ADAPTIVE PARAMETRIC MODELLING VIA GRASSHOPPER FOR SIMULATION OF THE ERECTION SEQUENCE IN LARGE-SPAN CABLE ROOFS: CORRELATION WITH DATA RECORDED DURING CONSTRUCTION

Andoni Borjabaz[*] **, Iñigo Hernández**[*] **, Javier Llarena**[*] **, Armando Bilbao**[*] **,**

and Ainhoa Solar[†]

[*] IDOM, Bilbao, Spain
Zarandoa Etorbidea, 23, 48015 Bilbao, Spain
E-mail: andoni.borjabaz@idom.com
Web page: https://www.idom.com/en/sector/science-technology/special-structures/

[†] IDOM Inc., Atlanta, USA
1375 Peachtree St NE suite 180N, Atlanta, GA 30309, USA

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Summary. *This paper presents a parametric modelling methodology for simulating the erection sequence of large-span cable roofs using Grasshopper and a structural analysis software. This parametric model is adaptable to different erection sequences, allowing for flexible simulation of various construction strategies. It was validated through application to real-world cases, including the Ciutat de València Stadium, and the simulation results were correlated with construction data.*

1 INTRODUCTION

Tensile and cable-supported structures have gained significant traction in modern architecture and engineering, especially for large-span roofs in stadiums and public venues. Their visual elegance, structural efficiency, and material economy make them an appealing solution for covering wide areas with minimal support.

A key advantage of cable-supported roofs is their reduced structural weight compared to traditional cantilever systems, particularly as the span increases.

Despite their structural benefits, cable roofs present considerable challenges during construction. The erection process involves a sequence of operations that must be carefully planned and executed to ensure safety and structural integrity. These systems exhibit highly nonlinear behavior and are extremely sensitive to the order in which elements are assembled and tensioned. An inadequate sequence may lead to excessive deformations, unbalanced force distributions, or even instability during construction. Conversely, a well-planned sequence can reduce the need for temporary supports, optimize the use of lifting equipment, improve coordination between construction teams, and shorten the overall construction time.

In this context, the ability to simulate and evaluate different erection scenarios becomes essential. Traditional simulation methods often lack the flexibility to accommodate the unique geometries and evolving constraints of each project. Parametric modeling tools offer a powerful

means to explore these alternatives efficiently, enabling the identification of the most effective and structurally sound sequence.

1.1 Objectives of the work

This paper introduces a methodology for simulating the erection sequence of cable roof structures, based on the use of a parametric model developed in Grasshopper. The core innovation lies in the adaptability of this model, which enables engineers to efficiently simulate various stadium configurations and construction scenarios. By integrating the flexible parametric model of Grasshopper with a structural analysis software, the methodology enhances the accuracy, speed, and responsiveness of erection simulations for complex tensile structures.

2   STATE OF THE ART

The simulation of the erection process in cable-supported structures is critical for ensuring both structural integrity and the feasibility of the construction sequence. These systems are highly sensitive to tensioning and geometric configurations, and the behavior of each structural element is closely influenced by the others. Therefore, accurate simulation is essential to predict the structural response at each stage of erection.

2.1 Overview of conventional simulation approaches

The simulation of the erection sequence has traditionally been approached using manual modeling techniques or finite element analysis (FEA) tools configured with predefined static load cases. These methods typically involve building a series of discrete models, each representing a specific stage of the erection process. Engineers manually define the geometry, boundary conditions, and loads for each step, often relying on spreadsheets or external scripts to manage the sequence.

Although these approaches can yield accurate results, they are generally time-consuming and require significant manual effort. Furthermore, they often lack integration between geometric modeling and structural analysis, resulting in fragmented workflows and limited feedback between design intent and structural performance.

2.2 Limitations of conventional simulation methods

The main limitation of conventional simulation methods lies in their lack of adaptability. Once a model is established, it becomes difficult to modify, which is particularly problematic during the early design phases when geometry and structural concepts are subject to frequent changes in response to client requirements.

Each modification, whether due to design evolution, construction constraints, or coordination needs, may require a complete rebuild or substantial reconfiguration of the model. This makes it challenging to explore alternative erection strategies or to respond quickly to changes during the design or construction phases.

Moreover, the lack of integration between modeling and analysis tools can lead to inefficiencies, inconsistencies, and missed opportunities for optimization, especially in complex projects where geometry and load paths are tightly coupled.

3   PROPOSED METHODOLOGY VIA PARAMETRIC MODELLING

To overcome the limitations of conventional simulation methods, a parametric modeling strategy has been developed to simulate the erection sequence of cable roof structures. While the overall workflow for defining and validating the erection process follows a structured and iterative logic, the key innovation lies in the adaptability of the parametric model itself.

The methodology is built around the use of Grasshopper, a visual programming environment for parametric modeling, and a structural analysis software. Grasshopper enables the creation of a flexible and modular model that can be easily adapted to different geometries, support conditions, and types of cable roof systems. This adaptability allows engineers to quickly reconfigure the model for various stadium designs without rebuilding it from scratch.
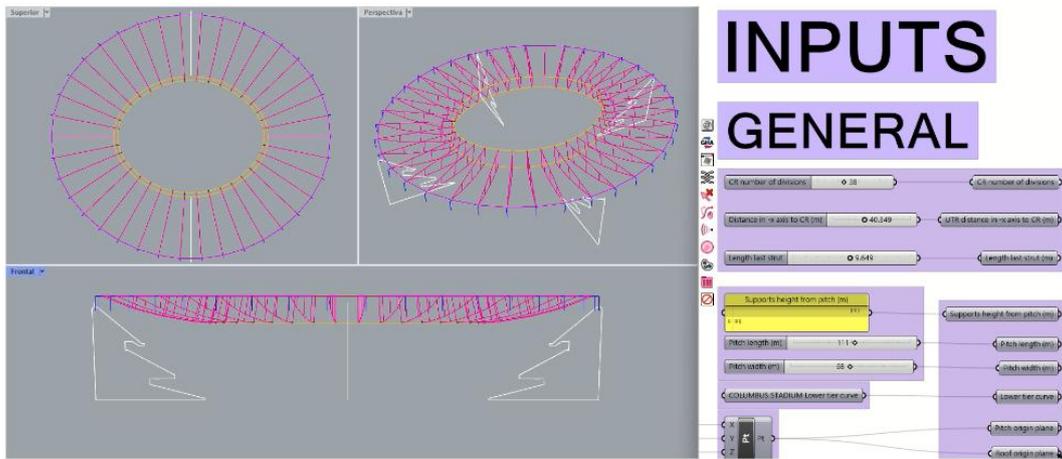
Figure 1. Grasshopper parametric model view

The parametric model is then linked to the structural analysis software, which performs the structural analysis of each erection step. This integration enables a dynamic simulation environment where changes in geometry or erection sequence are automatically reflected in the analysis results.

The overall workflow for simulating the erection of cable roof structures follows an iterative process aimed at ensuring structural feasibility under erection-imposed loads. As illustrated in the flowchart (see Figure 2), the process begins with the initial design of the cable roof, followed by the development of a Biglift model in Grasshopper, which incorporates erection loads and external loads, such as special connections and auxiliary equipment, during the construction phase.

Once the erection sequence is defined, the model is evaluated in the structural analysis software to determine whether the structure can withstand the imposed loads. If the design is deemed adequate, the erection definition is finalized. If not, the process checks whether the structural design allows for modifications. If changes in the design are not possible, the workflow loops back to update the Biglift model accordingly. If changes are permitted, the process returns to the initial design stage.
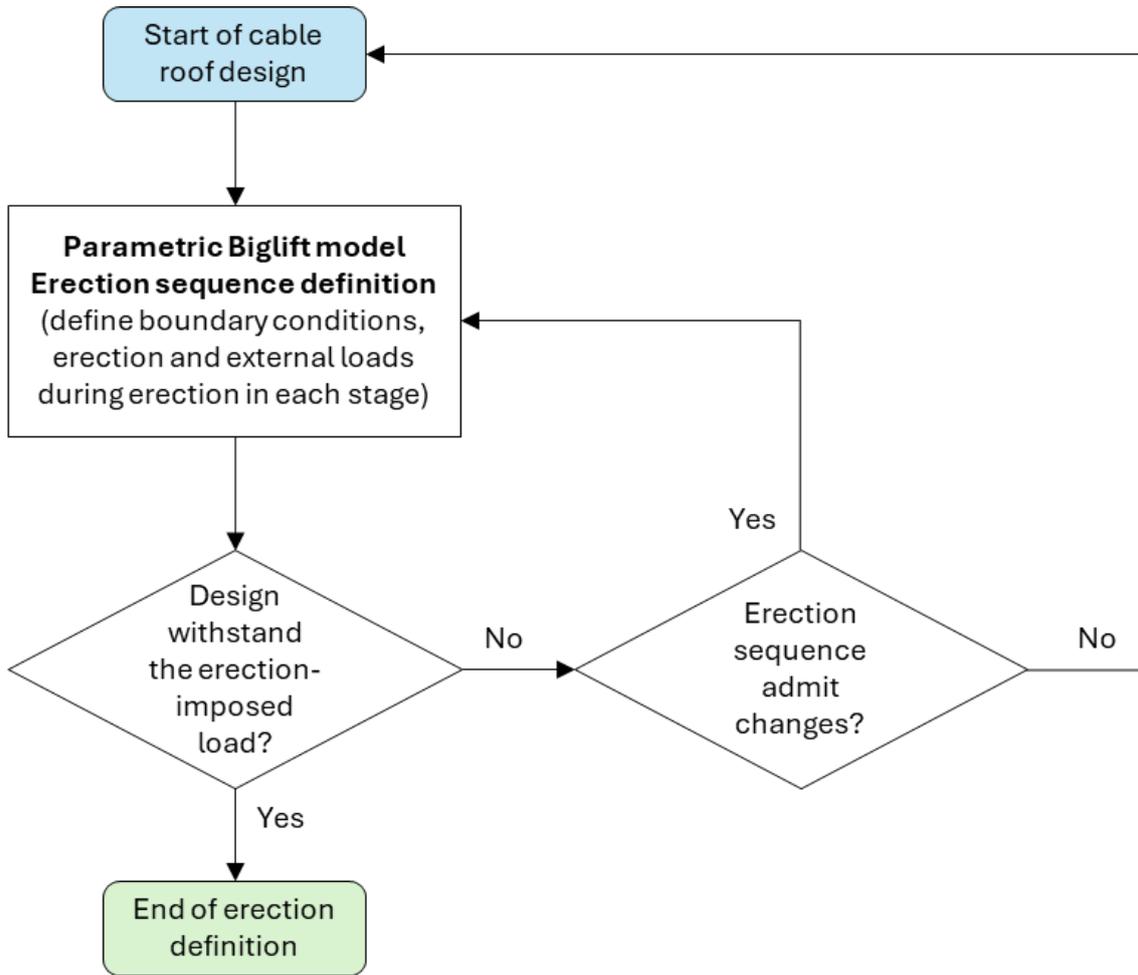
Figure 2. Proposed methodology for simulating the erection sequence workflow diagram

4   CASE STUDY

The Ciutat de València Stadium, home of Levante UD, was selected as the case study for this research due to several key factors. First, it represents a real-world application of a cable roof system, making it highly relevant for testing the proposed methodology. Second, the project involved a complex erection process, which provided an ideal scenario to evaluate the flexibility and accuracy of the parametric model. Third, detailed construction data were available, allowing for a direct comparison between simulated and recorded results. Finally, the stadium's renovation is a representative example of the growing trend in tensile roof structures within sports architecture.

### 4.1 Cable roof structure description

The original structure of the Ciutat de València Stadium dates to 1969 and consists of a series of reinforced concrete frames, each formed by three to five columns. These frames are arranged in a roughly parallel configuration along the sides of the football pitch and converge at the corners of the stadium. Originally, only the main stand was partially covered by a cantilever roof, while the rest of the stadium remained uncovered.

The need to adapt to the new regulatory requirements of La Liga and UEFA, such as sports lighting, sound systems, scoreboards, and zenithal cameras, along with the goal of improving spectator comfort, led to the design of a new roof for the existing Levante UD stadium. This roof had to accommodate the necessary equipment while protecting spectators from inclement weather. To achieve this, a lightweight membrane roof supported by cables was chosen. However, the project faced significant technical challenges: the original concrete structure, which was never intended to support a full-span roof, had to be preserved without altering the stadium's footprint. These constraints limited the structural typologies available and critically shaped the geometry of the new system. To avoid interference with existing foundations, a solution based on micropiles crossing the original footings was adopted, ensuring no additional loads were introduced. Combined with a tight construction schedule aimed at minimizing disruption to football matches, the project demanded a highly coordinated effort in both structural design and execution.

This new structural cable roof system, shown in Figure 3, is composed of the following main elements:

- **Compression Ring**: Implemented as a spatial tubular steel structure with the necessary stiffness and load-bearing capacity to absorb all forces transmitted by the roof.
- **Cable System**: Made of closed steel cables and compression struts fabricated from structural steel. The system includes:
  - **Radial Cables**: Connecting the tension ring to the compression ring.
  - **Annular Cables**: Arranged in two levels (upper and lower) to stabilize the radial cable network.
  - **Struts**: Providing vertical separation between the upper and lower cable layers and transmitting loads between them.

Additionally, bracing cables have been installed between the upper and lower annular cables to prevent instability mechanisms such as articulated quadrilateral deformation within the cable network plane.
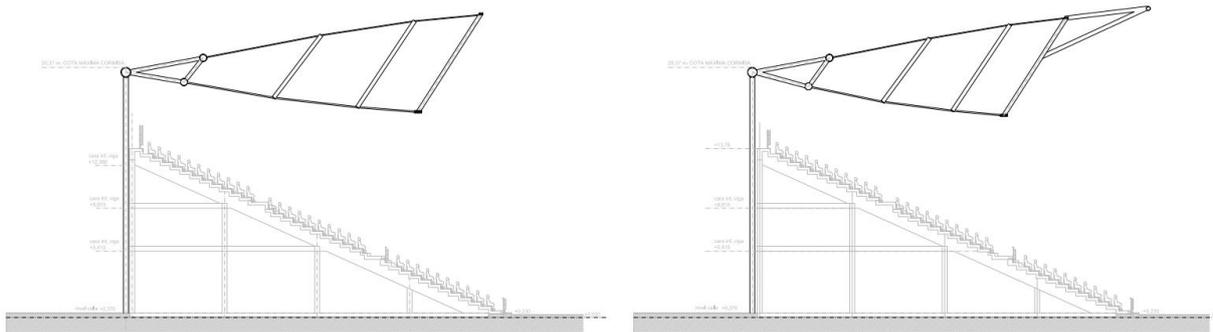

Figure 3. Stadium section views at the ends (left) and sides (right)

4.2 Erection sequence description

The erection process of the Ciutat de València Stadium[2] was carried out in a series of carefully coordinated steps, each of which was modeled in the parametric environment. The sequence was as follows:

1. **Site-preparation**. Preliminary works included the installation of temporary supports or scaffolding, wooden ramps and platforms, and lifting equipment.
2. **Steel structure and compression ring assembly**. Before lifting the cable roof, the steel structure that supports it was assembled, along with the compression ring. The ring required temporary supports until the cable system was fully tensioned.
3. **Lay down of the upper tension ring and radial cables**. The upper annular cables and radial cables were laid down on the ground in their final geometric configuration.
4. **Lifting of the upper cable layer and connection to the compression ring**. The upper cable layer was lifted using hydraulic jacks and connected to the compression ring.
5. **Strut installation**. Some vertical struts were installed suspended from the upper cable layer, hanging freely.
6. **Lay down of the lower tension ring and radial cables**. The lower annular cables and radial cables were laid down on the ground in their final geometric configuration.
7. **Lifting of the lower cable layer**. The lower cable layer was lifted to a defined position using hydraulic jacks.
8. **Connection of the struts to the lower cable layer**. The lower ends of the struts were fixed to the lower cable layer.
9. **Pinning of the lower cable layer to the compression ring**. The lower radial cables were anchored to the compression ring.
10. **Installation of the struts closest to the compression ring**. Additional struts located near the perimeter were installed.
11. **Installation of the membrane, video scoreboard, and secondary structure**. Finally, the membrane roof was installed over the cable network, followed by the placement of the video scoreboard and other secondary structural elements.
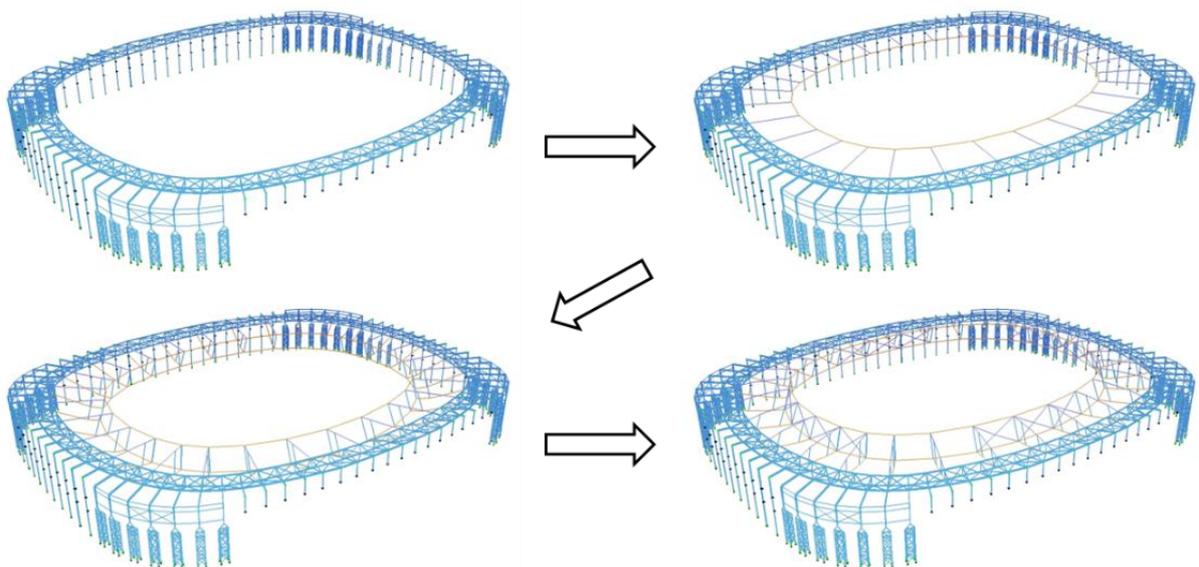
Figure 4. Finite element model views of the erection sequence: steel structure and compression ring assembly (upper left), upper cable layer lifting (upper right), lower cable layer lifting (lower left), and final strut installation (lower right)

Each of these phases was analyzed in the calculation model, allowing for a step-by-step simulation of the erection process. The parametric nature of the model enabled the definition of construction stages, load application, and structural response analysis in a flexible and automated manner.

5 CORRELATION WITH REAL DATA

During the erection process, a comprehensive monitoring system was implemented to ensure the correct sequence and structural behavior of the cable roof. The recorded data included:
- Hydraulics jacks' stresses.
- Temporary supports loads and displacements.
- Spheric supports displacement.
- Compression ring displacements.

To validate the accuracy of the proposed methodology, a series of comparisons were made between the simulated results and the actual data recorded during the erection of the Ciutat de València cable roof.

One of the comparisons focused on the pinning forces of the cables, as these forces are typically a limiting factor in determining both the capacity and the number of hydraulic jacks required during the lifting process. Specifically, the analysis concentrated on the lower radial cables, since their pinning forces are higher than those of the upper radial cables, making them more critical from a structural and operational standpoint.

The following figure shows the designation of the cables used in the analysis:
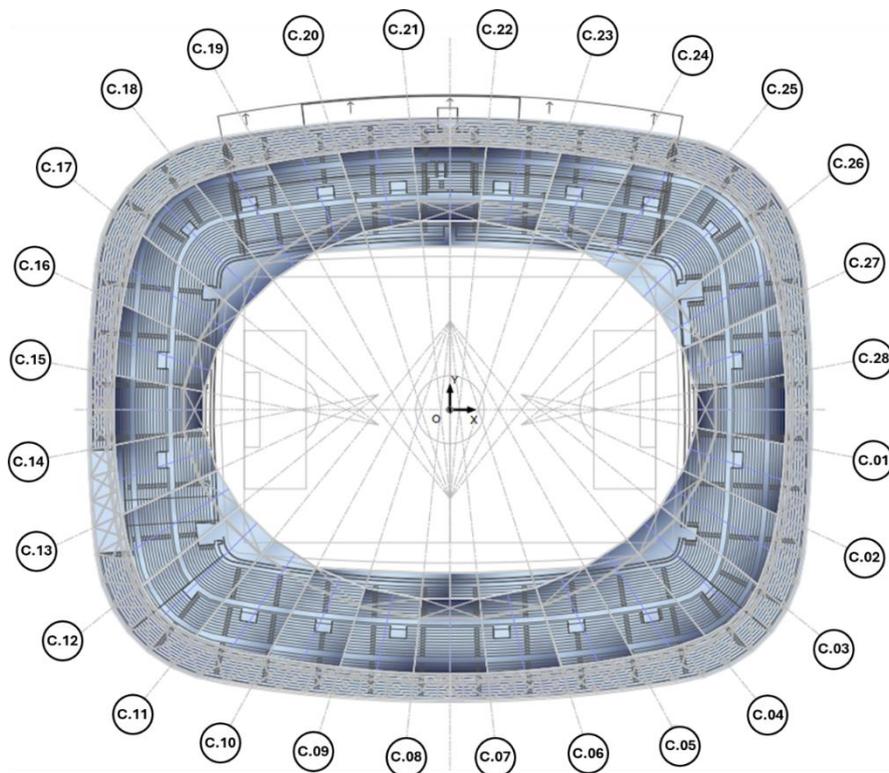
Figure 5 Cable reference numbers

The graphic below presents a comparison between the pinning forces obtained from the parametric model and those recorded on site:
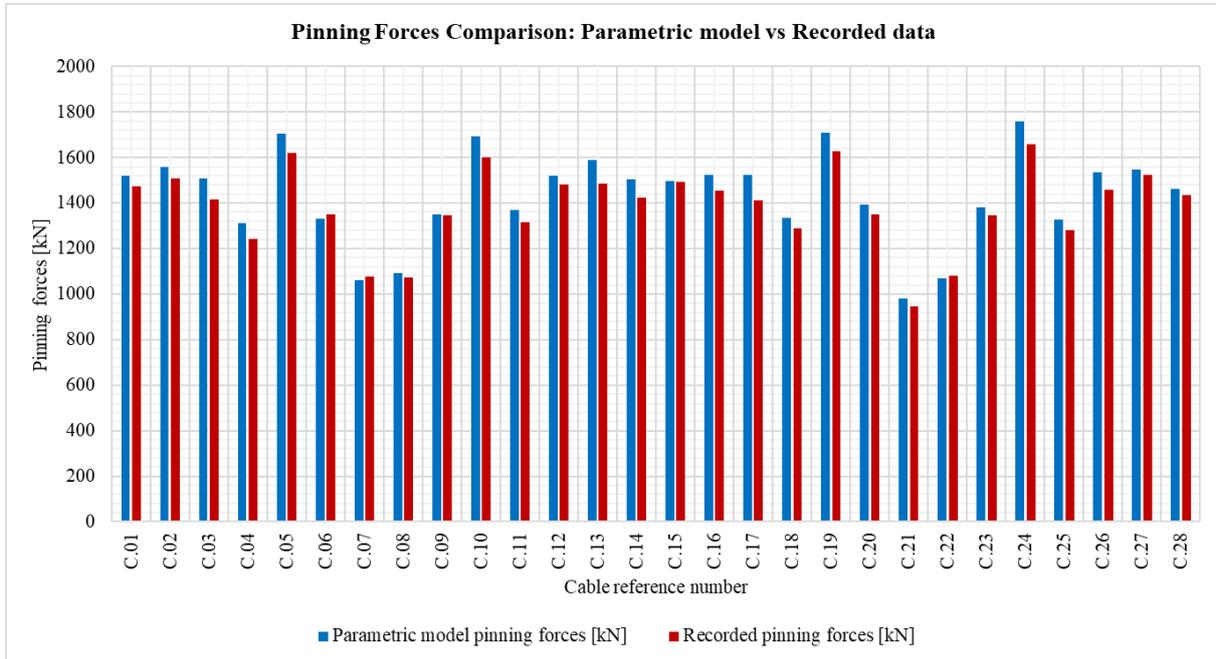
Figure 6. Pinning forces comparison between the parametric model and the recorded data

As shown in the chart, the results from the parametric model closely match the recorded data, with most affinity values falling within a ±5% range. This high level of agreement confirms the reliability of the simulation in capturing the structural behavior during the erection process.

6   CONCLUSIONS

This paper has presented a methodology, based on parametric modelling, for simulating the erection sequence of cable roof structures, addressing the limitations of conventional modeling approaches that often lack flexibility and adaptability. By integrating Grasshopper for parametric modeling and a structural analysis software for calculation, the proposed workflow enables a dynamic and iterative simulation process that can be tailored to a wide range of geometries and construction scenarios.

The methodology was applied to the real-world case of the Ciutat de València Stadium, where the erection of a large-span cable roof was simulated and validated against actual construction data. The comparison focused on the pinning forces of the lower radial cables, critical parameters in the lifting process, and showed a high level of agreement between simulated and recorded values, with deviations generally within ±5%. This validation confirms the reliability and accuracy of the proposed approach.

6.1 Advantages of the proposed methodology

Beyond its technical robustness, the methodology offers several practical advantages:

- **Adaptability**: The parametric model can be easily reconfigured to accommodate changes in geometry, support conditions, or construction strategies.
- **Efficiency**: The integration of design and analysis tools reduces the time and effort required to update models and test alternative erection sequences.
- **Design–construction integration**: The workflow facilitates better coordination between design and construction teams, supporting informed decision-making throughout the project lifecycle.

These features make the methodology particularly valuable for engineers and designers working on complex tensile structures, especially in large-span applications where construction planning is critical to structural performance and safety.

Moreover, the approach contributes to the broader field of digital construction by demonstrating how parametric tools can bridge the gap between conceptual design and construction execution, enabling more responsive and optimized workflows.

REFERENCES

[1] IDOM. (2021, May 6). Ciutat de València Stadium – Cable roof erection sequence [Video]. YouTube. https://www.youtube.com/watch?v=WqOxWS1jIM0