulations and estimations using resource – based unit cost method.
- The actual costs that will be compared during the development of the project.

These are usually used for the preliminary cost estimation at the design phase, for financial feasibility studies, for decision making on project economics. This detailed cost estimates are based on market prices, which is a time-consuming process that requires knowledge of market prices on construction materials, labor rates and costs of renting equipment.

BIM adoption for enhancing construction efficiency. It needs automatizing by joining the functional possibilities by BIM technology (Quantity takeoffs – This will be done using different software for comparing results) and established cost estimation techniques. (Ghazaryan, 2019).

“Integrating the 5th dimension ‘cost’ to the BIM model generates the 5D model, which enables the instant generation of cost budgets and genetic financial representations of the model against time. This reduces the time taken for quantity take-off and estimation from weeks to minutes, improves the accuracy of estimates, minimizes the incidents for disputes from ambiguities in CAD data, and allows cost consultants to spend more time on value improvement.” (Kameedan, 2010, p. 285) (Smith, 2007)

6.1. Cost estimation using Primus (ACCA software)

For this initial management of the costs, the first approach that will be considered is developing the cost analysis using an Italian software called Primus.

Primus is a very powerful software for any kind of project for calculating the cost of all the materials/processes having the quantity of each one of them and the corresponding unit. As we already have the final design of the bridge in Edificius (an architectural software from the ACCA family) we could use this real design to connect it with Primus and in this way have the real quantities of the materials involved for the total costing of the bridge.

For this initial estimation it will be used an Italian “Prezzario”, this booklet includes a medium average of the main costs of some materials depending on the local region we are located, these prices may vary from region to region.

For this project it was considered one of the booklets that has the prices of the region of Piemonte, which is the actual region where the bridge will be constructed.

Is important to mention that these prices are not the real prices at which the project will be buying the materials for construction, this is just for an initial estimate.

These prices were obtained by “DEI, tipografia del genio civile”, and this “Prezzario DEI” (List of prices) represent an average cost of each “voce” (voice) of this line in this region. Each booklet has different costs. (DEI - Tipografia del genio civile, 2020)

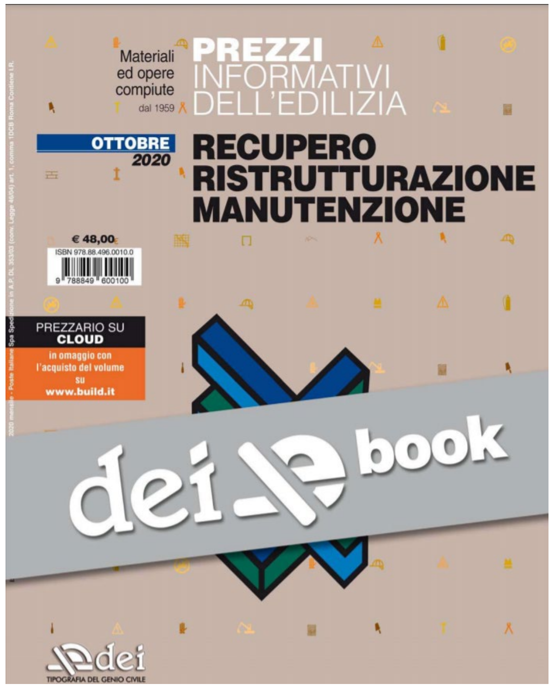


Figure 64: DEI prices booklet (DEI - Tipografia del genio civile, 2020)

For the voices of the superstructure of the bridge, where it is considered all the wooden (Glulam) elements, the concrete for the construction of the wall foundation and the railing were all found in this booklet, which considers the average of the prices for the region.

In this project the quantities will be obtained directly from Edificius. So, for this we will start with the Edificius architectural design file using a BIM interoperability extension that will connect this modelling software to Primus.

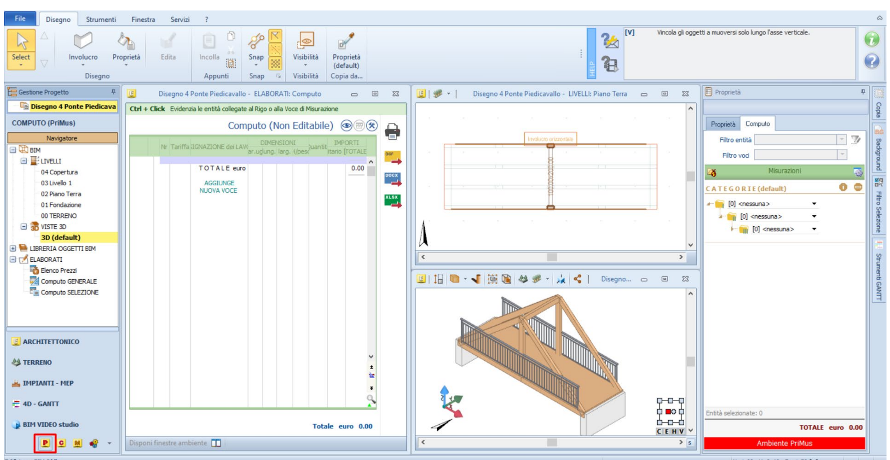


Figure 65: Edificius window connected quantity function to Primus

After this, the real quantities obtained from the architectural design could be used with the mentioned prices lists, by choosing the element in the drawing, then relate the corresponding line with this element and have in mind in a correct way the units.

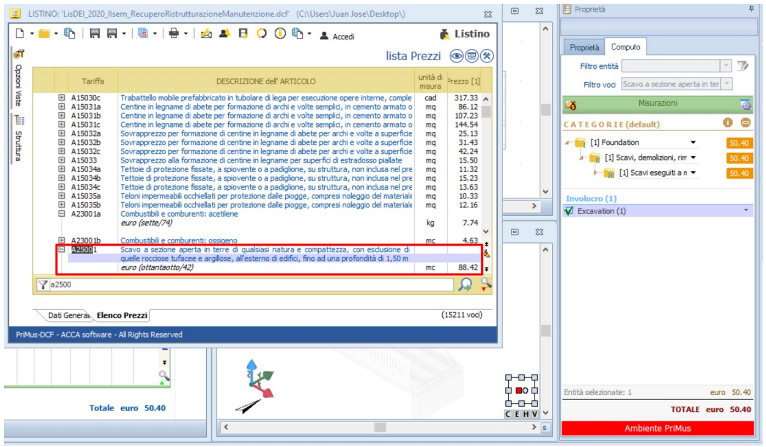


Figure 66: Prices list (Voices) connected to quantities in Edificius

In this way we choose the price with the unit for the corresponding activity and the quantity obtained is the one selected depending on the units of the voice.

Then by having the considered elements in each case, we select the quantity of this element that must be measured for the total price related to this item in the project. In this case the voice we are selecting is the concrete that goes inside a foundation wall that sustains the bridge, the cost of the concrete in the structure is measured in cubic meters, so we extract as a quantity the volume in cubic meters of the foundation wall.

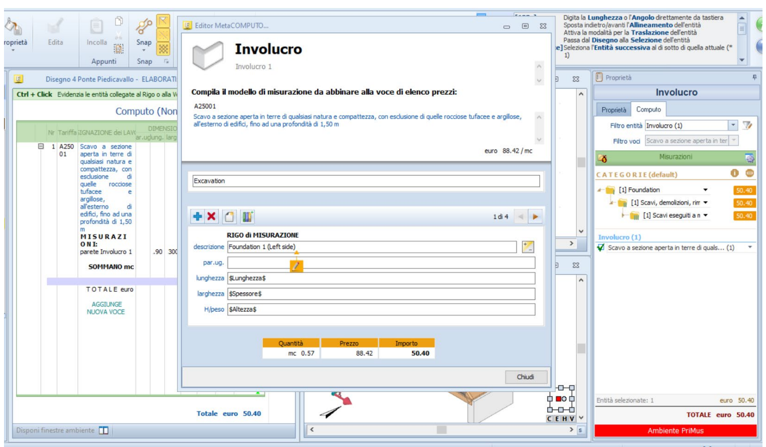


Figure 67: Description of quantity of element related to the specific voice.

For example, before putting the concrete as a foundation there must be an excavation, the volume of this excavation is the same volume of the foundation wall. So, this element is selected, and this specific voice of excavation will be related to the volume of the wall foundation in the same unit (m3).

For each voice selected in Edificius for the quantity of each material or activity for achieving that material, it must be organized in categories, that represent the type of work done, to have at the end a more summarized information with the given costs of each category.

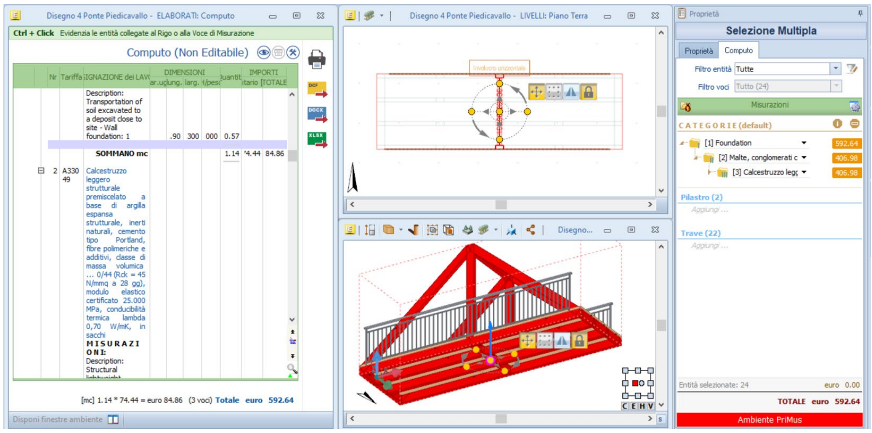


Figure 68: Edificius connection with Primus screen - Selection of components for assigning the corresponding activities

Any component that will be constructed during the development of this project could be developed using several activities, for example for the construction of the Piedicavallo bridge, we do not only have the voice that includes the prefabricated construction of the bridge, with all connections in steel included with the volume of the wood, but also any complementary works that must be done for this, such as the painting of the faces of the wood, which the unit of measurement is the squared meters of the face.

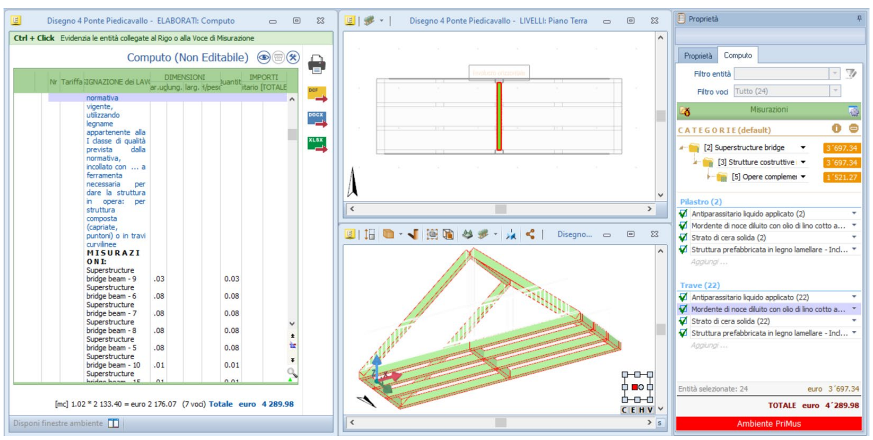


Figure 69: Edificius connection with Primus screen - Activities assigned including complementary works

Then we export the quantities of the materials wanted to Primus a specialized software for costing of the ACCA company. For this we go to the ACCA interoperability tools.

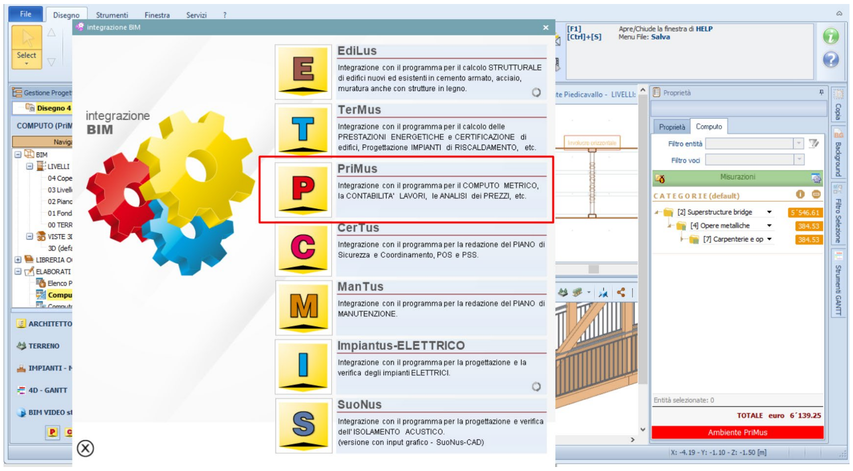


Figure 70: BIM integration - Edificius to Primus

As this Thesis is related to the BIM topics, is interesting to mention that for other projects, especially residential projects (Renovations), there are other software of this ACCA family that have different specialty functions. This software has a very good interoperability between them, with other design software, such as Revit or Tekla the interoperability is null.

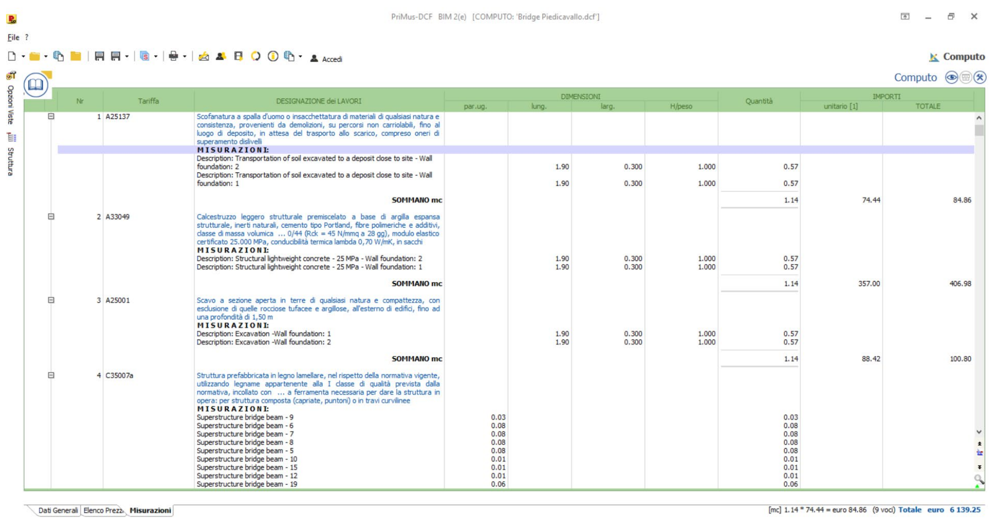


Figure 71: Primus screen - Costing of the activities for Bridge construction.

Now we are working in the Primus direct software for the development of this proper cost estimation, there is included in this phase some materials that cannot be measured using the Edificius architectural design, such as the connections that will fix the bridge to the wall foundation.

For this construction plan developed in Primus, the price obtained for the construction of the superstructure of the Glulam bridge, was obtained as a function of the volume of the same, this unitary price included also the connection needed to work properly following all the regulations for joints. For the construction phase this option will be chosen and all the superstructures will be prefabricated and transported to site complete, while in site it will be fixed to the wall foundation.

This is the justification for the selection of this voice for all the superstructure, but this process is going to be explained with better detail further in this Thesis.

Exported bridge costing Primus. The costing official report in Italian with the corresponding voices representing the average prices in the region of Piemonte (Italy) is presented as Annex 1.

Estimated costs using DEI and Piemonte region average pricing.

Nr. Ord.	TARIFFA	Description	Unit of measure	Quantity	Value	
					Unitary price	**TOTAL COST**
1	A25137	Transportation of the excavated soil material (Sand) - Transport to a deposit close to site.				
		Soil material volume of wall foundation 1	m3	0.57		
		Soil material volume of wall foundation 2	m3	0.57		
		Total volume of sand transported	**m3**	**1.14**	**€ 74.44**	**€ 84.86**
2	A33049	Pre-mixed structural lightweight concrete based on structural expanded clay, natural aggregates, Portland cement, polymeric fibers and additives - elastic modulus 25.000 Mpa. - In bags				
		Structural lightweight concrete - 25 MPa - Wall foundation: 2	m3	0.57		
		Structural lightweight concrete - 25 MPa - Wall foundation: 1	m3	0.57		
		Total volume of Structural lightweight concrete	**m3**	**1.14**	**€ 357.00**	**€ 406.98**
3	A25001	Excavation up to a maximum depth of 1.50 m.				
		Excavation -Wall foundation: 1	m3	0.57		
		Excavation -Wall foundation: 2	m3	0.57		
		Total volume of excavation		**1.14**	**€ 88.42**	**€ 100.80**
4	C35007a	Prefabricated structure in laminated wood, in compliance with current legislation. Glued with synthetic resin-based products and impregnated, planed visible structures; including joints, metal attachments and hardware necessary to give the structure in place. For composite structure (trusses)				
		Superstructure bridge beam - 9	m3	0.03		

		Superstructure bridge beam - 6	m3	0.08		
		Superstructure bridge beam - 7	m3	0.08		
		Superstructure bridge beam - 8	m3	0.08		
		Superstructure bridge beam - 5	m3	0.08		
		Superstructure bridge beam - 10	m3	0.01		
		Superstructure bridge beam - 15	m3	0.01		
		Superstructure bridge beam - 12	m3	0.01		
		Superstructure bridge beam - 19	m3	0.06		
		Superstructure bridge beam - 21	m3	0.06		
		Superstructure bridge beam - 22	m3	0.06		
		Superstructure bridge beam - 20	m3	0.06		
		Superstructure bridge beam - 16	m3	0.01		
		Superstructure bridge beam - 18	m3	0.01		
		Superstructure bridge beam - 17	m3	0.01		
		Superstructure bridge beam - 2	m3	0.06		
		Superstructure bridge beam - 3	m3	0.06		
		Superstructure bridge beam - 4	m3	0.06		
		Superstructure bridge beam - 11	m3	0.01		
		Superstructure bridge beam - 14	m3	0.01		
		Superstructure bridge beam - 1	m3	0.06		
		Superstructure bridge beam - 13	m3	0.01		
		Superstructure bridge Column - 2	m3	0.05		
		Superstructure bridge Column - 1	m3	0.05		
		Prefabricated superstructure of bridge	**m3**	**1.02**	**€ 2,133.40**	**€ 2,176.07**
5	C35008b	Liquid pesticide applied for the prevention and conservation of wooden structures				
		Superstructure bridge column - 2	m2	1.50		
		Superstructure bridge column - 1	m2	1.50		
		Superstructure bridge beam - 9	m2	1.02		
		Superstructure bridge beam - 6	m2	2.35		
		Superstructure bridge beam - 7	m2	2.35		
		Superstructure bridge beam - 8	m2	2.35		
		Superstructure bridge beam - 5	m2	2.35		
		Superstructure bridge beam - 10	m2	0.33		
		Superstructure bridge beam - 15	m2	0.37		
		Superstructure bridge beam - 12	m2	0.32		
		Superstructure bridge beam - 19	m2	1.86		
		Superstructure bridge beam - 21	m2	1.86		
		Superstructure bridge beam - 22	m2	1.86		
		Superstructure bridge beam - 20	m2	1.86		
		Superstructure bridge beam - 16	m2	0.33		
		Superstructure bridge beam - 18	m2	0.37		

		Superstructure bridge beam - 17	m2	0.32		
		Superstructure bridge beam - 2	m2	1.86		
		Superstructure bridge beam - 3	m2	1.86		
		Superstructure bridge beam - 4	m2	1.86		
		Superstructure bridge beam - 11	m2	0.33		
		Superstructure bridge beam - 14	m2	0.37		
		Superstructure bridge beam - 1	m2	1.86		
		Superstructure bridge beam - 13	m2	0.32		
		Cross - Lam slab	m2	11.78		
		Application of pesticide in whole superstructure	**m2**	**43.14**	**€ 20.34**	**€ 877.47**
6	C35009	Solid wax layer dissolved with suitable thinners and applied with a cloth				
		Superstructure bridge column - 2	m2	1.50		
		Superstructure bridge column - 1	m2	1.50		
		Superstructure bridge beam - 9	m2	1.02		
		Superstructure bridge beam - 6	m2	2.35		
		Superstructure bridge beam - 7	m2	2.35		
		Superstructure bridge beam - 8	m2	2.35		
		Superstructure bridge beam - 5	m2	2.35		
		Superstructure bridge beam - 10	m2	0.33		
		Superstructure bridge beam - 15	m2	0.37		
		Superstructure bridge beam - 12	m2	0.32		
		Superstructure bridge beam - 19	m2	1.86		
		Superstructure bridge beam - 21	m2	1.86		
		Superstructure bridge beam - 22	m2	1.86		
		Superstructure bridge beam - 20	m2	1.86		
		Superstructure bridge beam - 16	m2	0.33		
		Superstructure bridge beam - 18	m2	0.37		
		Superstructure bridge beam - 17	m2	0.32		
		Superstructure bridge beam - 2	m2	1.86		
		Superstructure bridge beam - 3	m2	1.86		
		Superstructure bridge beam - 4	m2	1.86		
		Superstructure bridge beam - 11	m2	0.33		
		Superstructure bridge beam - 14	m2	0.37		
		Superstructure bridge beam - 1	m2	1.86		
		Superstructure bridge beam - 13	m2	0.32		
		Cross - Lam slab	m2	11.78		
		Application of solid wax layer in supestructure of bridge	**m2**	**43.14**	**€ 14.62**	**€ 630.71**

7	C35010	Walnut mordant diluted with boiled linseed oil applied by brush with two coats on exposed wood				
		Superstructure bridge column - 2	m2	1.50		
		Superstructure bridge column - 1	m2	1.50		
		Superstructure bridge beam - 9	m2	1.02		
		Superstructure bridge beam - 6	m2	2.35		
		Superstructure bridge beam - 7	m2	2.35		
		Superstructure bridge beam - 8	m2	2.35		
		Superstructure bridge beam - 5	m2	2.35		
		Superstructure bridge beam - 10	m2	0.33		
		Superstructure bridge beam - 15	m2	0.37		
		Superstructure bridge beam - 12	m2	0.32		
		Superstructure bridge beam - 19	m2	1.86		
		Superstructure bridge beam - 21	m2	1.86		
		Superstructure bridge beam - 22	m2	1.86		
		Superstructure bridge beam - 20	m2	1.86		
		Superstructure bridge beam - 16	m2	0.33		
		Superstructure bridge beam - 18	m2	0.37		
		Superstructure bridge beam - 17	m2	0.32		
		Superstructure bridge beam - 2	m2	1.86		
		Superstructure bridge beam - 3	m2	1.86		
		Superstructure bridge beam - 4	m2	1.86		
		Superstructure bridge beam - 11	m2	0.33		
		Superstructure bridge beam - 14	m2	0.37		
		Superstructure bridge beam - 1	m2	1.86		
		Superstructure bridge beam - 13	m2	0.32		
		Cross - Lam slab	m2	11.78		
		Application of Walnut mordant over bridge superstructure	**m2**	**43.14**	**€ 13.55**	**€ 584.55**
8	C35094a	Cros - lam slab: Thickness of 60 mm. All costs of transportation and handling in construction site are included.				
		Cross - lam slab Thickness 60 mm.	m2	11.78		
		Cross - lam slab over superstructure	**m2**	**11.78**	**€ 75.83**	**€ 893.28**
9	C15019d	The fence for safety of users of the bridge - Includes the construction and all the bolts for construction.				
		Fence - Side 1	Kg	22.76		
		Fence - Side 2	Kg	22.32		
		Fence for safety	**Kg**	**45.08**	**€ 8.53**	**€ 384.53**

10	C35143b	Suport joint in stainless steel - Including connection to the wood - Excluding anchors and bolts that connect to foundation.				
		Support for superstructure joints	Unit	4.00		
		Support for superstructure joints	**Unit**	**4.00**	**€ 37.99**	**€ 151.96**
11	C35175m	Smooth, calibrated and ground pin - Connection with support and foundation. 4 units per each connection.				
		Bolts for joint connecting superstructure and foundation wall	Unit	16.00		
		Bolts for joint connecting superstructure and foundation wall	**Unit**	**16.00**	**€ 4.89**	**€ 78.24**
12	01.P01.A20.005	Qualificated worker				
		For excavation (4 workers)	Hours	51.00		
		For pouring of concrete (4 workers)	Hours	35.00		
		For installation of superstructure in joints connected to foundation walls (4 workers)	Hours	18.00		
		Total Hours of qualified worker	**Hours**	**104.00**	**€ 34.21**	**€ 3,557.84**
13	01.P01.A10.005	Specialized worker				
		M I S U R A Z I O N I:				
		For excavation (1)	Hours	15.00		
		For pouring of concrete (1)	Hours	11.00		
		For installation of superstructure in joints connected to foundation walls (1)	Hours	6.00		
		Total hours of specialized worker	**Hours**	**32.00**	**€ 36.91**	**€ 1,181.12**
14	18.P08.A05.005	Transportation in hellicopter for the prefabricated superstructure of Glulam bridge - Includes the loading and unloading. For a working operation (Hook transport) up to 600 Kg. - The weight of Piedicavallo bridge is of 492 Kg. For the Piemonte region				
		Transportation of Superstructure from Biella to Piedicavallo construction site	Minutes	400.00		
		Total minutes for transportation in helicopter	**Minutes**	**400.00**	**€ 20.67**	**€ 8,268.00**
		Total cost of Piedicavallo bridge				**€ 19,376.40**

Table 4: Costing Piedicavallo bridge, Biella

6.2. Tekla and Navisworks quantities takeoff.

Tekla provides a BIM software environment that can be shared by contractors, structural engineers, steel detailers and fabricators. This highly detailed software enables the highest level of constructability and production control. Centralizing building information into the model allows for more collaborative and integrated project management and delivery, which will increase productivity and eliminate waste, making construction more sustainable.

For a more detailed quantities takeoff and a better control of the project during the construction phase, it was also used Tekla software, this software is a very complete software for a proper executive design, as it can perform a structural analysis, architectural design, design of connection, rendering and construction management of the facility, all in the same software.

Tekla will be used for estimating the complete quantities in the structure as well as Navisworks, the results must be very similar as it refers to the same architectural design with the same material.

Tekla Executive design

For this, it was first checked the interoperability of Tekla with the other used software, such as Revit, the interoperability was not very good, so it was needed to reconfigure the original drawing to the verified architectural design.

For this it was necessary to draw the elements using the proper dimensions of each element.

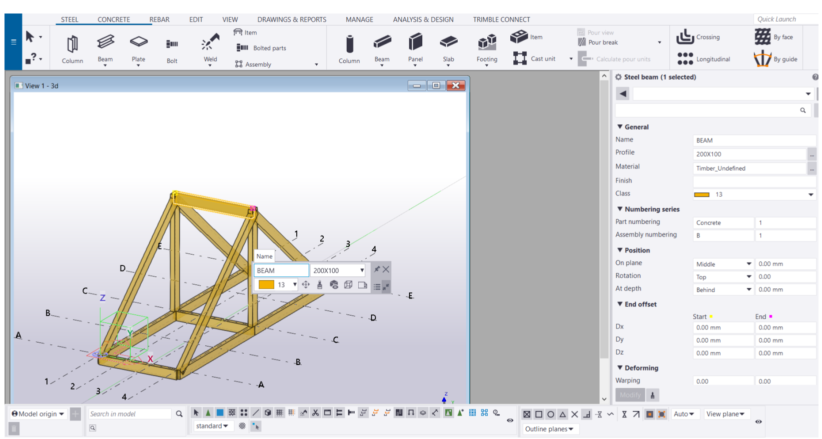


Figure 72: Construction of the architectural design, Tekla view.

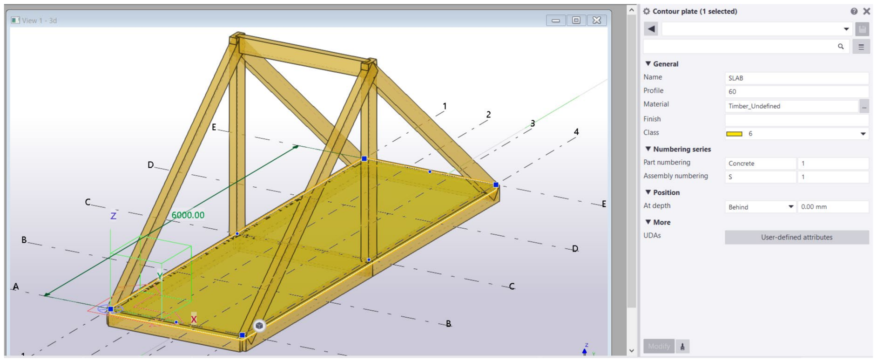


Figure 73: Superstructure (Piedicavallo bridge) using Tekla

All the elements were redrawn with the proper dimensions and materials, including the concrete foundations.

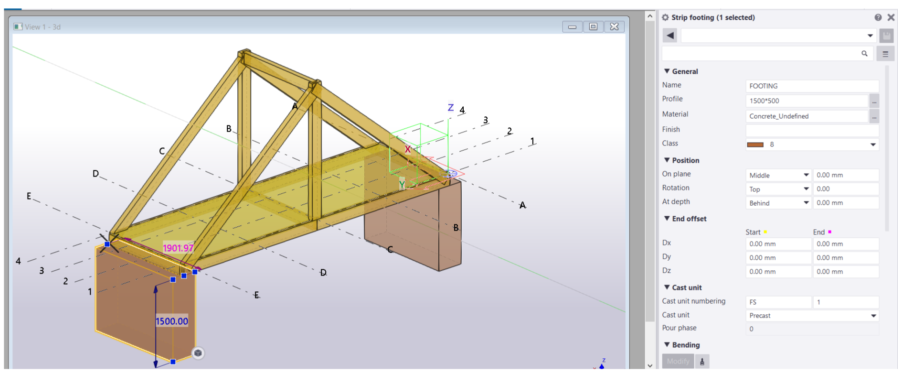


Figure 74: Piedicavallo bridge partial design using Tekla

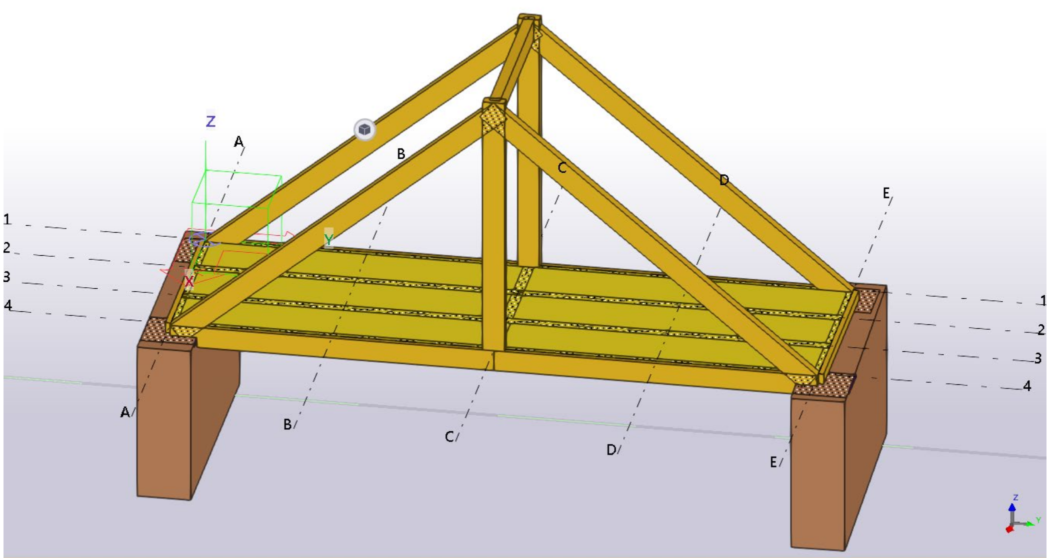


Figure 75: Final Executive architectural design, including joint assembly with foundation

After having now completed the Executive design in Tekla and Navisworks, in both software it was performed a quantities takeoff. The quantities obtained were the same as the design is the same.

In the case of Navisworks, it was used an exported connection from the Advance steel file, which they have a very good interoperability, and with this model exported the quantities could be extracted using metric units.

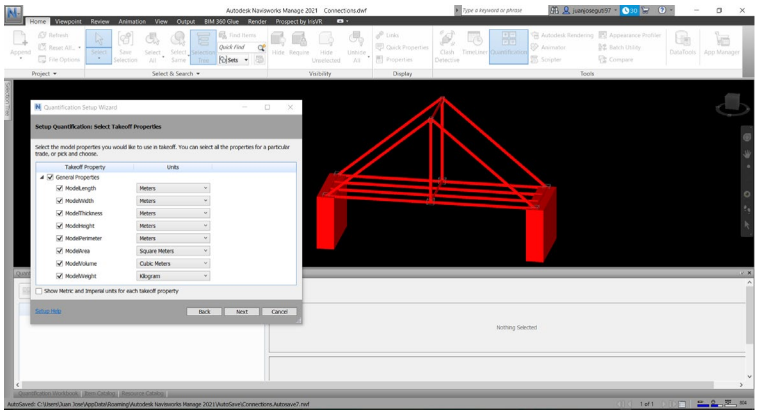


Figure 76: Project quantification - Using Navisworks

After having the proper metric configuration, as they are considered in the unitary prices obtained, it could be performed a model takeoff for each element.

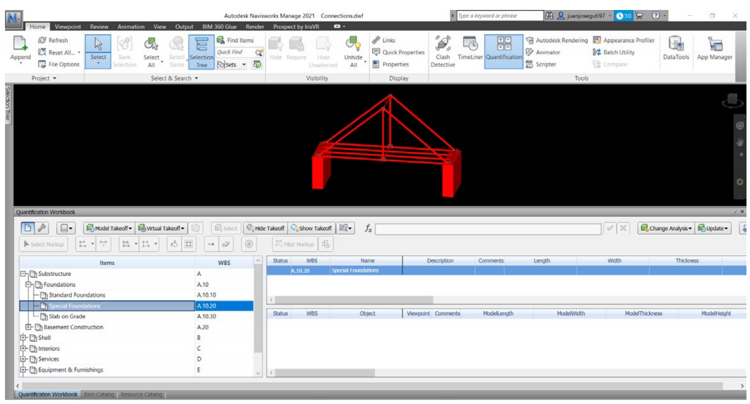


Figure 77: Model takeoff - Using Navisworks

After having exported the quantities to Excel, and doing some corrections in this information, it was performed the cost analysis of the bridge, using Excel. As it was expected the results obtained are the same as the ones obtained using Edificius/Primus, as we are referring to the exact same quantities.

The results obtained summarized for each voice price were:

Voice	Description	Unit of measure	Quantity	Unitary price	Total cost
A25137	Tranportation of the excavated soil material (Sand) - Transport to a deposit close to site.	m3	1.14	€ 74.44	€ 84.86
A33049	Pre-mixed structural lightweight concrete based on structural expanded clay, natural aggregates, Portland cement, polymeric fibers and additives - elastic modulus 25.000 Mpa. - In bags	m3	1.14	€ 357.00	€ 406.98
A25001	Excavation up to a maximum depth of 1.50 m.	m3	1.14	€ 88.42	€ 100.80
C35007a	Prefabricated structure in laminated wood, in compliance with current legislation. Glued with synthetic resin-based products and impregnated, planed visible structures; including joints, metal attachments and hardware necessary to give the structure in place. For composite structure (trusses)	m3	1.02	€ 2,133.40	€ 2,176.07
C35008b	Liquid pesticide applied for the prevention and conservation of wooden structures	m2	43.14	€ 20.34	€ 877.47
C35009	Solid wax layer dissolved with suitable thinners and applied with a cloth	m2	43.14	€ 14.62	€ 630.71
C35010	Walnut mordant diluted with boiled linseed oil applied by brush with two coats on exposed wood	m2	43.14	€ 13.55	€ 584.55
C35094a	Cros - lam slab: Thickness of 60 mm. All costs of transportation and handling in construction site are included.	m2	11.78	€ 75.83	€ 893.28
C15019d	The fence for safety of users of the bridge - Includes the construction and all the bolts for construction.	Kg	45.08	€ 8.53	€ 384.53
C35143b	Suport joint in stainless steel - Including connection to the wood - Excluding anchors and bolts that connect to foundation.	Unit	4	€ 37.99	€ 151.96
C35175m	Smooth, calibrated and ground pin - Connection with support and foundation. 4 units per each connection.	Unit	16	€ 4.89	€ 78.24
01.P01.A20.005	Qualificated worker	Hours	104	€ 34.21	€ 3,557.84
01.P01.A10.005	Specialized worker	Hours	32	€ 36.91	€ 1,181.12
18.P08.A05.005	Transportation for the prefabricated superstructure of Glulam bridge - Includes the loading and unloading. For a working operation (Hook transport) up to 600 Kg. - The weight of Piedicavallo bridge is of 492 Kg. For the Piemonte region	Minutes	400	€ 20.67	€ 8,268.00
	Total Construction Piedicavallo bridge				**€ 19,376.40**

Table 5: Summary costing Piedicavallo bridge

Each of the presented voices costs are presented with better detail in the local language in Annexes 1 documents, as they are obtained from a local prizing list "prezzario".

Quantities and schedules were extracted from the model environment. Including the correct data, attributes, and classifications. Automated quantities takeoff from the model provides quantities and schedules.

Takeoff as an analogue process is laborious and long – winded. The exchange of digital information with suppliers, manufacturers and subcontractors will improve the quality and accuracy of the procurement. (Fontana, 2016)

7. Time analysis (4D)

For this 4D, management of the time analysis it will be used a timetable, in which it will be possible to manage the project times of realization related to the workloads, in both the preliminary phase and in the detailed one. This includes the execution of the individual processes, that requires the definition of an appropriate project planning system.

After is performed the cost estimation, the main phases for the development of the scheduling model are:

- 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.

The performance for developing an activity by the human resources using the physical resources, will be used to estimate the proper times for each activity. These performances rates have been taken from literature in surveys at site and experience.

"*Construction means all human actions, including those undertaken with the help of or solely by plant and equipment, intended to produce or alter facilities*" (Radosavljevic & Bennett, 2012).

The construction project is defined as a set of essential actions to produce a new facility, which has a start date and an end date. Every project must organize construction programs. A construction program is a series of construction projects, which have sufficient characteristics in common to justify treating them as an integrated whole.

Usually in projects it is normal that the customers organize their demands based in construction programs. Also, the construction is arranged based in this construction programs. Construction management purpose is of identifying, developing, and exploiting these opportunities to improve efficiency.

Each construction project has several teams working on the activity needed. This teams tend to coordinate efforts of individual for performing a proposed activity. For the description of this procedure, in the construction of the bridge, this teams (Human resources), needed for the activities will be differenced as if the work performed is part of a subcontractor or is a resource consider for any assembly that must be done out of the subcontractors' terms. For these activities is essential to have qualified individual and a proper supervisor.

"*4D is a planning process to link the construction activities represented in time schedules with 3D models to develop a real-time graphical simulation of construction progress against time. Adding the 4th dimension 'Time' offers an opportunity to evaluate the* *buildability and workflow planning of a project. Project participants can effectively visualize, analyze, and communicate problems regarding sequential, spatial, and temporal aspects of construction progress. Consequently, much more robust schedules, and site layout and logistic plans can be generated to improve productivity."* (Kameedan, 2010, p. 285) (Smith, 2007)

In this chapter, it will be done a complete description in how the works are going to take place in the site, and then the description of the complete program for the construction management using Microsoft Project.

For the Microsoft project estimation of prices and costs, it must be considered the WBS (Work breakdown structure), in which we divide a complete work (Construction of a 6 m bridge), into a group of specific activities that must be done to complete this final goal. This division of works into certain activities that must be performed is an essential part of a construction manager work, as he must also organize the schedule these activities will take place during the construction and the resources needed for this activities to be done.

7.1. Detail explanation on how the works will be done

For the construction of this small bridge, there are two main parts of the bridge, first the substructure, which is the foundations made of concrete and the superstructure, which is the prefabricated bridge made of glued laminated wood.

The total works will be performed in a very short period and having a total cost of the bridge around 19.407 € (This price will obviously vary depending on the actual deals that are done with the subcontractors' teams that will perform the activities).

The superstructure of the bridge will be fully prefabricated, including all the trusses proper connections the superstructure has from the design. This will make a collaborative job, as the design will be passed in advance to the subcontractor, that will oversee the construction and transportation of the bridge. The step by step of the bridge will be done in the following way:

1) The design of the superstructure of the bridge will be passed to a manufacturer company in charge of the construction of prefabricated bridges. To all the considered companies will be sent a formal request of cost and this result will make part of the final evaluation for selecting this subcontractor.
   The companies due to the geographic location that have been considered for this are:
   - Grosso LegnoArchitetture Srl. – Venezia

Figure 78: Venezia Ponte della Academia (Grosso Srl, s.f.)

Good experience in the construction of wooden bridges. Good reputation.
Experience with wooden prefabricated constructions and using CAD and BIM.
Located in the north of Italy: Venezia
Certifications: https://www.grossolegno.it/en/about/certifications/
Taken from: (Grosso Srl, s.f.).
Evaluation before final formal response on real cost: 7/10

- Barbirato Srl. Carisio, Vercelli.

Figure 79: Cantina Beni di Batasiolo a La Morra (Cn), completed in 13 days more than 900 m2 of structure in Glulam.

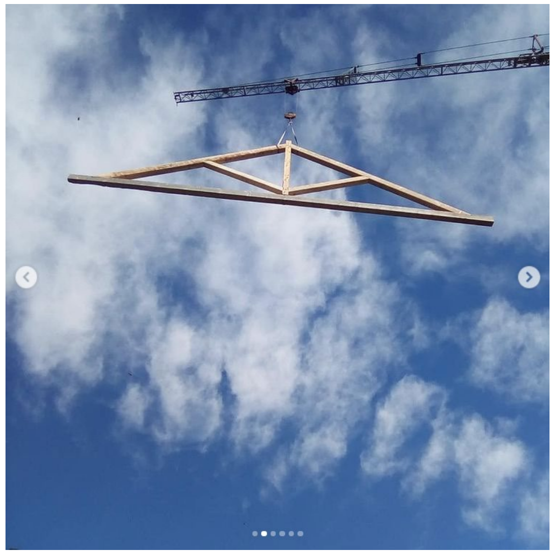


Figure 80: Church Ameno Novara de San Rocco assembling of all trusses and construction with altitude.

Good experience with all types of wooden structures, especially with Glued laminated timber and cross – laminated timber, which are both needed in superstructure. Good reputation.
Experienced working at high altitudes and use of helicopters for remote places.
Located in Vercelli, very close to the construction site in Piedicavallo, Biella.
Taken from: (Barbirato Srl, s.f.)
Evaluation without final formal response on real cost: 9/10

- Baschild drying technology: Bergamo.
  Big company. Good reputation. Experience with all types of wooden structures.
  Location: Bergamo, Lombardia – Northern Italy, not very far to construction site.
  Taken from: (BASCHILD, s.f.)
  Evaluation without final formal response on real cost: 6/10

For the construction and design of the prefabricated superstructure, the most probable company to be selected before the formal cost response will be Barbirato Srl, as the location is optimal, for arriving to the bridge and they have great experience with similar projects using the same materials. It will also consider the price, lead time and payment methods for the final evaluation. In any case the costs will not differ in a significant way to the costs already determined in the cost analysis.

After sending the designs to all the mentioned companies and selecting the best option for the prefabricated truss bridge, it will be given an advance payment in the way it was stipulated in the contract for starting the construction of the superstructure of the bridge.

It will be considered the agreed **lead construction time** that was stipulated in the contract agreement and having in consideration these times we must be ready for the next steps of transporting and assembling the bridge in site.

So, this first step is to pay the advance payment to the subcontractor that oversees the construction of the bridge superstructure. – Start of the construction of the prefabricated superstructure. Estimated time: 10 days.

2) Before the superstructure is built, at the site, we must be ready for receiving and installing the superstructure. So, 2 days before the end of the lead time of construction we will start the excavation for the wall foundation.

   This excavation will be done by hand, so it will be considered a typical performance of 1 m of depth per day (Typical working time per day 8 hours), so for the total depth of 1.5 meters, it will be required 12 hours.

   As resources for this there will be 1 person inside the excavation hole, excavating the material and one assistant lifting the extracted material in a can and transport it into a provisional deposit. In total for efficiency, it will be needed 2 per each foundation to do it simultaneously, so 4 qualified workers. Also, during the whole construction, it will be needed a specialized worker that will be in charge that the processes are as planned.

Figure 81: Wall foundation process of excavation. Taken from: (Yepes, 2016)

   Activity: Excavation of the wall foundations – 12 hours – Resources: 4 qualified workers + 1 specialized worker in site.

3) Installation of reinforcement and pouring of concrete inside the excavated foundations. For this to have a better adhesion with the connections the plate will be adhered to the concrete before curing, so when it cures the bolts are properly fixing the steel plate, that will be used for these four main external connections.

   The works performed will include the pouring of concrete inside the excavated foundation wall. For this volume it is considered a performance of 1 m depth per hour, which is a conservative measure, so both foundation walls pouring will be done in 3 hours. All this activity will last for 12 hours, as it must also be included the proper location of the plates joints for sustaining the superstructure, the minimum reinforcement, and the proper formwork to pour the concrete inside the excavation. This may not be removed.

Figure 82: Pouring of concrete, Taken from: (Alfano, 2020)

The resources used will be the same 4 qualified workers, two per foundation wall and one specialized worker, that will make sure the correct mixing of materials for the concrete pouring and the in-situ tests.

4) Transportation of prefabricated superstructure, due to the difficult access conditions the best proposed solution is to transport the complete bridge using a helicopter. The prices for the time of the helicopter are given by the average price per minute of renting a helicopter in the region of Piemonte.

   The Vercelli subcontractor which is best evaluated before the formal contract has experience in transportation of trusses using helicopters, so this is an advantage.

   The helicopter that will be needed conditions are already considered in the specifications of the helicopter. This includes the weight of the bridge, which in this case we refer to a relatively light structural material (Glulam), which is 492 Kg. Is essential to have experienced subcontractors as the transportation must be done in a proper way to avoid any damage in the structure that is being transported.

   In the transportation of the bridge, it will also be included the 60 mm cross laminated slab that will be connected in top of the beams of the bridge and will be assembled by the same subcontractor before transportation.

Figure 83: Aereal transportation of bridge. Location: Scotland; Contractor: CTS bridges. Taken from: (CTS bridges limited, s.f.)

Figure 84: FRP bridge, Eastburn reservoir, Stirling - 13.5m x 1.2m; Taken from: (CTS bridges limited, s.f.)

For the transportation, the helicopter will pick up the assembled prefabricated superstructure, by well tidying the bridge distributing the loads in the center of gravity in a proper way, to avoid rotations or excessive moving during transportation, for this is important to have experienced subcontractors performing this job. The cost of transportation in helicopter at this weight is of around 20 € per minute, so as this activity is expensive, time is gold, so it must be a very good coordination and preparation in the manufacturer site and the construction site to send and receive the structure.

This price includes the loading and unloading of the bridge as well as the transportation, for the project even knowing that Vercelli is close to Biella, it was selected 3 hours of aerial transportation in the cost analysis.

The bridge will be transported from the manufacturer and received in the site by the same workers that worked in the excavation and the pouring of concrete for the wall foundation, there will be the same specialized worker in charge of the proper operation. The prefabricated bridge will descent slowly and will be received by these workers in site. They will adjust the bridge to put it in the proper place where it is located the joint plates that will connect the bridge. For this it is needed specially a well-qualified operator in the helicopter and the proper direction of the specialized worker.

After this we have now the prefabricated bridge (superstructure) connected to the substructure (Foundation walls) by means of the 4 connections.

5) Now we have the bridge almost finished, but it must be necessary to adjust some safety details, such as the fence at the sides of the bridges. For this, just after finishing the construction of the bridge, it will be developed a fence at the sides of the bridge for the operation of the pedestrian bridge to avoid accidents of the users.

   For this, depending on the subcontractor (manufacturer), it will also be evaluated the option of the construction of these fences in both sides of the bridge during the prefabrication of the bridge, to avoid bringing qualified workers to site.
   If not, these steel materials will be transported in the same helicopter that transported the bridge to site and installed after the installation of the bridge.

   This option of having the bridge with the steel fence before the transportation is viable as it will increase the weight in 50 Kg, which will make a total weight of 542 Kg, which is still below to 600 Kg, which is the maximum weight for this transportation fee.
   The possibility of being able to perform the steel fence in the prefabrication fence, will also affect the evaluation of the prefabricated bridge subcontractor.

Figure 85: Steel fence proposed for bridge design; taken from: (Sicom, 2017)

Both programs' schedules will be performed, but the total analysis having the subcontractor to develop the steel fence in factory will be preferred for the final analyses.

7.2. Program scheduling using Microsoft project

Microsoft project is a pure project management software which permit the user to organize each project as a group of activities that must be completed to reach a final goal of completing a desired project, in this case a construction project.

For the completion of the project, this program is useful as it permit us to breakdown the work into a group of activities/tasks that must be completed, in order to have a better control of the project work and advancement as well as a better estimation of the real times of construction, not seeing the whole project as a total but determining the advancement as the completion of a group of activities, based on this estimate the real time for the project conclusion.

This work organization will be very useful for determining the critic route and which activities, are the ones that could affect the most the real delays in the project and that will affect the most the total budget, to pay special attention to these tasks.

As a construction manager, using this program for long construction will be useful to determine the time space for the entrance of cash for developing the construction during the projected times without risking a defund in the project. In this case the flux of cash will be minimum as it is required only a total budget of 19.407 €, but it is essential to have the advance payment and the final payment in time as agreed in the contract agreement with subcontractors.

Each project has a beginning point, after this for each activity it will be estimated a finalization time based on typical performances, in each activity it will be included in the software the resources used (Human or physical) for completing in time this activity.

"*BIM is largely associated with product design model, while construction – specific work breakdown structure (WBS), or work package information, is not sufficiently represented or readily available in the BIM system for BIM – based activity – level construction scheduling*" (Liu, Al-Hussein, & Lu, 2015). Knowing this for this project the work breakdown structure will be performed using Microsoft Project and will contain a series of activities that will entirely hold the final construction of the bridge.

For developing the Microsoft project with the activities performed, it was estimated the duration of each activity, considering that each day has 8 working hours and that in a week it will make a total of 40 hours as there are 5 working days. Adjusting this will make clear the time schedule avoiding having delays or to pay hours extra to the workers.

A functionality of Microsoft project that must be performed in a proper way for the construction management of the project is the allocation of resources. Either human or physical resources in each activity for its execution.

So, it is performed a list of resources that are costed in the project. All this for a better control during the execution of the project.

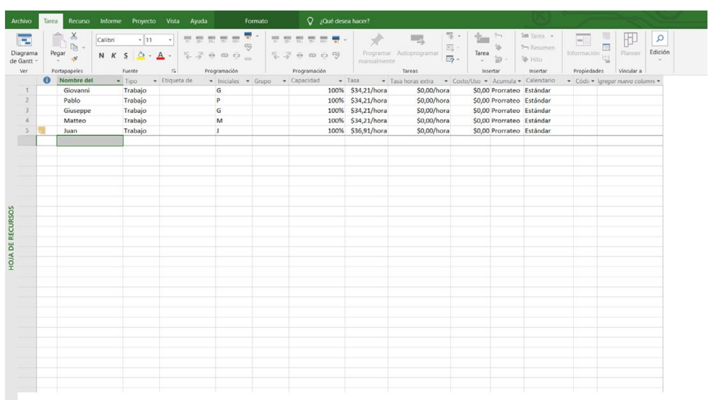


Figure 86: Process of developing - List of resources - Microsoft Project

For each resource it could be added some information about the type of worker, contact and charge per unit hour. This is important for the planning to determine as so the total cost, as it was done during the costing, and in the execution of works for having information about the worker and the works he will execute during the construction process. We must certainly know which resources (Human or physical) are being used for which activities.

It was also identified 4 main activities that could hold all the activities developed in the project.

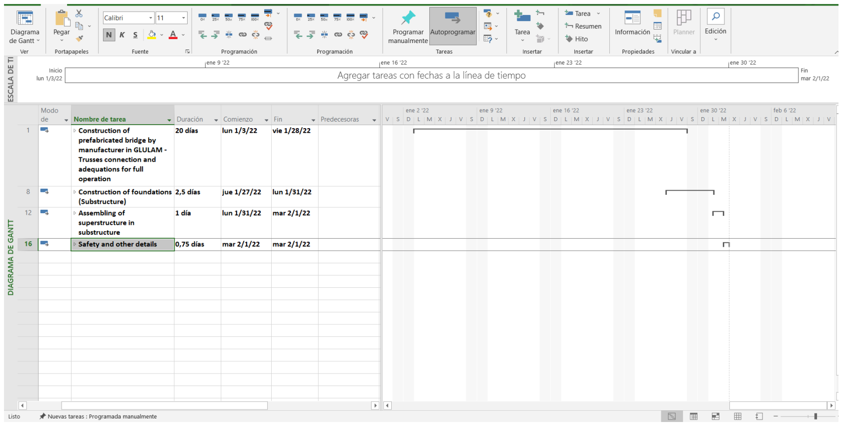


Figure 87: Main activities - Gantt and cost analyses

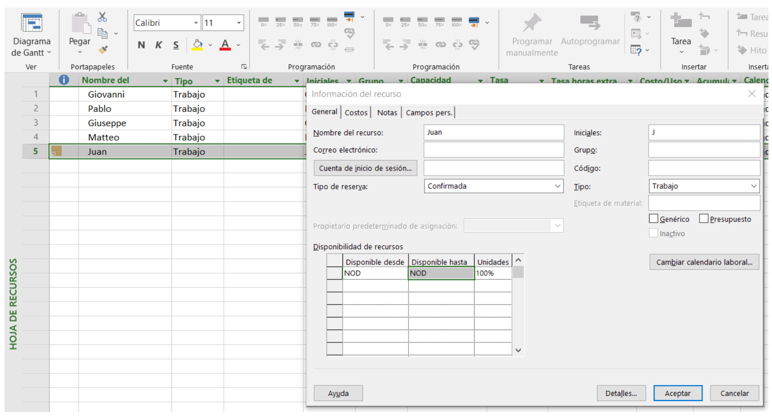


Figure 88: Relevant information about each resource - Microsoft Project

In the project program, there are also identified the two classical milestones that any project must have to know that it has a beginning and end. The start milestone and the end milestone.

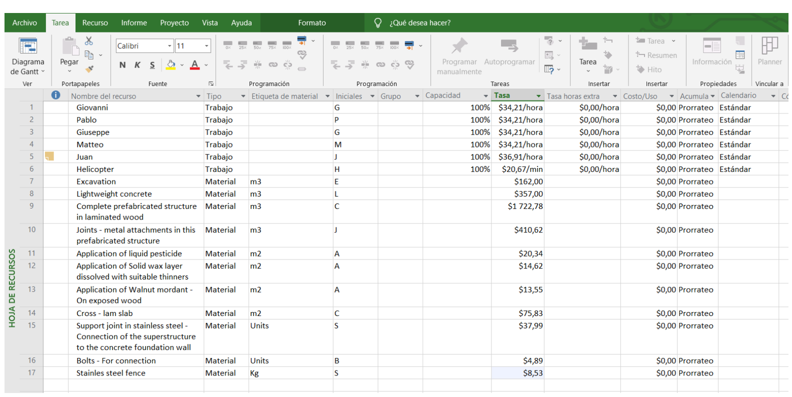


Figure 89: List of resources - Microsoft Project

Now we have completed the list of resources, this list includes as work the cost per unit of time in the schedule, which is usually the workers time, but in this case, it is also the helicopter which the total price depends in the working time.

For the materials it is considered the cost per unit of measure that is agreed for the material or for the work per unit measure with the subcontractor. In each activity, it will be inserted the actual quantities needed for the activity.

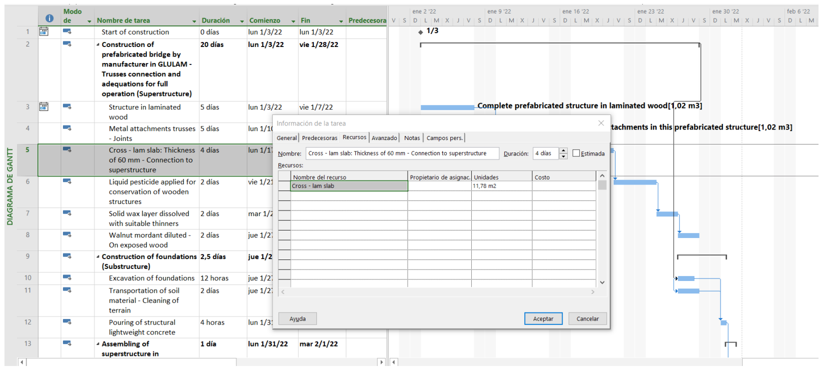


Figure 90: Materials quantities needed for each activity

After considering all the durations of the individual activities, identifying the dependencies between the various activities, and allocating the resources for the execution of each individual activity/task, we can proceed in doing some planning analyses.

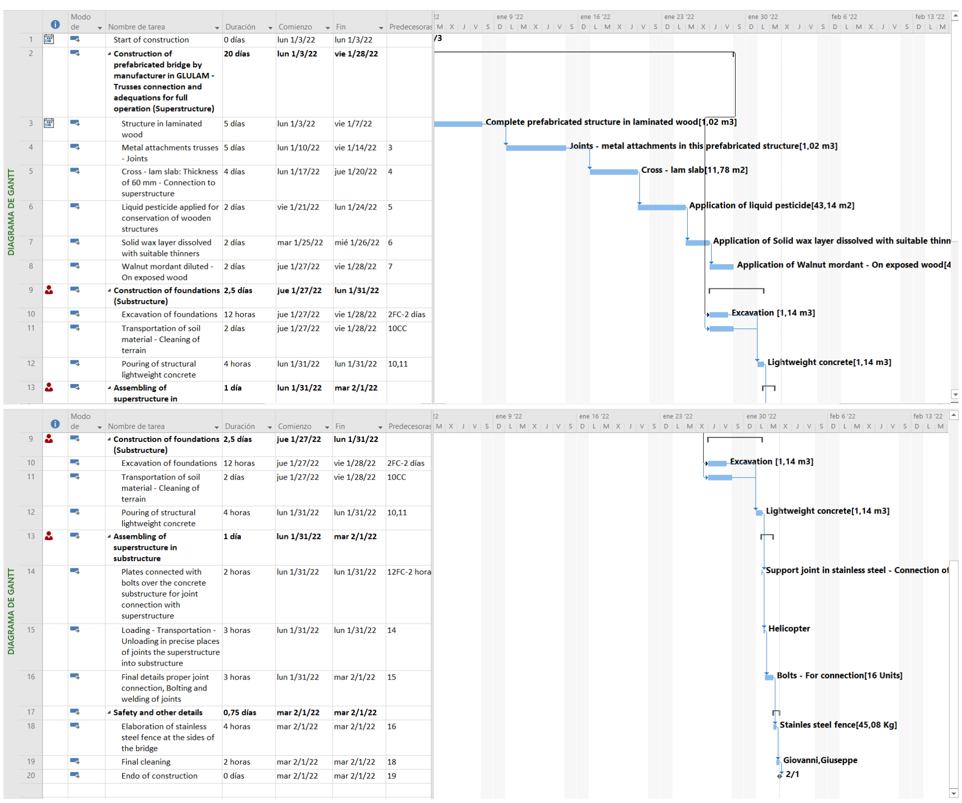


Figure 91: Gantt diagram

7.3. Construction management planning results

After performing the Gantt diagram, allocating to each activity the proper dependencies, resources, and duration, it could be developed some interesting analyses for a better planning of the construction.

Is important to mention that the final total cost will slightly vary with respect to the past cost estimation, as it was added an additional cleaning activity at the end of the construction, and for a more precise construction an increase in the total hours of "Juan", the specialized worker, that will supervise all the activities performed in site.

The duration of the project is of 22 working days, but the duration of the works in site are only of 4 days, in case of having the fence installed in the factory during the prefabrication of the bridge these working days in site will get reduced to 3 days, as well as the total cost that will be decreased.

- Time of construction: 22 days.
- Time of construction in facility: 3 – 4 days.

For the project it is considered to start in the beginning of 2022, in the first working day that will be the 3 of January (Monday), in which the technical offer to the prefabricated bridge subcontractor will be accepted, and we will proceed with an advanced payment, they will start the manufacturing of the prefabricated bridge, giving them a lead time of 20 working days, as it is specified in the contract.

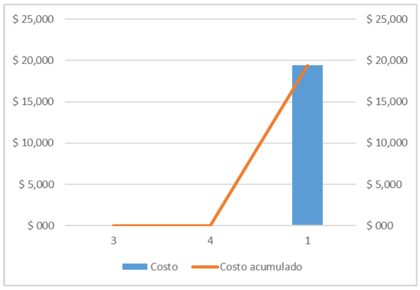
The works in site facility will be developed will start 27 – 28 of January (Thursday and Friday), that it will be performed the excavation and adjustment of terrain before pouring the concrete to create substructure. Then 31 of January (Monday), the lightweight concrete will be poured, as well as the joint – plate connections that will connect the substructure to superstructure will be in place, the bridge will be transported from manufacturer to site, and these external joints will be revised and completed successfully.

This day will be a crucial day, as any important delay will become an important increase in the total costs of the project.

Cashflow

FLUJO DE CAJA

Costo real	Costo de línea base	Costo restante	Variación de costo
$0,00	$0,00	$19 406,57	$19 406,57



El gráfico muestra el costo acumulado del proyecto y el costo por trimestre.
Para ver los costos de un período de tiempo diferente, selecciona la opción Editar en la lista de campos.

La siguiente tabla muestra información sobre los costos para todas las tareas de nivel superior.
Para ver estadísticas del costo de todas las tareas, establece el nivel de esquema en la lista de campos.

Nombre	Costo restante	Costo real	Costo	CRTR	CPTR	CPTP
Start of construction	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00
Construction of prefabricated bridge by manufacturer in GLULAM - Trusses connection and adequations for full operation (Superstructure)	$5 546,60	$0,00	$5 546,60	$0,00	$0,00	$0,00
Construction of foundations (Substructure)	$4 066,66	$0,00	$4 066,66	$0,00	$0,00	$0,00
Assembling of superstructure in substructure	$9 582,65	$0,00	$9 582,65	$0,00	$0,00	$0,00
Other details	$210,66	$0,00	$210,66	$0,00	$0,00	$0,00
End of construction	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00

Figure 92: Cashflow report - Microsoft Project

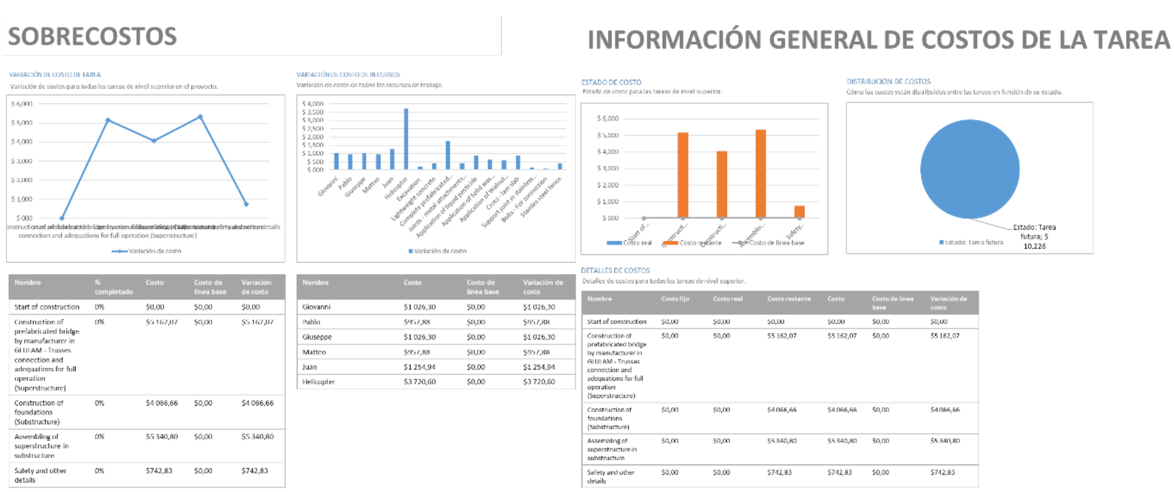
For the activities, it was referred to main activities, that each of this have different sub activities. This cost estimate was done separating all the construction in these main activities. The idea of cashflow for this project is complicated due to the duration of the same, so all the cash must be present at the instant of construction, different to long constructions, in which the construction lasts for months, so the cashflows can vary weekly or monthly.

In any case is good to understand the main titles in which the costs are divided for the resolution of the project, these are:

- Construction of prefabricated bridge by manufacturer in Glulam: This includes the prefabricated bridge with trusses steel connections as agreed in design meeting all the strength regulations, The top cross-lam slab (Thickness of 60 mm) and its assembling in superstructure and additional works to preserve the wood in time (Liquid pesticide, solid wax layer, and walnut mordant).
  + These works are not in site, but in a subcontractor's suitable location.
  + Duration: 20 working days
  + Estimated cost: 5.162 €.
- Construction of foundations substructure: Includes the excavation, cleaning, and preparation of the terrain for the pile walls designed, and the pouring of structural lightweight concrete.
  + These works are in the site facility location. Piedicavallo, Biella – Knowing the difficult access conditions.
  + Duration: 2.5 working days

+Dependencies: These activities are planned to start 2 days before the construction of the prefabricated bridge, preparing the terrain for receiving the bridge.
+ Estimated cost: 4.067 €

- Assembling of superstructure in substructure: Includes the complete connection detailing substructure – superstructure, as well as the loading, transportation and unloading of the bridge, this is by helicopter and represent the most important cost. Also, the additional transportation costs: Include the transportation in difficult conditions via helicopter of the materials and the workers from Biella to the project site.
+ These works represent the transportation of the main structure and the joining to the substructure that takes place in the site facility.
+ Duration: 1 working day.
+ Dependencies: The external connections will be done simultaneously to the pouring of the structural lightweight concrete. Then after receiving the main structure in site this joint will be subjected to further works.
+ Estimated costs: 9.583 €
- Safety and other details: Include the elaboration of the stainless-steel fence at the sides of the bridge and a final cleaning of the structure before putting the structure in operation.
+ These works are in the site facility location. Piedicavallo, Biella – Knowing the difficult access conditions.
+ Duration: 1 working day.
+ Dependencies: The elaboration of the stainless-steel fence, could be done in the manufacturer's location before transportation, or could be done in site.
+ Estimated costs: 743 €



Nombre	% completado	Costo	Costo de línea base	Variación de costo
Start of construction	0%	$0,00	$0,00	$0,00
Construction of prefabricated bridge by manufacturer in GLULAM - Trusses connection and adequations for full operation (Superstructure)	0%	$5 162,07	$0,00	$5 162,07
Construction of foundations (Substructure)	0%	$4 066,66	$0,00	$4 066,66
Assembling of superstructure in substructure	0%	$5 340,80	$0,00	$5 340,80
Safety and other details	0%	$742,83	$0,00	$742,83

Nombre	Costo	Costo de línea base	Variación de costo
Giovanni	$1 026,30	$0,00	$1 026,30
Pablo	$957,88	$0,00	$957,88
Giuseppe	$1 026,30	$0,00	$1 026,30
Matteo	$957,88	$0,00	$957,88
Juan	$1 254,94	$0,00	$1 254,94
Helicopter	$3 720,60	$0,00	$3 720,60

Nombre	Costo fijo	Costo real	Costo restante	Costo	Costo de línea base	Variación de costo
Start of construction	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00
Construction of prefabricated bridge by manufacturer in GLULAM - Trusses connection and adequations for full operation (Superstructure)	$0,00	$0,00	$5 162,07	$5 162,07	$0,00	$5 162,07
Construction of foundations (Substructure)	$0,00	$0,00	$4 066,66	$4 066,66	$0,00	$4 066,66
Assembling of superstructure in substructure	$0,00	$0,00	$5 340,80	$5 340,80	$0,00	$5 340,80
Safety and other details	$0,00	$0,00	$742,83	$742,83	$0,00	$742,83

Figure 93: Distribution of costs - Microsoft Project

In this report we find an overview of the distribution of costs per each main activity. As we are in the planning phase, there is not % of advance in any activity, but this must be well managed and monitor during the execution phase of the project. In this thesis it will also include in how to effectively control and monitor this % of advancement in a proper way.

This cost analysis is very useful for us to have a quick overview in which activities, are critical and affect in a bigger amount the total cost of the project.

To the costs in Figure 93, it must be included some extra cost related to the transportation of resources different to the superstructure, that are already in the whole project, this graphs shows the cost distribution without this estimated extra cost of transportation.

Pareto Analysis

Pareto analysis is a decision – making technique for assessing competing problems and measuring the impact of fixing them. Allowing the project manager to focus on solutions that will provide the most benefit. Named after the Italian economist Vilfredo Pareto. (CFI Education, 2015)

Also known as 80/20 law, which means that the 80 percent of the costs are carried by the 20 % of the activities, this will help us focus on this materials or processes that have bigger effects in the total project.

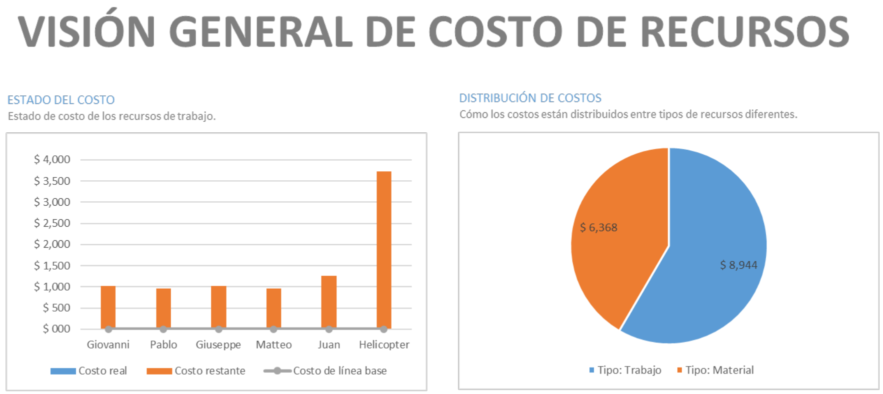
For example, usually in construction projects, in which we have a thousand of different materials, is usual that the ones that affect the most in the total cost are concrete and steel if the project is constructed using structural concrete.

In this project, it is identified 3 main sources of cost increases.

- The helicopter, used for the bridge transportation: 7.440 €
- The construction of the Glulam prefabricated structure: 5.162 €

Just these two main processes of the main structure represent a 60 % of the total cost of the project. For this reason, is very important to have a good and effective negotiation about these two materials/processes.

A good negotiation, an additional discount in these items will have big impact in the total cost of the project.



DETALLES DE COSTOS
Detalles de costos de todos los recursos de trabajo.

Nombre	Trabajo real	Costo real	Tasa estándar
Giovanni	0 horas	$0,00	$34,21/hora
Pablo	0 horas	$0,00	$34,21/hora
Giuseppe	0 horas	$0,00	$34,21/hora
Matteo	0 horas	$0,00	$34,21/hora
Juan	0 horas	$0,00	$36,91/hora
Helicopter	0 horas	$0,00	$20,67/min

Figure 94: Overview Costs of the resources - Microsoft Project

Critical path of the project

The critical path is a series of tasks/activities that controls the calculated start or finish date of a project. The tasks that make up the critical path are interrelated by time dependencies. When the last task in the critical path is completed, the project is also completed.

This critical path is the route that will drive the estimated time of start and finish of the project, this depend on the dependencies, some tasks can be done in a parallel way, but some to start an activity you need to finish another activity.

For this specific project, the main tasks we have in site, are to put in operation the prefabricated bridge, with coordinated logistics transportation and in the times planned. So, in this case the critical route literally represents all the activities of the bridge. Is important to avoid any delay in any task as it will affect all the project.

TAREAS CRÍTICAS

Una tarea es crítica si no hay espacio en la programación para que se retrase.

Conozca más acerca de cómo administrar la ruta crítica del proyecto.

Nombre	Comienzo	Fin	% completado	Trabajo restante	Nombres de los recursos
Structure in laminated wood	lun 1/3/22	vie 1/7/22	0%	0 horas	Complete prefabricated structure in laminated wood[1,02 m3]
Metal attachments trusses - Joints	lun 1/10/22	vie 1/14/22	0%	0 horas	Joints - metal attachments in this prefabricated structure[1,02 m3]
Cross - lam slab: Thickness of 60 mm - Connection to superstructure	lun 1/17/22	jue 1/20/22	0%	0 horas	Cross - lam slab[11,78 m2]
Liquid pesticide applied for conservation of wooden structures	vie 1/21/22	lun 1/24/22	0%	0 horas	Application of liquid pesticide[43,14 m2]
Solid wax layer dissolved with suitable thinners	mar 1/25/22	mié 1/26/22	0%	0 horas	Application of Solid wax layer dissolved with suitable thinners[43,14 m2]
Walnut mordant diluted - On exposed wood	jue 1/27/22	vie 1/28/22	0%	0 horas	Application of Walnut mordant - On exposed wood[43,14 m2]
Excavation of foundations	jue 1/27/22	vie 1/28/22	0%	0 horas	Excavation [1,14 m3]
Transportation of soil material - Cleaning of terrain	jue 1/27/22	vie 1/28/22	0%	0 horas	
Pouring of structural lightweight concrete	lun 1/31/22	lun 1/31/22	0%	0 horas	Lightweight concrete[1,14 m3]
Plates connected with bolts over the concrete substructure for joint connection with superstructure	lun 1/31/22	lun 1/31/22	0%	0 horas	Support joint in stainless steel - Connection of the superstructure to the concrete foundation wall[4 Units]
Loading - Transportation - Unloading in precise places of joints the superstructure into substructure	lun 1/31/22	lun 1/31/22	0%	3 horas	Helicopter
Final details proper joint connection, Bolting and welding of joints	lun 1/31/22	mar 2/1/22	0%	0 horas	Bolts - For connection[16 Units]
Elaboration of stainless steel fence at the sides of the bridge	mar 2/1/22	mar 2/1/22	0%	0 horas	Stainles steel fence[45,08 Kg]
Final cleaning	mar 2/1/22	mar 2/1/22	0%	4 horas	Giovanni,Giuseppe
Endo of construction	mar 2/1/22	mar 2/1/22	0%	0 horas	

Figure 95: Critical path tasks

There will be presented 2 different programs options, which will be preferred the second option, but this will depend in the final negotiation with the subcontractor, the only modification is the stainless-steel fence if it can be elaborated before transportation (Case 2) and not in site (Case 1). The cost analyses are developed using Case 1 but is a positive option that could reduce costs of construction in case of a good negotiation with subcontractors.

Case 1

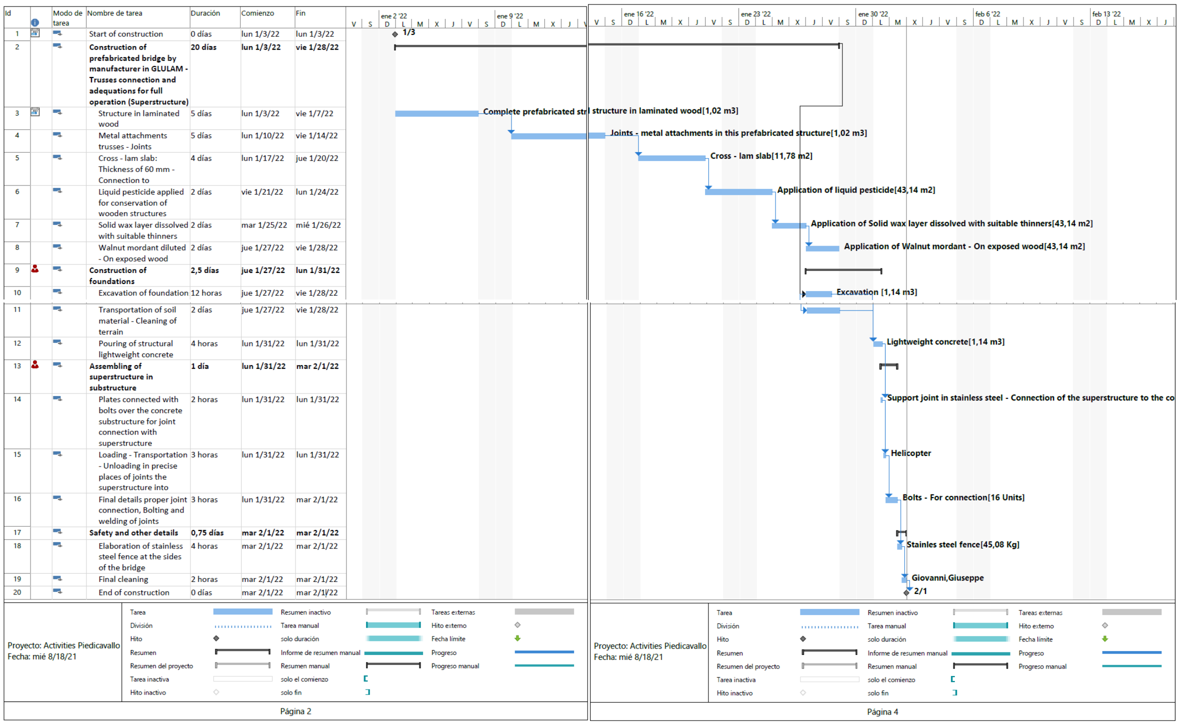


Figure 96: Case 1; Gantt diagram

This Gantt diagram report exported from Microsoft Project, will be presented as Annexes 2.

This program plan could suffer some modifications depending in the negotiations obtained with suppliers, specifically the subcontractor that oversees the manufacturing of the prefabricated bridge.

Case 2

COSTO

19 406,57 €

Nombre	Costo real	Costo restante	Costo de línea base	Costo	Variación de costo
Start of construction	$0,00	$0,00	$0,00	$0,00	$0,00
Construction of prefabricated bridge by manufacturer in GLULAM - Trusses connection and adequations for full operation (Superstructure)	$0,00	$5 546,60	$0,00	$5 546,60	$5 546,60
Construction of foundations (Substructure)	$0,00	$4 066,66	$0,00	$4 066,66	$4 066,66
Assembling of superstructure in substructure	$0,00	$9 582,65	$0,00	$9 582,65	$9 582,65
Other details	$0,00	$210,66	$0,00	$210,66	$210,66
End of construction	$0,00	$0,00	$0,00	$0,00	$0,00

Figure 97: Costs case 2

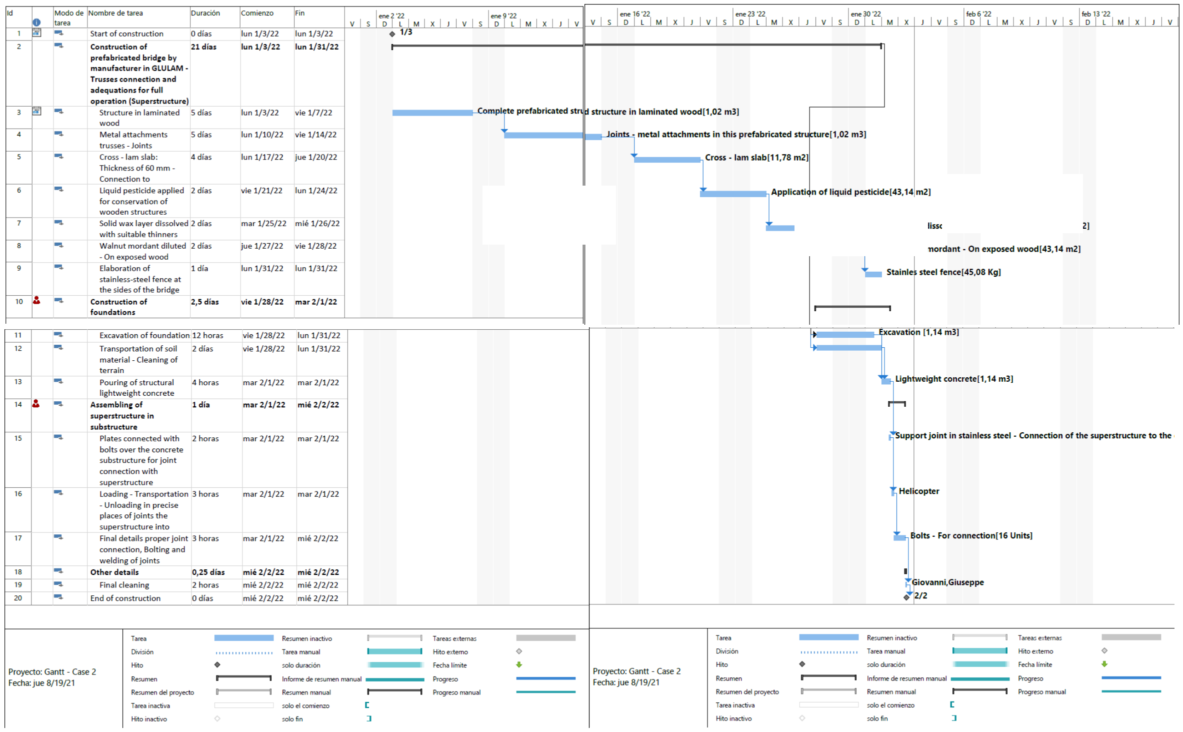


Figure 98: Case 2 – Gantt diagram

For this new analyzed case, which will be preferred in the event of a direct comparison, costs are reduced in around a 1 %, but this could become in a bigger discount if there is a good negotiation for the installation of this stainless-steel fence.

The times of construction in site are also reduced in a matter of certain hours, which the decrease in the total cost is due that if the fence is constructed in factory, it will not be needed the specialized worker time at site during this installation.

In any case the principal analyses will be performed using case 1, but it could be considered a case 2 scenario, in case it could bring a better negotiation with subcontractor, and the time in site is reduced, but case 1 is a typical construction scenario that has been analyzed.

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.

Applying the 4D BIM methodology in this specific work case started with the correct software search to guarantee the interoperability and coordination between the work done, as it we were prompted to use Autodesk software in the other designs, the more logical way to proceed was to use as main software Autodesk Navisworks. In any case for the program itself it was used mainly Microsoft Project, but for the simulation of the execution it was also used Navisworks Manage in the Execution chapter.

For the cost analysis it must be added additional cost values that will consider the transportation of the initial material (Concrete and workers tools) and the transportation of the workers to the site in the days of work. All this will add an additional cost related to the helicopter hours.

So, it will be added 3 extra hours of helicopter, that will consider all this transportations during the 3 days of construction, adding up this extra cost to the project the total cost of the project will be:

18.P08.A05.005	Transportation for the prefabricated superstructure of Glulam bridge - Includes the loading and unloading. For a working operation (Hook transport) up to 600 Kg. - The weight of Piedicavallo bridge is of 492 Kg. For the Piemonte region	Minutes	180	€ 20.67	€ 3,720.60

Figure 99: Cost voice - Piemonte list of prices, Cost of helicopter per time

Total cost: 19,406.57€.

For the final cost analysis, the considered prices from the list of prices, which considers the average prices of each unit of work or material considered are for normal conditions, now a days with the covid situation the prices are increasing in an impressively fast way, in a way that some of these costs could even duplicate.

8. Tracking/Controlling advancement of the project.

During any construction is imperative to monitor that the activities that were planned during the design phase will take proper action during the execution phase, this activity is also part of the construction management job.

For this particular construction all the tasks and percentage of advancement will be proposed to be done using Tekla, which is an Executive design software, but is also good for modeling the solution and showing a model of the percentage of advancement in each phase, and the actual phase of the project.

As it was mentioned Tekla is a software that could be used for the complete executive design, this software is able to do the structural analysis of the loads in the structure, the architectural design, the design of the proper connections and the project management of the project, organizing the proper timetable for the activities that must be performed and the proper controlling of the activities performed and that must be performed for the completion of the project.

This proper control for this project will be done using Microsoft Project, also the control and the planning timetable, this is the best software for this as this is a pure project management software that is able to deal with the timetables, resources, activities that are completed, and the percentage of completion on each activity.

For this specific project this controlling is crucial to be done during the time of construction, to be aware of any possible delay and to manage the construction in the best possible way. Especially in this project as it is a short term, as all the superstructure is already prefabricated, but there must be careful control the resources are in place for these days, a proper transportation, and a good assembling for connecting the concrete substructure to the glulam superstructure.

The facility, which is the place that will be modified, where the constructions will take place needs to be efficiently managed during and after the construction.

Now we will focus on a different phase, which is the Execution phase, for this is essential to monitor that the construction is going as planned.

8.1. Execution of the construction project using Tekla Structures

To track the advancement of a project, is important that the constructor manager is in constant retrofitting about the actual performance of the activities in site.

In constant revision that the actual works performed in the structure, that they must fit the programmed activities, that the times are being respected to avoid and forecast possible delays, that the quality of the works correspond to the quality agreed in design. The construction manager must be in constant retrofitting about the advancement of the activities.

In this case the project in site lasts for few days, so is essential that he is in site or at least has a specialized worker that can replace him for a well understanding for all the stakeholders on the activities that will be performed.

For this Execution control, it will be used Tekla Structures, which is a software that more than planning the construction, also aids in the execution of the activities that will be developed. For these activities, we will have a record in real time of the percentage of advantage in any activity and the delays and promptness of the project.

For this specific project is quite difficult compared to other project in which you have activities that last weeks, so you can weekly modify the percentage of advancement. For this project as the activities in site are of a matter of hours, there must be a well previous coordination with workers in understanding the activities each one needs to perform as a team and when.

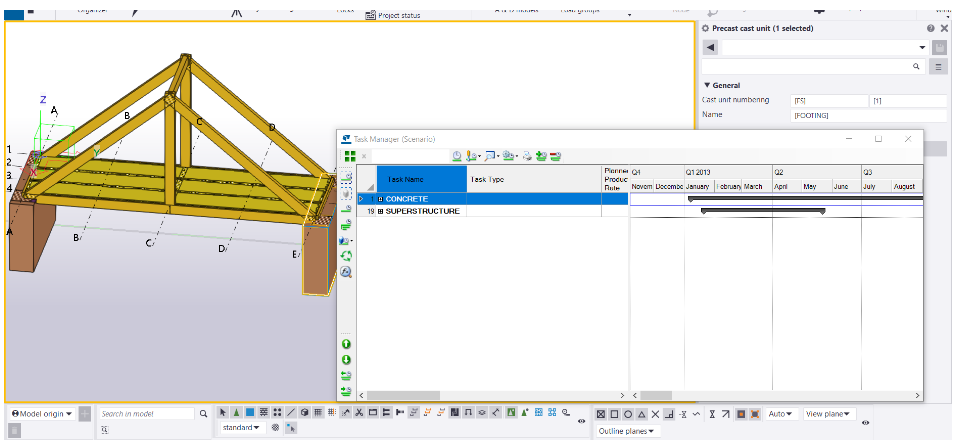


Figure 100: Program of activities - Using Tekla Structures

This tool will permit us a complete executive design, from the structural analysis to all the construction management, such as the Gantt diagrams and costing tools.

In this last drawing the bridge structure is divided in two main parts, the substructure, and the superstructure. Both have a time schedule that will relate each activity, during the construction/execution phase, the difference is that in addition to the cost view of the activities, it could be seen graphically the real progress of the project.

So, the task manager is like the one presented in Microsoft Project, except for having not only the written observation of the costs related but also the actual visual representation of the project, considering the finished tasks and the advancements.

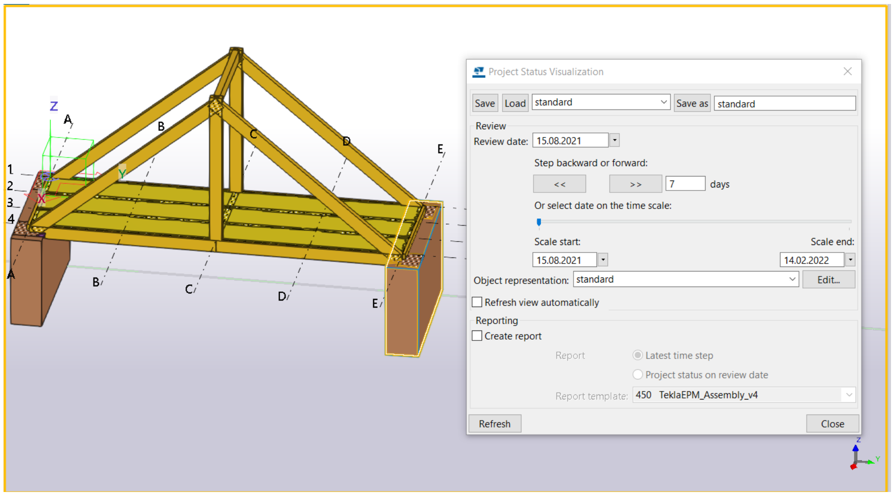


Figure 101: Project Status - Using Tekla Structures

For each activity during the execution phase, it will be inserted a percentage of advancement, based in experience in this activity, also this percentage could be requested to the subcontractor during the development of the project, for us to have a complete control of the project times.

As it was mentioned Tekla is a very complete construction software, for a complete executive design, this software also permits us the visualization of the real time changes during the construction. Is useful to have in mind this tool for the execution of the project, as it will complement Microsoft Project tracking as it gives a graphic visualization of the activities completed in the actual aspect of the facility.

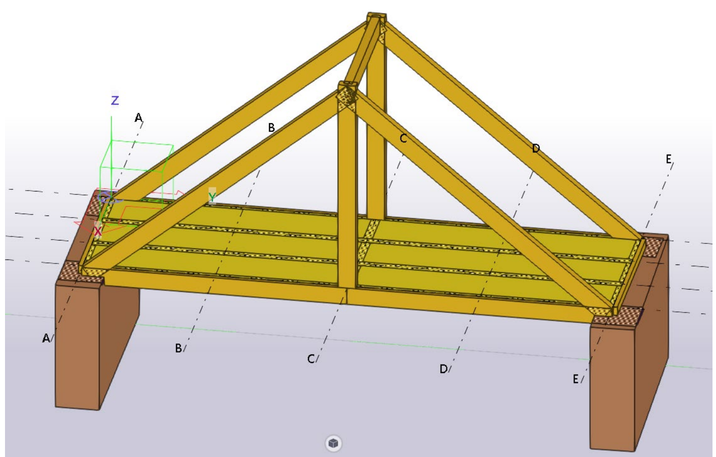


Figure 102: Facility aspect after 100% of advancement - Using Tekla Structures

8.2. Execution phase – Using Microsoft Project

Microsoft Project is a pure project management software, which is widely used not only for the planning phase, but also for the execution phase.

For this Execution phase, Microsoft Project software is better than Tekla, as it is a typical project management software for projects of any nature, so it will be preferred for the tracking of costs and execution of the program over Tekla Structures, the advantage Tekla has for a construction project, is that Tekla is able to model the construction in a graphical way, so it could be observed the process of construction in time and the real time advancement.

For any other tracking, such as costs and resources, all the changes will be performed in Microsoft Project which will give us a result based on the real prices, real quantities and real resources used.

The success of a project is based in how well these estimations are done, and to avoid extra costs during the execution phase.

This variability can become for a project to be unsuccessful and could risk the future finances of the company, for this reason is usually performed a proper feasibility analysis and is suggested, as it was worked during this project, to use BIM methodology software, as it could calculate the quantities in a software – based way, as well as multiple adjustments due to unsuccessful designs looking for the best option. In this way quantities and results are precise, as well to the actual prices as we could anticipate to these needs for the best options.

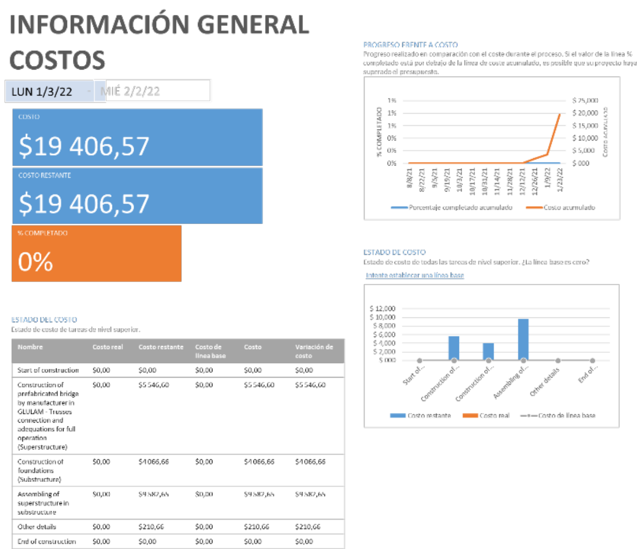


Figure 103: Cost tracking during the Execution phase of a project - Using Microsoft Project.

During the execution of the project, like Tekla Structures, for each activity it will be inserted a percentage of advancement, this will permit us contrast the toral budget with the actual real cost during the construction phase, in real time. Some unitary prices could change.

In normal condition the price after including the 3 extra hours for the transportation of materials, workers tools and workers will be in 19,406.57 €.

For this it must also be considered that the list of average prices used for the region, where the project is located, is quite precise for costs estimations, but after covid situation the prices in the construction cases have increased in a tremendous way, even sometimes duplicating compared to the normal conditions prices.

8.3. Simulation Execution phase – Using Navisworks

Navisworks is a powerful construction management software, it permits us perform a good rendering, an appropriate quantification of the takeoff material, a timeline schedule of the performed activities in the chronological space (Run this simulation of events either in the real conditions or in the planned conditions) and a clash detection in case of a big project we are dealing with MEP and structural components, forecast before construction this clash detection.

In this project, this software was used for the quantification of the material takeoff during the cost analysis, now it will be also used for the simulation of the Execution phase, this simulation will permit us to have a graphic understanding of the chronological activities that will take place before the bridge construction.

During construction, it will be used performing several contrast scenarios in which it could be present a delay or a promptness respect the design program. This simulation will permit us retrofit in the software the planned starting day of the activity and the actual starting day of each activity and constantly retrofit this information during the execution phase, running in this way real scenarios of construction.

Process of working using Navisworks Manage:

First, the final design with Advance steel, after the final details and connections is performed, then we pass this model into Navisworks, which derive in a very good interoperability connection.

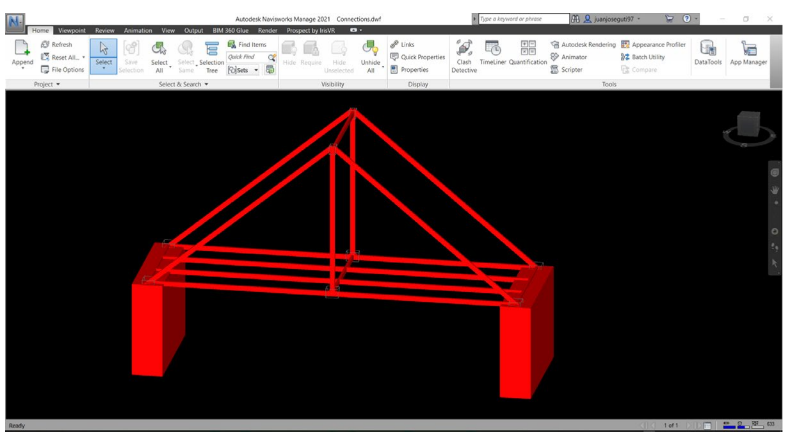


Figure 104: Model exported from Advanced steel to Navisworks

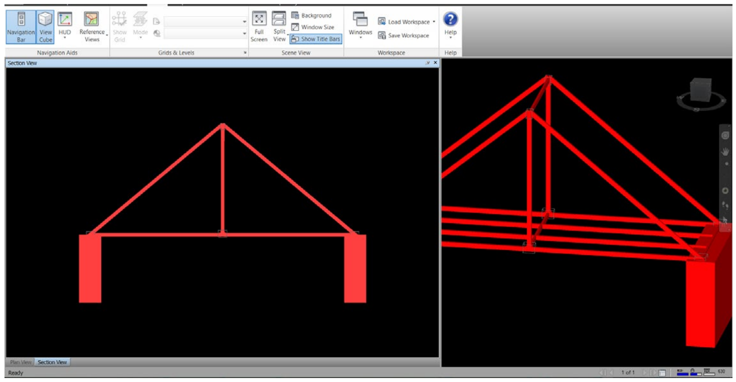


Figure 105: Section view - Using Navisworks

Microsoft Project tasks/activities will be linked to the model. Using an option in Navisworks that does so.

This could also be done using the software Primavera P6, another project management software, more specialized in ERP, but this project management program was done using only Microsoft Project.

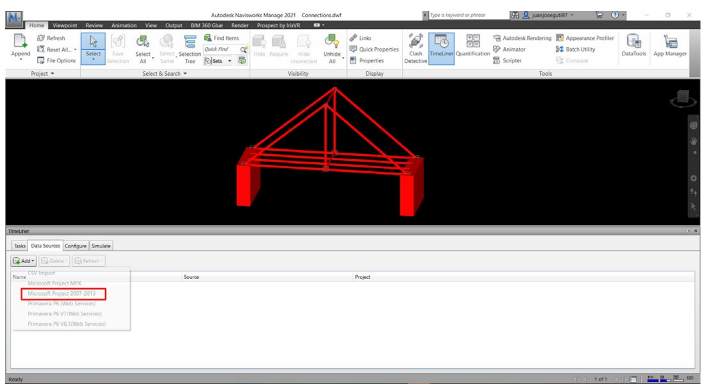


Figure 106: Connection Microsoft Project - Using Advanced steel

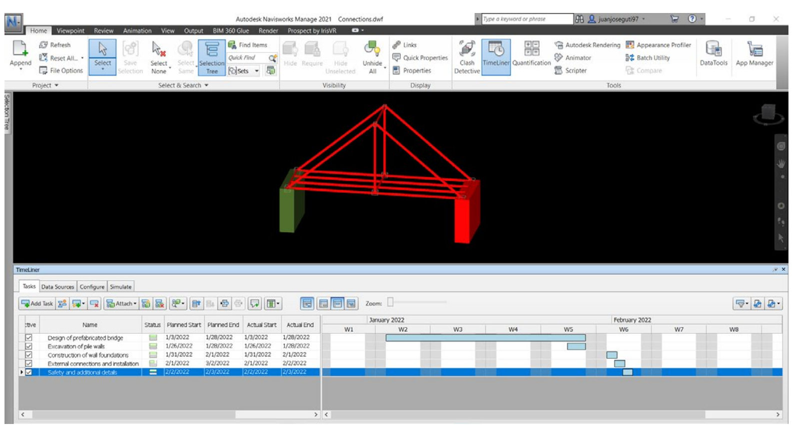


Figure 107: Timeline tasks/activities - Using Navisworks

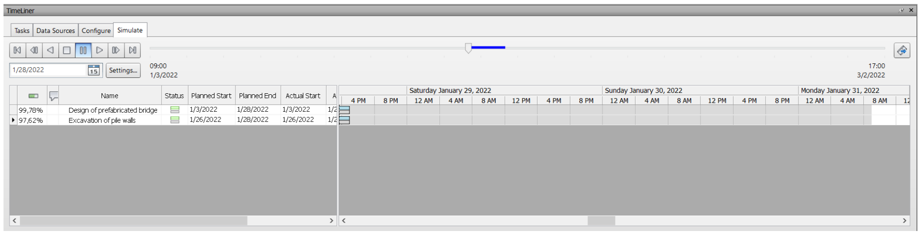


Figure 108: Capture of execution simulation (Parallel activities performed at the same time) - Using Navisworks Manage

Virtual Reality and Augmented Reality

Virtual reality is a computer - generated simulation, in which the person can interact with the 3D environment using electronic devices.

Augmented reality in represented by the world with virtual elements superimposed. Enhanced/Augmented by adding virtual computer – generated information to it. This augmented reality is useful to superpose over the real world a filter or information about what is being observed.

It could be used in this project for the stakeholders to visualize the project that is going to be performed the use of virtual reality, this virtual reality visualization can be obtained with an additional export from Navisworks.

This procedure is not suggested for this project as the structure is simple, but this will be highly suggested for scenarios of marketing for selling an apartment or a property, in which the buyer to have a better perception of the project.

This could also be useful to subcontractors to know the work that must be performed and to workers to have the objective and their role in the different project tasks.

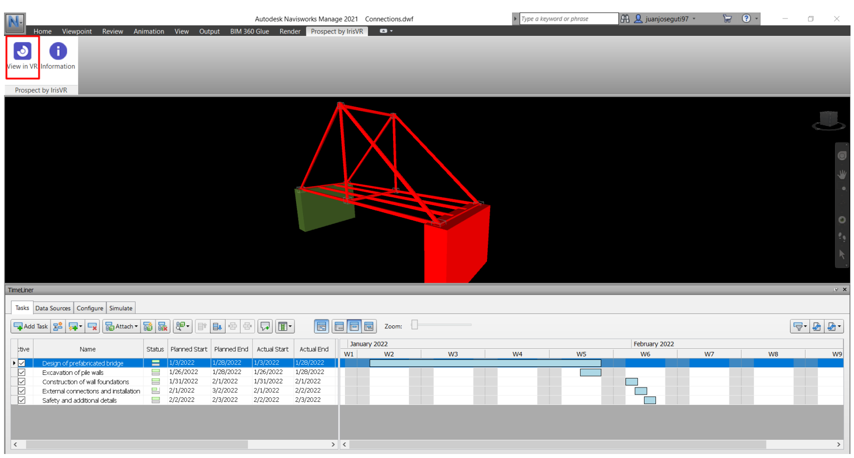


Figure 109: Export Detailed Piedicavallo bridge into a VR view - Using Navisworks Manage

This virtual reality experience was not performed nor used during the completion of the thesis.

8.4. AutoCAD planes 2D – For the execution of works in site.

For the execution, usually subcontractors and workers, they are used to work with 2D views instead of 3D models, in which they could see the different views, for this in the design the Tekla Structure model was exported to AutoCAD, and the layout views of the 3D model were obtained.

This design views will be used by subcontractors and all the workers in site to have a better understanding of what is going to be done.

This AutoCAD planes are: The real planes of the bridge will be added as **Annex 3**.

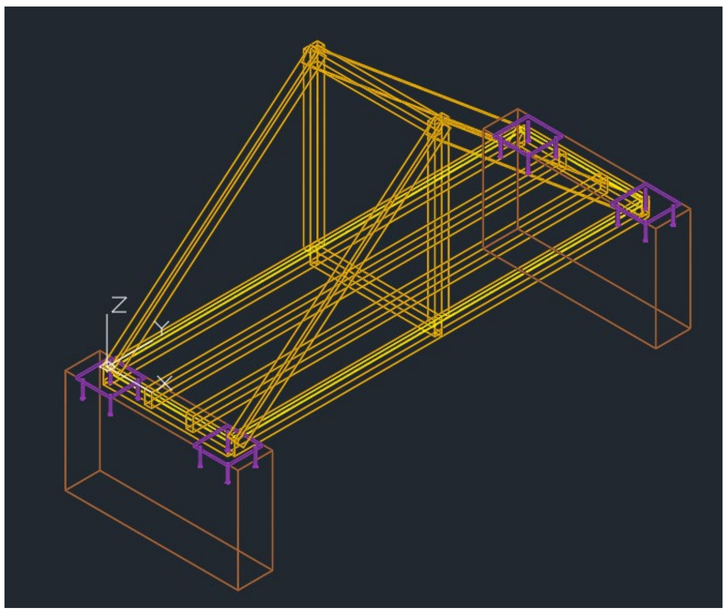


Figure 110: Bridge design – AutoCAD 3D

AutoCAD views:

Top view

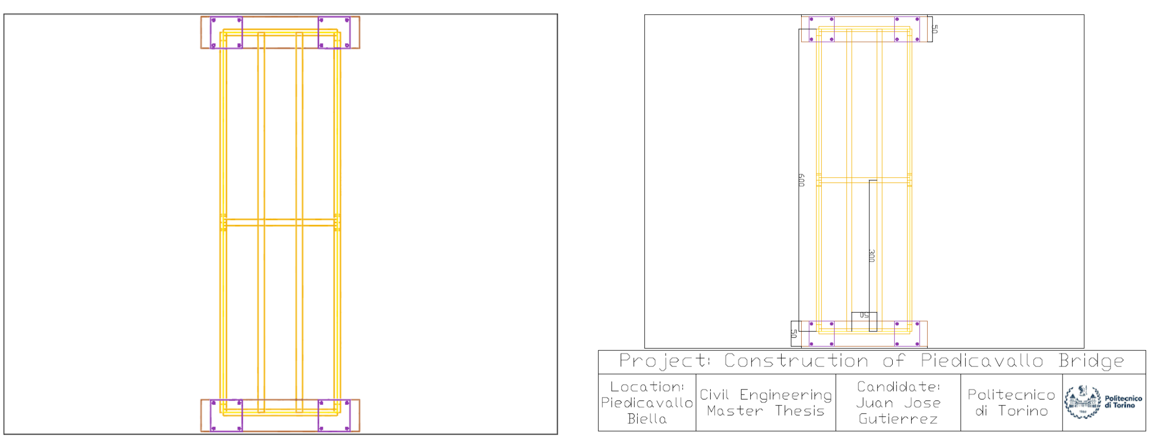


Figure 111: Top view - AutoCAD

Lateral view

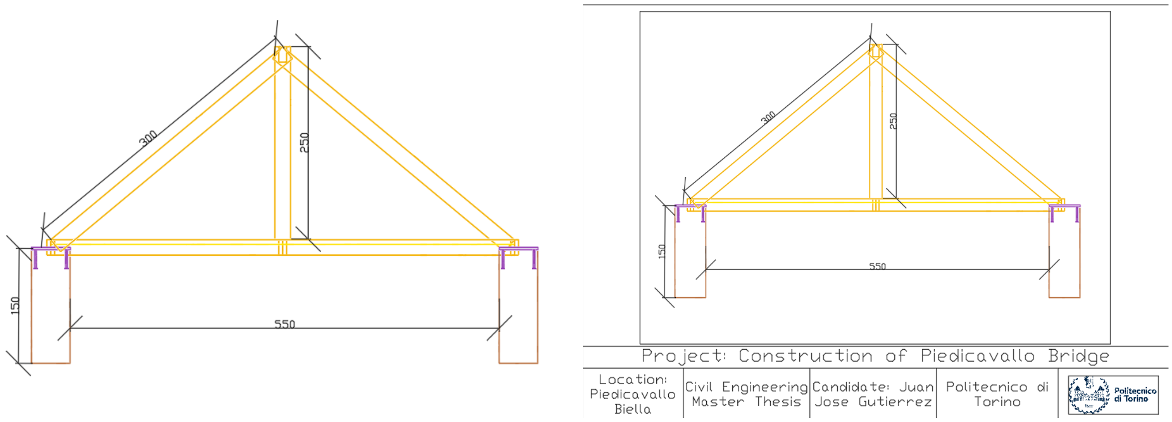


Figure 112: Lateral view - AutoCAD

Frontal view

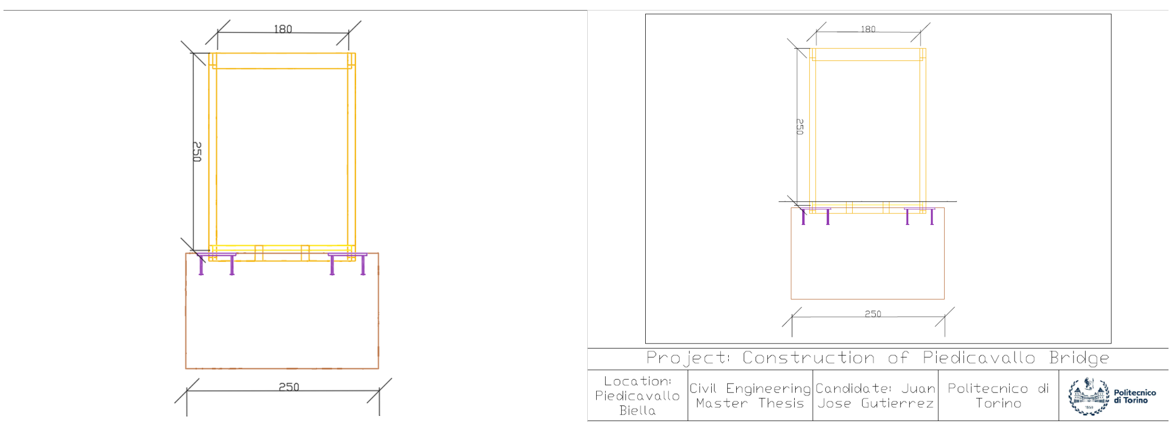


Figure 113: Frontal view - AutoCAD

9. Interoperability between software

Building information Modelling is a methodology or process, which has as an objective to integrate in an efficient way all the stakeholders related to the construction project, to generate a better and more effective sharing of information. This sharing of information that is referred is called interoperability, which is the process of effectively exchange information to generate a better result.

Interoperability is referred as the passing of information between actors of the project, this interoperability could be performed via links (Shared area to upload sub models) or workset (One central model – Local file for individual work and changes for central model to share). In this case as it was a small project, the work was done as workset with a central model, with the reference that all the work presented was performed by me, so it is not referred to teamwork.

Teamwork is the cooperation between individuals, which have individual skills (Different specialty fields) working in a total project, having in this way constructive feedbacks.

This interoperability depends in the software used. This data exchange is the objective of this process, but there are some softwares which are better integrating with others, than others. For a construction design, there are a lot of different design softwares, either for architectural design, structural design, construction management, detailing and so on, and there are many different companies of software that own this companies, usually the softwares that are fabricated by the same company have very good interoperability between them, such as, Bentley, Autodesk and Acca.

During this project it was used mainly softwares from Autodesk and Acca family, to have a good interoperability between them, but nevertheless during the Thesis it was used softwares very specialized as Tekla (for executive design), SAP 2000 (For structural analysis), Microsoft Project (For project management), Cloud Compare (For the taken point cloud in site) and IdeaStatica (Good add inn for local structural analysis – Connections). All this software, from different fabricators were also used effectively and integrated to the whole project.

Softwares used during project:

Software used	**Function**
Revit	Executive design
Edificius	Executive (Architectural) design
Sap 2000	Structural design
Robot Structural Analysis	Structural design
Tekla structures	Executive design

Microsoft Project	Project management - Schedule, resources to tasks, progress, budget and analyzing workloads
Navisworks model	4D modelling - Time depending, 3D elements linked with time
Advance Steel	Drawing and detailing
IdeaStatica	Local structural analysis
Primus	Costing analysis
Autocad	Classical use - Planes and views.
Cloud Compare	Point clouds

This interoperability section is very interesting as this is the main objective and core of BIM, which the main purpose is the construction management of the bridge using BIM methodology.

9.1. Interoperability between Autodesk and other classical softwares.

For this Interoperability it will be referred first to the classical softwares used during the academic years of university, then I will include some explanation in working in two new softwares of Civil Engineering of a Private Italian company called ACCA, that were very useful for modeling and cost analysis.

For the interoperability of the rest of the software is good to underline that the softwares owned by Autodesk have a very good Interoperability between them, having each of them different functionalities and strong points. When working with Autodesk software is simple to start with the structural design or the architectural design and then check the architectural design with the structural to modify the sections of the members if needed.

In this project, the first thing was the selection of the material, as a constraint of the thesis investigation, for then an appropriate comparison with other materials.

After the selection of the material (Glued Laminated timber), the work was developed in the following order:

i. The architectural design with a small and simple truss structure (Revit, Tekla).
ii. Then the sections were analyzed using structural design softwares (Robot and SAP).
iii. Cyclic process between architectural design (Modifying sections) and Structural design until we have proper structural conditions.
iv. Structural detailing of the selected sections of the structural elements (Steel connections).

v. Check – Local analysis of the structural detailing (connections) meeting the local (European) regulations.
vi. Cyclic process between the designed connection and the local analysis until well-designed connections are obtained.
vii. Quantities takeoff – Quantities of the designed bridge are extracted from executive design for cost analysis (Tekla and Navisworks takeoff to Excel), with quantities of each item we also include the appropriate average prices for the referred region.
viii. Cost analysis (Excel – Average prices booklet)
ix. Time management – Construction program plan (Microsoft Project and Navisworks)
x. Execution of project – Tracking (Microsoft Project, Navisworks and Tekla)

Other activities were done to complement this works of quantities takeoffs and the complete executive design using Acca software, this was done as a complement of the works and the interoperability procedure will also be explained.

Robot structural Analysis 2021 to Revit 2021:

Robot structural Analysis software provide us with advanced BIM-integrated analysis and design tools for the behavior of any structure type, also verifying code compliance. This software was used for the global structural analysis based in European library previously defined.

The file is saved as SMXX format as intermediate file format, for interoperability.

The drawing must be corrected as some information is not complete in the design, so is necessary to perform an additional correction in the information of the members.

Revit 2021 to Tekla structures 2021:

For this it was used the IFC (Industry foundation class) format, which is used by many softwares as a common language to exchange files. The export of files was mostly successful where not significant information was lost in the process, making both softwares compatible in this scope of the project. Tekla is used mainly for quantities takeoff

Tekla Structure 2021 to Revit 2021:

It is used also the IFC (Industry foundation class) format files. As a result of the workflow, the interoperability from Tekla to Revit can be considered effective, however some element cross – section data needed to be redefined in Revit.

Revit 2021 to Advance steel 2021:

Advance steel is a more specialized software for structural details, especially in steel and timber structure for the proper needed connections. For the design of the connections as we are increasing the level of development, the software is specialized in designing any kind of connections, making us to determine high details such as the type of bolts and the diameter of it. In this software we will be able to have the model with better detailing and precise information.

For this it was used a Revit add inn found in Autodesk. This add inn convert the file into a common SMLX format. After this the file could be used in Advance steel 2021.

Advance steel 2021 to IdeaStatica 20.1:

For the steel connection analysis, it was used as a software IdeaStatica with the integration of Advance steel. Loads are taken from the Robot structural analysis or Sap 2000 structural analysis, in which the global structural analysis was performed. For this connection we must calculate the inside connection which we evaluate using the internal strengths obtained in the global structural analysis.

The plug inn was downloaded using PoliTO Educational licenses. The IdeaStatica plug inn allow us to determine the final design forces applied to each joint connecting the load analysis in the global structural analysis to the local analysis joint data in IdeaStatica. By using IdeaStatica we are improving the Level of Information and the Level of Geometry. The result will be the detailed connection and the response to the applied loads.

Microsoft Project to Navisworks:

Microsoft Project is a project management software product, designed to assist a project manager in developing a schedule, assigning resources to tasks, tracking progress, managing the budget, and analyzing workloads. The project schedule of the present study case was performed in the mentioned software, which provides an .MPP format.

Once performing the schedule, it can be imported to Navisworks, to link with the main model. It is important to notice that the interoperability between this two software is completely reached without any inconveniences due to the common feature defined for both software.

Advance steel to Navisworks:

Navisworks is not a modelling software, is a pure 4D software, as is a time – dependent model, in which objects of the 3D digital model are intelligibly linked with time or schedule information. This 3D digital model could be extracted from Advance steel, after properly designing the connections, and all the sections and elements.

All these quantities of members and the connections are very well exported as the information model to Navisworks, using Navisworks this will permit us create animations and detect – space limit conflicts as well as the construction planning. Navisworks allows to generate planning simulations, space/time clash tests, animations and renderization to the work done.

Navisworks also has the option to insert by the user in the Timeliner tool the creation of tasks and activities, according to manuals the fastest and most efficient way is to import the schedule from a software purely dedicated to work planning as Microsoft Project of Primavera P6.

This interoperation is very good and simple, in the Advance steel software, there is an option which is to Export to Navisworks, and the design will open in Navisworks.

Good Interoperability Softwares:

✓ (Good)	80-100% Good
✓ (Fair)	30-79% Fair
✗ (Poor)	0-29% Poor
---	Unknown

Table 6: Evaluation of interoperability

	R	IDEA StatiCa	A	N	R PRO	A AUTODESK ADVANCE STEEL	Tekla Structures
R	✓ (Good)	✓ (Good)	✓ (Good)	✓ (Good)	✓ (Good)	✓ (Good)	✓ (Fair)
IDEA StatiCa	✓ (Good)	✓ (Good)	---	---	---	✓ (Good)	✓ (Good)
A	✓ (Good)	---	✓ (Good)	---	✓ (Good)	✓ (Good)	✓ (Good)
N	✓ (Good)	---	---	✓ (Good)	✓ (Fair)	✓ (Good)	✗ (Poor)
R PRO	✓ (Good)	✓ (Good)	✓ (Good)	✓ (Fair)	✓ (Good)	✓ (Fair)	✓ (Fair)
A AUTODESK ADVANCE STEEL	✓ (Good)	✓ (Good)	✓ (Good)	✓ (Good)	---	✓ (Good)	---
Tekla Structures	✓ (Fair)	✓ (Good)	✓ (Good)	✗ (Poor)	✓ (Fair)	---	✓ (Good)

Table 7: Interoperability of main used softwares

AutoCAD was not mentioned in the interoperability phase, but this software has a very good connection with all the mentioned Autodesk softwares, is easy to take the 3D model of the global structure or of the detail and take the views and sections exporting them to AutoCAD. This was done for having the plane designs for the execution of the works.

There are other softwares that were used during the works performed during the planning phase of the Piedicavallo bridge, that were not used for interoperability with other softwares, in this group of software it is found SAP 2000, Cloud compare and in some way Microsoft Project. One main characteristic of this lack of interoperability is the fact that this softwares are not in the Autodesk group, or Tekla, which has a good connection with Autodesk programs thanks to the IFC format for exchange of data.

SAP 2000: Is a pure structural and Earthquake Engineering design software. The structural analysis and design software CSI include Etabs, CSIBridge and SAP 2000 between others as top structural softwares. For structural design is well known around the world and include the specifications for the structural design around the world. For this the interoperability was not good, and so the complete structure and geometry was redesigned and calculated the structural analysis, to make sure the Glulam resisting forces are able to contain the increased loads.

Cloud Compare: Is a light software that can show the result of a point cloud, which was taken using a laser scanner in field. This software is free and easy to download. It has not interoperability at all, it was only used for viewing the point clouds taken in the laser scanner at the site.

Microsoft Project: Is a pure project management software, this software is very powerful as using it is easy to perform a GANTT diagram, identification of resources in each task and time duration of the construction as well as all the construction management before and during the construction. This software is not a civil engineering tool, in contrast to all the others, but is a project management tool, which fits perfect for the program 4D and 5D of the construction project combined with other softwares.

This software during the thesis was integrated to Navisworks and has a good connection in the development of the construction program, but for the simulation is also needed a model, which is exported from Advance Steel.

9.2. Interoperability between ACCA softwares

ACCA is a good Italian Software company for the AECO sector (Architecture, Engineering, construction, and Operation), this includes many softwares, such as Edificius, Primus and Edilus depending on the aimed solution goal of the design.

This ACCA software goal is to work in a BIM environment, in which it could be easily shared and modified all the information between softwares, each software with a different specialized field.

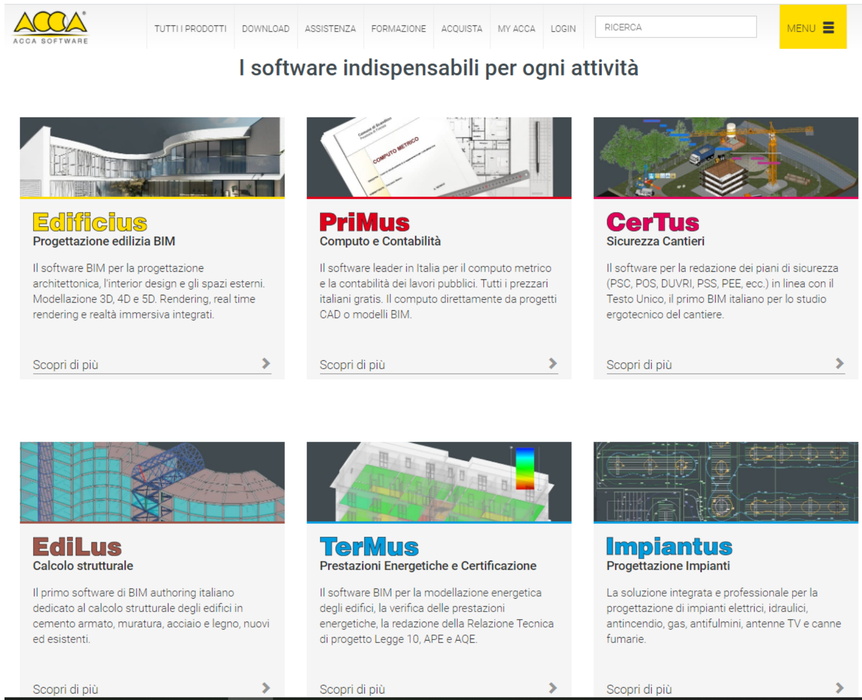


Figure 114: Softwares ACCA for AECO sector – Taken from (ACCA software S.p.A., 2021)

Between this same softwares, for the structural analysis in EdiLus, the executive design in Edificius and the cost analysis in PriMus there is a very good interoperability, in which the software integrates with each other to perform relate properties in the other software and then exported to the other software.

This softwares must be paid for using them, and there are not educational licenses, so is difficult to use this incredible softwares during the academic life. In this thesis, there was the main advantage that the candidate is working in an engineering company and using with this softwares and had the permission to use the license in this project for academic purposes in reviewing the results.

This ACCA software tries to create by itself a very complete BIM platform considering the main theoretical aspects of BIM methodology, it tries to integrate in an efficient way the different stakeholders of the project. For example, the structural engineering with the EdiLus calculations, civil engineer, or architect in charge of the Edificius model design and cost specialist for the cost analysis in Primus. All this in a cloud BIM integrated system.

This cloud BIM integrated system can integrate all the stakeholders of the workers permitting to work in a more efficient way.

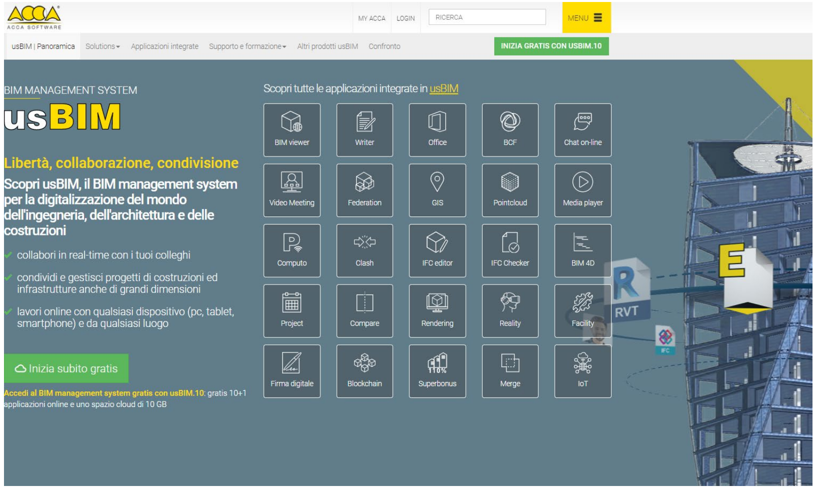


Figure 115: Cloud BIM integrated system (usBIM) - Taken from (ACCA software S.p.A., 2021)

This collaboration BIM cloud can connect the working data performed but each of the different professionals related to the project. This common environment can read and work with information in RFA (Revit families), RVT (Revit models), IFC (Common environment – Industry Foundation Class). Aiming for a real time collaboration project.

Figure 116: usBIM collaboration – Taken from (ACCA software S.p.A., 2021)

This shared environment could be used in teamworking for big projects in which there is a need of sharing information. Being able to receive data in form of almost any modelling file, point clouds, GIS locations, and many more. This is very beneficial for clash detection, and for an appropriate retrofitting of the project of all the participants of the project.

In this thesis it was used Edificius and PriMus, Edificius for the modelling of the structure including rendering, which was also performed, all this after the structural evaluation performed using SAP 2000. The Edificius design contained the section sizes and the materials used in the construction of the Piedicavallo bridge. This material quantities were considered using an interoperability window with Primus as the quantities for the corresponding items (Voices) with the proper units.

These voices were extracted from the actualized “Prezzario DEI” for the region of Piemonte and the list of prices of the Piemonte region. Based on this the final cost analysis was performed.

The interoperability between Edificius and PriMus is very good.

10. Future developments and other considerations

10.1. Development of Jacking technology

For the future developments of the construction management of this bridge in Piedicavallo, Biella. One important aspect is to deal with the fact that this past bridge has been reconstructed in this same point several times, because due to an unusual increase in the water level of the Cervo stream with a return period of around 30 years, the bridge collapses.

To develop a construction solution that can evaluate this water level increase and develop in the structure a system able to lift the bridge up in case of a water increase, in the state-of-the-art section it was mentioned and proposed as a solution a lifting construction system in the form of a jacking technology for bridges, showing real cases examples in China in which this technology was successfully used.

This jacking technology could lift the level of the bridge more than 50 cm, which is sufficient to handle this increase in water emergency.

The proposed jacking technology will be in the same place of the external connections, so the construction method will not change in a significant way, it will just be added the extra costs for the installation of the jacking technology and the proper monitoring tools that must be also included in the Cervo stream and Piedicavallo bridge. This installation will modify the schedule of tasks in a brief way, but not the rest of the costs or prices.

For the implementation of this jacking technology, it will be evaluated using past experiences in projects around the world. As a first example it will be considered a jack-up system, which provides precision control suitable for man demanding lifting/lowering applications. This jack-up system solution is commercially proposed by "Enerpac"

Figure 117: Enerpac Jack-up system. Taken from (ENERPAC, 2017)

For the size of this project and its weight, which is around 0.5 Ton, it will be considered a simpler lifting solution. So, the proposed solution will be a simultaneous jacking system, that will lift simultaneously the four edges of the bridge. This lifting must be synchronous and as this is a light bridge solution, the hydraulic jacking system does not have to be as complicated as the last solution.

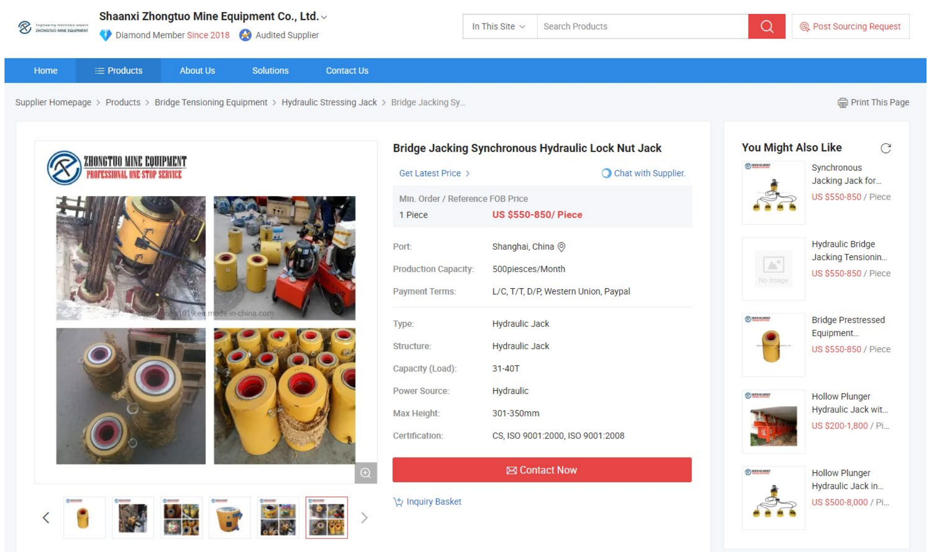


Figure 118: Bridge Jacking Synchronous hydraulic - Taken from (Shaanxi Zhongtuo Mine Equipment Co., Ltd., 2018)

This proposed solution considers a Bridge Jacking Synchronous Hydraulic, with a low lifting height of around 35 cm, which is appropriate for the desired height.

This solution will be imported from China (4 pieces), with the appropriate installation, transportation and sensors in the bridge superstructure is estimated that the price of this jacking system will triplicate.

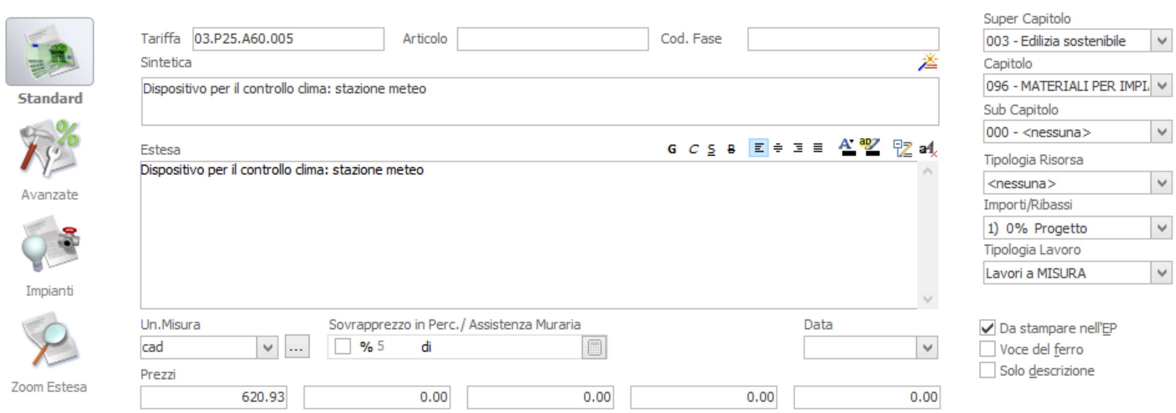


Figure 119: Sensor station for climate monitoring - Taken from "Listino "prezzi" Regione Piemonte"

Meteorological station for considering when to use the hydraulic jacking system, the values for using this station must be considered by doing a complete hydrological analysis of this section of the Cervo stream, which was not performed for this Thesis.

After this analysis the additional costs for this Jacking system in the bridge, could be estimated as (Further hydrological analysis must be done to seek for the viability of this solution):

Item	Number of units	Unitary price	Cost
Bridge Jacking Synchronous Hydraulic: Lock nut jack	4	800,00 €	3 200,00 €
Transportation to site	-	-	3 200,00 €
Installation - Bridge Jacking Synchronous Hydraulic: Lock nut jack	4	800,00 €	3 200,00 €
Meteorological station	1	620,93 €	620,93 €
Additional cost for Jack-up system in Piedicavallo bridge			10 220,93 €

Table 8: Additional cost for Jack-up system

After the cost analysis of this Jack-up system, it can be concluded a final preliminary cost analysis including the preliminary expenses of the Jack-up system. This cost could increase depending on the hydrological conditions and the installation process, as well as a hydrological analysis will determine if this Jack-up system is correct or not.

Original - Estimated - cost of Piedicavallo bridge	€ 19,406.57
Additional cost for Jack - up system in Piedicavallo bridge	€ 10,220.93
Total cost of bridge with Jack - up system	€ 29,627.50

Table 9: Cost of Piedicavallo bridge - including Jack-up system

The total cost of the bridge, including the hydraulic jack-up system will be around 29.627,50 €.

10.2. Implementation of 6D – Green Analysis

Green analysis simulates the behavior of the systems of energetic consumption and the management of resources, for better decision – making before construction.

For generating these results, it will be proposed to be used as a software, "Green Building Studio", which is an energetic analysis software from the Autodesk company. The energetic consumption and sustainable designs are not only the complete 6th Dimension, but also the "Value Engineering", which consist in optimize the construction systems, structures, and installations.

An energetic simulation software makes us perform the model of the building, its importance is in the impact of the energetic consumption, "green building studio" is an easy software, which as energetic simulator permit us to use advanced modelling functions of modelling. All this due to the versatile and powerful Energy Plus program.

Figure 120: Autodesk - Green Building Studio

By using this software, we could develop a sustainable element tracking and a LEED tracking, this could be performed and used for the performance of the bridge, even if it is mainly used in building applications.

Better decision making is achieved by doing this Performance analysis in the materials used for the bridge construction.

10.3. For wood construction – Sustainability and performance of wood - certificates.

For wood purposes is important to control the certificate of performance and controlled wood, from the wood supplier. For Glued Laminated Timber (Glulam), which will be used in the bridge construction we must make sure this wood meets the wanted Glulam parameters of the real performance, based in tests and experimental analysis.

The performance characteristics must be showed by the wood provider, as these were the ones used for the design and the structural analysis.

For sustainable reasons is also important that the supplier also shows a certificate of controlled wood custody. This in order not to buy wooden elements from illegal suppliers. Also considering sustainable reasons is pointless to build in a sustainable way, using timber, which could be seen as a renewable resource, if this is not true and we are not completely sure the supplier meets the controlled wood regulations.

NCS NORTHERN CERTIFICATION SERVICES

CERTIFICATE OF CONSTANCY OF PERFORMANCE

Notified Body No 2866

In compliance with Regulation 305/2011/EU of the European Parliament and of the Council of 9 March 2011 (the Construction Products Regulation or CPR), this certificate applies to the construction product

Glued laminated timber
Strength class: GL24h; GL28h; GL28c; GL30h; GL30c; GL32h; GL32c;
Adhesive: MUF, Type I; Species: Spruce (PCAB);
Intended use: In buildings, Service class 1, 2 and 3
Strength class: GL24h; GL28h; GL28c; GL30h; GL30c; GL32h; GL32c;
Adhesive: PUR, Type I; Species: Spruce (PCAB);
Intended use: In buildings, Service class 1 and 2

Produced by

Pinska Liimpuit OÜ

Abrami saeveski, Mäeltküla
Viljandi vald, Viljandimaa 70105
Estonia

This certificate attests that all provisions concerning the assessment and verification of constancy of performance described in Annex ZA of the standard

EN 14080:2013

under system 1 are applied and that the factory production control and the product fulfils all the prescribed requirements set out above.

This certificate will remain valid until the extension date, provided that the test methods and/ or factory production control requirements included in the harmonised standard, used to assess the performance of the declared characteristics, do not change, and the product, and the manufacturing conditions in the plant are not modified significantly.

Signed on behalf of NCS Estonia OÜ
Kerli Vislapuu, Certification Manager

NCS Estonia OÜ
Peterburi tee 81, 11415 Tallinn, Estonia

Certificate Number:
2866-CPR-0014
Version: v1
First Issue Date:
20.07.2020
Last Issue Date:
20.07.2020
Extension Date:
19.07.2021

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NEPCon OÜ hereby confirms that the Chain of Custody and Controlled Wood system of

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has been assessed and certified as meeting the requirements of
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The certificate is valid from 30-06-2017 to 29-06-2022
Certificate version date: 13-05-2020

Scope of certificate
Certificate type: Multisite Chain of Custody and Controlled Wood

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Figure 121: Certificates of Constancy of performance and Sustainable (Custody and controlled) wood system - Taken from (GlulamExperts, s.f.)

Conclusions and results

- The pedestrian bridge in Piedicavallo, Biella has been designed using mainly wood materials, such as, Glued Laminated Timber (Glulam) with a strength class of GL24h (Homogeneous Glued laminated timber with characteristic bending strength of 24 KPa) – (Softwood: Pine). The architectural design is made up of a simple truss structure and appropriate steel connections. The results of this design will be contrasted with a complete analysis performed using different construction materials.
- The total cost of the bridge, considering local average costs for each item, is of 19.406,57 €, using a prefabricated solution in which the construction on site schedule will consist only of 3 days. This considering the helicopter transportation solution as main transportation for construction.
- Glued Laminated timber (Glulam) is an interesting material for future construction, as it can achieve high strength and has a light weight. It could also be easily used in prefabricated fast constructions.
- For the different phases of the design of the pedestrian bridge, it has been used different BIM softwares, mainly from Trimble, Autodesk, Acca and CSI companies, the information was shared between softwares simulating the BIM process. For each design it was used an appropriate software, which was interoperated with the other softwares, with each aiming a different design analysis. All these different design analyses were performed by the writer of this work, which in the real project analysis is simulated to perform every step of the planning phase of the construction.
- The working order of this thesis case of study was performed in the following way: 1. Architectural design (Wood was used as part of the analysis – Truss structure chosen); 2. Structural Analysis (Check the architectural design is OK); 3. New architectural analysis with corrected sections of elements; 4. Local design of structure connections; 5. Local structural Analysis of structure connections; 6. Quantities takeoff of the pedestrian bridge structure; 7. Cost analysis based on quantities takeoff (Materials and tasks to do); 8. Times analysis – Schedule (Based in tasks durations, dependencies and resources). 9. Simulation of execution – Final planning of the execution phase.
- In the pedestrian bridge analysis, it was also analyzed the possibility of using a jacking system, for lifting the bridge in case of bad weather conditions and a possible increase in the water level of the Cervo stream. The proposal of this lifting will be done using a synchronous hydraulic jacking system, in all the 4 external connections. The final cost of the bridge using this lifting mechanism will be of 29.628 €. This is a proposed jacking system, for developing a complete proper analysis in which the results must be analyzed based in a hydrological analysis of this section of the Cervo stream.
- The LoD varied depending in the objective of the process performed and the software used.

- The prices for the construction quantities considered during the construction project are estimated based on an accurate list of prices that considers the average price of a unit of material in each Italian region (In this case Piemonte), after the covid situation these prices have rapidly increased, in some cases even duplicating respect the normal prices. This project prices are done using the normal conditions prices.

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