FINAL REPORT

Tekla Structures - 3D Optimisation Project (Phase IV)

Prepared by group 10:

TERRY WANG : 500495108
ARIELLA ZHAO : 500521119
JOSHUA LING : 510468017
ZEEZHAN ANSARI : 510370813
ZHE SUN : 490051469

Document Control

Document Name:	Tekla Structures – 3D Optimisation Project (Phase IV)
Document ID:	JFC - 10
Document Status:	Final
Version Number:	4.0
Authors:	Terry Wang Ariella Zhao Josh Ling Zeeshan Ansari Mark Sun
Document owner:	Jacaranda Flame Consulting - Group 10
Client	Hanlon Industries
Approved By: **Position:** **Signature:**	Anthony Dumbrell Project Supervisor Jacaranda Flame Consulting
Date of Issue:	6/02/2024
Update Details:	Draft 1
Last Updated by:	Jacaranda Flame Consulting - Group 10
Issued By:	Jacaranda Flame Consulting
Conflict of interest:	The authors declare no conflict of interest

Acknowledgements

Anthony Dumbrell	-	Project Supervisor (JFC)
Dean Talbot	-	Head of People & Growth (Hanlon Industries)
Dustin Popp	-	Steel Detailing Manager (Hanlon Industries)

Restrictions

This report can only be given to and accessed by any Hanlon Industries personnel and any JFC employees who have signed the Non-Disclosure Agreement with Hanlon Industries. Those contain the following groups:

- Phase 1 JFC
- Phase 2 JFC
- Phase 3 JFC
- Phase 4 JFC
- Future JFC groups or any other engineering professionals who are given access by Hanlon Industries.

The contents of the project that are restricted to the aforementioned group are as follows:

- Source code material (Phase IV)
- Final report (Phase IV)
- Technical report
- Technical documentation (Phase IV)
- User documentation (Phase IV)
- Updated application (Phase IV)
- Final presentation (Phase IV)
- Phase I, II and III materials

Table of Contents

Executive Summary

Further development of autonomous BIM software has been requested by Hanlon Industries and will be utilised to shorten the drawing time required for billboard production. This report describes the nature and progression of this work, more specifically, the integration of existing features from prior iterations into a curved billboard design.

Outlined in the project scope, the key developments have been encompassed by the major in-scope objective “to integrate all current features for curved billboards”. Following this, the key developments of this project include progressing an autonomous program that now generates a curved billboard model. This features:

- Basic box construction consisting of curved horizontal beams, columns, top bracing and side bracing
- Walkway knee rails, handrails, and trimmers
- Camera arm
- Curved walers
- LED screen panels
- Seating plates and Z brackets

It must be noted that the program is not fully fledged and thus generates several drafting discrepancies for extreme input cases.

Recommendations to be considered for future optimisation of work include:

- Prioritise refactoring the entire code base for optimisation and modularity
- Develop methods to account for highly variating design features such as back bracing, ladders and hatches for curved billboards
- Implement UI changes that improve efficiency and ease of use. Opportunities evident in elements such as dropdown menus, categorisation tabs and colour coordination.
- Amend all code bugs found in flat billboard generation.

By considering these recommendations, there will be noticeable usability improvements as well as reducing time spent troubleshooting. This will in turn reduce the time attributed to manual draftswork which will further streamline the business’ operations.

1. Introduction

A plugin program for Tekla Structures had been developed by previous groups from Jacaranda Flame Consulting to aid Hanlon Industries in designing and scaffolding their digital and static billboards. The C# program integrated with Tekla Open API to allow for autonomous communications with the modelling software (Tekla Structures), to streamline the process of modelling billboards. The objective of Phase IV is to further develop and implement the functionality of modelling curved billboards to the plugin program.

1.1 Background

Drafting of steel billboards takes between one to two weeks on average, depending on the intricacy and size of the supporting structure for the LED screens, as well as the drafter's expertise and familiarity with the Building Information Management modelling software (Tekla Structures). This meant the entire manufacturing process for each billboard was prolonged due to the excessive manual work required to model a structure. The solution Hanlon sought involved creating a tool for Tekla Structures to automate parts of the modelling process for each billboard design and shorten the time required for this phase of their billboard production process.

C# was the programming language used to develop this application, alongside the Tekla Open API. C# is a high-level language that is commonly used to develop applications similar to Javascript. It is also the supported language for the Tekla Open API, which offers an interface that enables applications to communicate with models, objects and properties within Tekla Structures. This provides users with the capability to modify their design in Tekla Structures in specific ways related to their project, speeding up the modelling process of a design.

2. Project Overview

2.1 Overview

The project is the 4th phase to continue the evolution of the program of 3D billboard models in Tekla Structures for Hanlon Industries. In the previous phases, a model was created to allow users to easily customise their billboard structures. By utilising an Open API plug-in application for Tekla Structures and developing a C# program coding that seamlessly integrates with the modelling software, a 3D model of the customised billboard structure can be autonomously generated in Tekla Structure. The model generation program significantly reduced the original time required to design the steel structure for billboards. Further improvements are expected in Phase IV of the project to simplify and enhance the process of creating and drafting billboards for Hanlon Industries.

2.2 Background Knowledge

The JFC team consisted of multidisciplinary members with various engineering backgrounds and skills. Tekla Structures, Tekla Open API and C# programming are new technologies for the team. Several days were spent learning about these new tools, Hanlon Industries, and the steel fabrication industry. A few members come from a coding background and some members come from a stronger mathematical background which helped with developing Phase IV of this product.

2.3 Project Scope

In scope:

- **Integrate all current features for curved billboards** - curved billboards are now a trend in the billboard manufacturing industry. A complete integration of all existing features is required which may require mathematical modelling to ensure all functions can be easily migrated to accommodate curved billboards. This would probably be achieved by developing a separate application since modifying the current application may cause a lot of existing functions to break.

In-between scope:

- **2D braced fascia frame** - although completed in Phase III, this requires optimisation for accuracy when placing bolts
- **Galvanising holes for enclosed steel members**
- **Explore and implement further User-interface improvements** - The software's user interface still has room for improvement. A real-time change reflection on the UI page is required for future versions to enhance the billboard design and modelling process.
- **Back bracings** - was started in Phase III but not fully completed due to the diverse styles of bracing and measurement. Will need to fix on endpoints placement and cutting planes insertion.

Out of scope:

- **Refactor the entire code base for optimisation and modularity for future development** - A well-structured codebase is the backbone of any robust software. As the program's features grow, there's an imminent need to optimise and modularise the code to ensure easy maintenance, quick troubleshooting, and efficient future developments.

2.4 Success Criteria

Below is the proposed success criteria for this project, with a main success criteria and a secondary criteria that is made up of items in-between and out of scope.

Main criteria:

- **The current software features successfully implemented for curved billboards without compromising their performance and functionality for linear billboards, as well as without increasing the drawing time required for:**
  - Horizontal and vertical Beams
  - Side bracing
  - Back bracing
  - 2D braced fascia frame
  - Installation of ladders
  - Installation of hatches
  - Camera arm
  - Billboard box rear door

Secondary criteria:

- **Rework time reduced by successfully performing several bug fixes:** Bug fixes must be performed without compromising the functionality of other sections/features of the program (i.e. without creating new bugs). Bugs fixes are listed below:
  - Improving accuracy when placing bolts for a 2D braced fascia frame
  - Correcting endpoints placement and cutting planes insertion for back bracings
  - Correcting placement of galvanising holes for enclosed steel members
  - Changing default option for Galvanising Holes to “none”
  - Correcting top and bottom cuts on diagonal bracing to include 1mm clearance for welding
  - Correcting ladder dimensions to be to the back of ladder rung (as described in “Box Program Bugs (1).pdf”
  - Correcting walkway mesh input not being filled
  - Correcting unknown bug where Tekla restarts but box program stays open when build is pressed
  - Correcting walkway mesh EA support clearance dimension inaccuracy
  - Correcting parts in model not correctly named

- **Improving the UI in a meaningful way:** Enhancing the usability of the app interface in terms of ease of access and being easy to understand for both new and experienced users. UI improvements:
  - Intuitive colour coding
  - Intuitive dropdown menus
  - Intuitive functional grouping
  - Removing loops for error messages

2.5 Familiarisation with the Previous Phases

Tekla Structures is a building information modelling (BIM) software designed to create 3D models primarily focused on steel and concrete constructions. This powerful software enables users to specify materials, fittings, and other components within the program itself. In the Tekla Billboard Aid Program context, user input for various parameters is utilised alongside the Tekla Open API to generate a model within Tekla Structures.

A fundamental understanding of the Tekla software and API was necessary to complete the project. During Phase I, the program was developed using C# since it is the supported programming language for the Tekla Open API. The project team collectively learned the basics of C#, reviewed the source code of the Phase I software, and familiarised themselves with Tekla Structures. In Phase II, some new features were added to the program, including a fascia box, walkways, and camera arm but also refactored the entire code base for modularity and future developments. In Phase III, more new features were added, including box assemblies, rear doors, ladders, hatches, and side bracings. Besides, several features including the 2D braced fascia frame and back bracings were developed but not completed.

The development of new features in Phase IV relied on engineering drawings provided by Phase I, II and III teams. Additionally, reference documents such as specification tables for materials and components and relevant standards were consulted to ensure accuracy and compliance. In Phase IV, more features are added to the straight billboard and the method of generating curved billboards in Tekla Structures is developed. Detailed scopes of Phase IV are shown in the scope section. Those adding features can help clients to have a clear image of the performance of billboards.

Overall, the project required a combination of expertise in Tekla Structures, C# programming, and close examination of engineering drawings and specifications to enhance the functionality of the software and meet the desired objectives of the Tekla Billboard Aid Program.

2.6 Project Deliveries

Deliverables consist of materials and products that will be available for the client at the completion stage of the project.

- Updated and executable Tekla Billboard Aid software
- Updated program source code
- Tekla Billboard Aid user documentation
- Tekla Billboard Aid technical documentation
- Final report

- Final presentation

2.7 Benefits

In this project, the improvements to be made on the Tekla billboard aid plugin will allow Hanlon Industries to draft 3D models of curved billboards, and flat billboards with increased accuracy and consistency. This can significantly reduce the initial design and drafting time required for both flat and curved billboards and subsequently improve business by enabling Hanlon Industries to provide their products and services more consistently and efficiently.

The program will generate dimensionally accurate curved models on top of also being able to generate dimensionally accurate linear models. This eliminates human error and saves time in initial drafting for curved billboard designs. The program will also allow the user to generate curved and linear models in the same Tekla project, which the user can connect to form more complex shapes for contexts such as a corner curve billboard.

2.8 Assumptions

These assumptions aim to assist in defining the project scope:

- **Only horizontal members are curved:** Curved billboards will only curve about the vertical axis, thus all vertical members like columns will remain linear.

- **Ladders and hatches should remain straight:** Related to the assumption above, ladders and hatches should not curve, and should be integrated in such a way that allows for it to be linear. Regarding ladder safety standards, we assume Hanlon Industries owns a copy of “AS 1657-2018 Fixed Platforms, Walkways, Stairways and Ladders - Design, Construction and Installation” safety standards.

- **Side bracings should remain straight:** Since the cross section of the billboard is flat in the vertical plane and the vertical beams are relatively thin, they do not need to be curved.

- **The user is knowledgeable:** Tekla Structures is aimed for professionals in the industry, thus we assume the end-user has a sufficient understanding of Tekla Structures as well as billboard design, including the specific parameters, beam/columns types, materials and bolts. Again, regarding ladder safety standards. While familiar with AS1657:2018, we assume the compliance with the standard is to be left to the design engineer.

- **The total height and length of the billboard is equal to the sum of the values added for rows and columns:** Each row added extends the billboard's height, and each row added will extend the billboard's width.

- **The Billboard only curves outwards (Convex):** A curved billboard should only be curved in such a way that the viewing side of the mounted LED screen is convex.

2.9 Key Stakeholders

The project involves several key stakeholders who will be impacted by or have influence over the project outcomes. Identifying and understanding these stakeholders is important for effective stakeholder management.

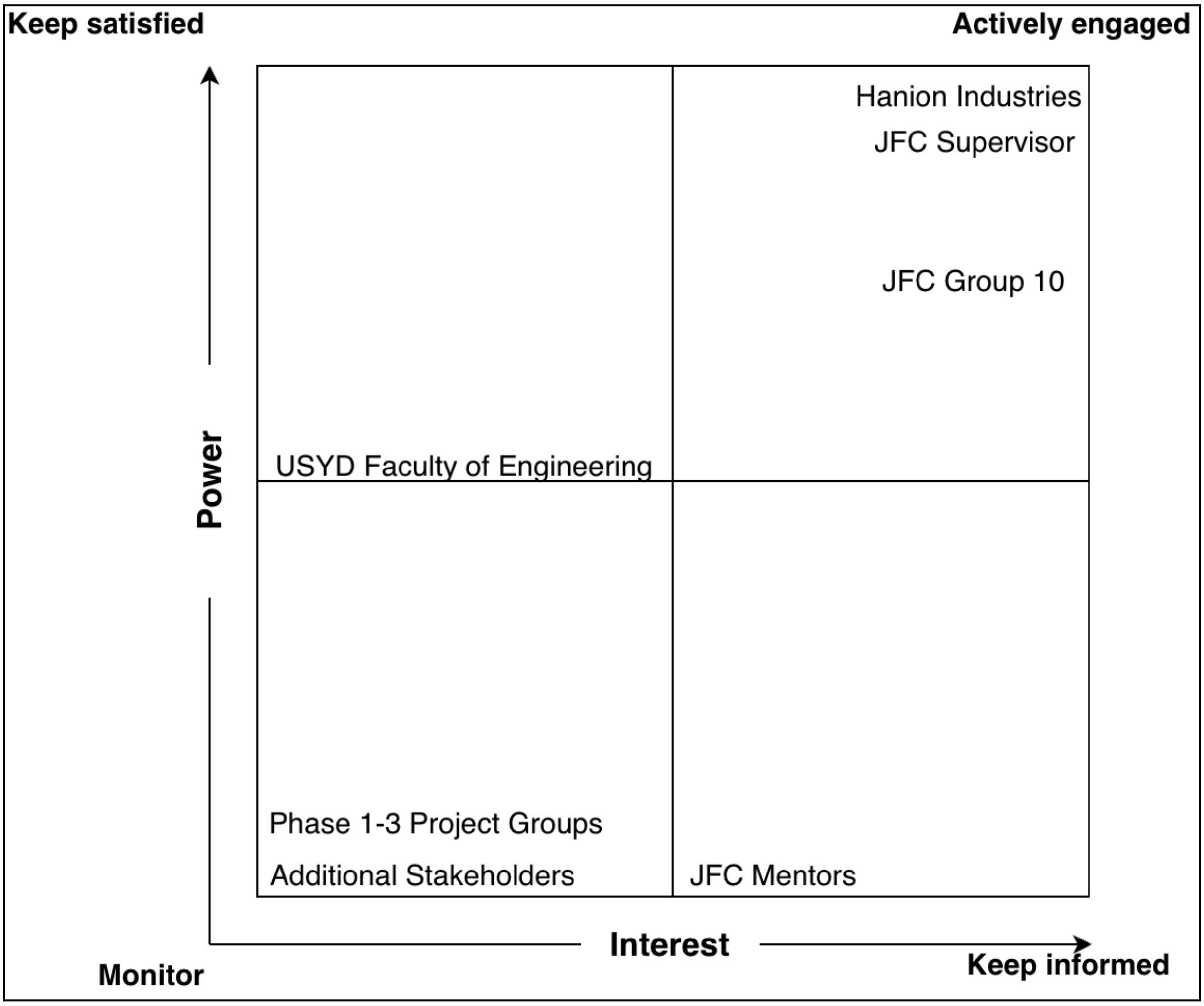

Figure 2.9.1: Stakeholder Matrix

Hanlon Industries

As the client, Hanlon Industries plays a very active role in defining project goals and scope. Their needs and requirements are the main drivers of the project. Ensuring high-quality deliverables that meet their needs is a top priority.

JFC Supervisor

The JFC Supervisor oversees the overall project progress and provides guidance to the project team. They help navigate any challenges and make decisions that impact timelines and deliverables.

Group 10 Project Team

The project team is responsible for implementing the project plan and delivering the agreed-upon outputs. Good communication and collaboration between the team members is essential for success.

Phase 1-3 Project Team

The work done in previous phases provides context and foundations for Phase 4. The previous teams offer important insights into features developed, lessons learned, and ideas for future enhancements.

JFC Mentors

JFC mentors lend their expertise and industry experience to advise and support the project team. They provide an additional perspective to draw from when challenges arise.

USYD Faculty of Engineering

As an educational institution, USYD has an interest in the project outcomes for learning purposes. They also provide resources and oversight to ensure project quality.

Additional Stakeholders

Others with interest in the project outcomes include future client employees using the software, steel fabrication suppliers involved in billboard production, and regulatory bodies establishing standards for outdoor structures. While less involved than the above stakeholders, their considerations are also factored in.

2.10 Cost

It is deemed that the client, Hanlon Industries, does not take on any additional product costs as educational licences are provided for JFC consultants and it is assumed that Tekla Structures is already accessible by the client. In addition, the project is being integrated into the organisation's operations and does not induce any costs for operational and maintenance means (Tekla Open API). JFC consultants have been engaged to streamline the drafting process and are not involved in the material fabrication or construction stages, thus incurring no financial cost for this stage of work.

Activities/Deliverables	Due Date	Cost
N/A	N/A	N/A
TOTAL		$0

Table 2.10.1: Cost Table

3. Methodology

To take full advantage of the work done in previous phases, we prioritised getting familiar with the source code, technical documentation and user documentation from Phase III. This allowed us to plan an appropriate approach for developing features of modelling curved billboards in Phase IV. The nature of this project means that it is subject to constant change. We need an approach that allows us to adapt to changes and make changes with no compromises to budget, time and functionality, thus we have decided to follow a spiral model as shown in the figure below.

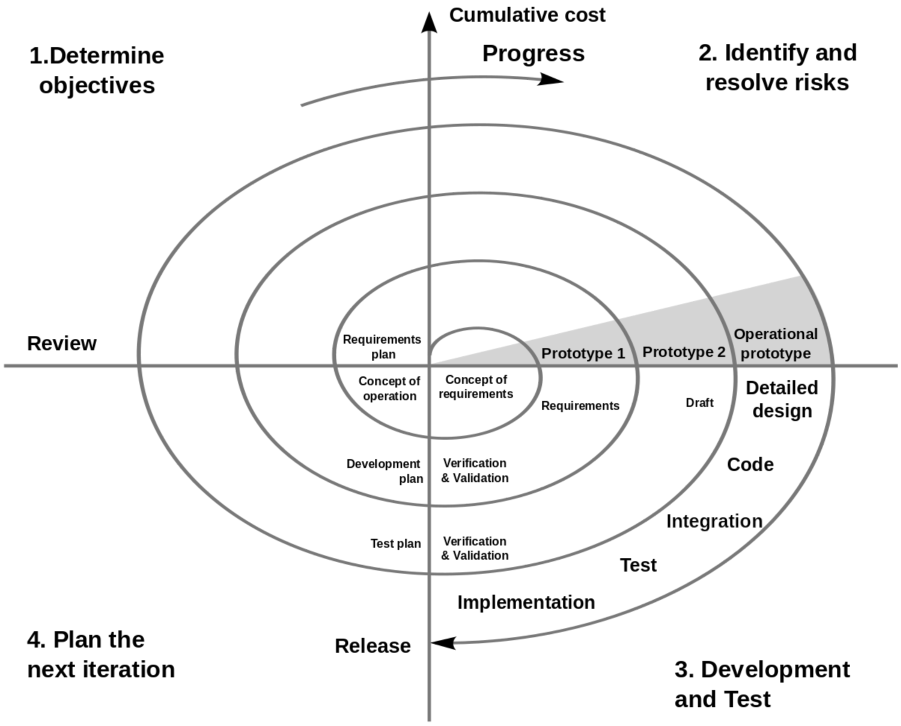

Figure 3.1: Spiral Model For Project Management

3.1 Milestones

Project milestones are described below.

Curved Box Assembly

- Following on from the box assembly approach adopted during Phase III, Phase IV has created a curved box assembly class using Tekla Open API. This enables the plugin to automatically generate curved billboard box assemblies with custom components such as C1, C2 columns and B1, B3 beams.
- Includes varying horizontal primary and secondary beams as shown in figure x. The horizontal secondary beams tilt accordingly with the curve to minimise welding gap error.
- Includes equidistant curved Walers constructed with B1 beams. The quantity of Waler beams is set by the user.
- Horizontal columns tilt relative to the curvature of the box assembly to allow for flat or another curved billboard to be aligned for manual attachment.

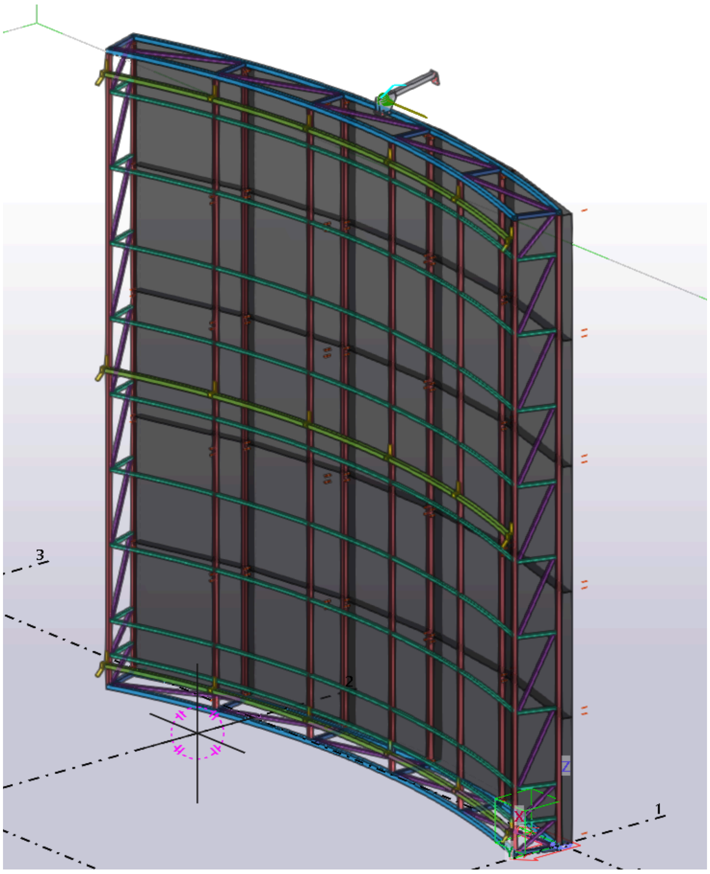

Figure 3.1.1: Curved box assembly

Side bracing

- Side bracings are constructed using B3 beams between each horizontal secondary beam.

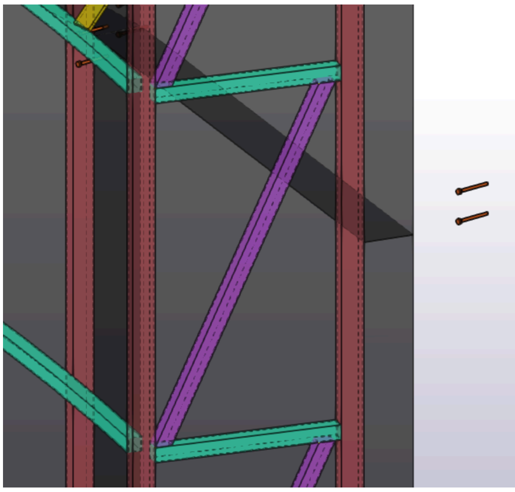

Figure 3.1.2: Side bracings on box assembly

Walkway Railings

- The spacing for the knee rails and handrails are set to constant dimensions complying with clause 5.6.2 in the AS1657:2018 standards.Trimmers are divided equidistantly depending on a max length set by the user.

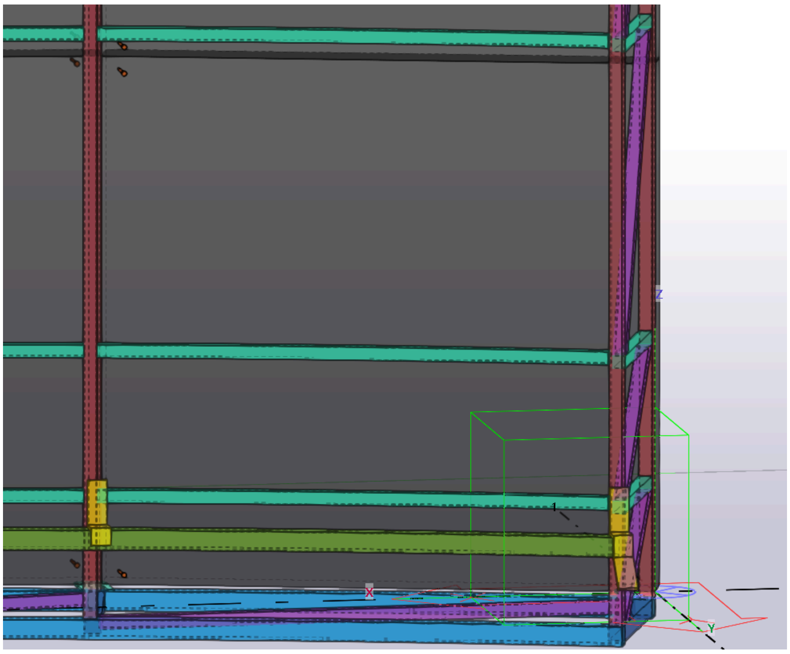

Figure 3.1.3: Knee rail, handrail and trimmers

LED Clearance and seating plate

- The height offset at the top and bottom of the billboard for LED screen clearance is set by the user. The seating plate thickness does not need to be considered within the billboard's bottom offset.

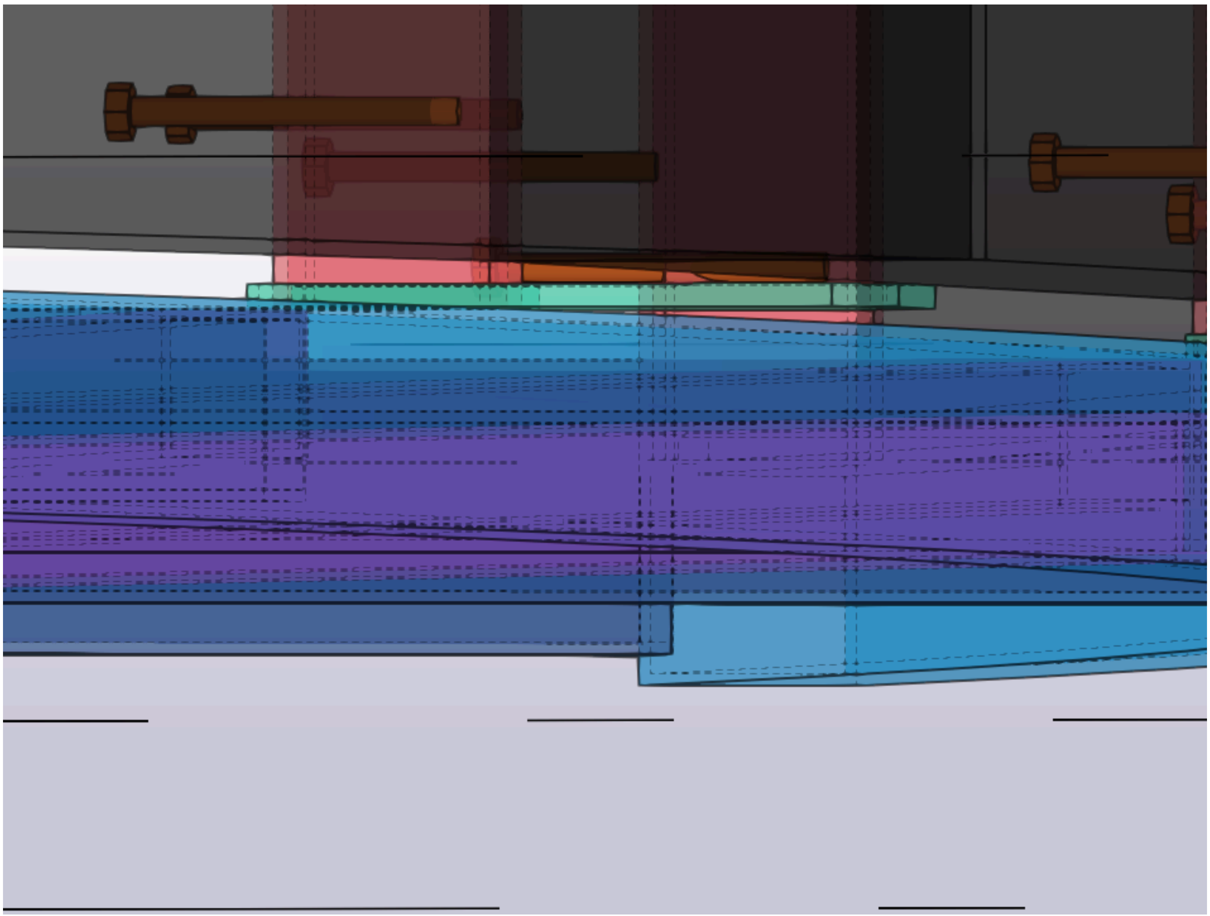

Figure 3.1.4: Height offset and seating plate

3.2 Model Validation

A validation process was implemented to validate the accuracy and fidelity of the models produced by the Tekla Billboard Aid Program. This involved generating models using the program and inputting the dimensions obtained from the engineering drawings provided by the client.

Prototype 1: Basic curved box
A basic box with curved horizontal beams to form a curved billboard box.

Prototype 2: Side bracing and vertical column tuning
Includes Side bracing beams and vertical columns that tilt accordingly to the curve

Prototype 3: Walkway
Includes walkway knee rails, handrails and trimmers

Prototype 4: Waler & LED screen clearance tuning
Includes knee rails, handrails and trimmers for walkways and curved walers.

4. Challenges

The challenges and limitations of developing the Tekla Structure plug-in software are illustrated in this section.

Unfamiliar Technology

Only 2 out of 5 members of our team have experience coding in the past, thus, they are the only members who have a deep understanding of the code and coding design. As this project is entirely coding-based, the lack of technology familiarisation significantly affects our productivity.

Adaptability of Hardware to Software

Some of our team members do not have a Windows laptop, while Tekla Structure can only be accessed by the Windows system. Therefore, only 3 of 5 members are able to access the code and the software. This is also a major restraint to our productivity.

Time Constraint

9 weeks is insufficient to develop and implement all current flat billboard features for a curved billboard. This is due to the software (Tekla Structures) and C# being new tools for our team, as well as the complex nature of a curved billboard compared to a linear flat billboard.

Complex mathematical derivation

Since we are implementing features for a curved billboard, some challenging mathematical problems need to be solved relating to circular geometry.

5. Project Outcome

The project team has collaborated effectively to develop a functional program that significantly improved the efficiency of the operational process of generating billboard designs. The main planned feature of integrating all current features of the flat billboard into the curved billboard has been successfully implemented. Based on communication with the client, since the back bracing varies depending on the unique designs and the operation of manually adding back bracing in Tekla Structure is not complicated, the back bracing would not be allocated by the code. Besides, due to time constraints, 2D braced fascia frame, galvanising holes for enclosed steel members, exploring and implementing further User-interface improvements, and refactoring the entire code base for optimisation and modularity for future development cannot be completed in this phase.

Throughout the project, the team maintained regular communication with the client, providing weekly progress updates. This interactive feedback loop allowed us to incorporate the client’s input and ensure that their specific requirements were effectively addressed and met.

Achievements in further automatisation in Tekla Structures can improve efficiency, accuracy, and productivity by reducing manual efforts and streamlining repetitive tasks. Also, customisation in Tekla Structures allows users to adapt the software to their specific project requirements, industry standards, or company workflows. Moreover, developing curved billboard generation can adapt to the expanding requirements of more flexible billboard shapes. It facilitates a more efficient and user-friendly modelling and detailing experience.

6. Risks

RISK	RISK RATING	MITIGATION STRATEGIES	PRIORITY
Time: The project time frame is insufficient for achieving all the deliveries in scope	12	Set detailed milestones and deadlines to manage the workload and ensure all deliveries are achievable.	High
Manpower: The project team is not adequately staffed, or the responsibilities are unclear.	10	Allocate clear and specific tasks to each team member and set detailed milestones.	High

Hardware: Significant technical limitations. Eg. software does not operate in the OS, or has insufficient capabilities to download and operate the software.	20	Have a sufficient number of Windows system laptops or PCs. Find alternative software that can operate on Macbooks. Connect to external hard drives.	Extreme
Coding background: Unable to meet the requirements in scope or unable to finish the delivery within the deadline due to the lack of coding skills.	15	Complete LinkedIn Learning courses to ensure each team member has adequate C# programming skills. Go through the Tekla tutorials to become familiar with the use of Tekla Structures.	Extreme
NDA: Exposure of confidential content.	5	Make sure all team members sign the non-disclosure agreement (NDA). Never input detailed information into ChatGPT.	Medium

Table 6.1: Possible risks

7. Future Improvements

This section is dedicated to suggestions and future development directions for the Tekla Plug-in software, including incomplete tasks from Phases III and IV.

Integrate more features for curved billboards

While we have implemented the basic and main features of a curved billboard there remain several peripheral features that may also have a large impact on streamlining the development process. Features such as back bracing, ladders & hatches and galvanising holes.

Explore and implement further User-interface improvements

The software's user interface has been adjusted to accommodate curved billboards, however, it still has much room for improvement. Features like dropdown menus and colour coding can assist in decreasing clutter and improving the grouping of features.

Refactor the entire code base of optimisation and modularity for further development

A well-structured codebase is the backbone of any robust software. As the program's features grow, there's an imminent need to optimise and modularise the code to allow for easy maintenance, troubleshooting and efficient future developments. We think this may be a top priority if the intention is to further develop this software for the foreseeable future, as it will only become increasingly more difficult for future teams to add new features with the current codebase.

Perform bug fixes for flat billboard features

To ensure all existing features for a flat billboard are functional, unresolved bug fixes from Phase III still need to be addressed. Addressing these bugs may improve the user friendliness of the software as new users have fewer oddly specific things to be aware of.

8. Conclusion

This report has provided an overview of the Tekla Structures -3D Optimisation Project Phase IV completed by the Jacaranda Flame Consulting Team from the University of Sydney. The core deliverable of the project, the 'Tekla Billboard Aid', is a plug-in software that creates 3D billboard structures in Tekla Structures based on the essential design parameters specified in the user interface. Most of the inclusive features have been added and completed.

New features that have been added are:

- Curved billboard frame
- Curved billboard side and top bracings
- Curved billboard z brackets
- Curved billboard camera arm
- Curved LED screen
- Curved billboard knee railings, handrails and trimmers
- Systems of changing handrails, knee railings and trimmers distance
- Fixed the bug for the bottom distance (not including the sitting plate).

Overall, good progress has been made for in-scope features. However, due to time constraints, in-between scope features including galvanising holes for enclosed steel members and exploring and implementing future user-interface improvements were not completed. The in-between scope feature of generating back bracing was moved out of scope regarding the diverse styles of bracing and measurement as well as the simplicity of the manual process. The updated and executable Tekla Billboard Aid software, updated program source code, and Tekla Billboard Aid technical user documentation were successfully handed to Hanlon Industries. The software and related paperwork will increase the efficiency of billboard design and provide a solid foundation for future software implementation.

9. References

[1] AS1657:2018 Fixed platforms, walkways, stairways and ladders - Design, construction and installation. Standards Australia, 04/18/2018. https://www.techstreet.com/standards/as-1657-2018?product_id=2062147

10. Appendix

10.1. Risk Likelihood Rating

The likelihood rating was allocated based on the scale seen below in Table 10.1.1

LIKELIHOOD	CODE	DESCRIPTION
ALMOST CERTAIN	5	Expected to be the most likely outcome
LIKELY	4	Will probably occur in most circumstances
POSSIBLE	3	Might occur at some time
UNLIKELY	2	Not expected to occur in normal circumstances, but could occur.
RARE	1	Rare that this would occur - no previous occurrence in similar circumstances

Table 10.1.1: Risk likelihood rating

10.2. Risk Impact Rating

The risk impact rating was allocated based on the scale seen below in Table 10.1.2.

IMPACT	CODE	DESCRIPTION
INSIGNIFICANT	1	A risk event, should it occur, that will have little to no impact on achieving the desired result of the project.
MINOR	2	A risk event, should it occur, that will have a minor impact on achieving the desired result of the project.
MODERATE	3	A risk event, should it occur, that will have a moderate impact on achieving the desired result of the project.
MAJOR	4	A risk event, should it occur, that will have a significant impact on achieving the desired result of the project.
EXTREME	5	A risk event, should it occur, that will have a severe impact on achieving the desired result of the project.

Table 10.1.2: Risk impact rating

10.3. Risk Rating

The risk rating is calculated using the likelihood and impact ratings (i.e. risk likelihood x risk impact = risk rating) and rated as low, medium, high or extreme based on the range the rating was within as seen in Table 10.1.3 below.

RATING	RANGE	DESCRIPTION
E	15-25	**Extreme** – Immediate action required. Detailed control measures and responsibility specified.
H	8-12	**High** – Immediate action required. Detailed control measures and responsibility specified.
M	4-6	**Medium** – Control measures and responsibility specified.
L	1-3	**Low** – Manage by routine procedures.

Table 10.1.3: Risk rating

10.4. Risk Priority

The risk priority was allocated based on the scale seen below in Table 10.1.4.

PRIORITY	RANGE	DESCRIPTION
High	12-25	**Extreme** – Immediate action required. Detailed control measures and responsibility specified.
Medium	4-10	**Medium** – Control measures and responsibility specified.
Low	1-3	**Low** – Manage by routine procedures.

Table 10.1.4: Risk priority