Modeling Civil Engineered Systems

Individual Project 2

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1. Introduction

With the increasing complexity of modern architectural engineering, parametric modeling offers an efficient and flexible solution. Stakeholders such as architects, engineers, and owners can utilize this tool at different stages for various analyses and simulations, including schematic design, structural simulations, and climate simulations. This study focus on the influence of building dimension of velodrome toward construction cost and carbon footprint performance, by simulating the planning of a velodrome with a minimum of 5,000 seats in Hong Kong. Compared to other types of buildings, stadiums are unique in that they typically center around the sports space as the core of the architecture, with secondary spaces added as ancillary components. As a result, architects often begin by planning the sports space and use it as the foundation to develop various design alternatives. This type of design process, which follows a fixed logic, is particularly well-suited for implementation using parametric software like Dynamo.

1.1 Scope and Goal

The goal of this study is to examine how adjustments to geometric input parameters impact the cost and carbon footprint performance of different design alternatives. The cost variations across these alternatives primarily stem from differences in architectural structural design and land usage. To maintain focus and reduce complexity, the study's scope is confined to the building's main structure and the land it occupies, assuming a site coverage ratio of 100% and excluding any considerations for outdoor open spaces.

1.2 Design Challenges & Limitations

The primary challenge in designing a velodrome lies in ensuring that any design alternative integrates seamlessly with the racing track, which imposes significant constraints and increases the complexity of the overall design process. Additionally, due to the difficulty of incorporating all aspects, such as functional spaces or indoor circulation, into this simulation, this study focuses on presenting a systematic method for integrating multiple design parameters.

2. Methods

2.1 Design Parameters

This study primarily explores the impact of changes in building dimension on construction costs and carbon emissions. The design parameters are categorized into fixed parameters and input parameters (see Table1), and the former reflects the building's physical composition and basic spatial requirements for this building type, while the latter decides the configuration of stands and building area in order to compare different types of dimension of the building mass.

Fixed parameters	Input parameters
• Beam dimension • Column dimension • Track dimension • Stories height	• Number of Stories(stands) • Number of row of seats • Stands location

Table 1 Fixed & Input parameters

2.1.1 Fixed parameters

The fixed parameters includes the basic standard of the racing track and specification of stands, such as track dimension or the height of each row of seats, referencing to the LCI documents[1] and common practice[2]. Additionally, to simplify the simulations, it is assumed that the dimensions of structural components remain consistent across all options.

Fixed parameters	
Building	
Structural dimension	Beam: 35cm*35cm Column: =1.5m, 60cm*60cm, 45cm*45cm
Level height	1st floor: 4m Stands floor: 6.5m
Track	
Track dimension	Perimeter: 250m Width: 7m
Curve radius	19m
Track slope	Straight track: 12° Turn track: 45°
Blue zone width	0.7m
Safe zone width	3.3m
Stands	
Passage width	0.5m
Seat dimension	Width: 0.5m Depth: 0.5m
Height of each row of seat	0.16*3=0.48m

Table 2 Fixed parameters specification

2.1.2 Input parameters

The input parameters include the amount of stands stories and seat rows, which basically decide the structure system, required building area and the view of audience. Typically, these 2 parameters are set depend on the land cost and also the required capacity. Moreover, the location of the stands (or the types of stands) not only influences the building area, but also affects audiences' view. For instance, seats in the curved zone may have a more limited view compared to those in the straight side which is next to the straight track.

Input parameters	
Number of stands stories	Ranging from 1 to 4
Number of row of seats	Ranging from 8 to 21 to meet the basic requirements
Stands location	Only straight side and both straight side & curve side.

Table 3 Input parameters specification

2.2 High-performance Criteria

The high-performance criteria in this study include monetary cost and carbon footprint. It's worth noting that due to regional differences, these two criteria often vary depending on the location. To meet the realistic simulation, the study mainly refers to data of Hong Kong[4][5][6] and Singapore[7].

2.2.1 Cost: Structural Elements & Land

Unlike private fitness centers and other building types such as shopping malls or office buildings, most sports venues are non-profit-oriented spaces. Therefore, for managers (often government officials or architects), a key consideration for this type of building is how to control construction costs within a reasonable range while meeting spatial requirements.

2.2.2 Greenhouse gas emission

Construction industry is one of the major output sources of greenhouse gas emissions. According to an UN report[3], buildings and construction industry contributes about 37% of global greenhouse gas emissions. With growing awareness in the industry, companies are increasingly adopting a wide range of environmental, social, and governance (ESG) practices and regulations. This shift is not only a proactive approach to fulfilling corporate social responsibility but also becomes a supplier standard for banks, governments, and major clients in the construction and real estate sectors.

2.3 Design Alternatives

2.3.1 Alternatives description

I proposes 4 different options based on the aforementioned input parameters, including number of stories and also the type of stands (with or without the curve-side stands). Meanwhile, to meet the requirement of a minimum capacity of 5000 people, the number of seat row are also assigned with different amounts. Normally, due to the vision of audience, velodrome design organize most of the seats in the straight side area that next to the straight track, which also be adopted in the setting of alternative 1, 2 and 4. While alternative 3 design seats in both straight side and curve side to maximize the revenue per square meter.

Options	Scenario description	Input parameters
1	• Building stories: 2 • Stands stories: 2nd	• Stands stories: 1 • Stands row: 21
2	• Building stories: 3 • Stands stories: 2nd & 3rd	• Stands stories: 2 • Stands row: 14
3	• Building stories: 3 • Stands stories: 2nd & 3rd	• Stands stories: 2 • Stands row: 11 & 13
4	• Building stories: 4 • Stands stories: 2nd & 3rd & 4th	• Stands stories: 3 • Stands row: 8

Table 2 Design alternatives description

2.3.2 Modeling logic

The modeling process consists of two parts. The first involves constructing the mass of the track zone, including the track, blue band, safety zone, infield zone, and wall. Following this, the structure of the stands is designed based on the track configuration, while keeping it partially adjustable to accommodate the requirement of 5,000 seats.

- **Construct track zone**

I create curves that could adjust the length and angle as the section and sweep path to construct track and other related elements that fullfills LCI regulation. The green groups represent those fundamental elements while the orange ones represent the final geometries we need.

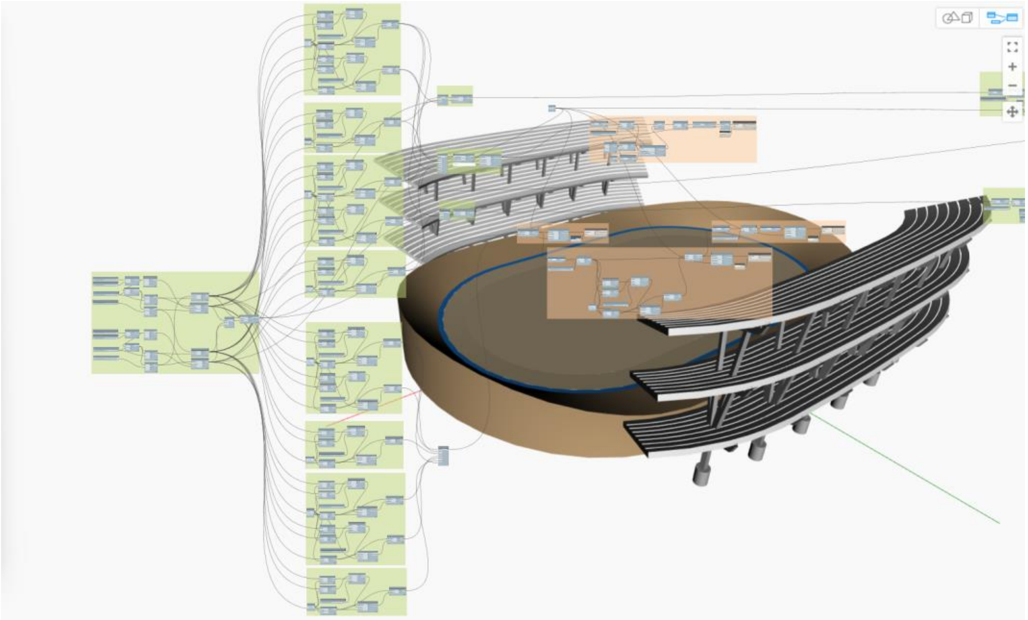


Figure 1 Dynamo script(1)

- **Construct stands**

Next, I used the outer boundary curve of the track as a reference to create the inner boundary curve of the stands. I assume the dimensions of each seat to be 50 cm × 50 cm, with a row height of 48 cm and a story height of 6.5 m for the stands. These specifications were used to offset the curve and generate the geometry of the stands. Based on these geometries, I calculate the corresponding building area, total seating capacity, and building height.

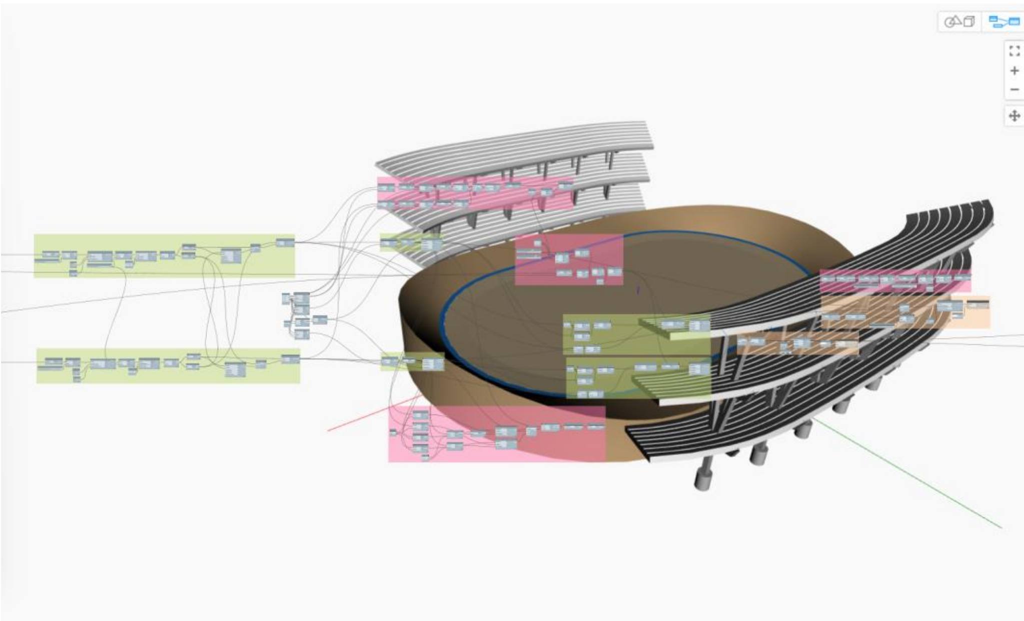


Figure 2 Dynamo script(2)

- **Construct strutures**

In the final section, I used the geometries of the stands as references to create structural guidelines, including columns, beams, and trusses. I assumed that the required dimensions of structural elements remain consistent across different options and generated solid geometries for the structural system. Based on these geometries, I calculated the material quantities by extracting their corresponding values.

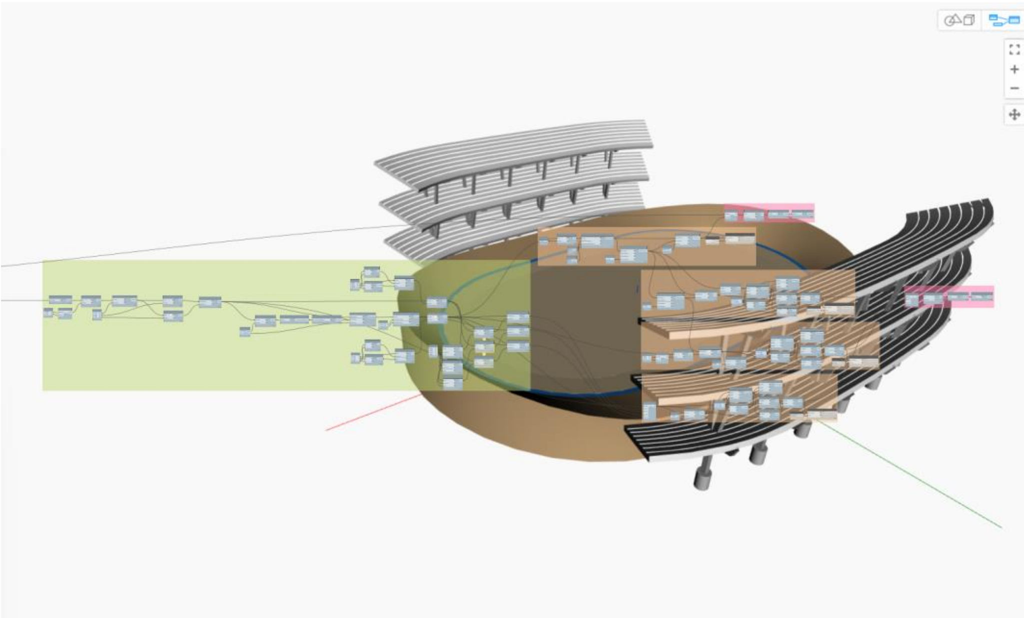


Figure 3 Dynamo script(3)

3. Results and Discussion

3.1 Design Space

In most cases, the design space is constrained by various factors including building regulation, design requirement or stakeholder experience, etc. In this model, I established fundamental building components as control variables, and used adjustable parameters to modify the spatial composition, aiming to understand the impact of these parameters on the final outcome(see Table 3 and Table 4). However, because real-world scenarios account on more realistic factors, including scheduling, budgets, and local regulations, these settings may only be a prototype as developing multidisciplinary design, while not be fully applicable to actual design cases.

3.2 High performance solutions

Within chosen scenarios, we could see 2 types of comparison of building dimensions:

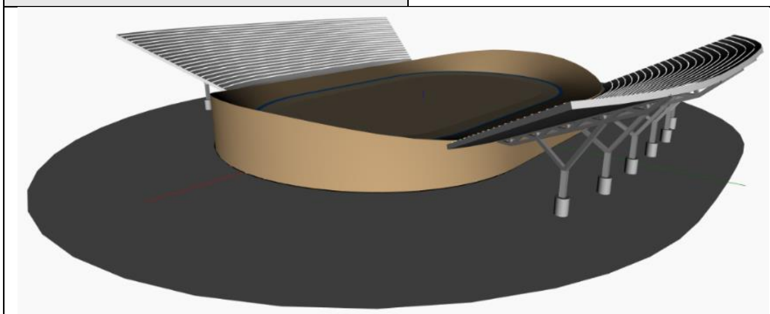
- Difference between floor count: Alternative 1 v.s. Alternative 2 v.s. Alternative 4
- Difference between stands location: Alternative 2 v.s. Alternative 3

According to given results, the number of stories shows a significant impact on both structure cost and land cost. For each additional floor, the average land cost decreases by almost 23.1 %(about €44,384,038.85), while an opposite pattern could be seen in the structure cost, with an average increase by roughly 9.55 %. On the other hand, the effect of stands location is much less than that of floor count. Since alternative 2 and 3 are both 3-story building, the average difference between costs is only roughly 3 % and that of CO2 emission is also about 6 %.

<table>
<tr><th rowspan="2">Alternative Description</th><th rowspan="2">Input Parameters</th><th colspan="2">Estimated Cost</th><th rowspan="2">CO2 emission</th></tr>
<tr><th>Structure</th><th>Land</th></tr>
<tr><td rowspan="4">#1
1st floor:
Service area
2nd floor:
Stands area
Seat amount: 5242</td><td>Stands stories:
1
Stands line:
21</td><td>Amount:
18.5 m3
(steel)
1774.9 m3
(concrete)

Cost:
583448.07 €</td><td>Area:
9522.4 m2

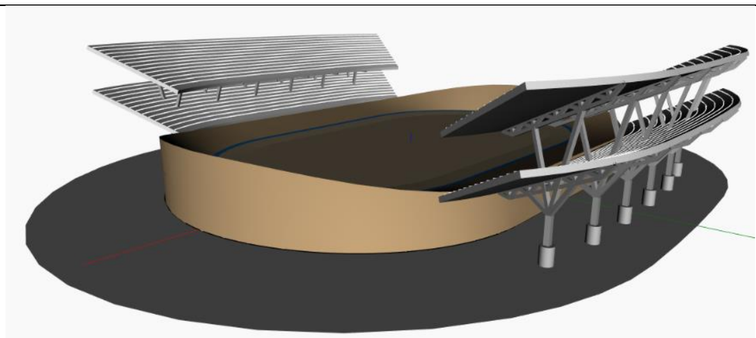
Cost:
210931063.3
€</td><td>Total amount:
1427353.62 ton

Carbon Tax:
4282060.86 €</td></tr>
<tr><td colspan="2">Cost (carbon tax excluded)</td><td colspan="2">211514511.37 €</td></tr>
<tr><td colspan="2">Total Cost (all included)</td><td colspan="2">215796572.23 €</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="3">#2
1st floor:
Service area
2nd & 3rd floor:
Stands area
Seat amount: 5032</td><td>Stands stories:
2
Stands line:
14</td><td>Amount:
24.5 m3
(steel)
1735.7 m3
(concrete)

Cost:
606578.25 €</td><td>Area:
6345.5 m2

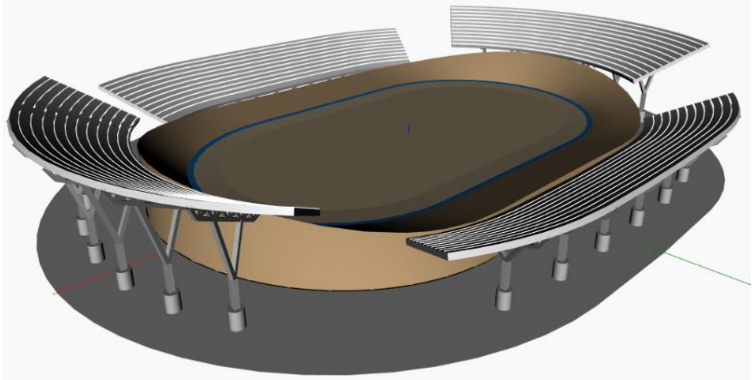
Cost:
140559424.32
€</td><td>Total amount:
1395945.15 ton

Carbon Tax:
4187835.45 €</td></tr>
<tr><td colspan="2">Cost (carbon tax excluded)</td><td colspan="2">141166002.57 €</td></tr>
<tr><td colspan="2">Total Cost (all included)</td><td colspan="2">145353838.02 €</td></tr>
</table>

<table>
<tr><td></td><td colspan="4"></td></tr>
<tr><td rowspan="4">#3
1st floor:
Service area
2nd & 3rd floor:
Stands area
(straight & curve side)
Seat amount: 5024</td><td>Stands stories:
2
Stands line:
11 & 13</td><td>Amount:
23.4 m3
(steel)
1629.5 m3
(concrete)

Cost:
571706.99 €</td><td>Area:
6332.3 m2

Cost:
140267030.59
€</td><td>Total amount:
1310540.49 ton

Carbon Tax:
3931621.47 €</td></tr>
<tr><td colspan="2">Cost (carbon tax excluded)</td><td colspan="2">140838737.58 €</td></tr>
<tr><td colspan="2">Total Cost (all included)</td><td colspan="2">144770359.05 €</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="4">#4
1st floor:
Service area
2nd & 3rd & 4th floor:
Stands area
Seat amount: 5334</td><td>Stands stories:
3
Stands line:
8</td><td>Amount:
35 m3
(steel)
1868.8 m3
(concrete)

Cost:
701544.13 €</td><td>Area:
5515 m2

Cost:
122162985.6
€</td><td>Total amount:
1503147.13 ton

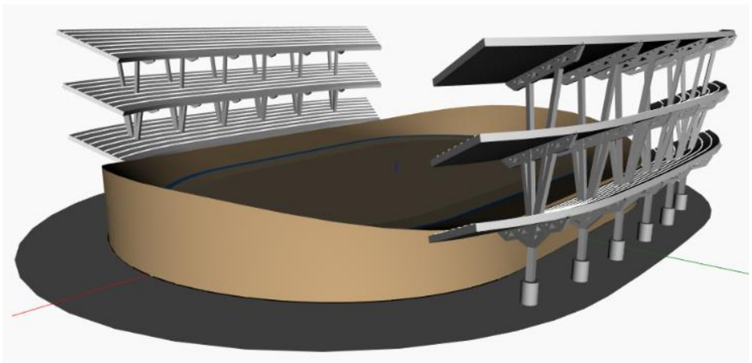
Carbon Tax:
4509441.39 €</td></tr>
<tr><td colspan="2">Cost (carbon tax excluded)</td><td colspan="2">122864529.73 €</td></tr>
<tr><td colspan="2">Total Cost (all included)</td><td colspan="2">127373971.12 €</td></tr>
<tr><td colspan="4"></td></tr>
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Table 3 Descriptions and results of alternatives

Based on the chosen criteria, I choose option 4, 3, 2 as the 3 best performance solutions, since costs of option 1 are significantly more expensive than others. Among all, the option 4 performs the best, with the lowest total cost (carbon tax included). Although the carbon footprint is also more than others(+5%, +7%, +13%), compared to the fact that the major costs is 34% and 15% less than other 3 choices. On the other hand, option 2 and 3 has a better output than the option 1, no matter in costs or carbon dioxides emission.

Ranking	Description	Cost	Greenhouse gas output
1	Building stories: 4 Stands stories: 2nd & 3rd & 4th	122864529.73 €	Amount: 1503147.13 ton Carbon tax: 4509441.39 €
2	Building stories: 3 Stands stories: 2nd & 3rd	140838737.58 €	Amount: 1310540.49 ton Carbon tax: 3931621.47 €
3	Building stories: 3 Stands stories: 2nd & 3rd	141166002.57 €	Amount: 1395945.15 ton Carbon tax: 4187835.45 €

Table 4 Comparison of high performance alternatives

Reference

[1]Union Cycliste Internationale, 2023. UCI Cycing Regulations.
[2]Maciej Tomasz Solarczyk, 2020. Geometry of the cycling track.
[3]United Nations Environmental Programme, Yale Center for Ecosystems + Architecture, 2023. Building Materials and the Climate: Constructing a New Future
[4] Hong Kong Special Administrative Region, 2024. Average Wholesale Prices of Selected Building Materials
[5]Global Property Guide, 2024. Square Meter/Square Foot Prices in Hong Kong compared to Asia
[6]Vincent J L Gan, C M Chan, K T Tse, Jack C P Cheng and Irene M C Lo, 2017. Sustainability analyses of embodied carbon and construction cost in high-rise buildings using different materials and structural forms
[7]National Climate Change Secretariat Singapore. Carbon Tax.