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Parametric modelling of bridge railing

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Abstract

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This thesis was commissioned by WSP Finland Ltd, a construction company with a strong tradition of bridge projects in Finland and abroad. The purpose was to improve WSP's bridge design capabilities by generating a parametric model that can create four distinct types of DK H2 bridge rails from a single parametric file. The created file employs a parametric algorithm for modelling bridge rails elements in a design software programme as well as for generating and analysing the model in Tekla structural analysis software application. Parametric modelling is an essential approach utilised in architecture, engineering, construction, and operations, and incorporates many features that have rendered previously impossible ideas and designs feasible. Consequently, this thesis uses parametric modelling to create a parametric model that can generate a variety of (sparse, dense, slatted, or mesh) bridge railings. The parametric model contains numerous options and features, allowing complete control of the model.

The aim of the thesis project was to provide a parametric model that could be used in future projects at WSP to save the time and effort manual modelling requires. Grasshopper and Rhino algorithmic modelling software programmes are used to model bridge railings with parametric modelling and then the elements of the bridge rails on the Tekla Structures software are displayed through the Tekla live plugin. The design of the bridge rail modelling in this research is based on instructions issued by the Finnish Transport Agency.

Keywords: Grasshopper and Rhino software, Tekla Structures, parametric modelling

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1 Introduction

The techniques used in architecture, engineering, construction, and operation are continuously improving, but this evolution is constantly being outpaced by increasingly complex building requirements, which are developing at an even quicker rate (1). Companies must create innovative methods to generate future plans and documents and manage changes and incoming information during the design process as large infrastructure projects become more widespread. To date, such plans have been monitored and amended as needed using the existing drawing tools (e.g. AutoCAD). However, building information modelling (BIM), which offers a significant advantage in terms of data integration, has recently begun to supplant this technology (1).

The BIM-related technologies, now widely used in building construction, are the most advanced for modelling simple to complicated structural elements. However, they are limited in their ability to manipulate curved geometries in three dimensions (1). The BIM technique was designed to be used primarily for building construction projects, with little attention paid to infrastructure projects, such as bridges. Significant geometric and semantic differences frequently exist across structures in such projects, making conventional BIM data formats challenging to use. Recent research has suggested that parametric modelling may be a viable approach for improving design efficiency and interoperability, although the research on the topic is still quite limited (2).

2 Knowledge Base

2.1 Data Modelling

The term BIM has a different meaning for different professionals. Some define BIM as a software application, whereas others regard it as a method for developing and documenting building information. Some professionals describe it as a comprehensive approach to building design, construction, and maintenance (3, p.14).

While several definitions of BIM exist, its description as a process for integrating information and technology to produce a digital representation of a construction is widely accepted. BIM integrates data from various sources and concurrently evolves with the actual project throughout the project timeframe, including the design, construction, and operating data (3, p.16).

The real value of BIM lies in the collected data that is integrated into the process and transparently shared among all the involved stakeholders. In this regard, the most essential construction “material” may be information. Throughout an asset’s lifecycle, the sector requires access to the appropriate information at the right time (3, p.16).

Significantly, many difficulties and mistakes occur during the building phase as a result of faults occurring in the design phase. Communication, coordination, and standards are just a few of the issues the industry faces in this regard. Effectively communicating design knowledge is critical to resolving these interoperability difficulties (3, p.16).

2.2 Algorithmic Modelling

The term "algorithm" began to be used in the sense relevant to this thesis in the early 20th century in the fields of mathematics and computing machinery, but its historical roots are much deeper. Old English gazetteers explain that the term refers to the system of decimal numerals called *algoritmi de numero* by Europeans. It is believed that the term is derived from the fusion of the words *algiros*, which means ‘pain’, and *arithmos*, which means ‘number’. Donald Knuth (Stanford University) was one of the first to explain that the term has been attributed to the 9th-century mathematician Abi Jafar Muhammad ibn Musa al-Khwarazmi, who was originally from Khwarazm which is now divided between Kazakhstan, Uzbekistan, and Turkmenistan. In their original form, algorithms served as a basis for the algebra of logic, which used variables in its calculations. (4)

As the term is understood today, algorithms are the result of the rise and development of mechanical engineering and its processes. Algorithms are used in mathematics and computer science to solve issues or perform computations. They comprise a finite series of well-defined, computer-implementable instructions, which are usually used to solve a class of specific problems or perform a calculation. Algorithms are transparent and specify how computations, data processing, automated reasoning, and other activities should be completed (4).

Algorithmic modelling is a BIM method that creates models through algorithms. Instead of creating the model directly in the BIM application, the modeller creates an algorithm that generates the model in the BIM programme. Similar to BIM, a model created with A-BIM contains information relevant to design and construction and is constrained by parameters and interrelated rules. Unlike BIM, the algorithm that produces the model is the source of all the model information, which can be shared and updated simultaneously by various design team members and thus provides a more flexible, controlled, and integrated method of managing project data (6).

2.3 Parametric Modelling

The term ‘parametric’ originated in mathematics before it was used in architecture. Feng Fu described parametric modelling as a technique in which the geometric shape of the structure alters as the structural dimensions change (Fu, 2018). According to David Gerber’s doctoral thesis titled ‘Parametric Practice’,(7) Maurice Ruiter was the first to use this term within design in 1988 in his paper ‘Parametric Design’. According to Robert Stiles, Luigi Moretti used the term ‘parametric’ in his work in the 1940s. According to Moretti, parametric architecture is the study of establishing a connection between dimensions and parameters.() The dimensions are connected or dependent on the parameters in this case (8).

Parametric modelling techniques are widely used in the construction sector. These techniques are used by architects to create a variety of designs and by structural engineers to research several design alternatives for the structure.

In the architectural, engineering, and construction sector, BIM and parametric modelling are two contemporary techniques. The two terms are often used interchangeably and are sometimes misunderstood. Both methods have the same goal: to combine all data into one project. By layering information on top of the core 3D model, the BIM process combines the relevant data. Computational design describes a method that adapts the model as new inputs are incorporated throughout the project's development (6, p.2).

There are many benefits to parametric design compared to drawing techniques. An engineer must design the layout and details of the design in an analogous drawing programme, such as AutoCAD or Tekla Structures, to guarantee a smooth workflow. This task necessitates the investment of a substantial amount of time and effort. However, throughout the process, it is inevitable that some changes will be made, and the drawings altered as a result of these changes. Consequently, the changes have a long-term influence on the project cost and resource efficiency. However, a more efficient use of resources and lower costs do not always result from such changes, especially in the early phases. Using parametric tools, such as Grasshopper, can reduce the time it takes to integrate significant changes. Thus, including parametric software in the workflow helps customers and designers.

3 Research Objectives

The research question can be expressed as follows: Can a single parametric file be developed that generates four different types of bridge rails and effectively uses the parametric file in design and analysis? The objective of the study is, therefore, to develop and evaluate a parametric file to enhance the generation of any of the four types of bridge rails while considering the curvatures present in the three spatial dimensions. One aspect that will also be focused on in this research is the inclusion of as many geometrical and non-geometrical parameters as needed to conform with expectations.

4 Research Methodology

The aim of the study is to improve the design of WSP Finland Ltd bridge projects by generating a parametric model that can produce four different types of DK H2 bridge rails. The bridge rail modelling design in this study is based on instructions issued by the Finnish Transport Agency.

In this study, Grasshopper algorithmic modelling software is used to model bridge railing by means of parametric modelling, which is then displayed on Tekla Structures software through the Tekla live link.

The process of modelling the bridge rail structure progresses through two different phases using Grasshopper and Rhino algorithmic modelling tools. In the first phase, the model will be generated and analysed in the Tekla Structures application and the link between the parameters and data is shown in Grasshopper and Tekla using the Tekla live link addon. This approach is illustrated in Figure1.

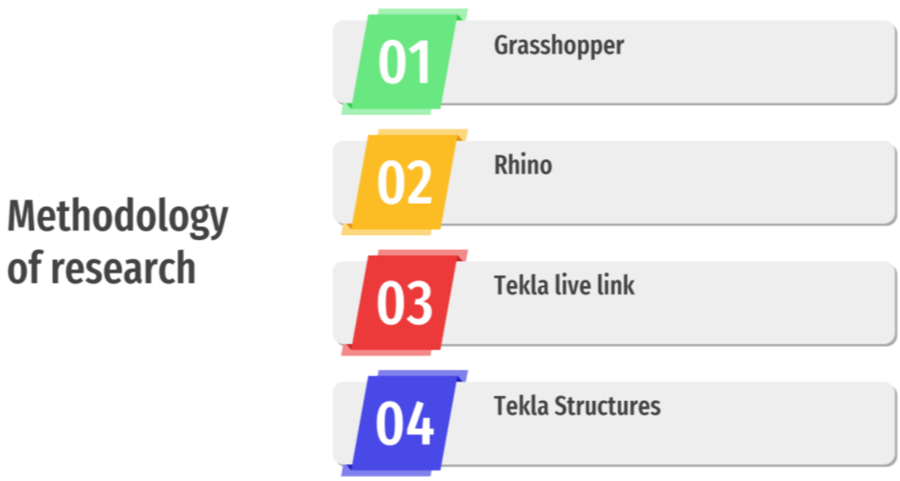

Figure 1. General approach for creating a parametric model

When the final modelling of the project is completed, the modeller is able to adjust the parametric model's inputs if required, saving time and effort when modelling similar projects in the future. The model provides considerable flexibility in terms of adjusting the parameters of the project, as any change that is applied to any element of the project automatically affects and updates the rest of the project. In contrast, the traditional method requires any changes to be applied to all elements of the project individually, which takes time and effort to model.

However, the shortage of available resources and research in the field of parametric modelling has impacted the implementation of the project, along with the dearth of literature on Grasshopper-Tekla Structures in the area of infrastructure.

5 Bridge Railing

5.1 Historical Overview

The purpose of railings is to prevent people and vehicles on the bridge from falling from the bridge. Nonetheless, for centuries bridges have been seen as ornamental structures, designed to be aesthetically beautiful and harmonised to their surroundings. Railings have traditionally been part of the overall architectural appearance of bridges and have often served to emphasise their role as a highlight connecting the social fabric. (8)

In Finland, the first bridges were made of wood in the 15th century. Railings were skilfully constructed and functioned as an integral part of the bridge structure. (8)The first steel bridges were built in the 1860s. The use of concrete in bridges began in 1894 with the construction of the Mannerheimintie overpass in Helsinki, as seen in Figure2. (8)

Figure 2. Mannerheimintie overpass in Helsinki (9)

It is difficult to determine how the types of railings have changed over time. The tried and tested railing structure was probably simply repeated, and only major bridges were given unique railings. The standard railing solution can be found, for example, in the superstructure drawings of the bridges built in the 1930s. (9)

Steel railings were introduced in the 1960s as traffic and driving speeds increased, and road safety requirements demanded more secure bridge solutions. Steel railings allowed crash safety to be ensured as the number of bridges increased. However, the appearance of the railings was not expected to be subject to much variation. In urban areas, safety requirements did not play as important a role due to low traffic speeds, and urban aesthetic criteria were also considered crucial. Thus, the culture underlying urban bridges has evolved towards a more aesthetic approach. (9)

Concrete precast or cast-in-place railings are mainly used abroad for central lanes. In Finland, concrete railings were originally developed in the late 1980s as a noise barrier. As an alternative, an airtight steel noise barrier made of crimped steel plate was also developed. The precast concrete railing was considered to have the advantages of frost resistance, minimal inconvenience to traffic caused by local casting, and the possibility for mass production. The precast technique allows for a higher quality surface treatment than spot casting. The concrete railing is still in the deployment phase, and its quality is still being developed. It appears that solutions that unilaterally emphasise safety criteria have been adopted at the expense of a distinctive building culture. (9)

5.2 General Requirements for Railings

1.1 DK H2 Railing

The current bridge construction culture uses DK H2 steel railing, which meets the current impact resistance requirements. The structure of the steel railings includes the railing frame and accessories. The steel railings can be sparse, dense, slatted, or mesh. A hot-dip galvanised steel railing is usually used for a bridge intended for vehicular traffic. (10, P.29)

Sparse bridge railing (Figure3, top left)

Sparse bridge railing is used on bridges on which light traffic is prohibited (e.g. motorways or highways). The railing consists of a handrail frame, which is comprised of handrail posts, an upper guide, a bridge guide, and a possible lower collision guide. The lower collision guide is used on the H2 bridge railing when the railing joins the low edge beam and also in connection with the high edge beam if a 240/5 open profile is used as the bridge conductor. (11, P.16.)

Dense bridge railing (Figure3, top right)

Dense bridge railing is used on bridges on which light traffic is permitted. The railing consists of a handrail frame with intermediate guides. However, a dense bridge railing with intermediate guides makes it easier to climb over the railing, hence, a dense bridge railing must not be used on the outer edge of a light traffic lane. (10, P.16.)

Mesh railing (Figure3, bottom left)

Mesh railing is used as a barrier for falling snow on the road below. The mesh railing is equipped with a high safety net. The safety net is also used at the outer edge of the light traffic lane to protect light traffic. It is not necessary to use intermediate conductors for the network, but a lower collision conductor is required. However, the use of intermediate conductors together with the net is possible in H2 bridge railings. (10, P.16.)

Slatted railing (Figure3, bottom right)

Slatted railing can be used on the outer edge of a light traffic lane in place of a mesh railing. However, it does not act as a structure to prevent ploughed snow from falling. A slatted railing must not be used as a railing for a road bridge if it forms a visual barrier, as is the case, for example, at rhombic level crossings when connecting from a ramp to a road on top of a bridge. The railing consists of a railing frame with a grating. (10, P16.)

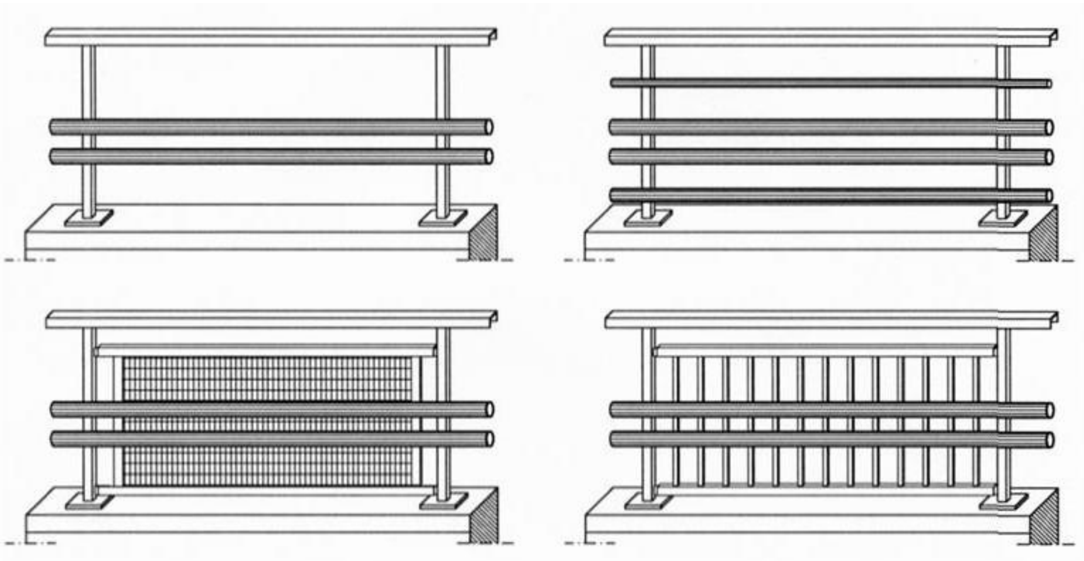

Figure 3. Basic examples of steel bridge railings with different equipment: sparse railing [top left], dense railing [top right], mesh railing [bottom left], and slatted railing [bottom right] (Liikenneviraston ohjeita 25/2012)

On bridges crossing an electrical power line, a contact barrier wall, lip, or a combination of both are used at the tracks following the Guidelines from the Finnish Transport Agency on contact barrier structures for bridges. (10, P11)

In all cases, the railing height must be at least 1200 mm from the level of the access surface or the level of the kerb, paving, concrete structure, and so on adjacent to the edge beam. A higher railing (for example, 1400 mm, agreed on an individual project basis) is used in the following cases:

- The railing is adjacent to a cycle track.
- The difference in height between the bridge deck and the street, ground, or water level below is > 7 m.
- If the railing is on a bridge deck where an abnormally large crowd may gather, a railing height of 1.2 m must be met on all bridges at the accessible surface adjacent to the railing (e.g. kerb and adjacent paving).
- A higher railing height (for example, 1.4 m) must be met at the level of the access surface. For light railings, the joint Helsinki, Espoo, and Vantaa light railing and railing guidelines, or a separate project-specific agreed rail structure must be followed that considers the above. (10, P.11)

6 Software

6.1 Rhinoceros 3D

Rhinoceros 3D, known as Rhino, is a 3D modelling software developed by Robert McNeel and Associates. Rhino is a 3D CAD application that allows designers, students, and instructors to build, modify, and convert polygon meshes, surfaces, nonuniform rational basis spline (NURBS), and other elements. The NURBS is a mathematical form that addresses analytical forms, such as lines and conics, and the problem of freeform shapes. As a result, basic and freeform forms are able to be accurately represented by NURBS. (11)

Users can utilise Rhino to create 2D drawings and illustrations using the platform annotation elements, such as arrows, text blocks, and measurements. The Rhino software based on NURBS is a mathematical paradigm for generating and visualising curves and surfaces in computer graphics (Figure4) (11).

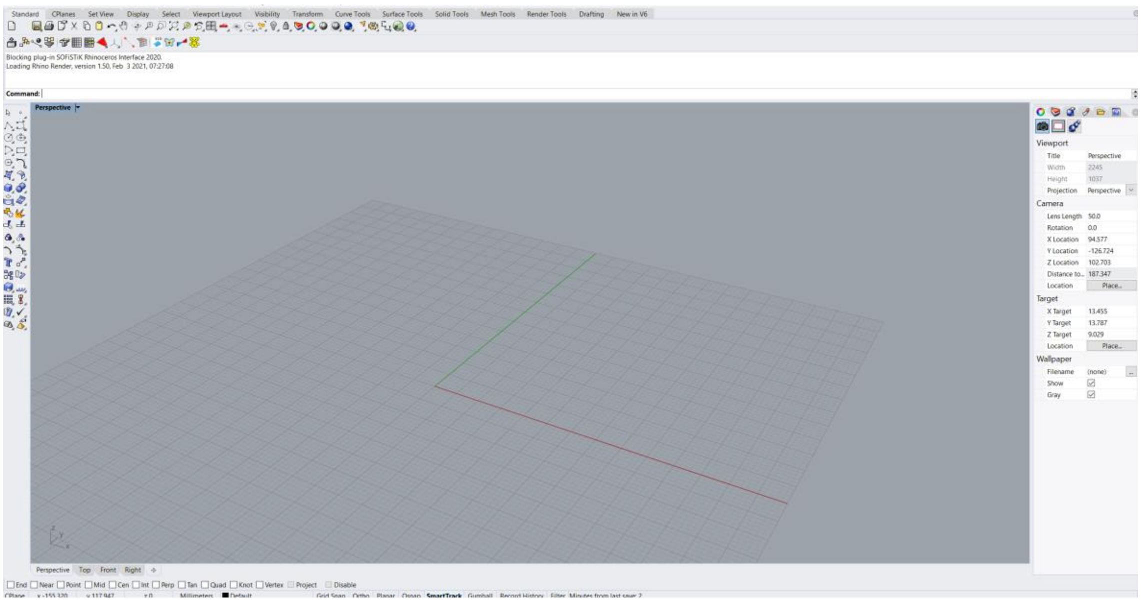

Figure 4 Rhino interface

6.2 Grasshopper

Grasshopper is an algorithmic modelling plugin based on the visual programming language for Rhino created by David Rutten and released as an official Rhino plugin. It is a tool for creating parametric designs (12). The Grasshopper plugin is flexible and elevates design complexity to a whole new level by pushing the boundaries of Rhino 3D. When designing and drawing building structures, such tools as Autodesk computer-aided design and drafting, Autodesk Revit, and 3DS Max offer a solid knowledge base. The creation of complex architectural shapes requires specialist software that can manipulate structures (13).

The Grasshopper plugin also frees the designer from being constrained by property or type factor restrictions. Grasshopper can be used for various other tasks, including manufacturing, performance analysis, structural engineering, and others (12). Recently, numerous architectural projects have been undertaken that employ algorithmic design phases. For example, the conceptual design for the Hazza Bin Zayed Stadium was generated mostly in Grasshopper, as was the bowl generation and sight line analysis. Grasshopper was also used in the detail design stage to justify the unique facade panel sizes and to model the roof's sweeping form seen in Figure5.

Figure 5 The Hazza Bin Zayed Stadium in Al Ain, UAE (https://www.grasshopper3d.com/)

6.2.1 Grasshopper Interface

The Grasshopper interface is divided into two parts: the component panels and the canvas. The component panels contain all the parts required for the design, and the canvas functions as a workspace. The user can move any object to the work area by clicking on it once and then clicking again on the canvas, as depicted in Figure 6.

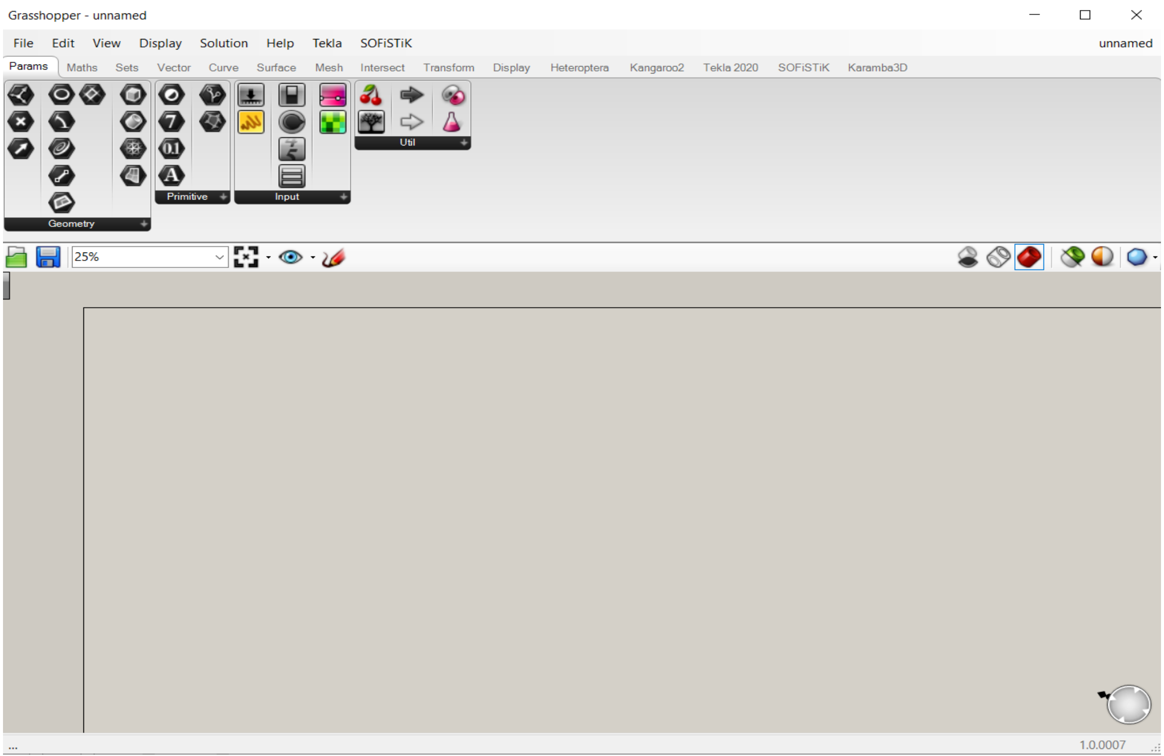

Figure 6 The Grasshopper canvas

In the Grasshopper component menu, many kinds of objects can be used in designs. The objects are organised under nine tabs: Params, Vector, Scalar, Surface , Curve, Logic, Mesh, Intersect, and XForm,.

6.3 Tekla Structures

Tekla Structures is a BIM software that allows the modelling of structures comprised of various construction materials, such as steel, concrete, timber, and glass. Tekla offers structural design professionals and engineers the tools they need to design a building structure and components in 3D, create 2D drawings, and access building data (14).

Using Tekla Structures, architects and engineers can design and build realistic multilateral models of any structure from residential buildings and offshore platforms to complicated landmark structures using a single application. Tekla has a flexible approach to BIM. To collaborate in an efficient and error-free manner, the software interacts with other solutions and production equipment (15).

Tekla Live Link

The Grasshopper-Tekla live link provides algorithmic modelling for Tekla Structures using Rhino/Grasshopper. The link offers a broad variety of components for Grasshopper that can create and modify different structures in Tekla. Figure7 illustrates the Tekla component tab in Grasshopper (16).

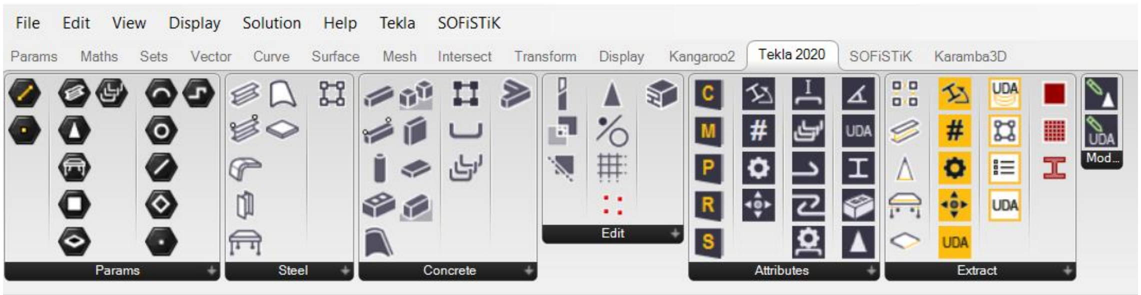

Figure 7 Grasshopper-Tekla live link plug-in components bar

7 Parametric Model of the Bridge Railing

7.1 The Modelling Process

To facilitate the creation of a parametric model containing four types of DK H2 bridge rails. The process commences by modelling the first type of rails – slatted bridge railing – and then exporting the shape containing all the modelled data and inputs to Tekla's shapes catalogue. The mesh railing has already been modelled in previous WSP internal development projects and is available for use, hence, it does not require re-modelling. After completing the modelling process, the archived shape is imported using a parametric model to ensure that it works according to the algorithm created in Grasshopper. To complete the modelling process for the first type of bridge rail, the compatibility between the Grasshopper input and the structures described in Tekla is tested. The second type of bridge rail (i.e. dense bridge) is modelled using the same method.

To model the bridge rails, the project is divided into three phases. The first phase involves the writing of the algorithmic scripts required to create the geometry of the bridge rail. This is accomplished using the Grasshopper and Rhino software, which allow the user to exert flexible control over the elemental measurements at the data limits available. In the second phase, the rail structure in Tekla is displayed through the live link plugin. The user can then identify the features of the structure, the type of cross-section, its position, and the rotation angle of the structure. When the first two phases have been completed and the parametric model has been verified, the third phase proceeds, which consists of continuing to process the second type of rail with the algorithmic scripts. Two tests are then run, and the desired result is a parametric model that can generate four types of rails without adding separate algorithmic scripts, as seen in Figure 8.

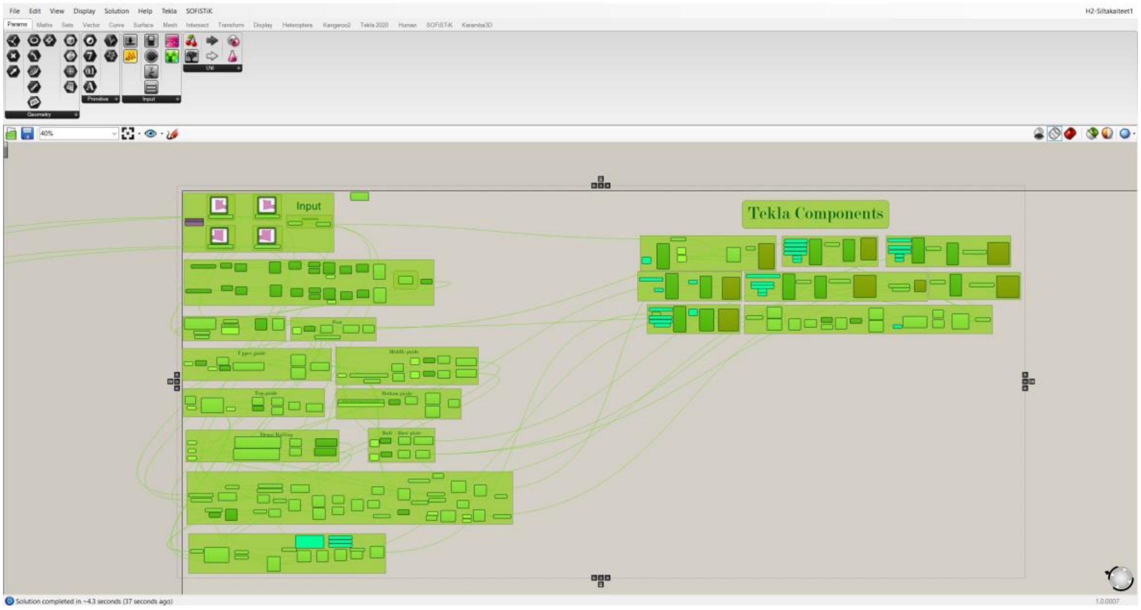

Figure 8 The final form of the parametric model

To assist in the parametric modelling process and create seamless models, one type of bridge rail is first modelled and then another two types are added after the completion of the first. The initial sparse bridge railing is selected, and its structure is separated into five groups: spot, upper and bottom guides, top guide, middle guide, and barrier, as is produced in Figure9.

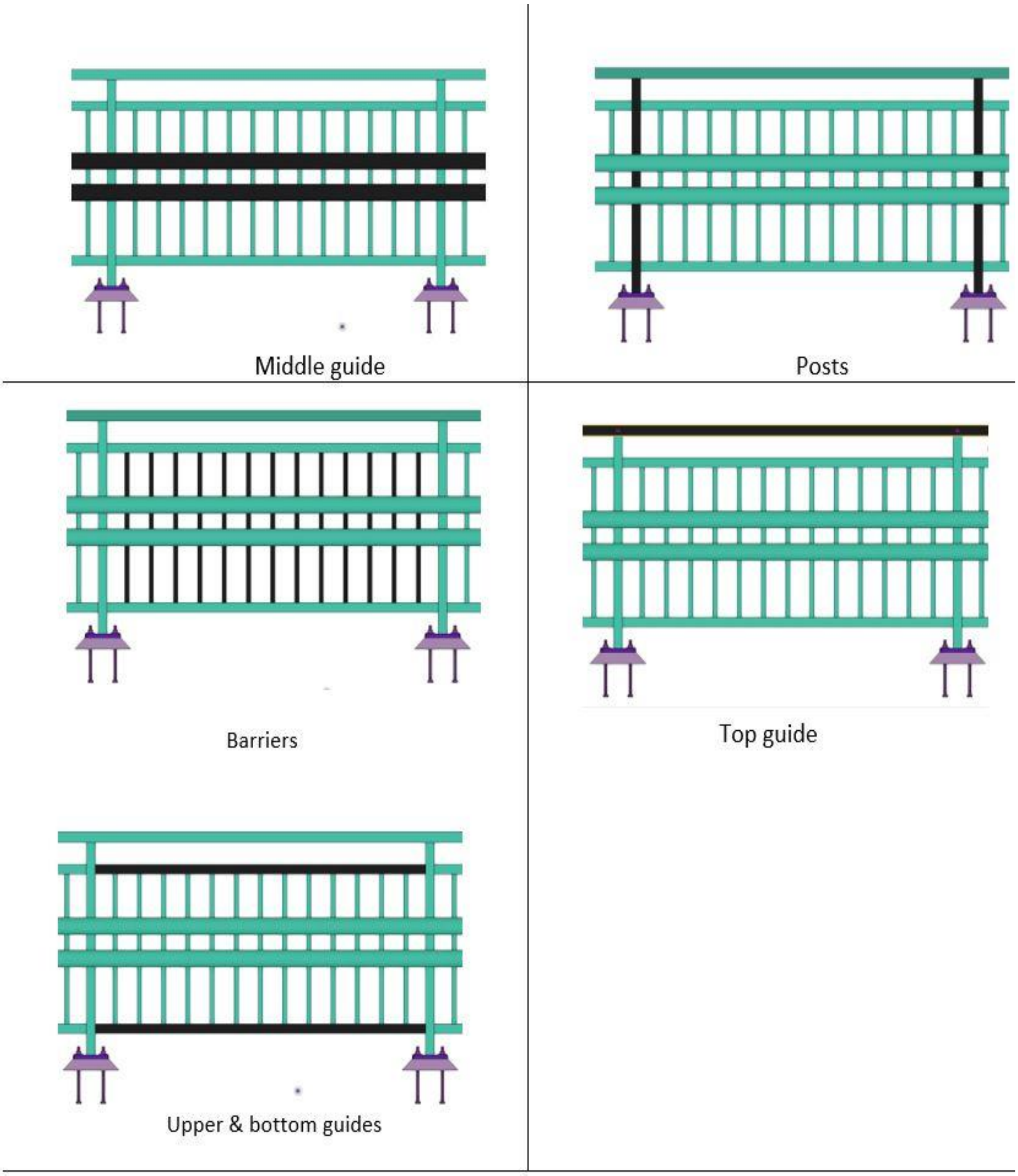

Figure 9 The sections of the bridge rail are colored and visualized by Tekla Structures.

7.2 Bridge Railing Geometry

The process of using scripts in Grasshopper begins with the determination of the start and end points of the object. In this case, all the parts are modelled in accordance with the drawings and instructions provided by the Finnish Transport Agency for the DK H2 slatted bridge railing, as shown in Appendix 2. The starting points of the model are located at the start of the handrail posts. The distance between each spot is 2 m, as presented in Figure10, hence the Series component in Grasshopper is used to copy the starting points with a 2 m distance. The points are then duplicated at 1100 mm in the XZ dimensions, which is the required height for these types of handrail spots. To connect the points, lines must be drawn between the beginning and duplicated points. This is accomplished by using the line compound that connects the points.

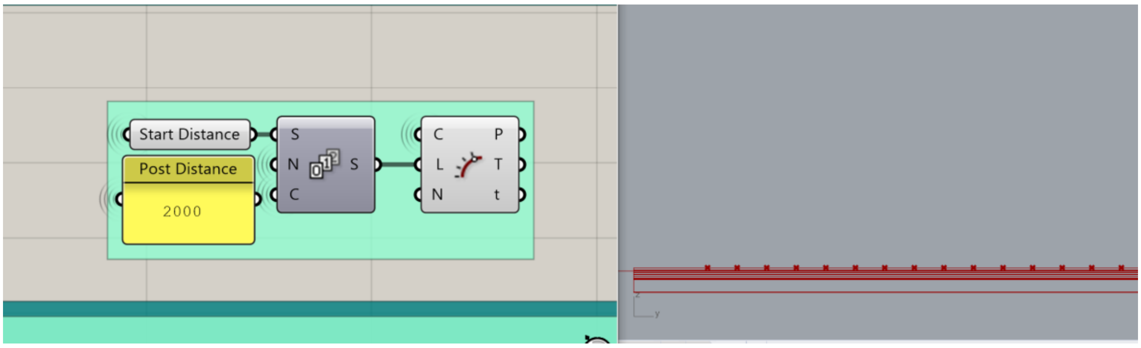

Figure 10. Composition of the starting points of the posts using the Series component

To create the top guide, the points representing the column heads must be connected with one another using the line component; this task requires the use of another component. Since it is not possible to connect points within the same dimension directly in Grasshopper, two shift list components are used and the points between them are distributed by removing the last point from each end of the two components. The procedure for producing the top guide is repeated for the upper, lower, and middle guides. The points of the top guide are copied below at -170 mm for the upper guide, - 690 mm for the lower guide, and -540 mm for the middle guides. The distance between the middle guides is 170 mm, as can be seen in Figure11. After verifying the distances between the guides, the points that resulted from the copying process are connected using the same method as was used for the upper bridge barriers.

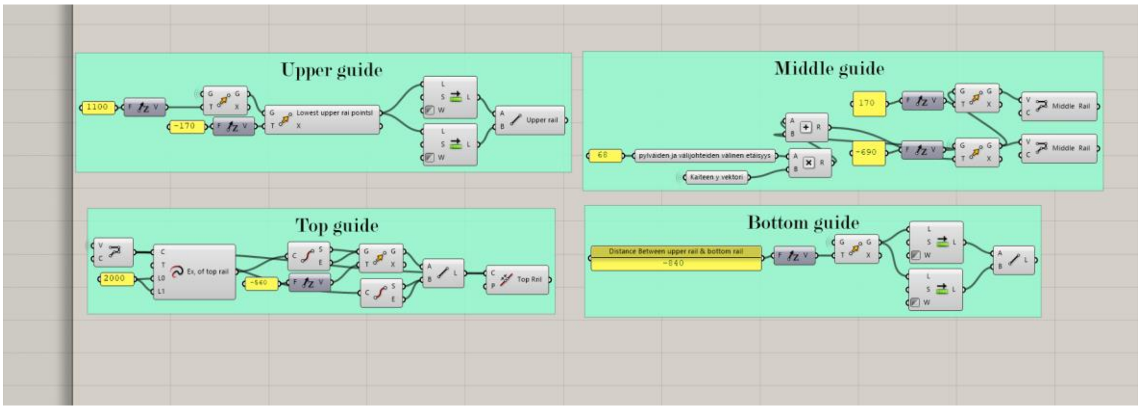

Figure 11. Grasshopper components used for creating bridge guides

The barrier is constructed of shorter spots than the main ones, with a spacing of 140 mm × 12 spots between them, as shown in the drawing in Appendix 2. To obtain these distances, the lower upper and lower guides are divided into points separated by a 140 cm gap and each point is attached to the line component as in the preceding guides.

Since each spot has a base plate with bolts attached to the bottom, the starting points in the project are copied twice. In the first step, they are copied at (-60) mm in the XZ dimensions, as shown in Figure 12; and in the second step, they are copied at (+21) mm, such that the base plate can be placed above the point as shown.

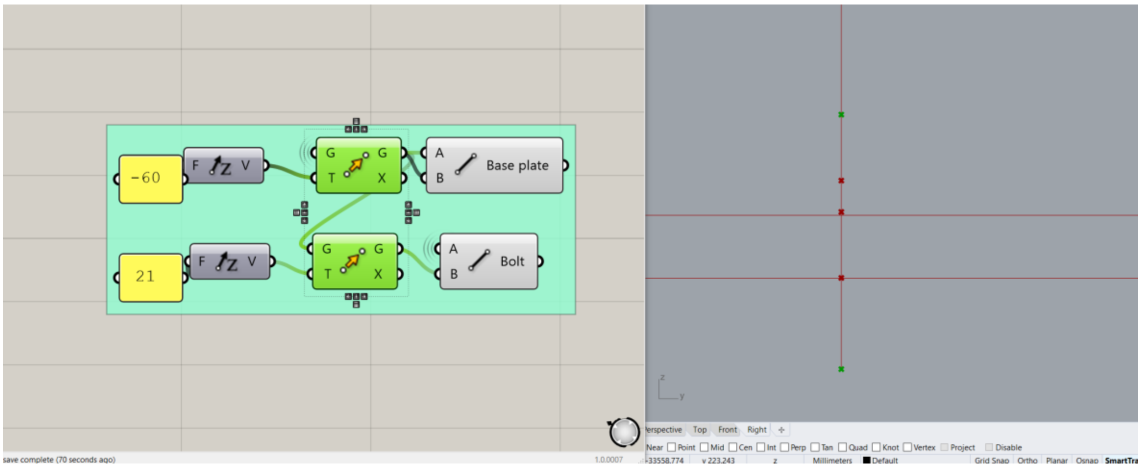

Figure12. Grasshopper components and Rhino points representing bolts and base plates

After creating the scripts for all the DK H2 railing components, what has been modelled is copied on the opposite side, on which the rails are placed. To this end, the Entwine component is used, as shown in Figure 13, and the placement of the rail guides on the other side, which must always be in the direction of the road, is accounted for. After the rails have been placed on both sides, the construction of the H2 rail in Grasshopper is completed. At this point, the user can control the main measurements of the H2 bridge rail, including changes in the length and number of columns, the number of middle columns, and the distances between them. The user can also modify the distance between the bridge guides and their heights, as well as various other options in this model.

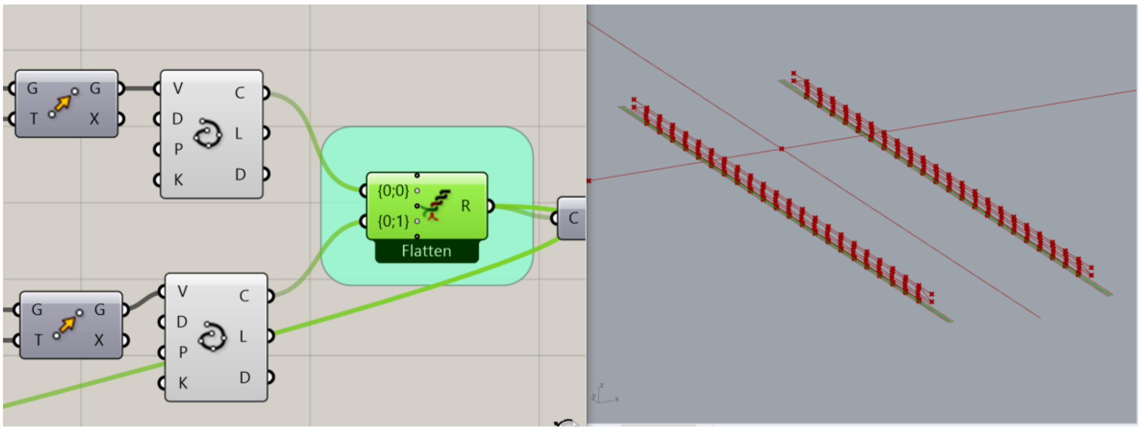

Figure 13. Rail placement on the opposite side by using the Entwine Grasshopper component

7.3 Integration With Tekla

The Grasshopper-Tekla live plugin is one of the most reliable tools for bridge designers because it links Grasshopper structures to Tekla, enabling the generation of complex designs that are difficult to create in Tekla due to the high level of detail and complex geometric shapes involved. Using this plugin, the model can be generated in the Tekla software.

Before opening Grasshopper or installing a Tekla component on Grasshopper's canvas, the user must first open the Tekla model to link the two software programmes. Since the use of Tekla's live component in parametric modelling comes at the end of the project in most cases, there is no need to open the Tekla model when scripting the algorithms at the beginning of the project.

In this thesis, three components of the plugin were used, as depicted in Figure14:

1. 'Beam' creates a beam along the associated curve or line. There are two types of beam components: concrete and steel beams.

2. 'Cut plane' in Grasshopper is similar to the analogous feature in Tekla. It cuts the parts according to the user-specified plane.

3. ‘Item’ generates a steel item from the mesh or surface geometry supplied. Alternatively, one can define an inserted profile (or shape) in the Tekla model. The optional line input allows users to specify the origin and orientation of the item.

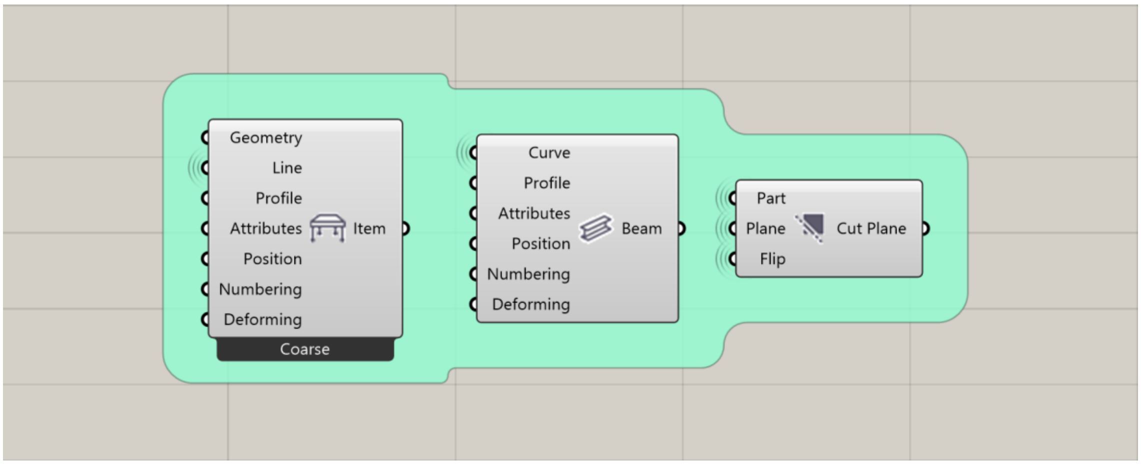

Figure14. Components used from Tekla live plug-in this thesis

To connect the Grasshopper components to the Tekla live feature, they must be represented by lines, curves, or geometric shapes to be identified by the Tekla components. Tekla live link components contain many properties through which the cross-sectional properties can be adjusted, as shown in Figure 15. These are the same properties that are available in the Tekla Structures.

To connect the Tekla and Grasshopper components, the necessary components are selected, such as the beam or columns, chosen from the Tekla component bar in Grasshopper. After creating all the components, the Grasshopper components are connected to the Tekla live link components, as shown in Figure 15, and the individual attributes for each component are then entered manually. This includes the attributes of all the guides (top, bottom, middle, lower upper) as well as the spots, barriers, base plates, and bolts attached to them.

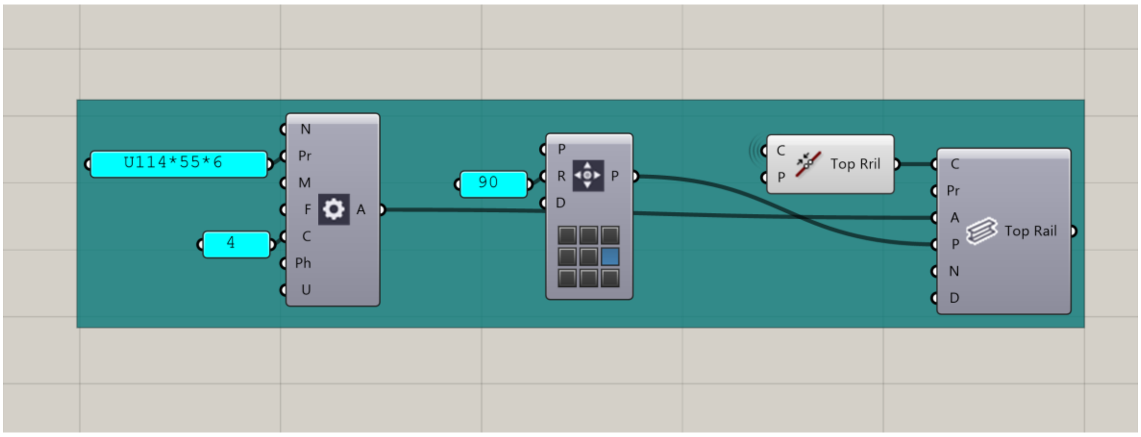

Figure15. Grasshopper components connecting to Tekla live link components

To generate a base plate in the Tekla model, the item component is used. First, all the input required to display the element is inserted in Tekla Structures. In this case, a section of the base plate intersects the edge beam. Therefore, to cut the section within the edge beam, ‘cut plane’ is used. As the name of the component suggests, the part to be cut and the plane must be identified, based on which the base plate will be cut. The plane is made by importing the required points from edge beams of the bridge. In this case, the required plane consists of three points: one point each on the left and right edge of the outer beam head and one point along the edge beam.

The plane that has been created is straight and works properly when modelling straight bridges. However, when modelling curved bridges, using this plane with the cut component during the cutting process results in cuts to incorrect parts of the base plate. Therefore, to ensure an error-free cutting process, a plane is created that considers the curvature of the bridge and its compatibility with the shape of the bridge is verified.

After creating the first bridge rail model, it needs to be tested in Tekla Structures to ensure that the parametric model works according to the algorithmic scripts. For example, the distances between the elements should be valid.

After confirming the validity of the parametric model, at this stage, the model is saved and the rails are inserted in Tekla as shapes. The modelling of the other types of DK H2 bridge rails is somewhat similar to the first type, and the differences between them can be summarised in the following four points:

1. Dense and sparse railings do not include the barriers in their composition. Therefore, the barrier must be hidden from the parametric model while it is being constructed.

2. This type does not contain the top guides or upper guiderail, implying that these parts, like the barriers, are hidden.

3. To make the dense bridge railing, two more intermediate guides to the dense railing are created by copying the middle guides twice: once in the direction of the upper guide with a value of 250 mm and once again downwards with a value of 220 mm in the Z dimension. Figure16 illustrates the algorithmic scripts of the dense bridge railing, and Appendix 1 illustrates the structure of the dense railing.

4. The sparse bridge rails are composed of two intermediate guide rails in the middle, and the middle guides are already in the models. Therefore, all that it is necessary to do is to create a component exposing only the middle guides and hide the rest of the parts.

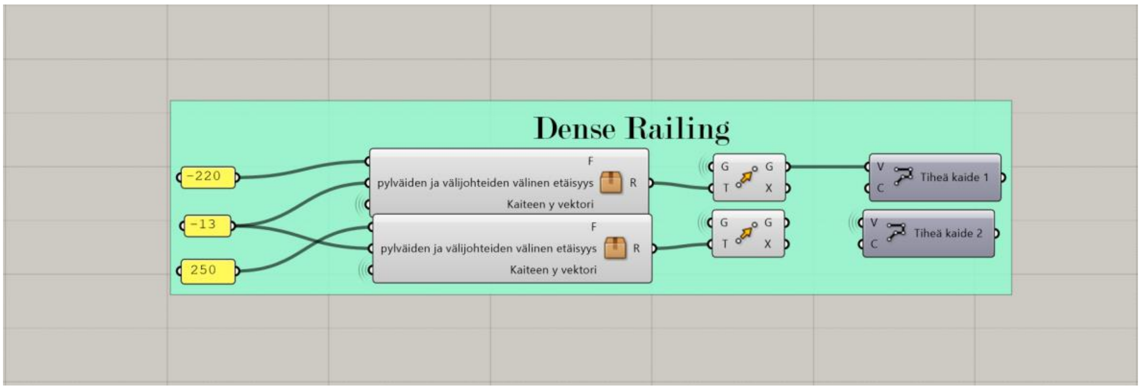

Figure16. Dense bridge with Grasshopper components

When modelling bridge railings, among other considerations is the angle of rotation for some elements that may vary with the curvature of the bridge; for example, the rotation angles of the columns and base plate could change if the bridge is curved, as shown in Figure17. This requires a special algorithmic script to be created to adjust the angle of rotation to the degree of bridge curvature, such that the angle of rotation is consistent with the direction of the bridge road. Figure17 and Figure18 shows this modification in greater detail.

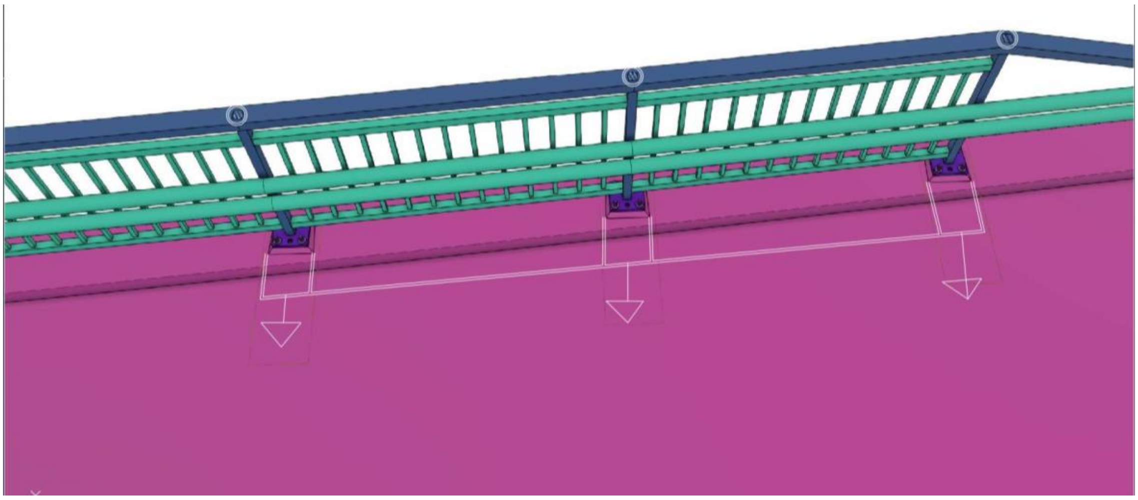

Figure17. Rotation angle for bolts, base plates, and posts in the wrong direction

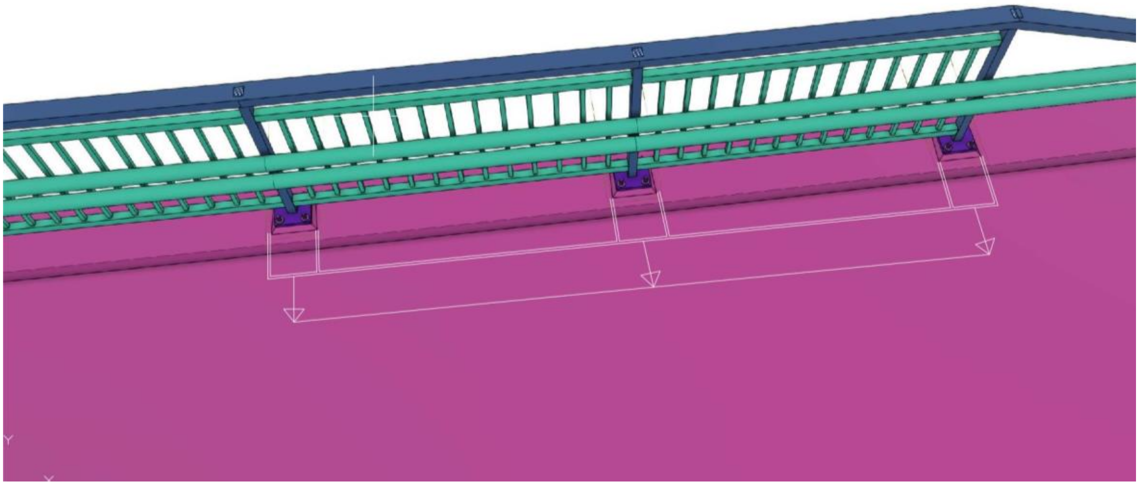

Figure18. Rotation angle for bolts, base plates, and posts in the correct direction

At this point, the modelled bridge railings appear as shapes in Tekla (accessible from the catalogue menu) to be used at the end of the project. To import the shapes saved in Tekla to the parametric model, the item component is used and the name of the desired shape is inputted into the profile entry.

After creating all the algorithmic scripts required to model slatted and dense bridge railings, an algorithm is needed that connects the rails to the edge beams of the bridge. To identify the contact points between the bridge rails and the edge beam, scripts are created that can automatically move the rails 200 mm from the inner side of the edge beam to the outer side. To test these scripts in Tekla, two lines are drawn along the beam edges and then exported to Grasshopper using the line component in the Tekla component bar. After connecting the lines to the algorithms, the algorithms automatically install the bridge rail in the correct position, as displayed in Figure18.

After adjusting the parametric model, an algorithmic script is added that compiles all the various bridge rails that have been modelled. This script allows the user to select the rail type needed for the project by simply clicking on it, without having to make further modifications to the parametric model, as shown in Figure 19.

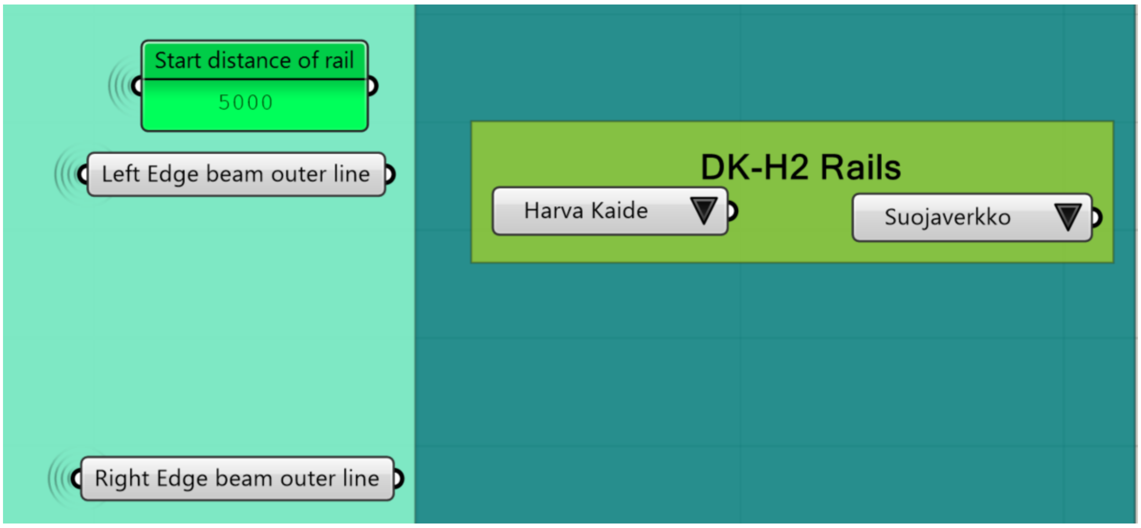

Figure19. Grasshopper components for selecting the type of bridge railings in Grasshopper

7.4 Testing the Parametric Model

Although the programmes used in this thesis allowed the outcome of the algorithm to be visualised step by step during its development, the algorithm had to still be tested upon completion of the parametric model to ensure that all the elements and compounds function properly. Therefore, two tests with different input data were conducted to verify the barrier model. The tests aimed to uncover possible mistakes in the parametric model. They focused on the following observations:

1. The ability to model the rails of curved bridges while keeping the rotation angles of some structure's constant.

2. The proper cut of the base plate according to the plane specified in the parametric model.

3. The validation of rail distances using parametric input.

4. Ensuring the rails modelled on the two sides of the bridge are similar, such that the visible parametric input on the right side is identical to that on the left side.

7.4.1 Test 1

First, Tekla Structures was opened, followed by the parametric model; Grasshopper cannot be opened before Tekla Structures when modelling with the former. In this test, the surface of a bridge was appended with different parameters to conduct the rail experiment.

The input required to perform the test was divided into two sections: a section on the rails, as shown in Figure20, with input components to connect the edge beam lines, as well as the starting distance of the barrier. The other section contained the parameters of the bridge on which the test was conducted.

In the test, the bridge was modelled on a straight line with a length of 40000 mm and width of 12815 mm. The starting and ending distances of the rails were 1000 mm and 6400 mm, that is, the modulation of the rails over the bridge start at 1000 mm and end at 6400 mm. The experiment in the first test was conducted on the slatted bridge railing. (Figure21)

Steel grade S355J2 for the slatted bridge railing structural members and profiles were used with the following values:

- Posts - PL50*60
- Base plate - PL_V330*330-210*210
- Middle guides - PD88.9*4
- Bolts - R115_DK_H2_pulttikiinnitys
- Top guides - U114*55*6

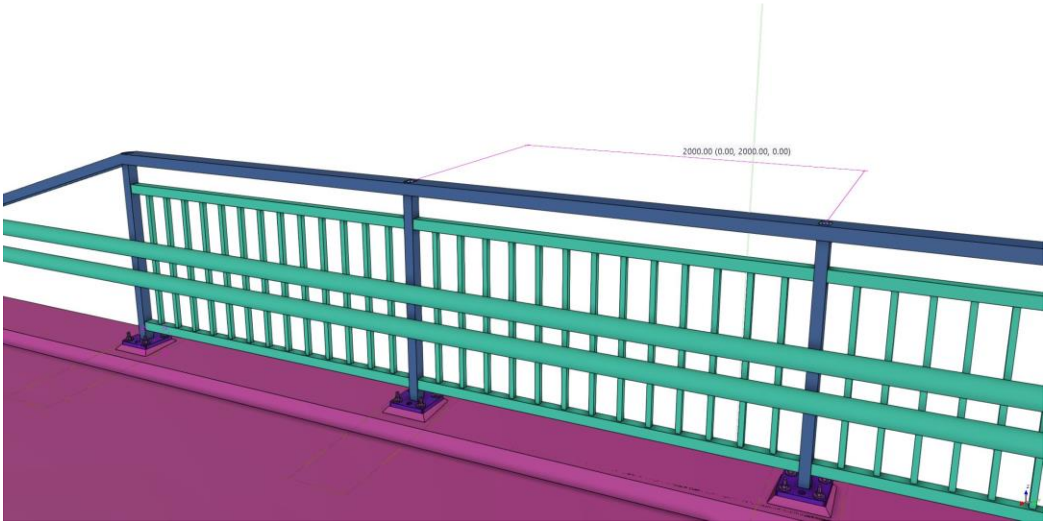

Figure20. Tekla Structures output from Test 1

7.4.2 Test 2

In this test, the bridge was modelled on a curve with a length of 50805 mm. and width of 12815 mm. The starting distance of the barrier was 1000 mm. The purpose of the test was to conduct the experiment for the dense bridge railing.(Figure21)

Steel grade S355J2 was chosen for dense bridge railing structural members and the profiles with the following values were used:

- Posts - PL50*60
- Base plate - PL_V330*330-210*210
- Middle guides - PD88.9*4
- Intermediate guide 1: PD76.1*4 PD48.3*2.6
- Intermediate guide 2: PD48.3*2.6
- Bolts - R115_DK_H2_pulttikiinnitys
- Top guides - U114*55*6

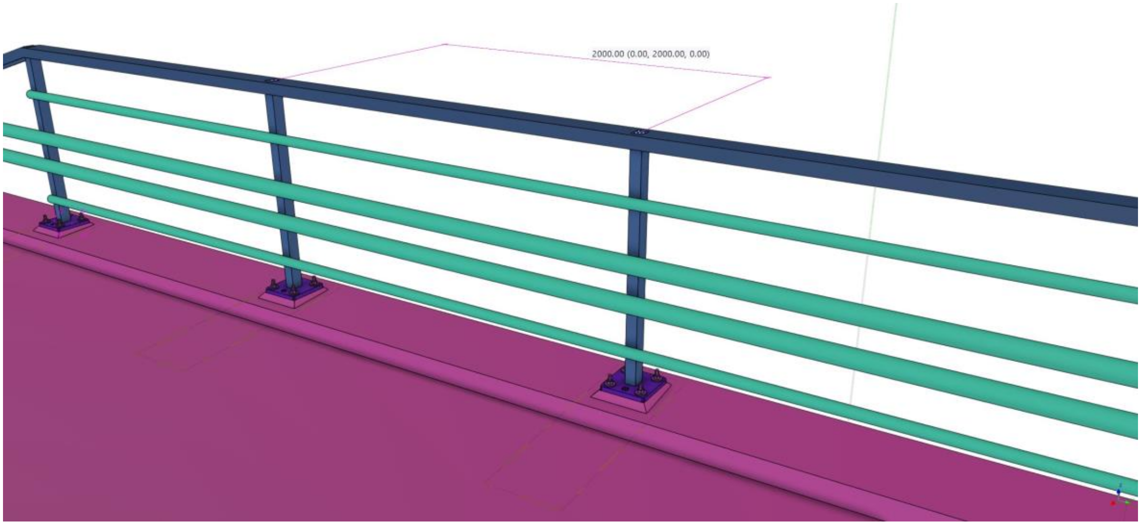

Figure21. Tekla Structures output from Test 2

Having confirmed the viability of the rails under all the circumstances mentioned, it can be concluded that the two tests indicate the production of a successful file.

8 Conclusion

The thesis' objective of creating a parametric model for DK H2 bridge rails has been realised. The model is ready for use as a separate tool that can be used in bridge projects when creating a DK H2 bridge railing. The user can define the type of rails, adjust some of the profile's cross-sections, and select the appropriate materials. The tests conducted on the model indicated no errors were present, thereby allowing the accurate generation of a structure consistent with the intended design. Nonetheless, while the model contributes to the possibility of increasing the number of bridge rails in future development projects, the many options and specifications that must be considered when modelling various rail types may hinder utilising such a parametric model. In this regard, the shortage of resources and research in the field of parametric modelling affected the implementation of this project, including the shortage of studies on Grasshopper and Tekla Structures in the infrastructure area.

It is also evident that parametric modelling initially takes longer than traditional approaches due to the large amount of information linked to the algorithm. Eventually, however, more complex and diverse models result in the parametric approach providing quicker and more accurate design solutions because any changes to the inputs of the parametric model modify all the other aspects and elements of the design, especially in large-scale projects. Conversely, in traditional methods, the designer must change each part manually. Overall, therefore, parametric modelling effectively produces design solutions that save time and effort in modelling a wide range of complex design constructions and extensive projects.

8.1 Further Use and Development

As previously mentioned, the Grasshopper algorithm can be further evolved into a more detailed and complete definition, which includes structural analysis and more flexible possibilities.

In this model, rails are imported directly from Tekla Structures with ready-made measurements that cannot be adjusted; for example, the distance between the rails is not subject to modification in the parametric model. In future projects, while adding more details to the parametric model may represent a major challenge, it will also provide the user with more flexibility in choosing the appropriate rails for a bridge project.

8.2 Final Thoughts

Recent navigations: During this thesis, it became clear that the use of parametric models provides a solution for designing bridge rails with curvatures in three spatial directions. This modelling approach not only saves considerable time, but also provides a way to centralise all the information about a single project in a single 3D model. This centralisation makes exchanges between the participants more flexible, more understandable, and faster. As a result of the large amount of data contained in the parameter file and details that fit all types of bridges, it is possible to use the file in a large number of projects and to make major design adjustments.

However, one of the aspects that limits the pace of development in this area is the absence of a knowledgeable hand in such a design approach, which reduces the desired benefit of the of this approach in modelling. What may also be considered a stumbling block for new users, may is the difficulty of reading algorithmic scripts that are not clearly arranged, thus, sometimes forcing users to rewrite those script from the beginning.

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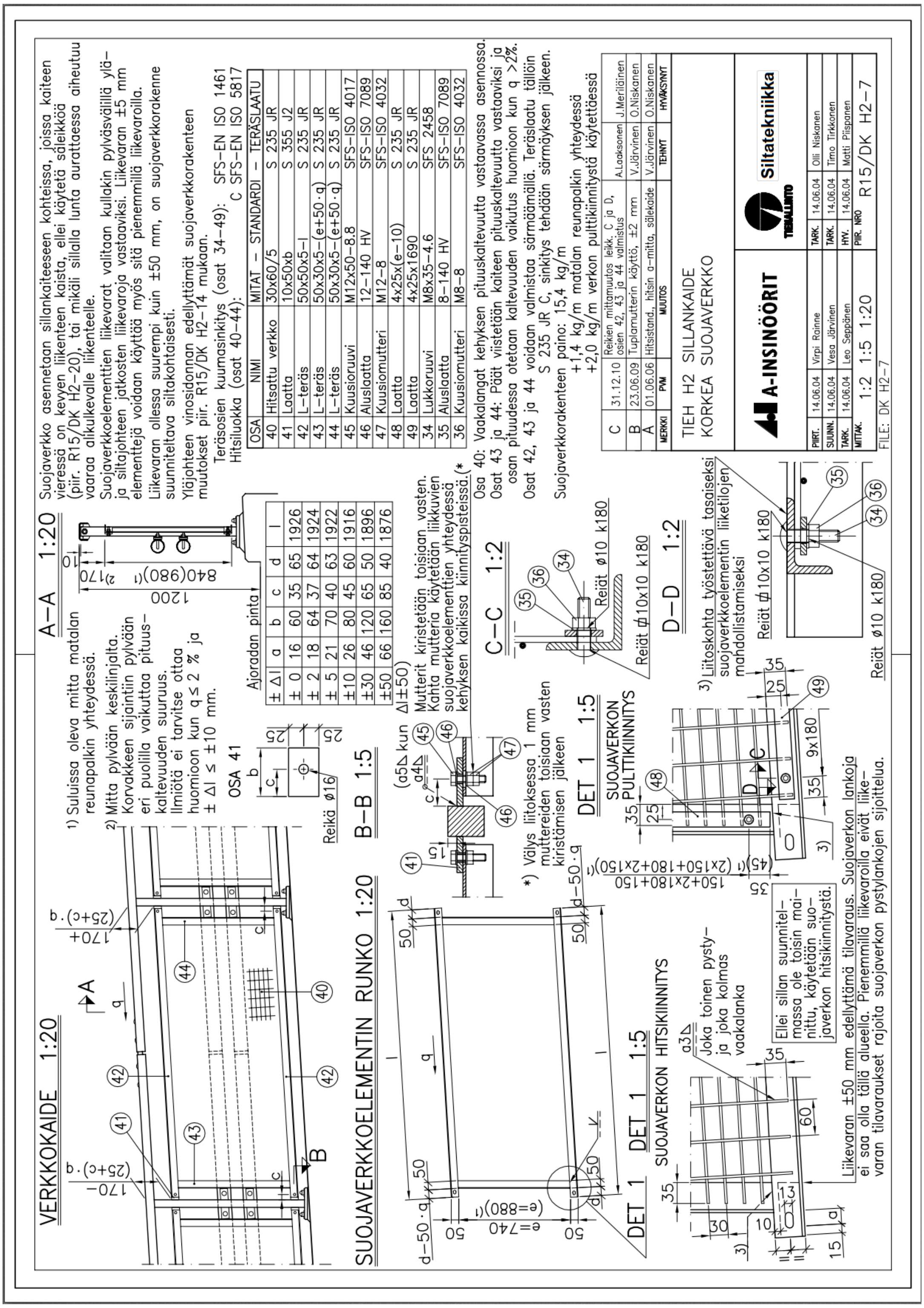
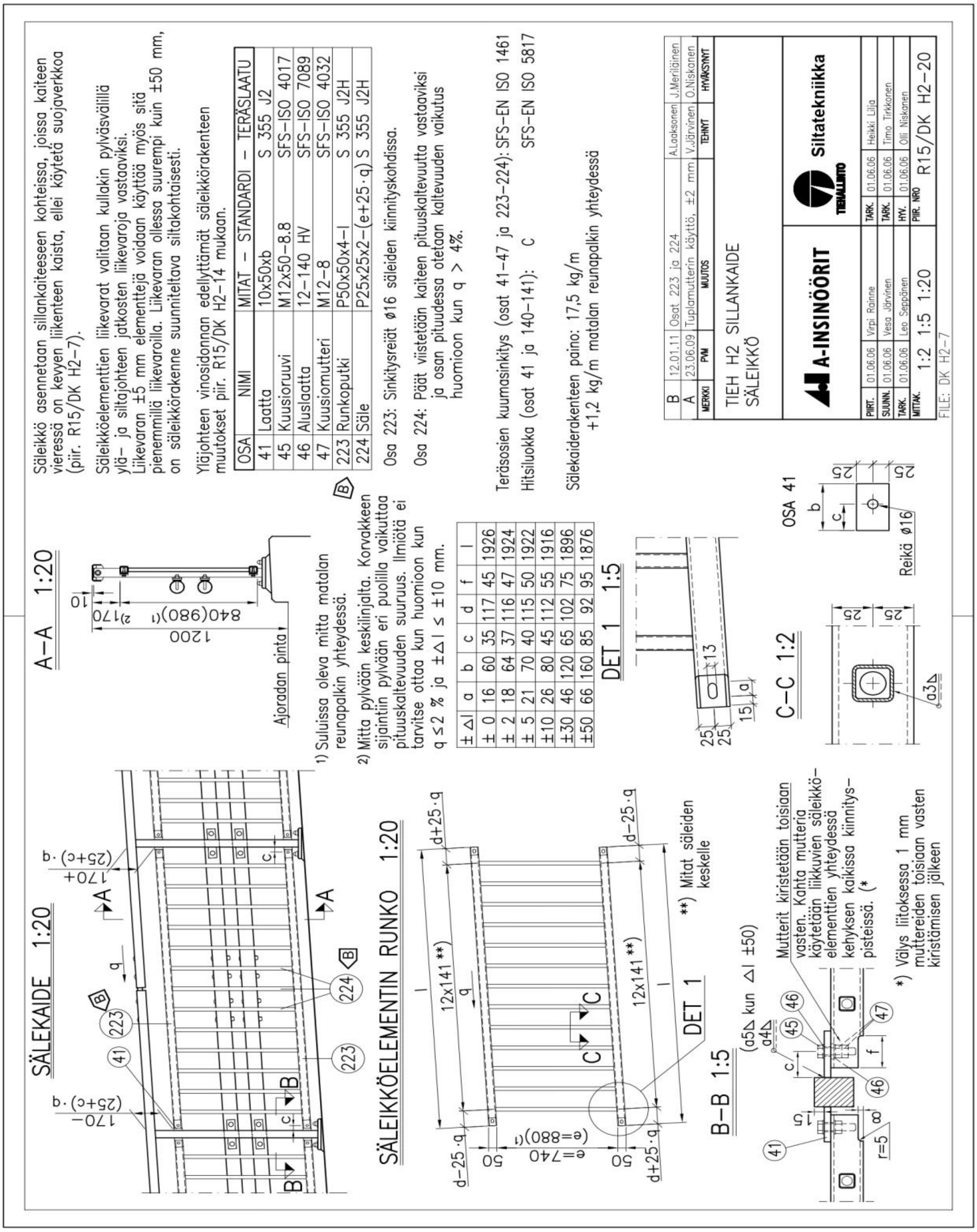
Appendix 1 Standard drawing of R15/Dk



Appendix 2 Standard drawing of R15/Dk H2-1 Slatted railing



±Δl	a	b	c	d	f	l
± 0	16	60	35	117	45	1926
± 2	18	64	37	116	47	1924
± 5	21	70	40	115	50	1922
±10	26	80	45	112	55	1916
±30	46	120	65	102	75	1896
±50	66	160	85	92	95	1876

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU
41	Laatta	10x50xb S 355 J2
45	Kuusioruuvi	M12x50–8.8 SFS-ISO 4017
46	Aluslaatta	12–140 HV SFS-ISO 7089
47	Kuusiomutteri	M12–8 SFS-ISO 4032
223	Runkoputki	P50x50x4–l S 355 J2H
224	Säle	P25x25x2–(e+25·q) S 355 J2H