COMPUTATIONAL METHOD FOR FOOTBALL STADIUM RENOVATION

A computational method for the renovation of football stadiums to facilitate designers into making decisions

BACKGROUND

(Source: Foxsports.it)

(Source: Foxsports.it)

(Source: korastats.org)

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(Source: korastats.org)

(Source: Skysports.com)

(Source: Foxsports.it)

(Source: korastats.org)

(Source: Skysports.com)

UEFA + FIFA

BUILD NEW GROUNDS

RENOVATE EXISTING STADIUMS

"IT'S ALL PART OF ENHANCING THE MATCHDAY EXPERIENCE. (...) WE HAVE SEEN A GROWING TREND FOR MORE FREQUENT STADIUM UPGRADES AND RENOVATIONS. (...) RATHER THAN REBUILD THEM ENTIRELY."

- TOM JONES, POPULOUS (2019)

"IT MAY BE THAT THERE IS A RECOGNISED BENEFIT TO BE DERIVED FROM INCREASING CAPACITY, THERE MAY BE A NEED TO IMPROVE COMFORT AND SAFETY LEVELS, NEW FACILITIES MAY BE REQUIRED TO GENERATE ADDITIONAL REVENUE (...)"

- UEFA (2011)

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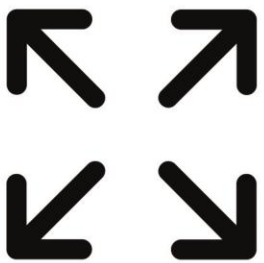

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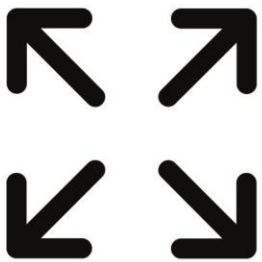

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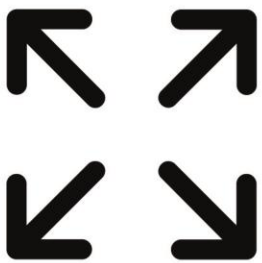

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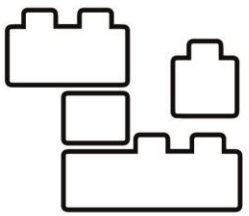
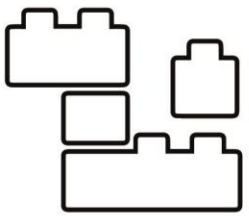
PROBLEM STATEMENT

STADIUM RENOVATION FEATURES



MULTIPLE COMPONENTS
TO BLEND TOGETHER

STADIUM RENOVATION FEATURES

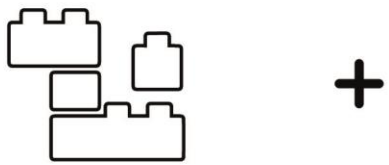


MULTIPLE COMPONENTS
TO BLEND TOGETHER

+

EVALUATION OF MULTIPLE
RELATED PERFORMANCES AND
REQUIREMENTS

STADIUM RENOVATION FEATURES



MULTIPLE COMPONENTS
TO BLEND TOGETHER

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EVALUATION OF MULTIPLE
RELATED PERFORMANCES AND
REQUIREMENTS

+

CONSTRAINTS OF THE
EXISTING STADIUM

PROBLEMATICS

DIFFICULT
DECISION-MAKING

PROBLEMATICS

DIFFICULT
DECISION-MAKING

+

LONG PATH TOWARDS
AN OPTIMAL SOLUTION

PROBLEMATICS

SHIFT TOWARDS PERFORMANCE ORIENTED DESIGN

+

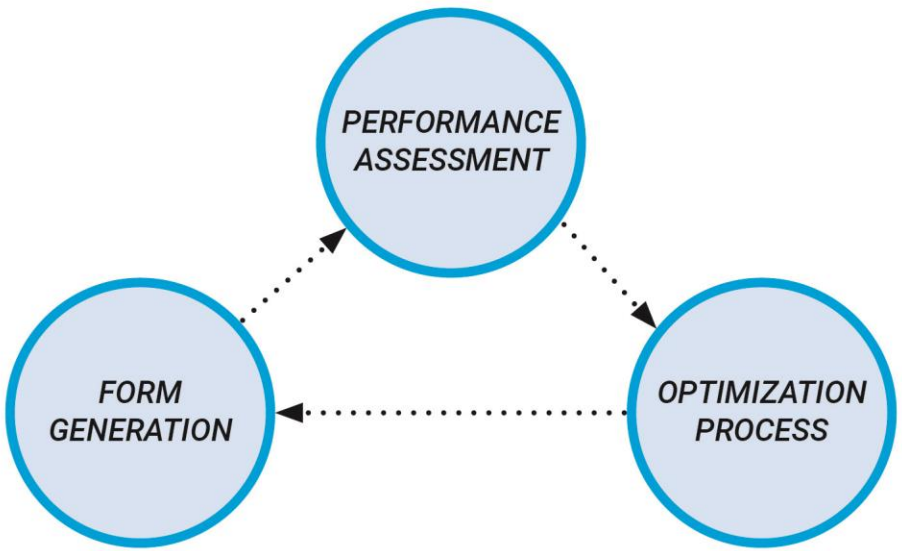
IMPLEMENTATION OF COMPUTATIONAL METHODS

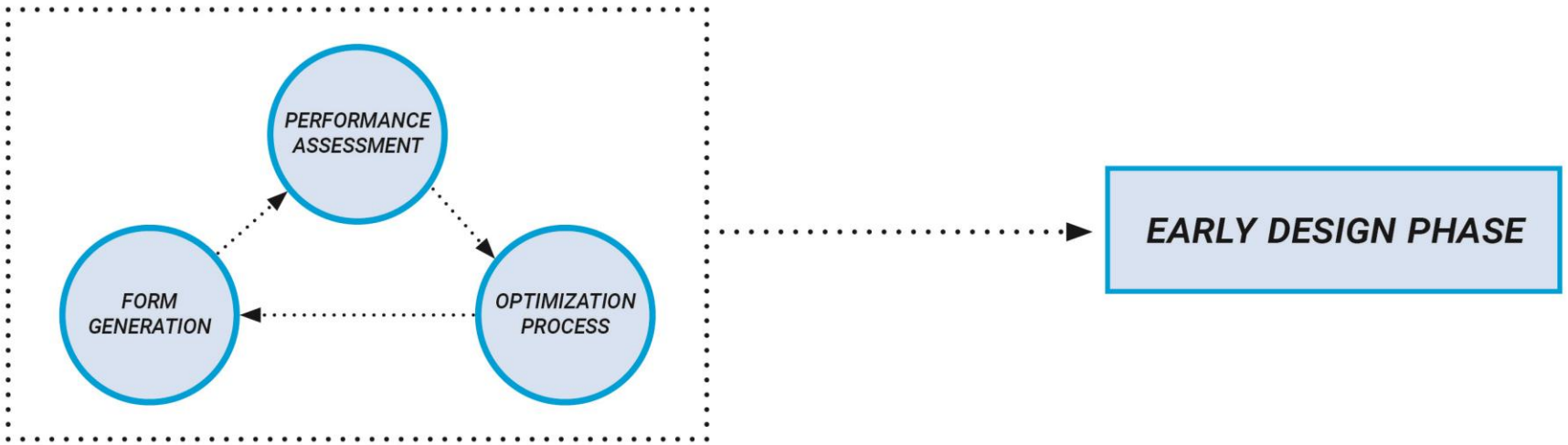
SHIFT TOWARDS PERFORMANCE ORIENTED DESIGN

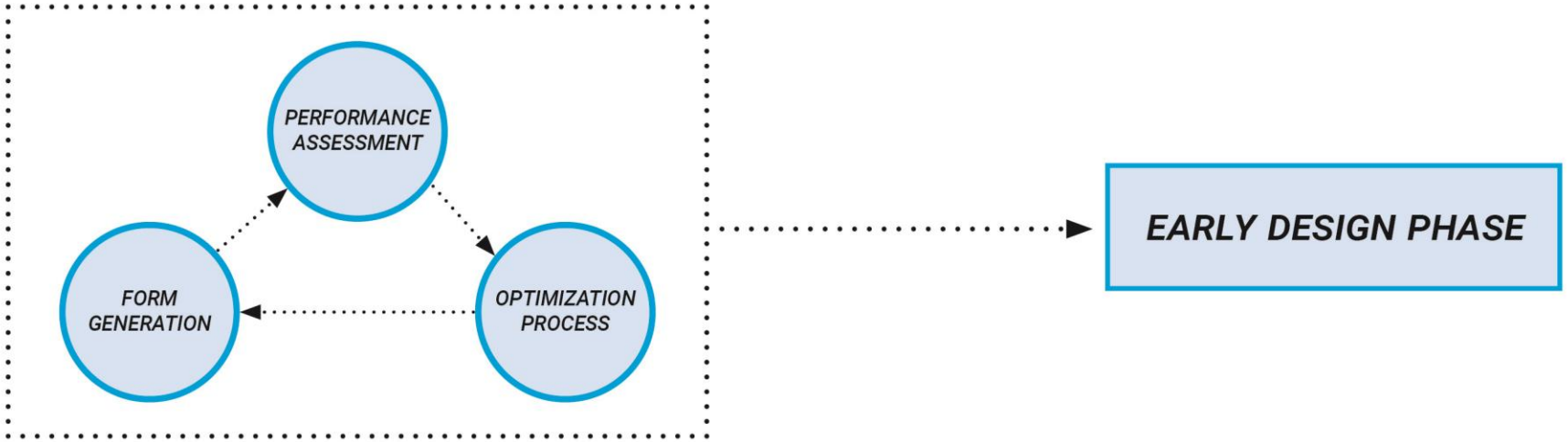
+

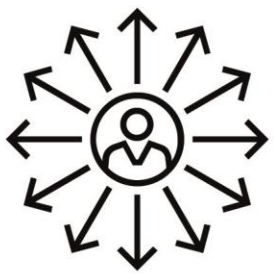
IMPLEMENTATION OF COMPUTATIONAL METHODS

PERFORMATIVE COMPUTATIONAL ARCHITECTURE (PCA)

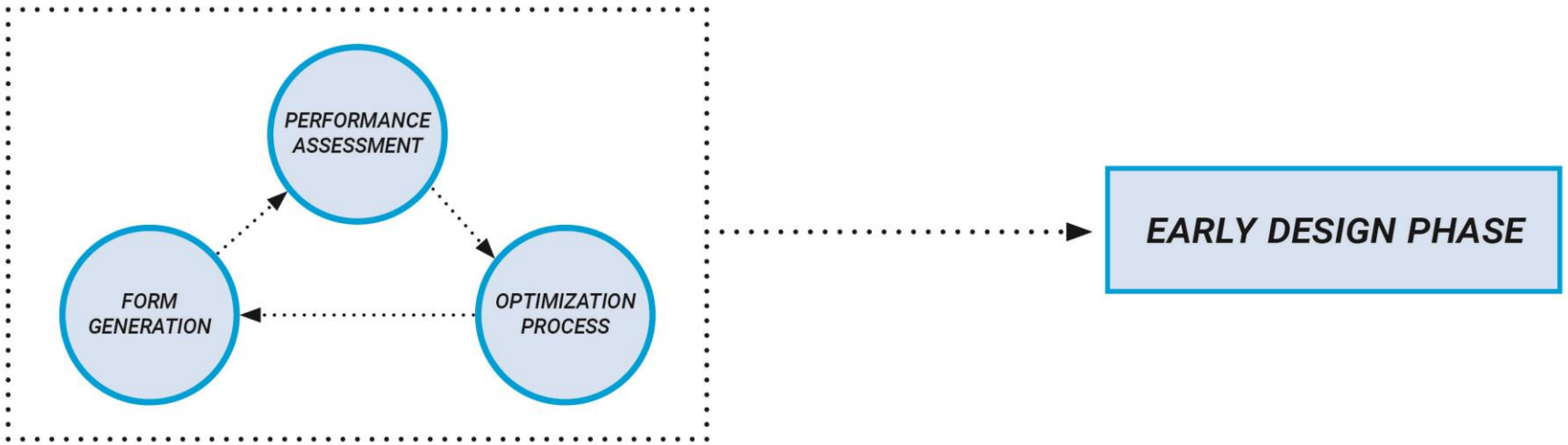


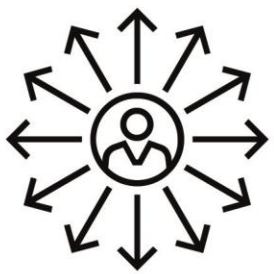

PERFORMANCE ASSESSMENT
FORM GENERATION
OPTIMIZATION PROCESS
EARLY DESIGN PHASE





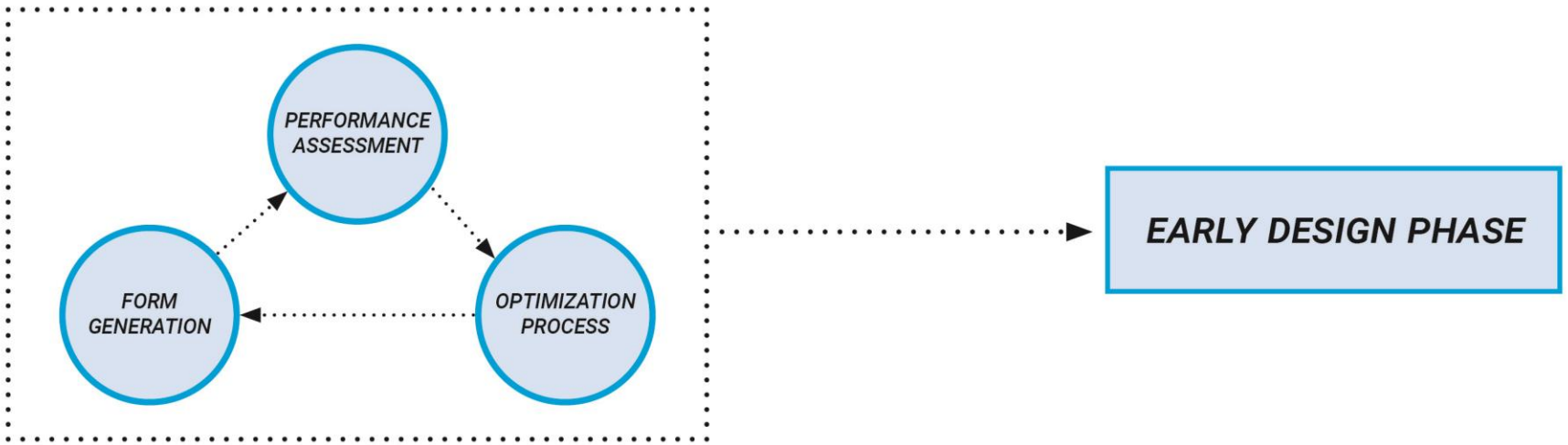
EXPLORE MULTIPLE ALTERNATIVES

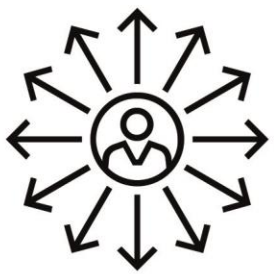




EXPLORE MULTIPLE ALTERNATIVES

TRADE-OFF OF ALTERNATIVES





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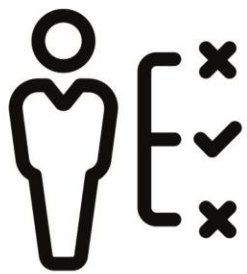
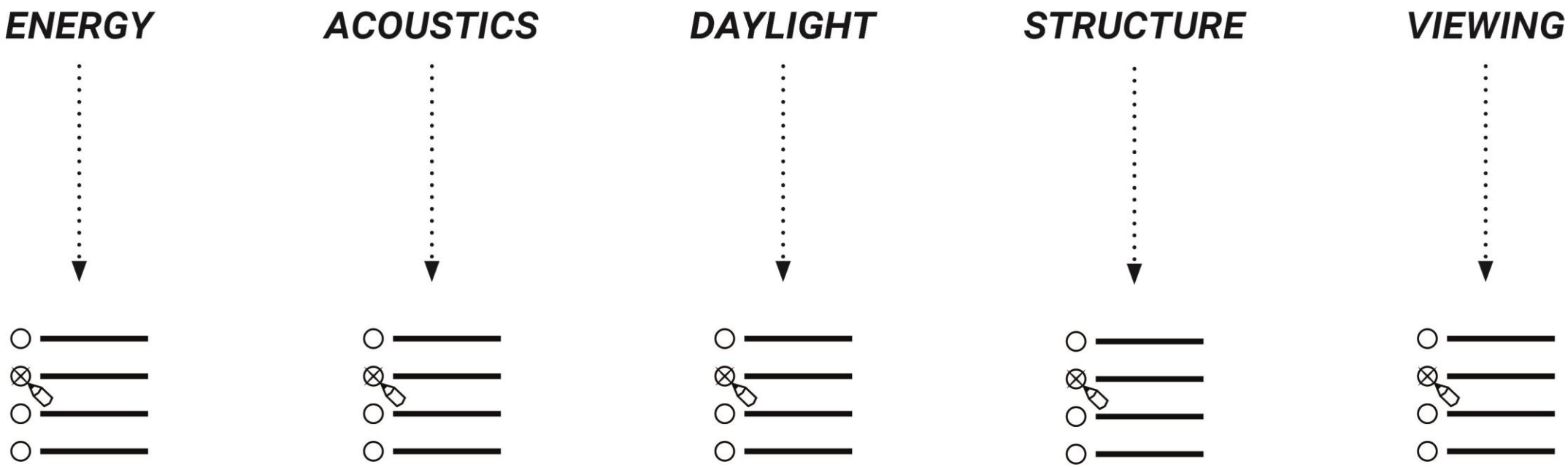


EASIER DECISION-MAKING

ENERGY ***ACOUSTICS*** ***DAYLIGHT*** ***STRUCTURE*** ***VIEWING***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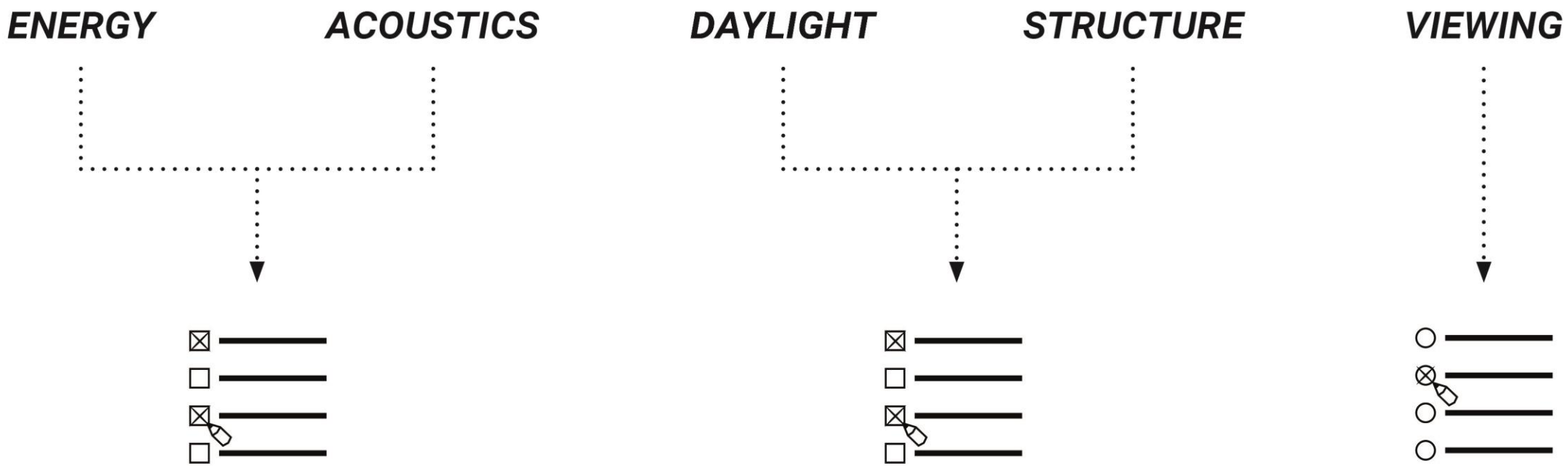
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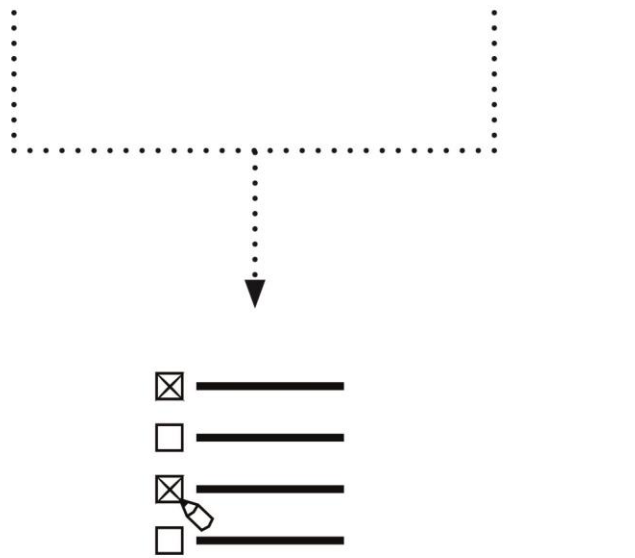
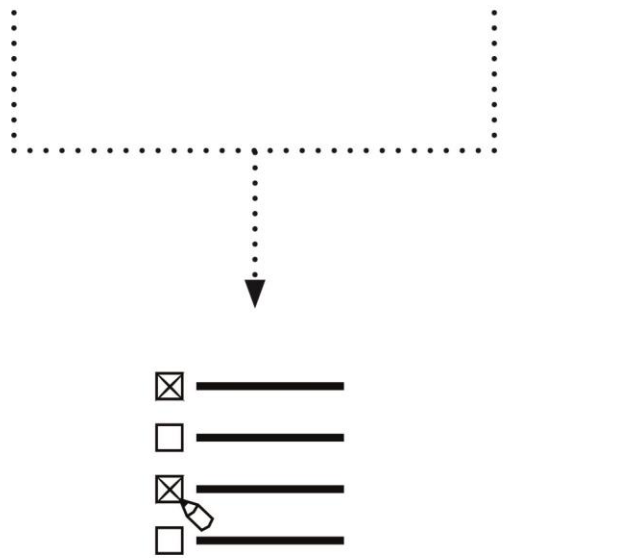


ENERGY ***ACOUSTICS*** ***DAYLIGHT*** ***STRUCTURE*** ***VIEWING***

"Integration of the (multi-) FUNCTIONAL SPACE and of the large-span STRUCTURE of the ROOF mainly DETERMINES the OVERALL GEOMETRY of the building, and is one of the most CHALLENGING phases of the design."

- PAN ET AL. (2019)



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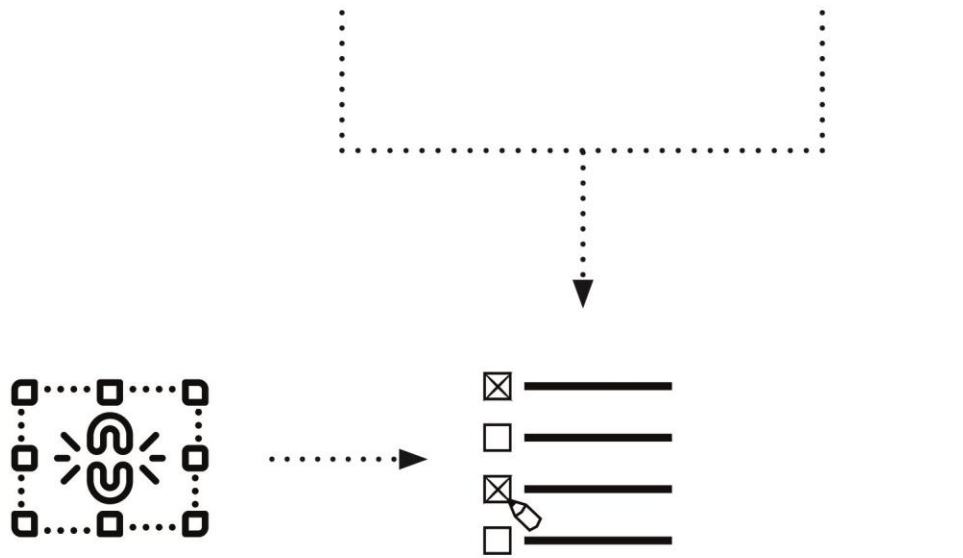


MAIN RESEARCH QUESTION

*How can a **COMPUTATIONAL METHOD** be designed for **STADIA RENOVATION PROCESS** to provide designers and engineers with an overview of the **CURRENT STRUCTURAL PERFORMANCE** of the **ROOF** structure and the **VIEWING QUALITY PERFORMANCE** of the **GRANDSTANDS**, while offering them the possibility to **OPTIMIZE** these **FEATURES JOINTLY**?*

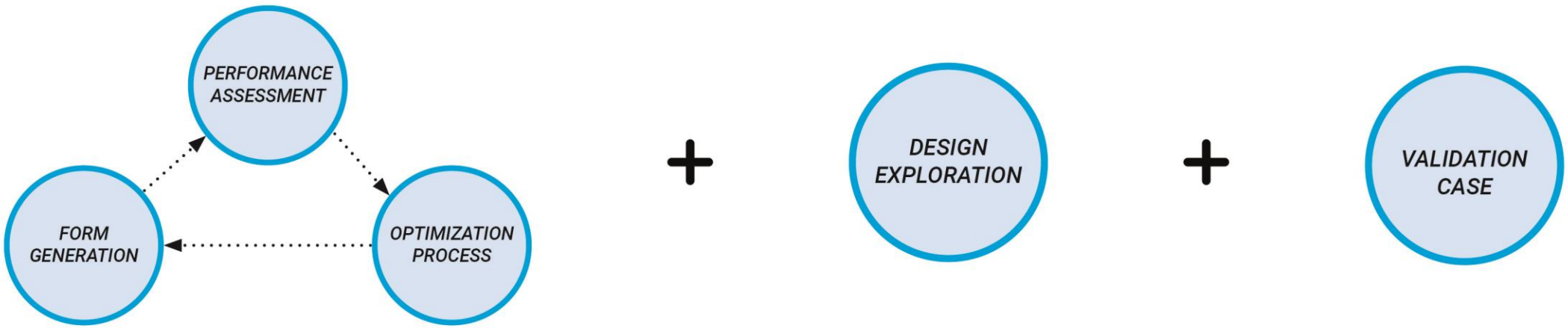
RESEARCH OBJECTIVE

*The development of a **COMPUTATIONAL METHOD** to provide designers and engineers with an overview of the **CURRENT VIEWING QUALITY PERFORMANCE** of the **GRANDSTAND** and the **STRUCTURAL PERFORMANCE** of the **ROOF** of the stadium.The computational method will be also implemented with a computational workflow to **EXPLORE SUITABLE DESIGN ALTERNATIVES** to **OPTIMISE** those performances **JOINTLY**. The computational method will be **VALIDATED** through its application on an appropriate **VALIDATION CASE.***

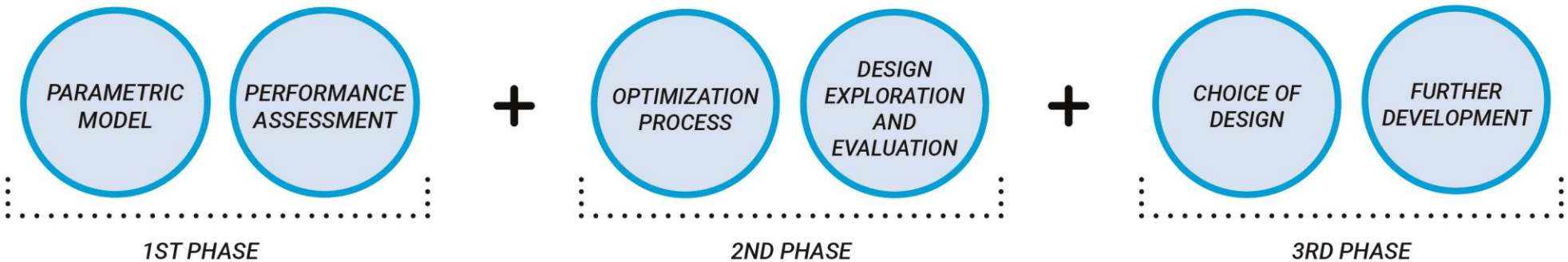
RESEARCH STRUCTURE

INITIAL STRUCTURE OF THE COMPUTATIONAL METHOD

PERFORMATIVE COMPUTATIONAL ARCHITECTURE



INITIAL STRUCTURE OF THE COMPUTATIONAL METHOD



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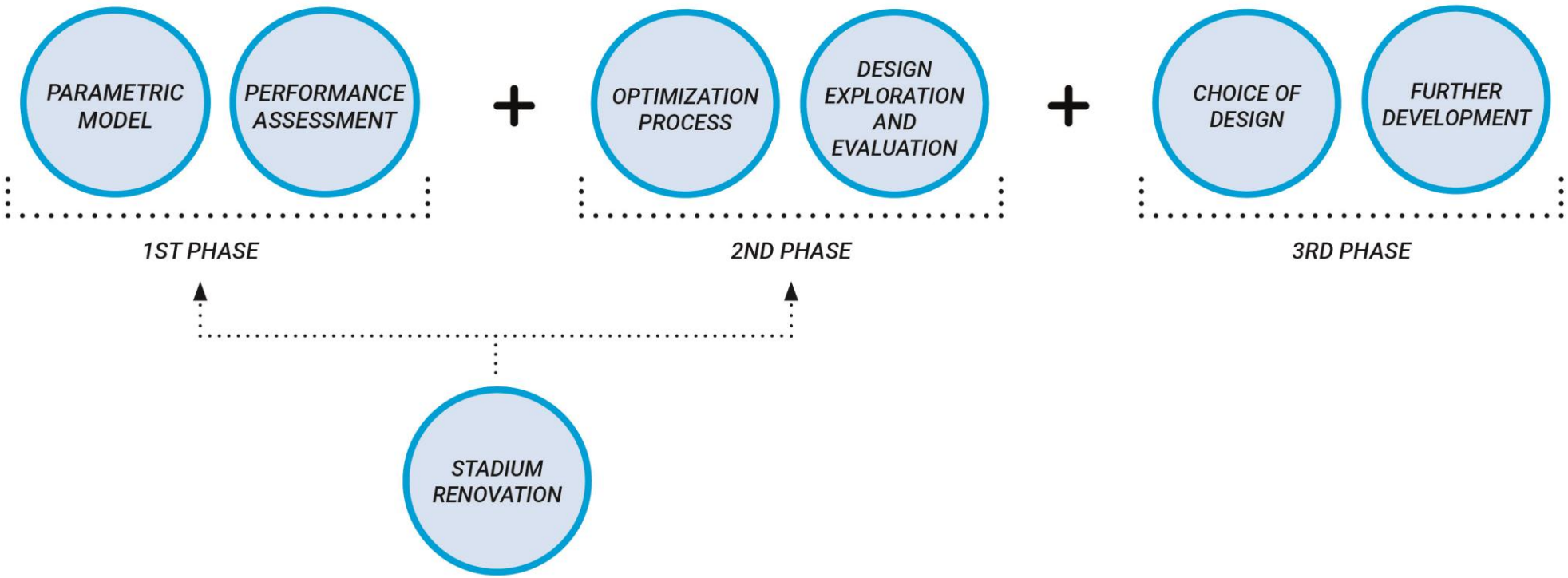

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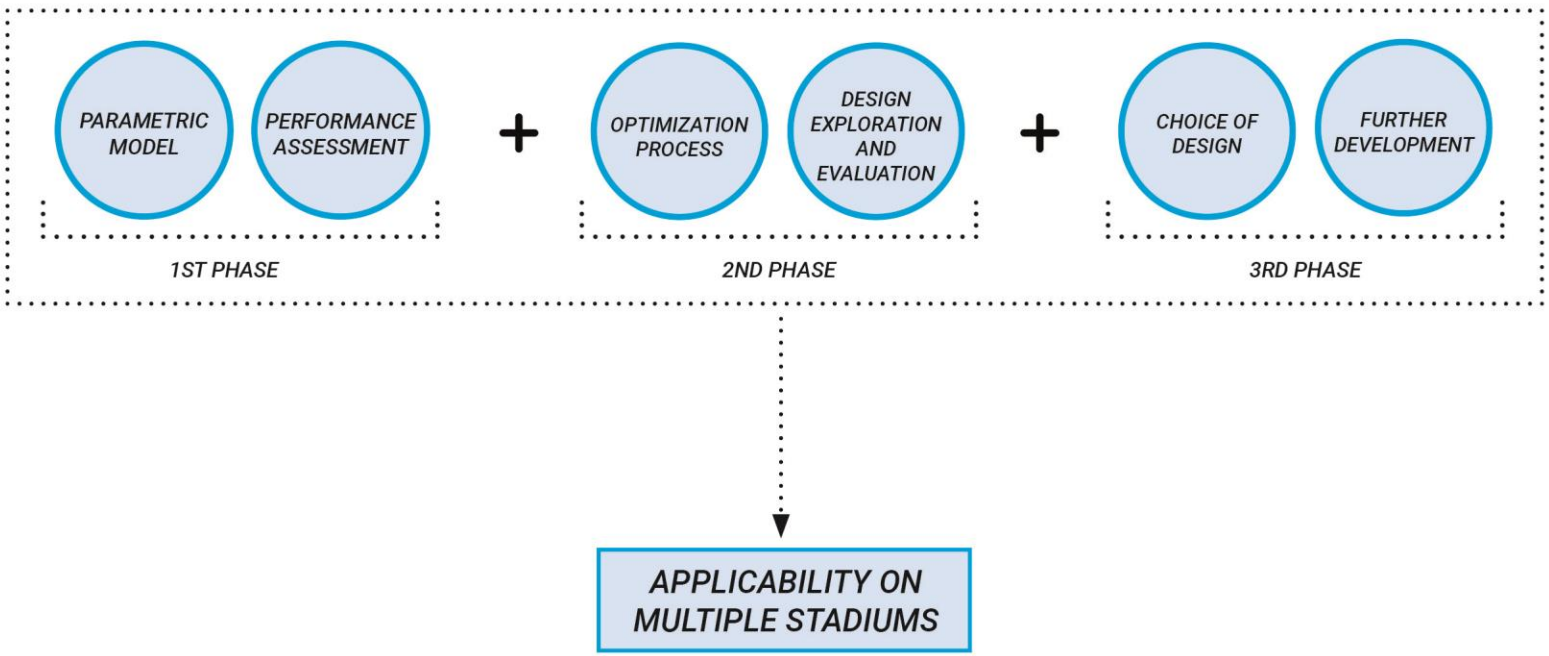

FORM GENERATION

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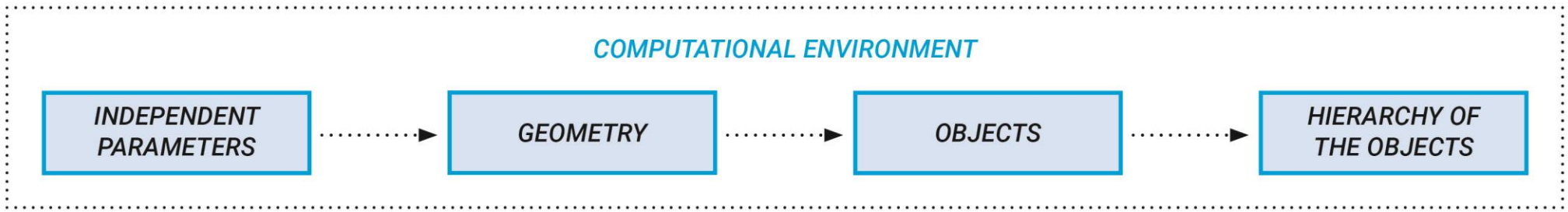

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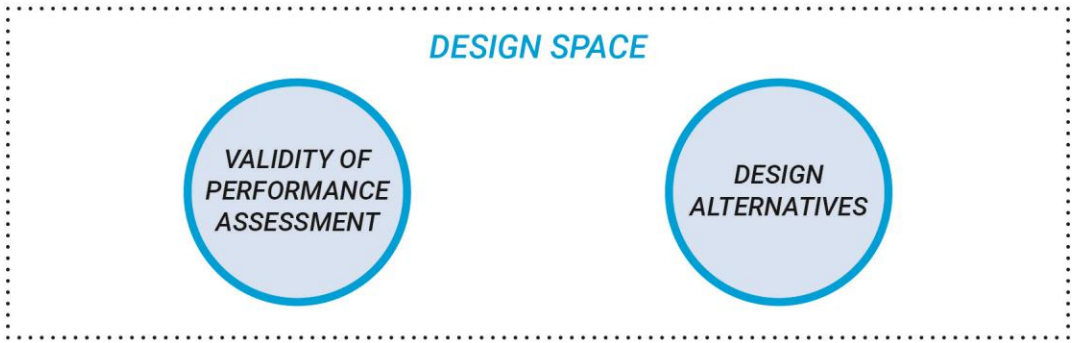
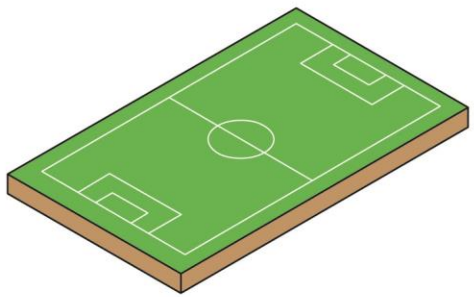


STADIUM COMPONENTS

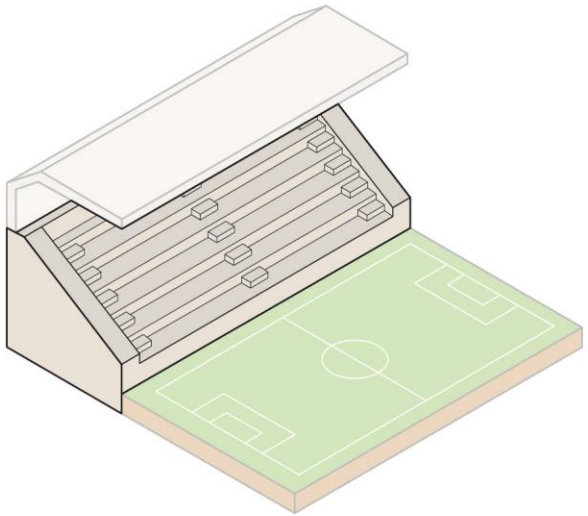
PLAYING AREA



- FOCUS POINT
- VIEWING QUALITY

+

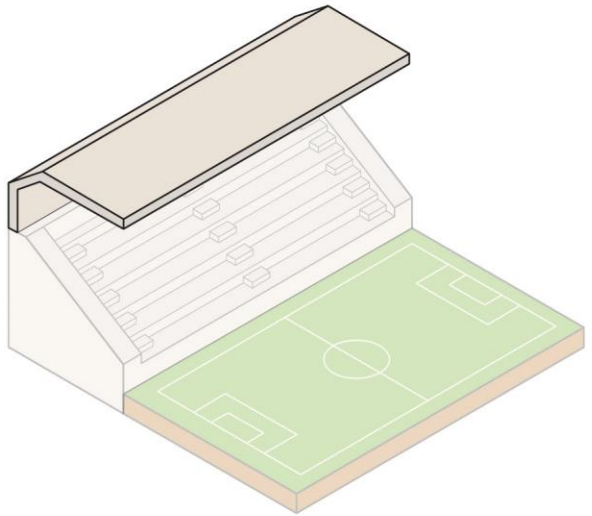
GRANDSTAND



- INFLUENCE ON VIEWING QUALITY
- INFLUENCE ON ROOF OUTLINE
- DETERMINES CAPACITY

+

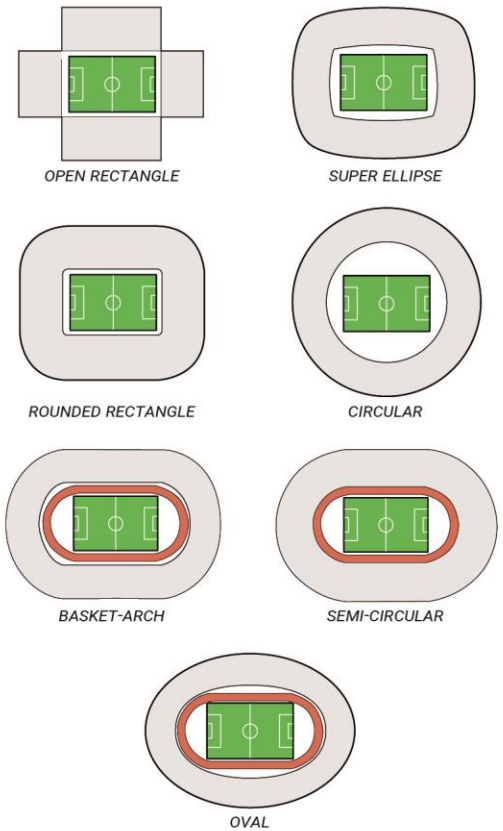
ROOF



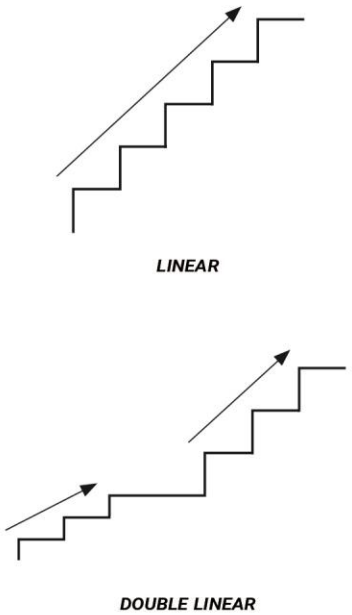
- STRUCTURAL PERFORMANCE
- OBSTRUCTION OF SPECTATORS' VIEW
- COVER OF GRANDSTAND
- GREAT INFLUENCE ON OVERALL COST

TYPOLOGIES OF COMPONENTS

LAYOUT TYPOLOGIES



STAND TYPOLOGIES

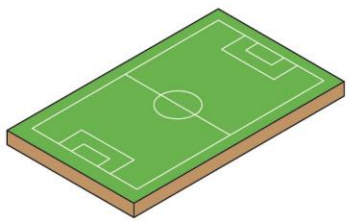


ROOF SYSTEMS

COMPUTATIONAL ENVIRONMENT

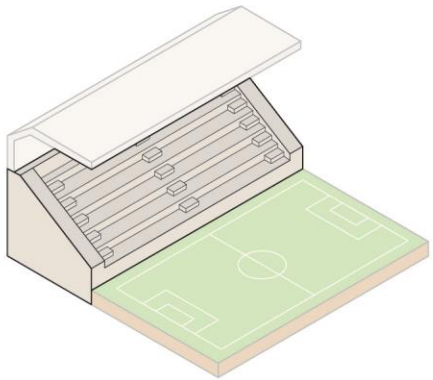
HIERARCHY OF THE OBJECTS

PLAYING AREA



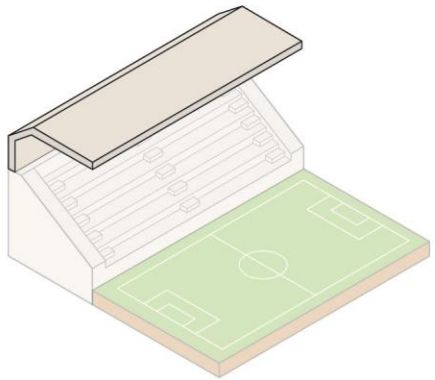
- FOCUS POINT

GRANDSTAND



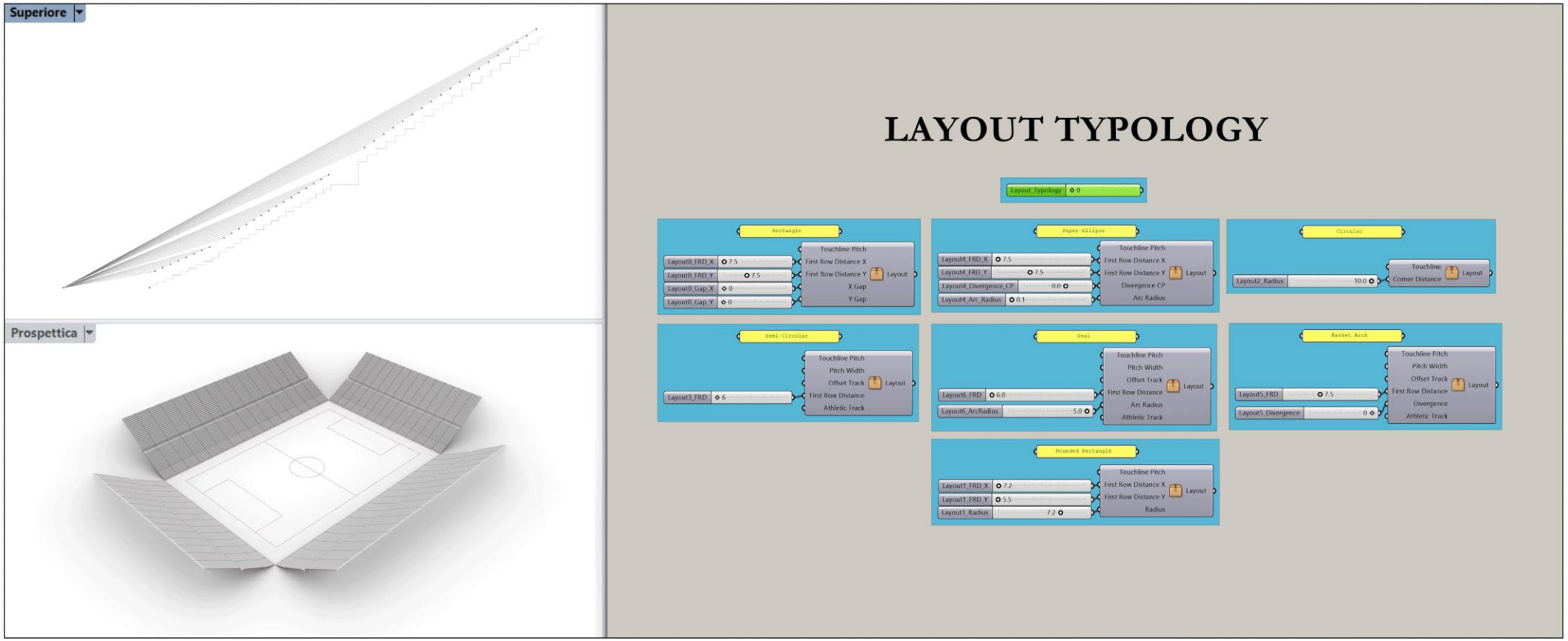
- LAYOUT
- TIERS
- STAND TYPOLOGY
- VERTICAL CIRCULATION

ROOF STRUCTURE

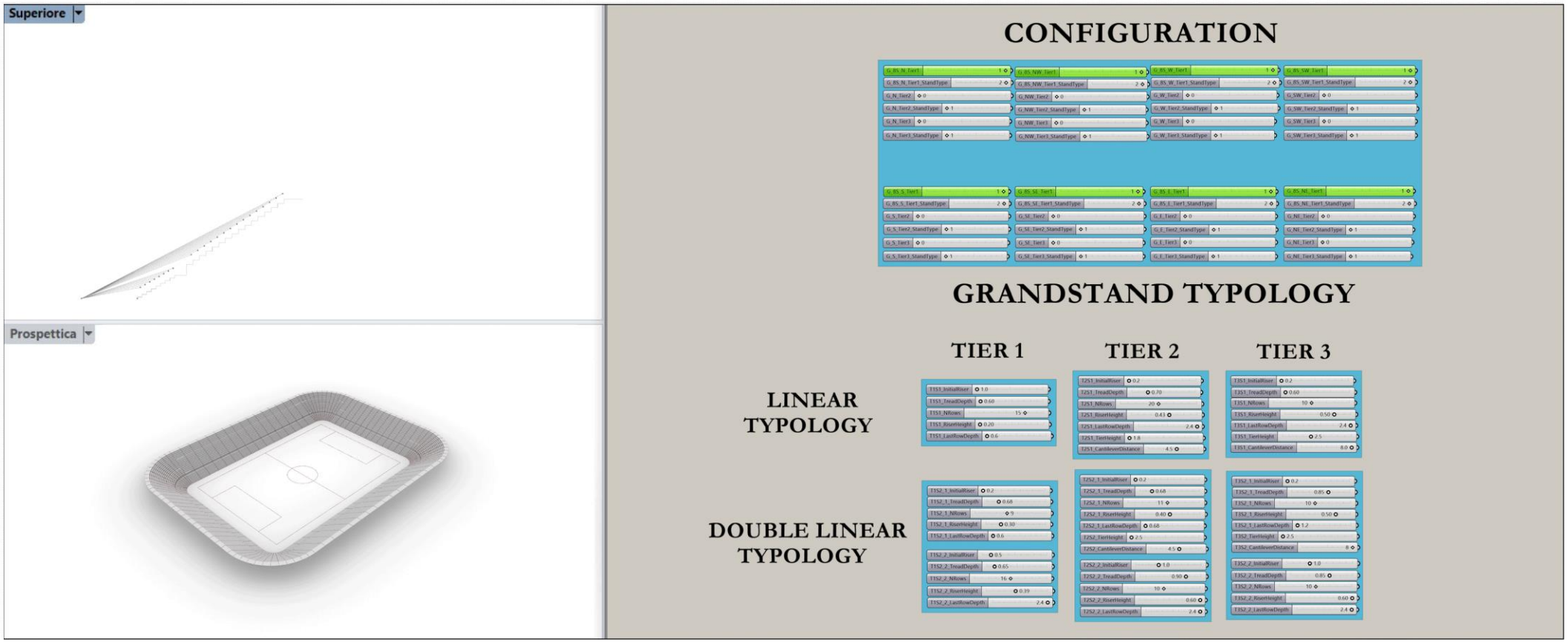


- SYSTEM
- SUPPORTS
- ELEMENTS

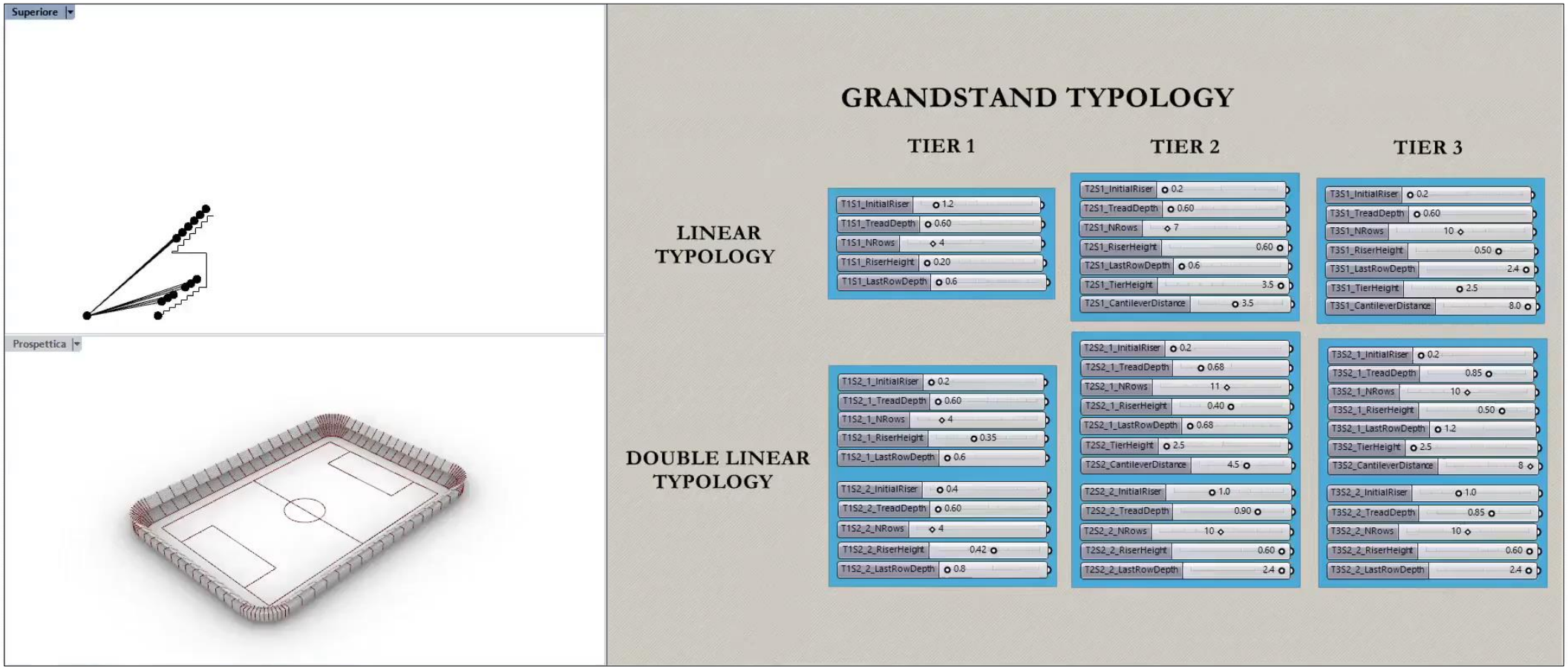
LAYOUT SELECTION



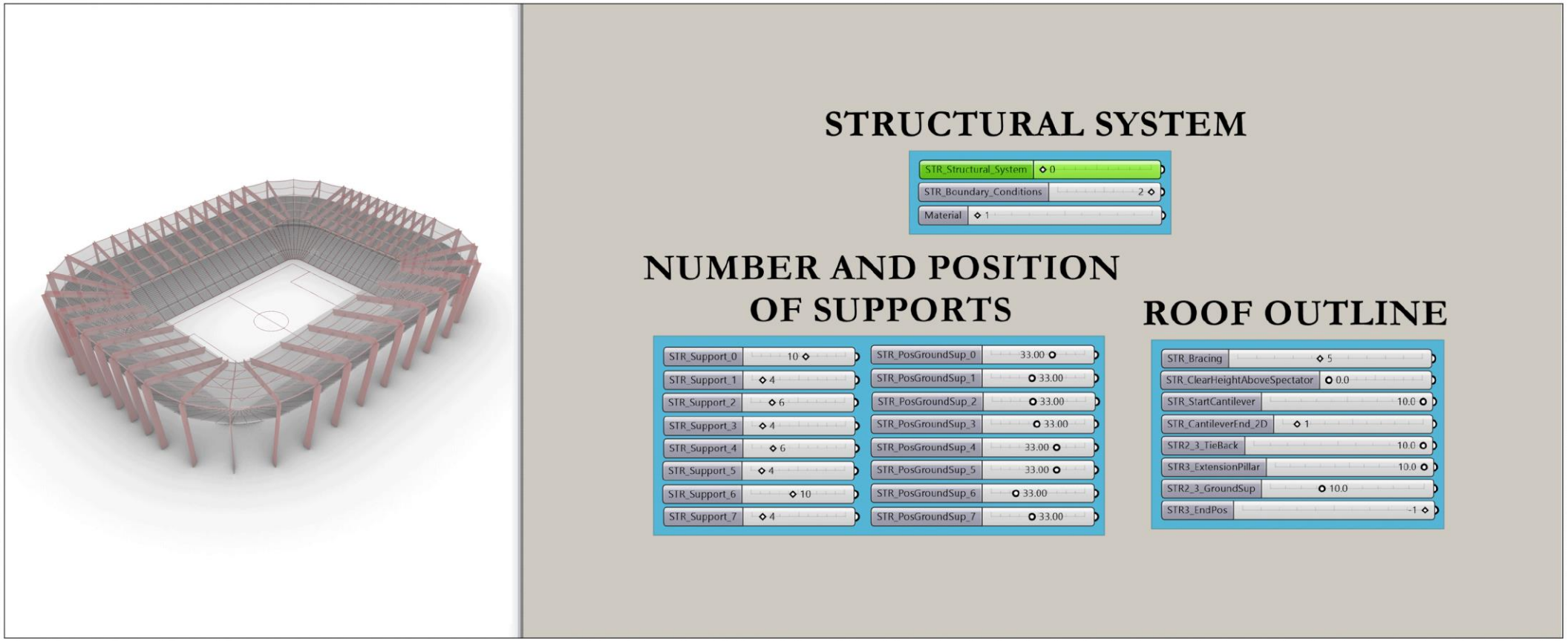
CONFIGURATION SET-UP



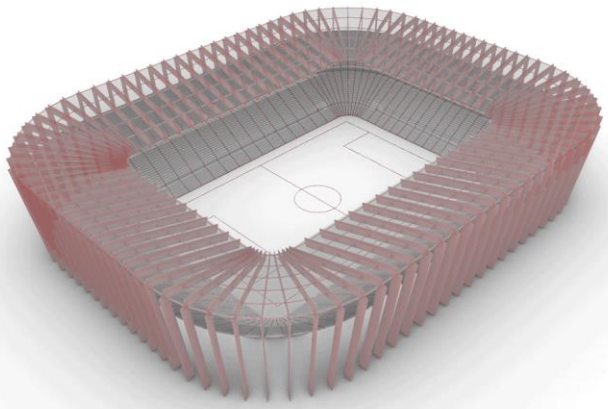
GRANDSTAND CONSTRUCTION



STRUCTURAL SYSTEM



CONTROL POINTS MOVEMENTS



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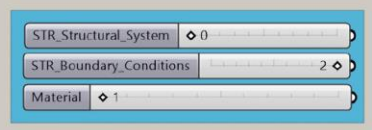


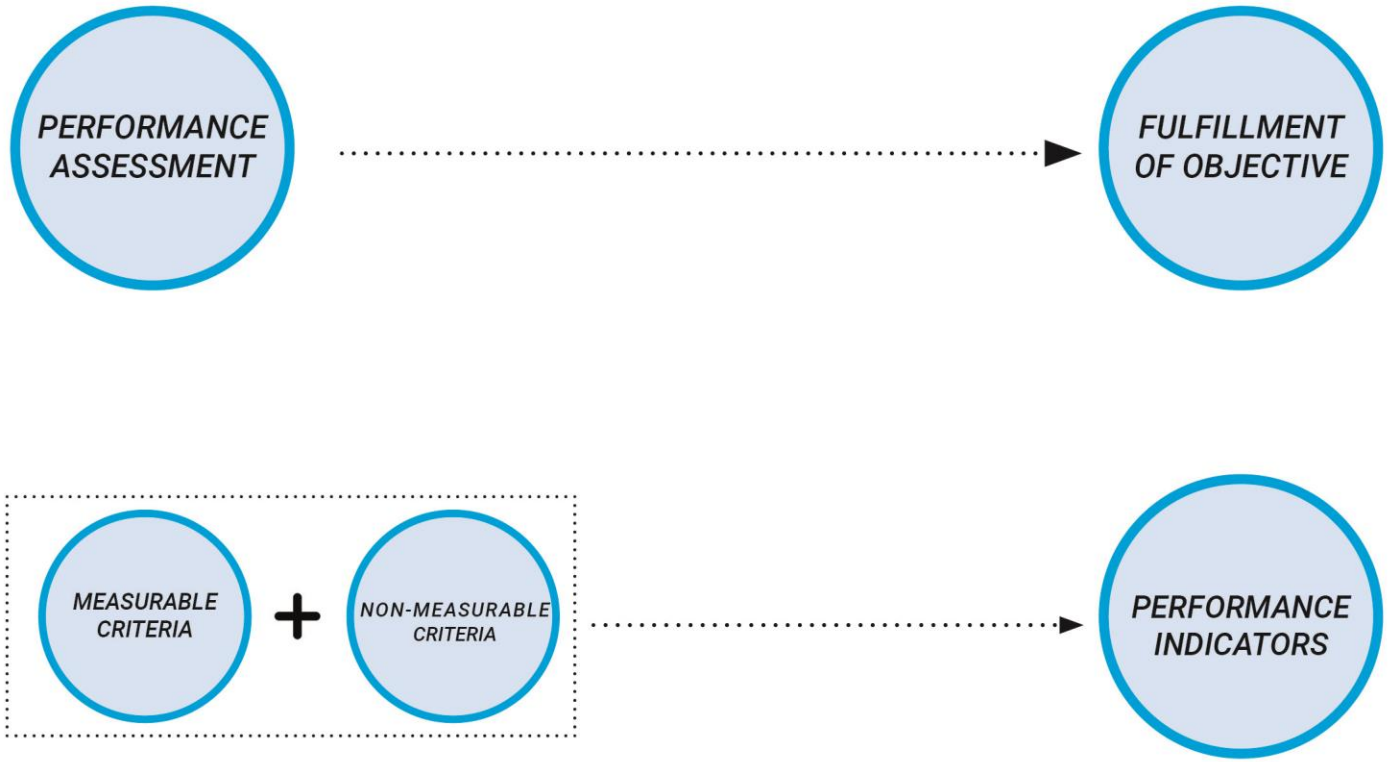
NUMBER AND POSITION OF SUPPORTS

ROOF OUTLINE

PERFORMANCE ASSESSMENT

PERFORMANCE ASSESSMENT

PERFORMANCE ASSESSMENT



PERFORMANCE ASSESSMENT

VIEWING QUALITY

COMFORT OF THE SPECTATORS IN *FOLLOWING* THE ACTIVITY

INDICATORS IN RELATION TO

- COMFORT
- UNOBSTRUCTED VIEW

ROOF STRUCTURE

TRANSFER OF DEAD-WEIGHT AND EXTERNAL *LOADS* TO THE GROUND

INDICATORS IN RELATION TO

- STABILITY
- COMPOSITION

PERFORMANCE ASSESSMENT

VIEWING QUALITY

COMFORT OF THE SPECTATORS IN *FOLLOWING* THE ACTIVITY

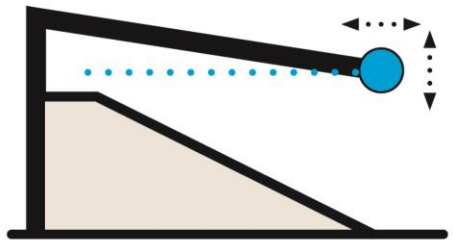
ROOF STRUCTURE

TRANSFER OF DEAD-WEIGHT AND EXTERNAL *LOADS* TO THE GROUND

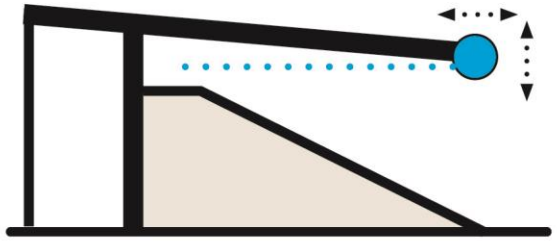
INDICATORS IN RELATION TO	JOINT RELATION	INDICATORS IN RELATION TO
COMFORT	OBSTRUCTION OF VIEW DUE TO ROOF	STABILITY
UNOBSTRUCTED VIEW	COVER OF STANDS	COMPOSITION

JOINT RELATION SOLUTION

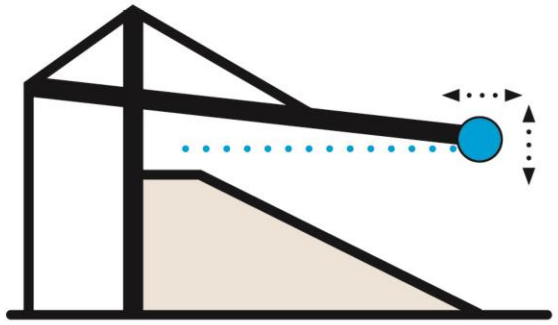
SIMPLE CANTILEVER



TIE-BACK CANTILEVER



RESTRAINED CANTILEVER



VIEW OBSTRUCTION

STAND COVERAGE

OPTIMIZATION

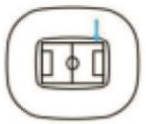
CONTROL OF RANGE OF VALUES

SAVE COMPUTATIONAL TIME

VIEWING QUALITY PERFORMANCES

C-VALUE

- % > 6 cm
- % 6 cm < X < 9 cm
- % > 9 cm
- % 9 cm < X < 12 cm
- % > 12 cm



MAXIMUM DISTANCE

- % SPECTATORS DISTANCE < 190 m
- MAX DISTANCE
- MIN DISTANCE

CAPACITY

- CAPACITY
- INCREMENT
- % INCREMENT

VERTICAL VIEWING ANGLE

- MAX ANGLE
- MIN ANGLE

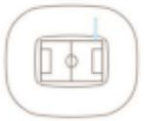
FIELD OF VIEW

- MAX ANGLE
- MIN ANGLE
- % SPECTATORS WITH ANGLE < 120°

C-VALUE EVALUATION

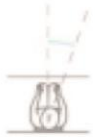
C-VALUE

- % > 6 cm
- % 6 cm < X < 9 cm
- % > 9 cm
- % 9 cm < X < 12 cm
- % > 12 cm



MAXIMUM DISTANCE

- % SPECTATORS DISTANCE < 190 m
- MAX DISTANCE
- MIN DISTANCE



CAPACITY

- CAPACITY
- INCREMENT
- % INCREMENT

VERTICAL VIEWING ANGLE

- MAX ANGLE
- MIN ANGLE

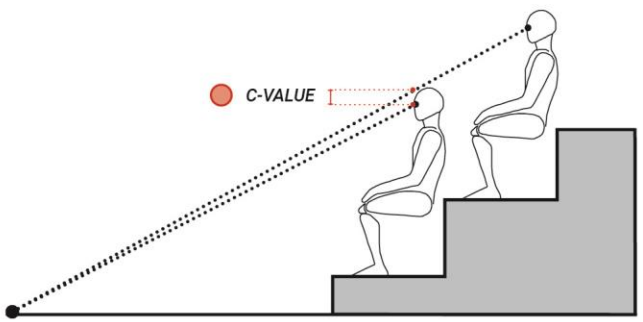
FIELD OF VIEW

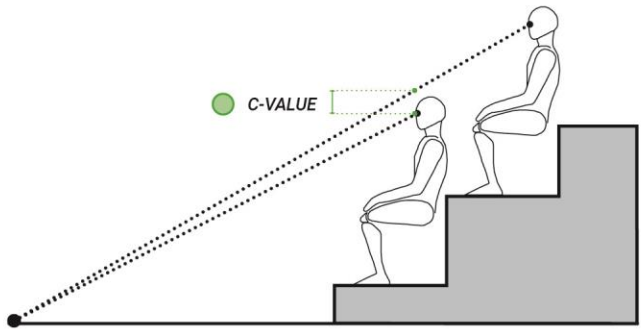
- MAX ANGLE
- MIN ANGLE
- % SPECTATORS WITH ANGLE < 120°

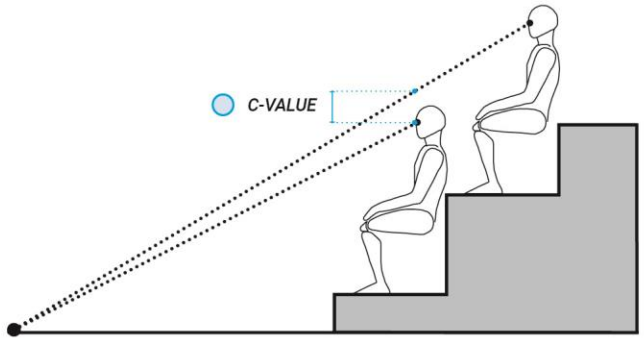
C-VALUE EVALUATION

C-VALUE

% > 6 cm	% 6 cm < X < 9 cm	% > 9 cm	% 9 cm < X < 12 cm	% > 12 cm



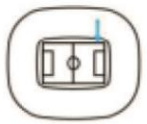




DESIGN ALTERNATIVES VS INITIAL SITUATION

C-VALUE

- % > 6 cm
- % 6 cm < X < 9 cm
- % > 9 cm
- % 9 cm < X < 12 cm
- % > 12 cm



MAXIMUM DISTANCE

- % SPECTATORS DISTANCE < 190 m
- MAX DISTANCE
- MIN DISTANCE

CAPACITY

- CAPACITY
- INCREMENT
- % INCREMENT

VERTICAL VIEWING ANGLE

- MAX ANGLE
- MIN ANGLE

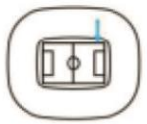
FIELD OF VIEW

- MAX ANGLE
- MIN ANGLE
- % SPECTATORS WITH ANGLE < 120°

EVALUATE RENOVATION

C-VALUE

- % > 6 cm
- % 6 cm < X < 9 cm
- % > 9 cm
- % 9 cm < X < 12 cm
- % > 12 cm



MAXIMUM DISTANCE

- % SPECTATORS DISTANCE < 190 m
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CAPACITY

- CAPACITY
- INCREMENT
- % INCREMENT

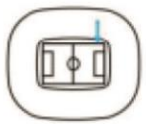
VERTICAL VIEWING ANGLE

- MAX ANGLE
- MIN ANGLE

FIELD OF VIEW

- MAX ANGLE
- MIN ANGLE
- % SPECTATORS WITH ANGLE < 120°

EVALUATE RENOVATION

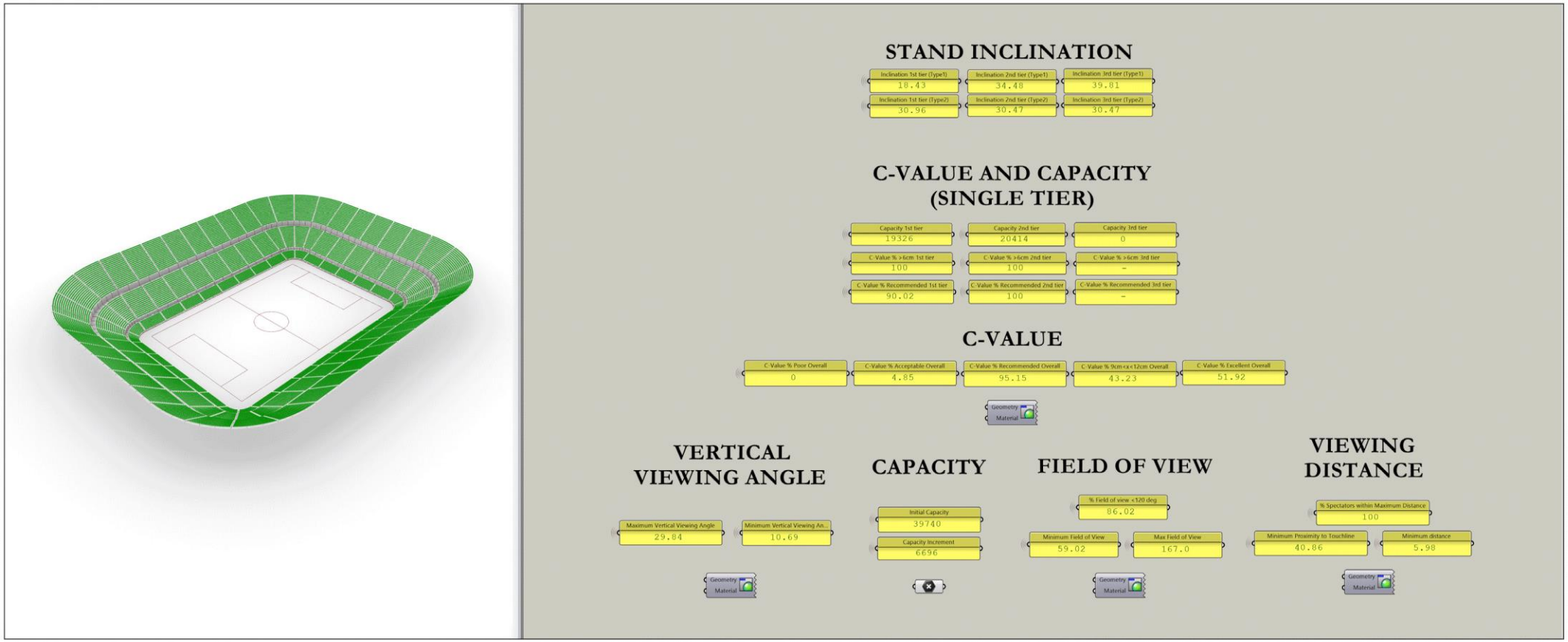


MAXIMUM DISTANCE	IMPLICATIONS	CONDITION TO BE MATCHED IN THE METHOD
% SPECTATORS DISTANCE < 190 m	COMFORTABLE	> 95%

C-VALUE	IMPLICATIONS	CONDITION TO BE MATCHED IN THE METHOD
% > 6 cm	VIEW IS OBSTRUCTED	= 0 %
% > 9 cm	VIEW UNOBSTRUCTED	> 80 %

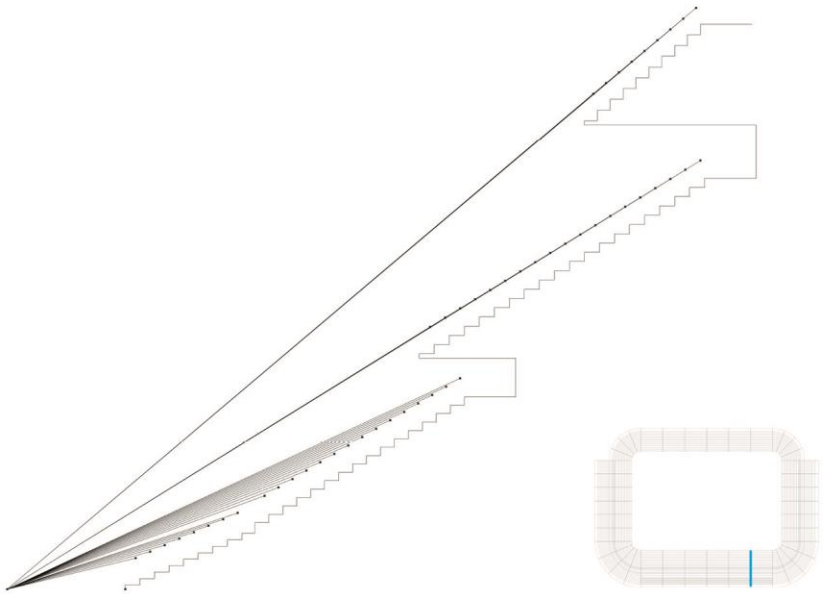
COMPUTATIONAL ENVIRONMENT

VISUALIZATION OF RESULTS

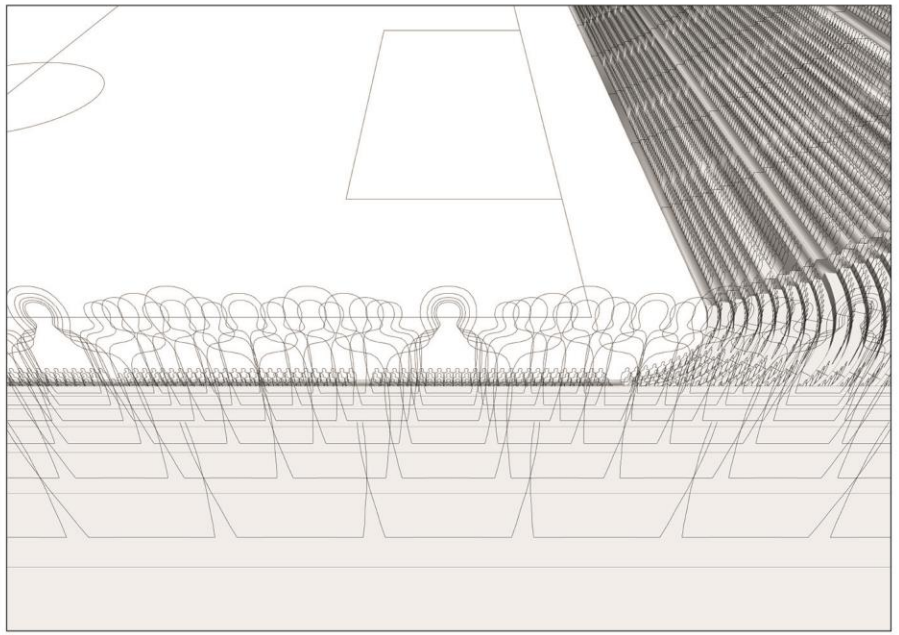


FURTHER DECISION-MAKING SUPPORT

2D SECTION VISUALIZATION



POINT OF VIEW VISUALIZATION



STRUCTURAL INDICATORS

ROOF STRUCTURE

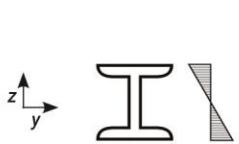
TRANSFER OF DEAD-WEIGHT AND EXTERNAL *LOADS* TO THE GROUND

DISPLACEMENT

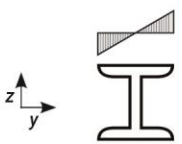
MAX = L / 150

MAX = L / 300

STRESSES



$$\sigma_x = \frac{M_y * z}{I_y} = \frac{M_y}{S_y}$$



$$\sigma_x = \frac{M_z * y}{I_z} = \frac{M_z}{S_z}$$

MAX = YIELD STRENGTH OF THE MATERIAL

INDICATORS

- TOTAL MASS
- NUMBER OF ELEMENTS
- NUMBER OF JOINTS

STRUCTURAL PERFORMANCES

DISPLACEMENT

- MAX DISPLACEMENT
- MAX DISPLACEMENT (OVERALL)

STRESSES

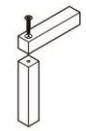
- MAX STRESS (My-direction)
- MAX STRESS (Mz-direction)
- MAX STRESS (OVERALL)

MASS

- TOTAL MASS
- MASS INCREMENT

NUMBER OF ELEMENTS

- NUMBER OF ELEMENTS
- ELEMENT INCREMENT



NUMBER OF JOINTS

- NUMBER OF JOINTS
- JOINTS INCREMENT

DESIGN ALTERNATIVES VS INITIAL SITUATION

DISPLACEMENT

- MAX DISPLACEMENT
- MAX DISPLACEMENT (OVERALL)

STRESSES

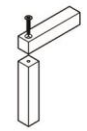
- MAX STRESS (My-direction)
- MAX STRESS (Mz-direction)
- MAX STRESS (OVERALL)

MASS

- TOTAL MASS
- MASS INCREMENT
- OBJECTIVE

NUMBER OF ELEMENTS

- NUMBER OF ELEMENTS
- ELEMENT INCREMENT
- OBJECTIVE



NUMBER OF JOINTS

- NUMBER OF JOINTS
- JOINTS INCREMENT
- OBJECTIVE

EVALUATION GROUP OF ELEMENTS

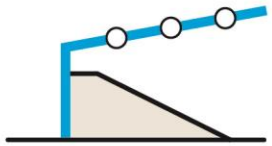
DISPLACEMENT

- MAX DISPLACEMENT
- MAX DISPLACEMENT (OVERALL)

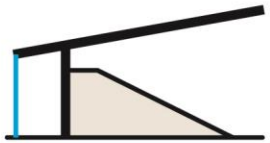
STRESSES

- MAX STRESS (My-direction)
- MAX STRESS (Mz-direction)
- MAX STRESS (OVERALL)

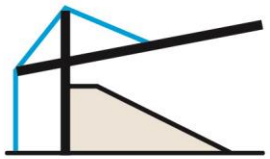
GROUPS OF STRUCTURAL ELEMENTS



- PILLARS
- CANTILEVERS
- BRACINGS



- PILLARS
- CANTILEVERS
- BRACINGS
- 1-RESTRAIN



- PILLARS
- CANTILEVERS
- BRACINGS
- 1-RESTRAIN
- 2-RESTRAIN
- 3-RESTRAIN

EVALUATION GROUP OF ELEMENTS

DISPLACEMENT

- MAX DISPLACEMENT
- MAX DISPLACEMENT (OVERALL)
- CONSTRAINT

STRESSES

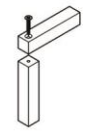
- MAX STRESS (My-direction)
- MAX STRESS (Mz-direction)
- MAX STRESS (OVERALL)
- CONSTRAINT

MASS

- TOTAL MASS
- MASS INCREMENT

NUMBER OF ELEMENTS

- NUMBER OF ELEMENTS
- ELEMENT INCREMENT

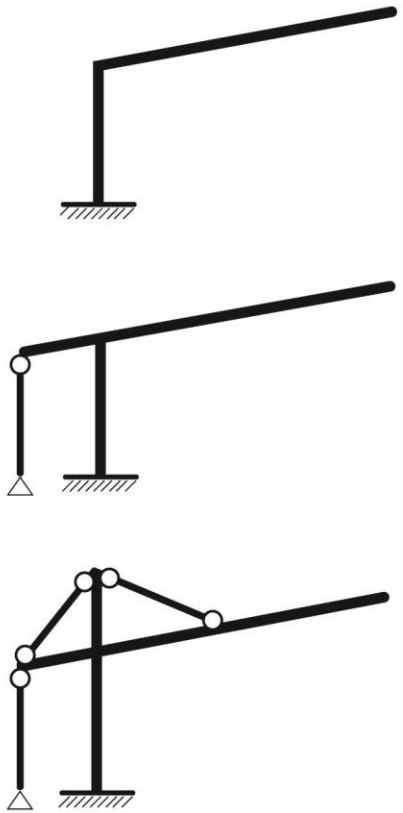


NUMBER OF JOINTS

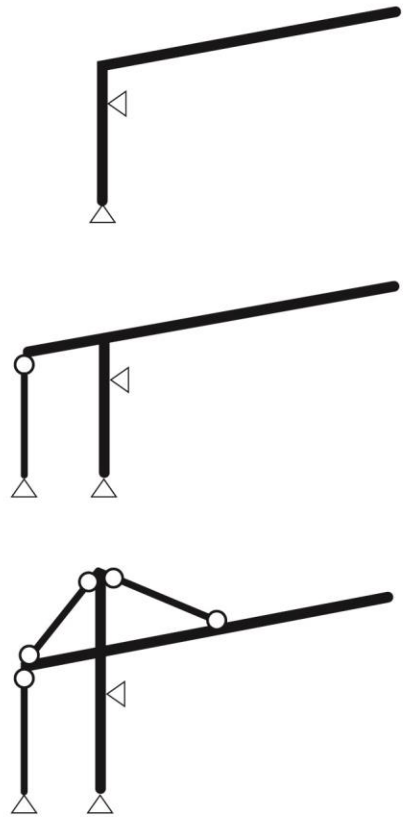
- NUMBER OF JOINTS
- JOINTS INCREMENT

SUPPORT SETS

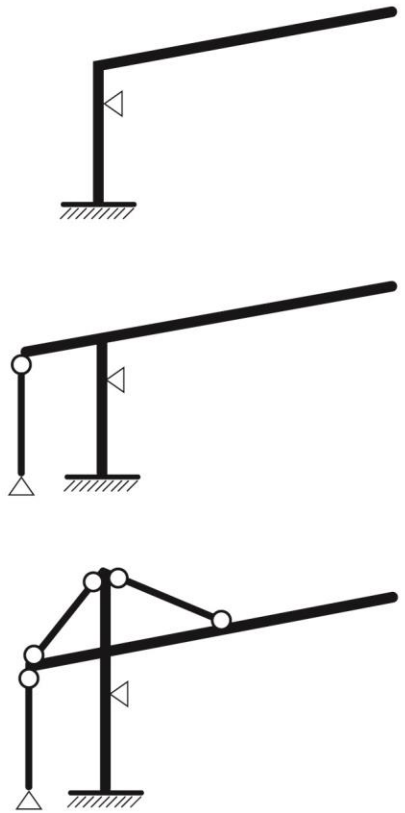
FIXED SUPPORT



HINGE + HINGE SUPPORT



FIXED + HINGE SUPPORT



CONSIDERED ELEMENTS

LOAD CONDITIONS

DEAD-WEIGHT

SNOW LOAD

1,5 kN/m²

WIND LOAD

0,8 kN/m²

CROSS SECTIONS

EU HEA

UK CHSC

MATERIALS

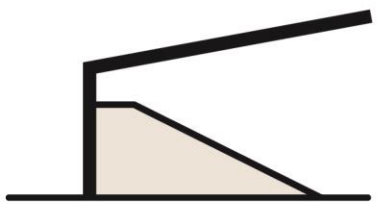
STEEL S235

STEEL S275

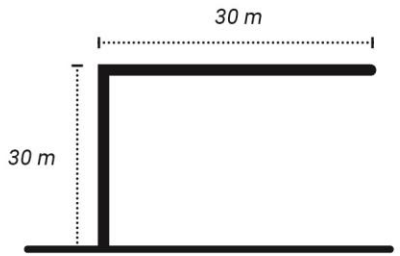
STEEL S355

BEHAVIOUR OF SYSTEMS

MODEL SET-UP

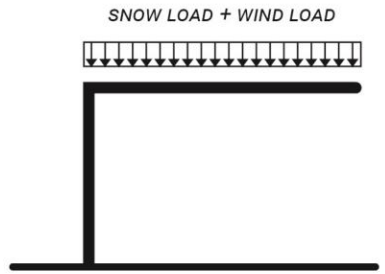


SIMPLE CANTILEVER



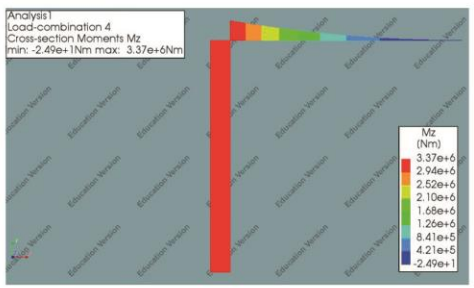
UK CHSC1016x30,0

STEEL S235

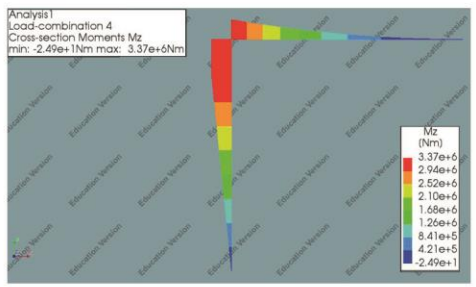


BEHAVIOUR OF SYSTEMS

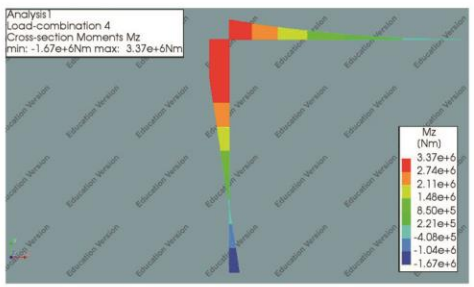
SUPPORT SET 0



SUPPORT SET 1

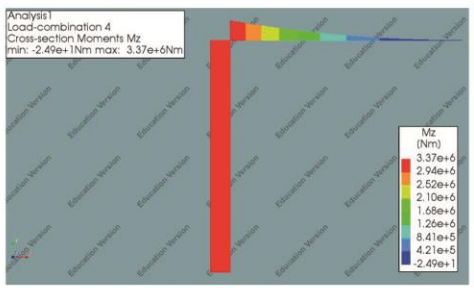


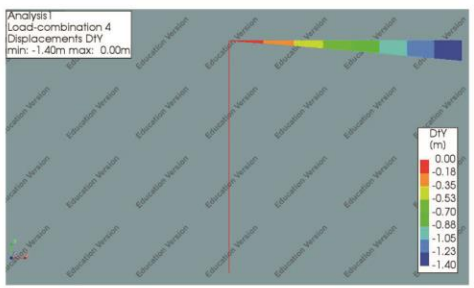
SUPPORT SET 2



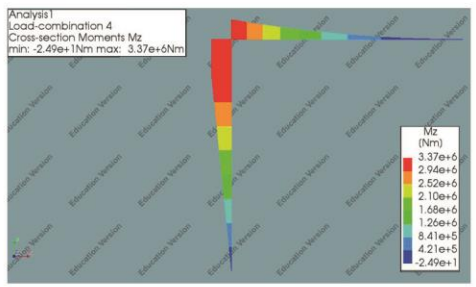
BEHAVIOUR OF SYSTEMS

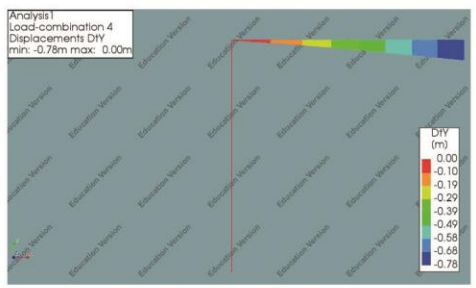
SUPPORT SET 0



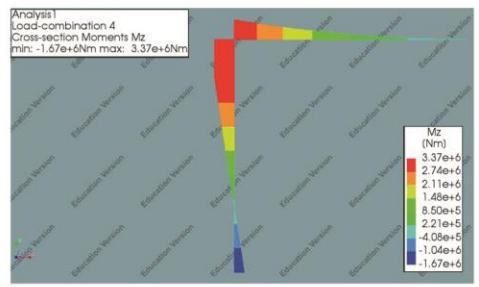


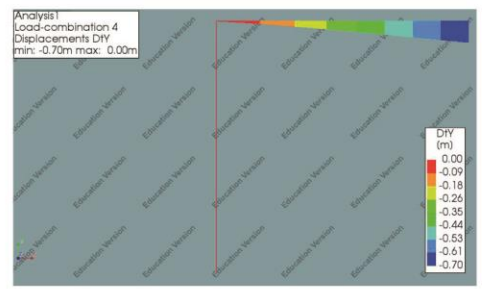
SUPPORT SET 1



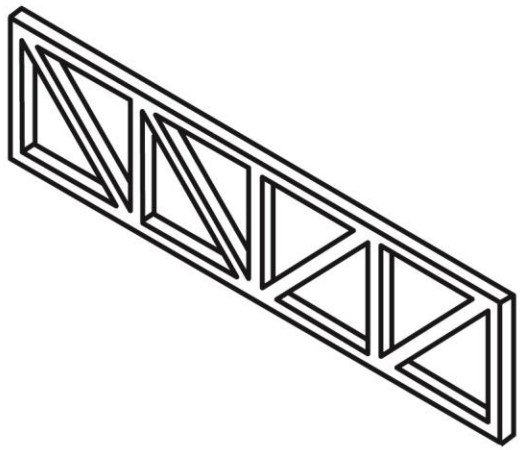


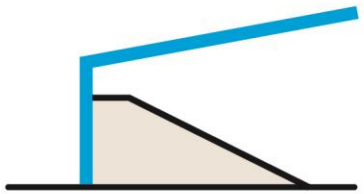
SUPPORT SET 2

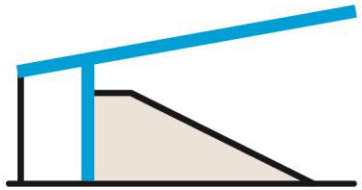


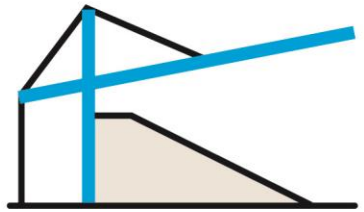


PARALLEL TRUSS IMPLEMENTATION

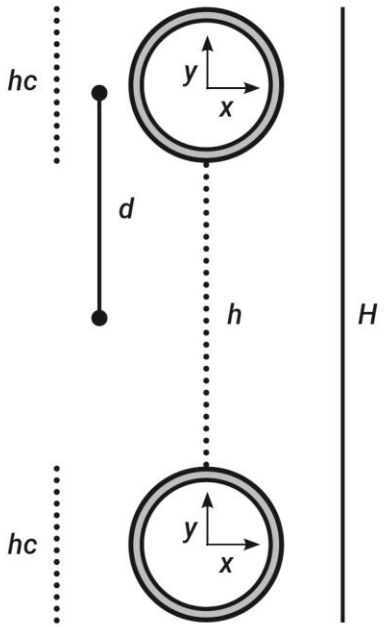


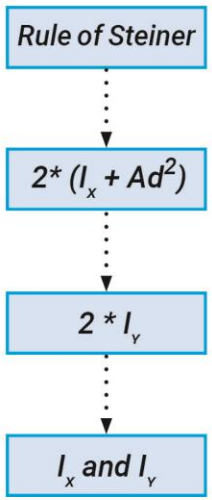




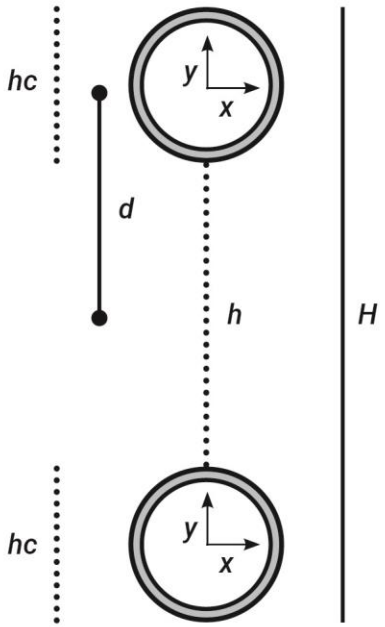


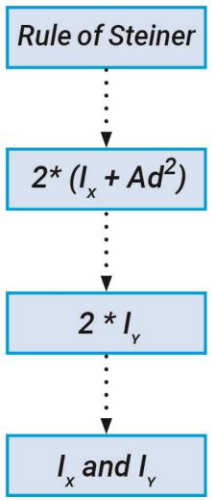
PARALLEL TRUSS IMPLEMENTATION

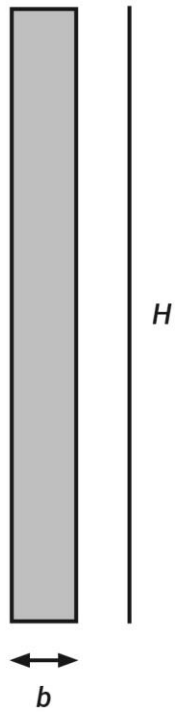


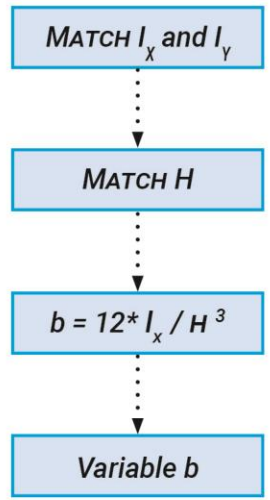


PARALLEL TRUSS IMPLEMENTATION

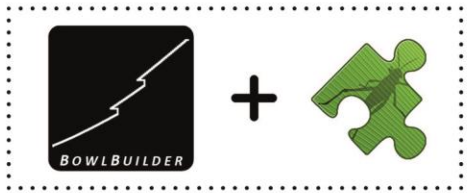






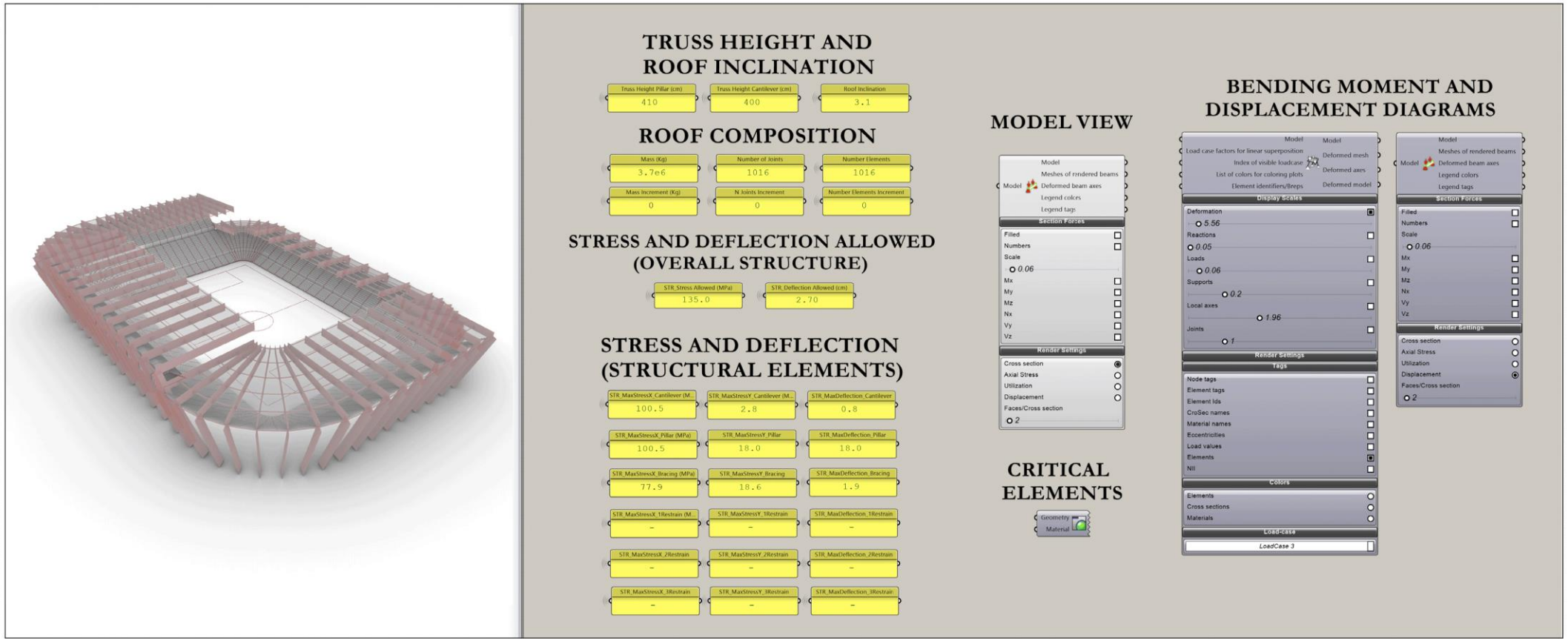


COMPUTATIONAL ENVIRONMENT



Karamba3D

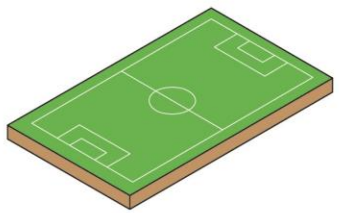
VISUALIZATION OF RESULTS



EXISTING STADIUM CONSTRAINTS

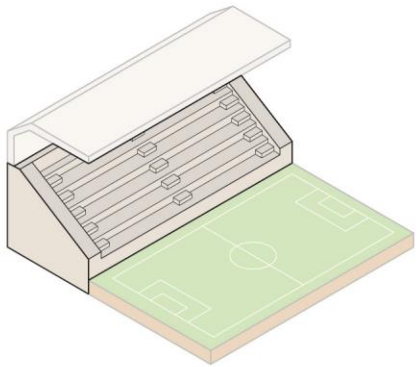
EXISTING STADIUM CONSTRAINTS

PLAYING AREA



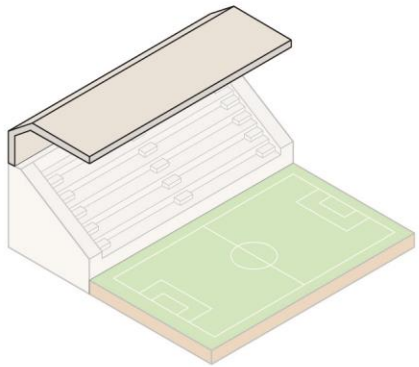
- FOCUS POINT
- DIMENSIONS

GRANDSTAND



- LAYOUT
- % C-VALUE > 9 cm > 80%
- % C-VALUE > 6 cm = 0%
- % SPECTATORS WITH MAX DISTANCE > 95%

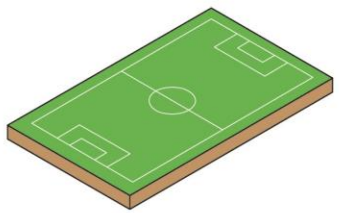
ROOF STRUCTURE



- POSITION OF SUPPORTS
- NUMBER OF SUPPORTS
- COVERAGE OF GRANDSTANDS
- CLEAR HEIGHT ABOVE SPECTATOR'S SIGHT

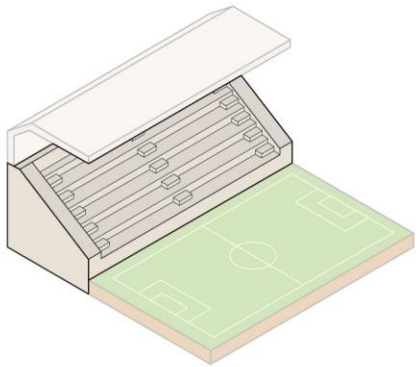
EXISTING STADIUM CONSTRAINTS

PLAYING AREA



- FOCUS POINT
- DIMENSIONS

GRANDSTAND



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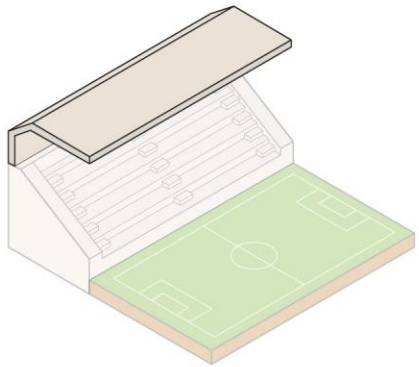
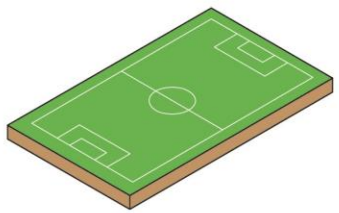


- POSITION OF SUPPORTS
- NUMBER OF SUPPORTS
- COVERAGE OF GRANDSTANDS
- CLEAR HEIGHT ABOVE SPECTATOR'S SIGHT

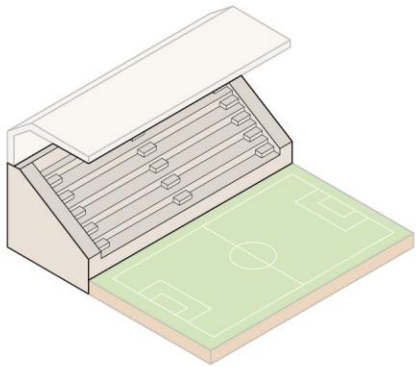
EXISTING STADIUM CONSTRAINTS

PLAYING AREA



- FOCUS POINT
- DIMENSIONS

GRANDSTAND



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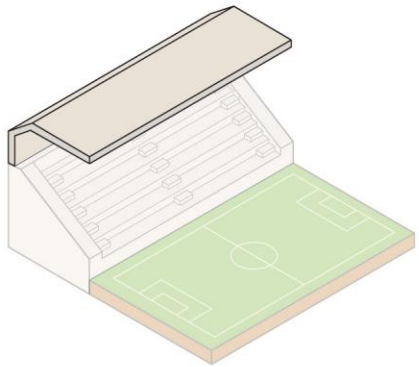
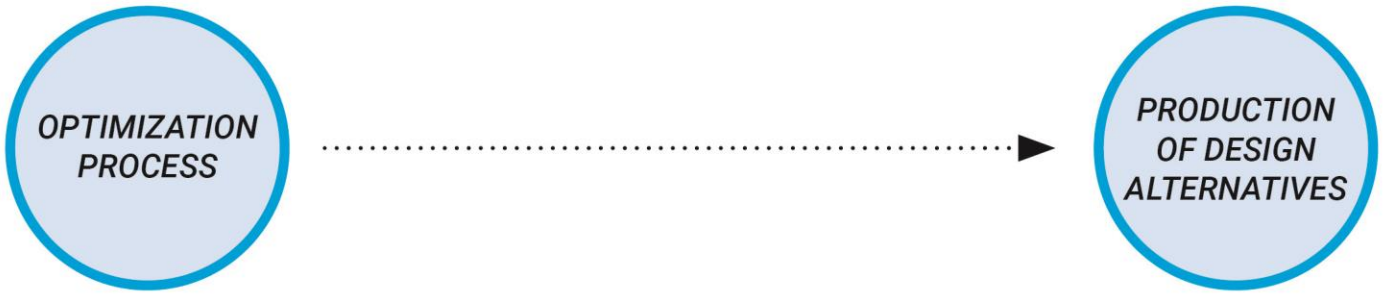
ROOF STRUCTURE



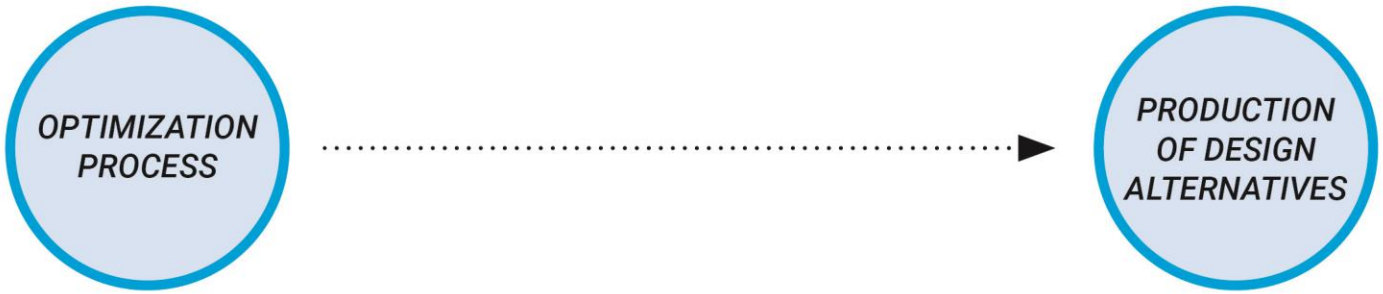
- POSITION OF SUPPORTS
- NUMBER OF SUPPORTS
- COVERAGE OF GRANDSTANDS
- CLEAR HEIGHT ABOVE SPECTATOR'S SIGHT

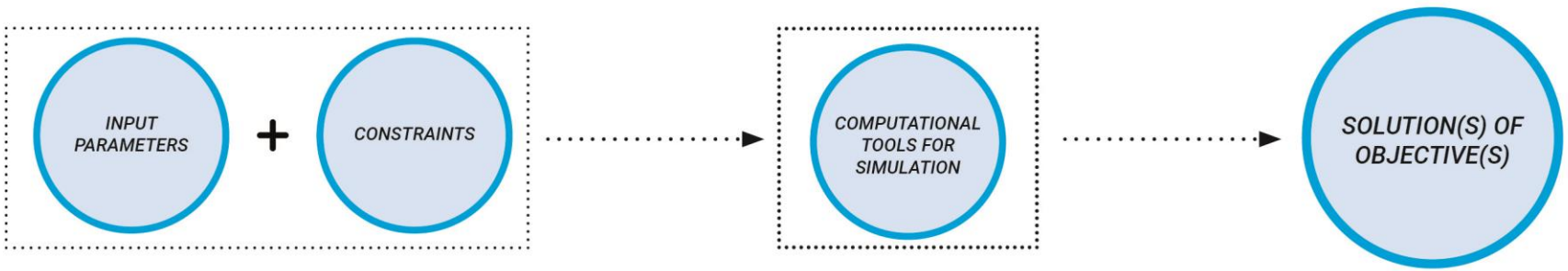
OPTIMIZATION AND DESIGN EXPLORATION

OPTIMIZATION PROCESS

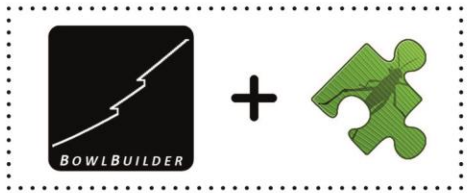


OPTIMIZATION PROCESS





COMPUTATIONAL ENVIRONMENT



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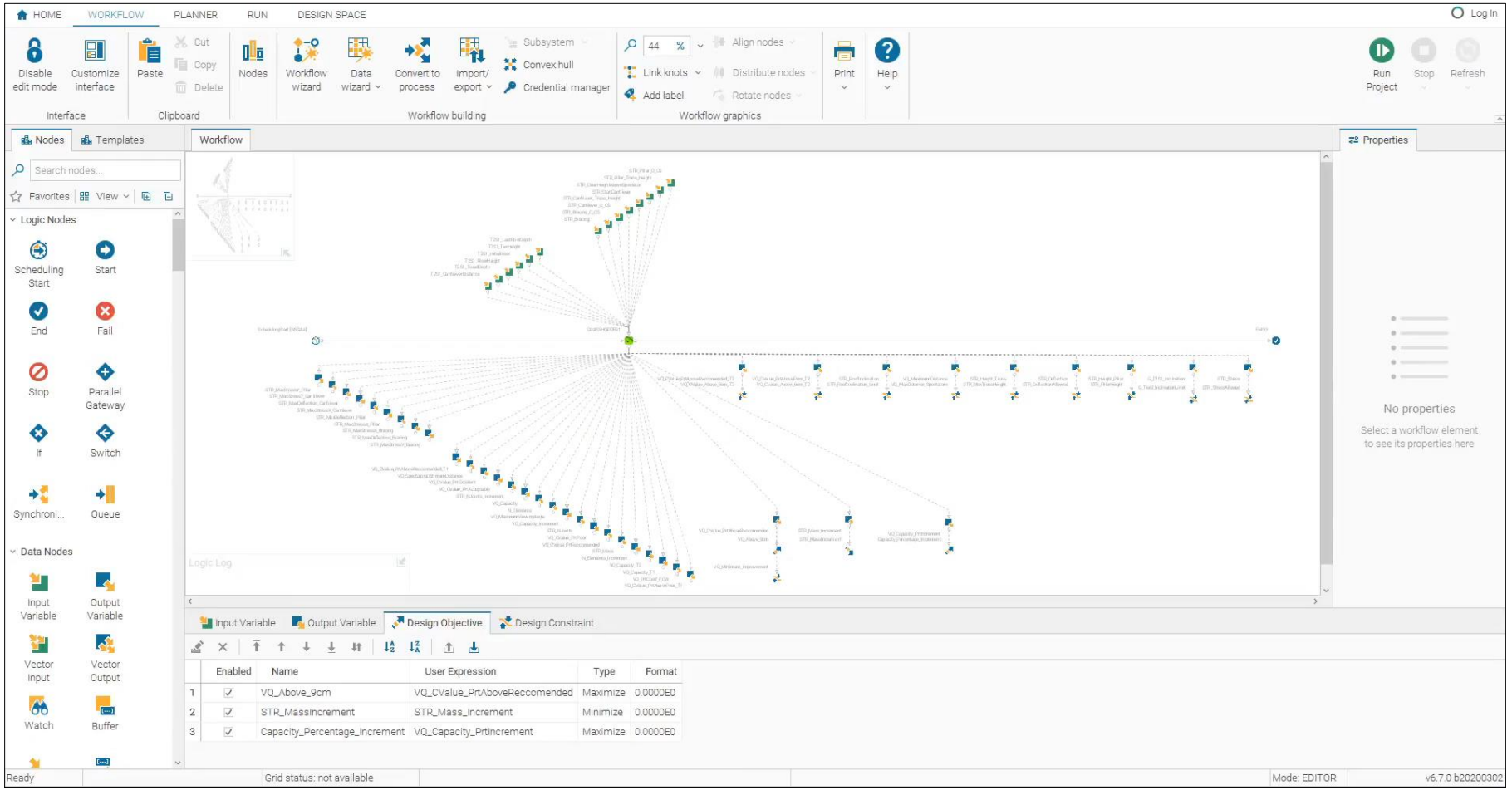
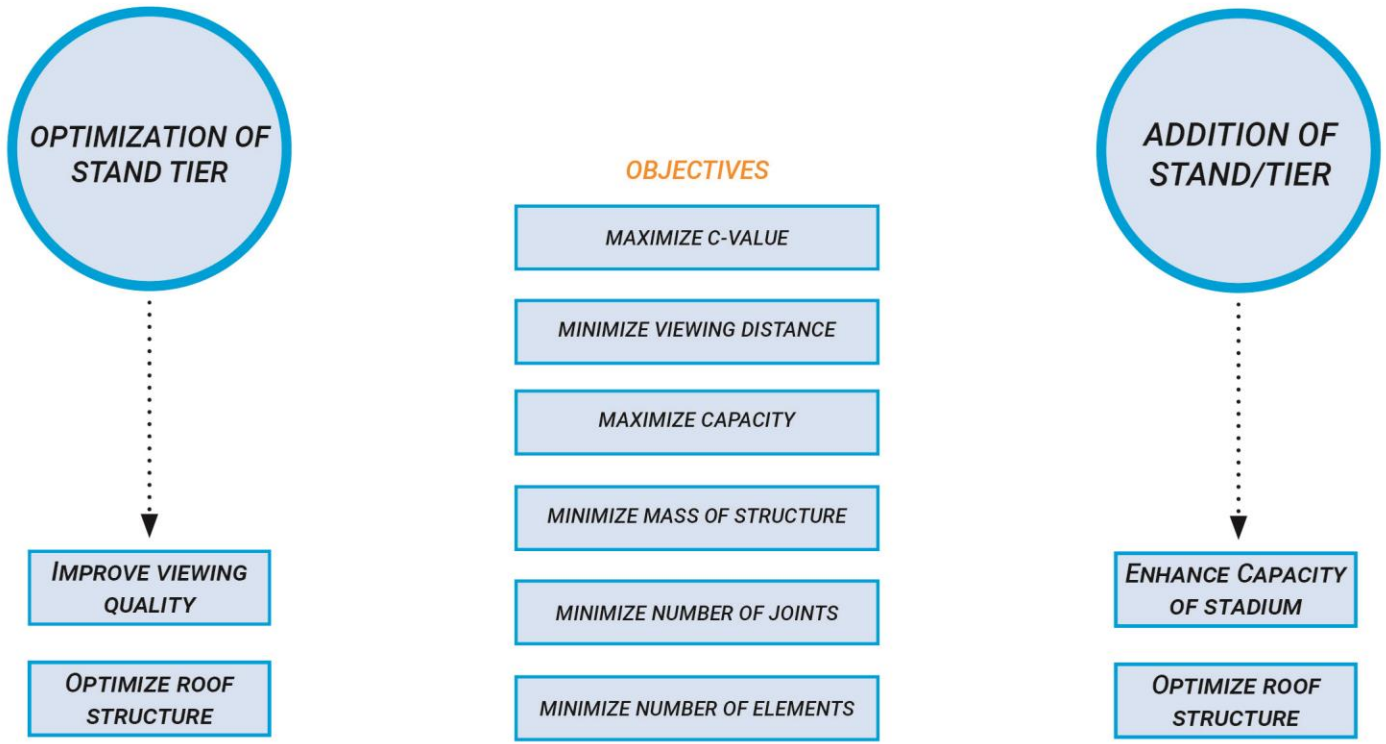
OPTIMIZATION SET-UP

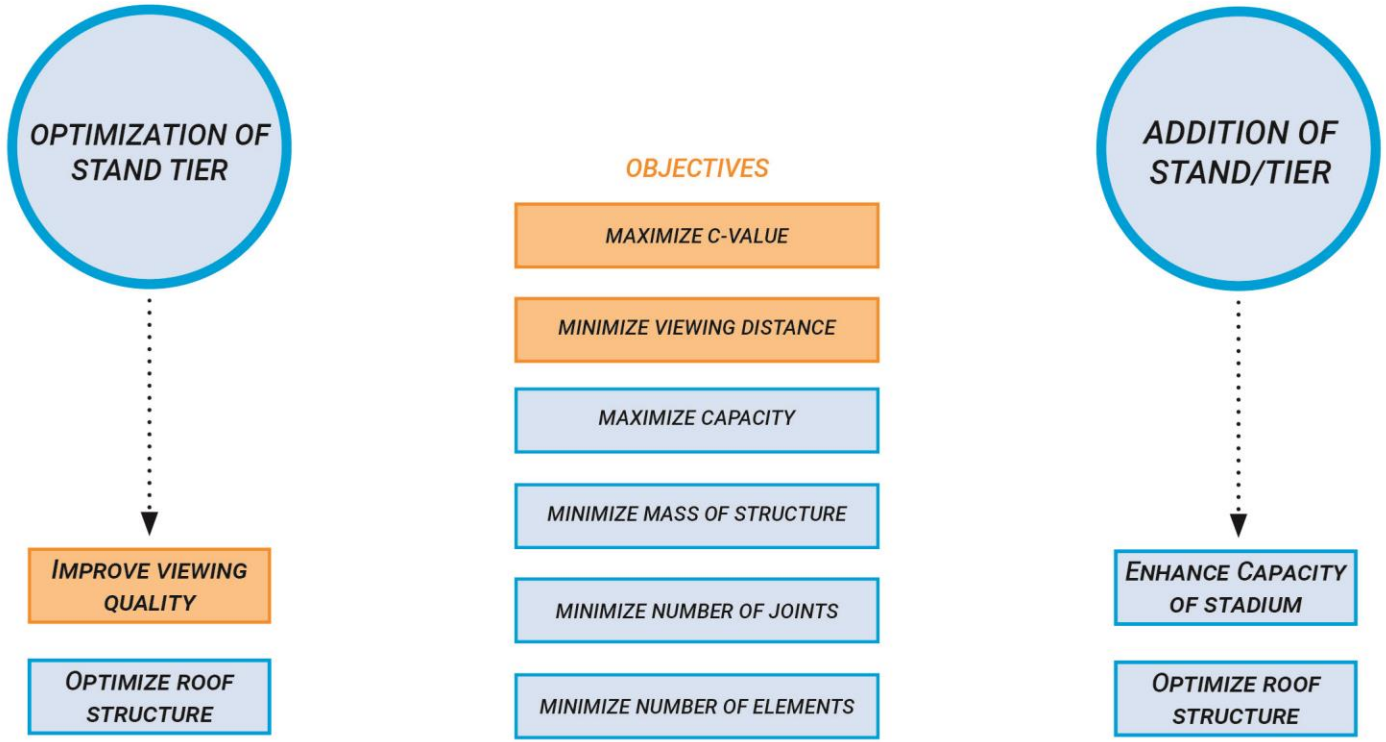


RENOVATION APPROACHES

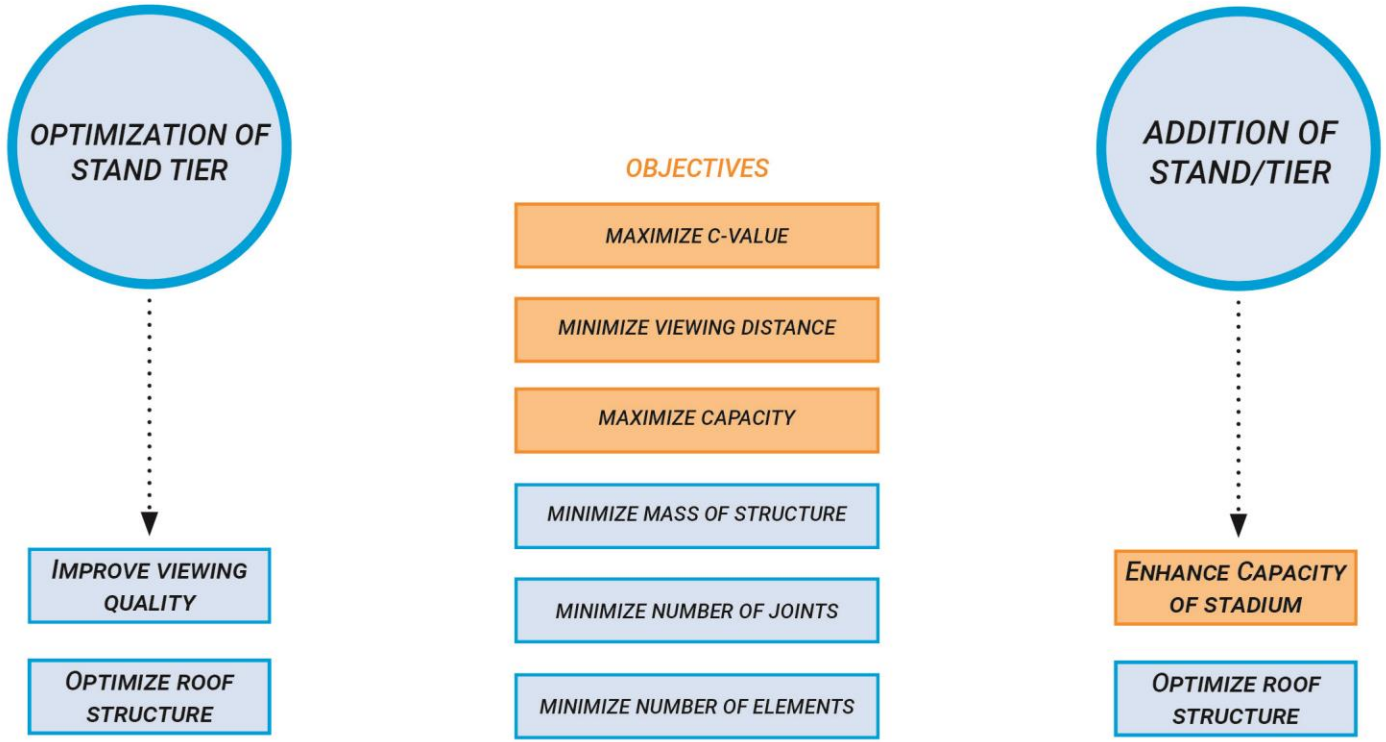
RENOVATION APPROACHES



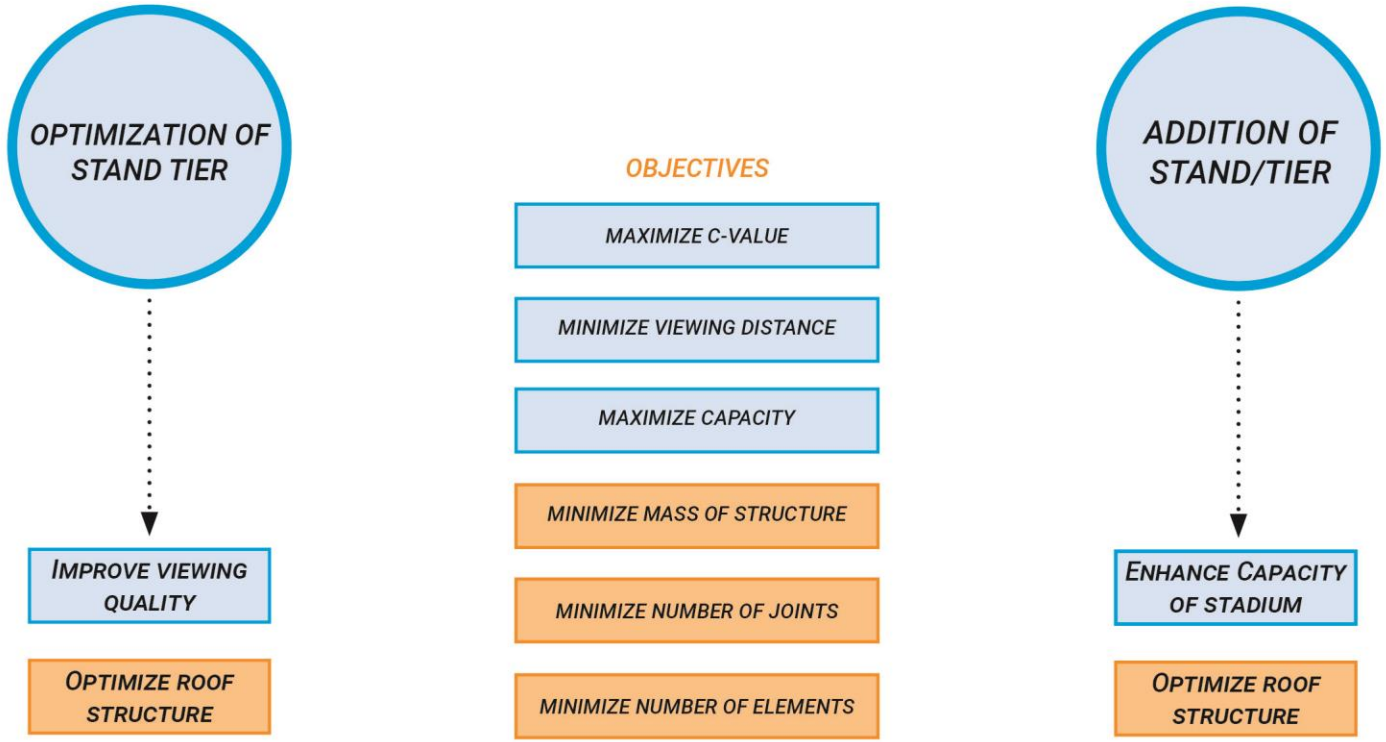
RENOVATION APPROACHES



RENOVATION APPROACHES



RENOVATION APPROACHES



SET-UP MODEFRONTIER (CONSTRAINTS)

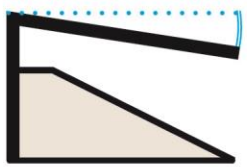
i.e. DESIGN CONSTRAINTS

TIER INCLINATION

< 35°

MAX STRESS

> 0 MPa



ROOF INCLINATION

> 1,5°

MAX DISPLACEMENT

> 0 cm

i.e. OBJECTIVE CONSTRAINTS

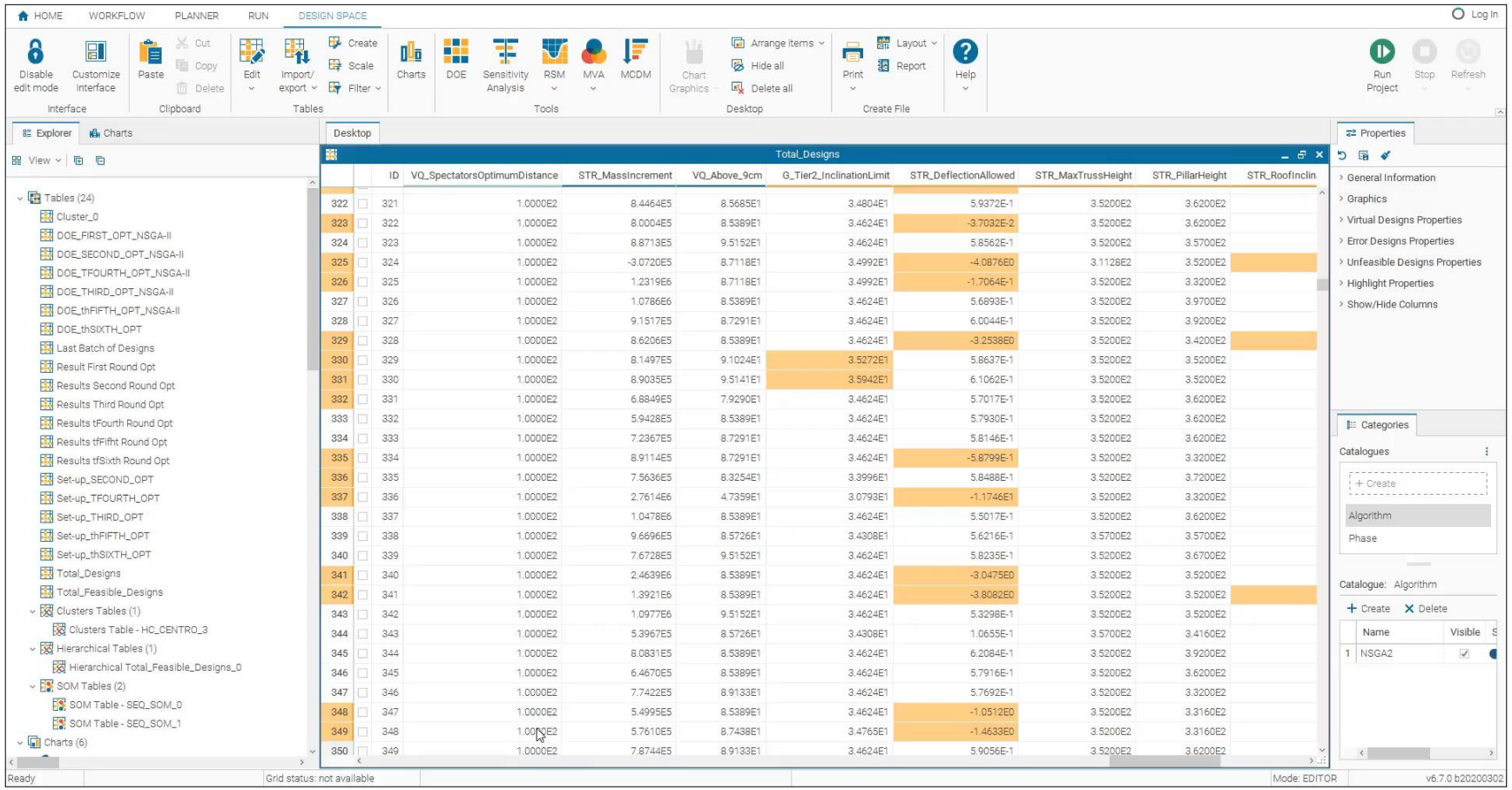
%C-VALUE > 6 cm

= 0%

%C-VALUE > 9 cm

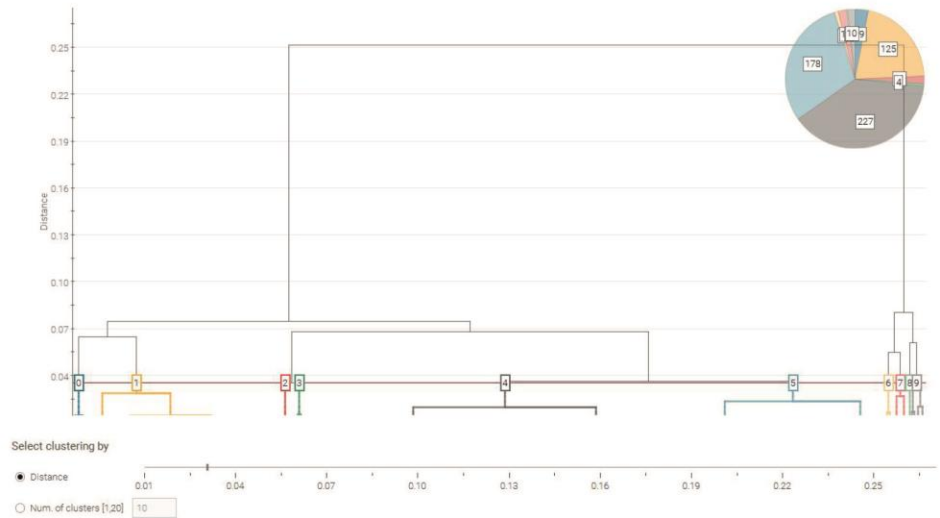
> 80%

OPTIMIZATION PROCESS



TRADE-OFF

HIERARCHICAL CLUSTERING (CENTROID-LINKAGE)

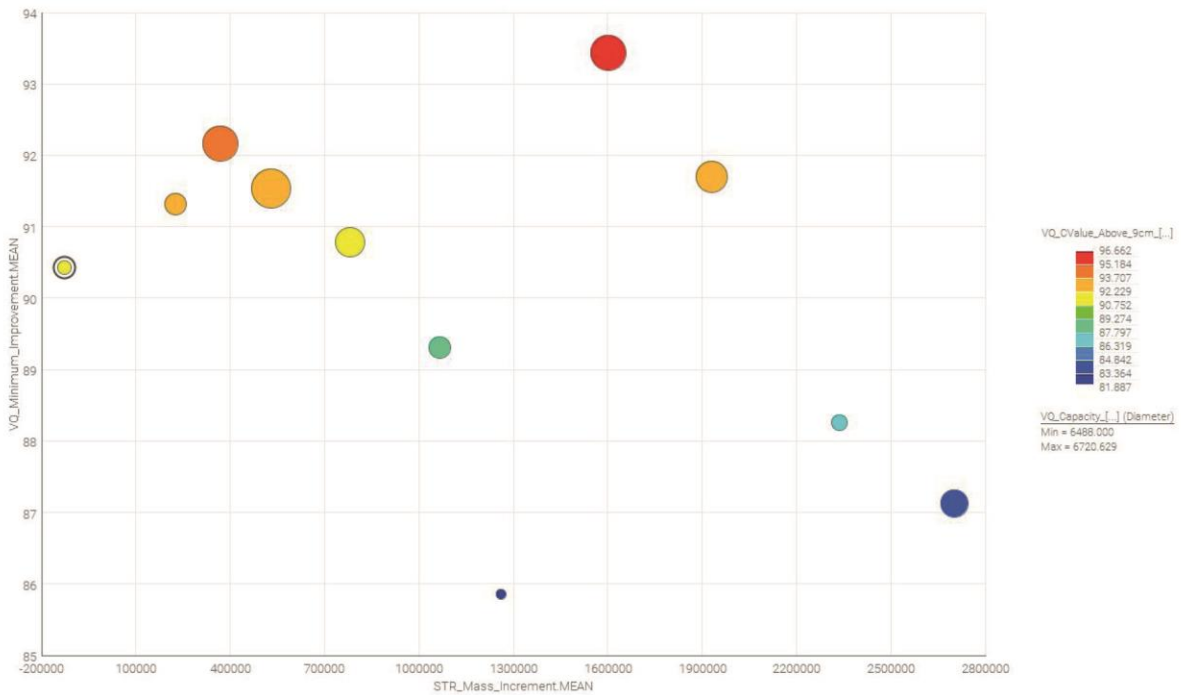


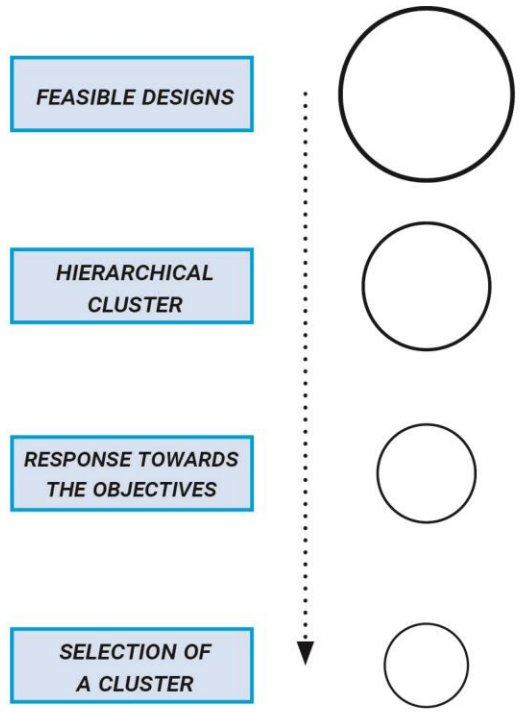
GROUP SOLUTIONS BASED ON DESIGN SPACE LOCATION

CONTROL OVER NUMBER OF GROUPS TO BE CREATED

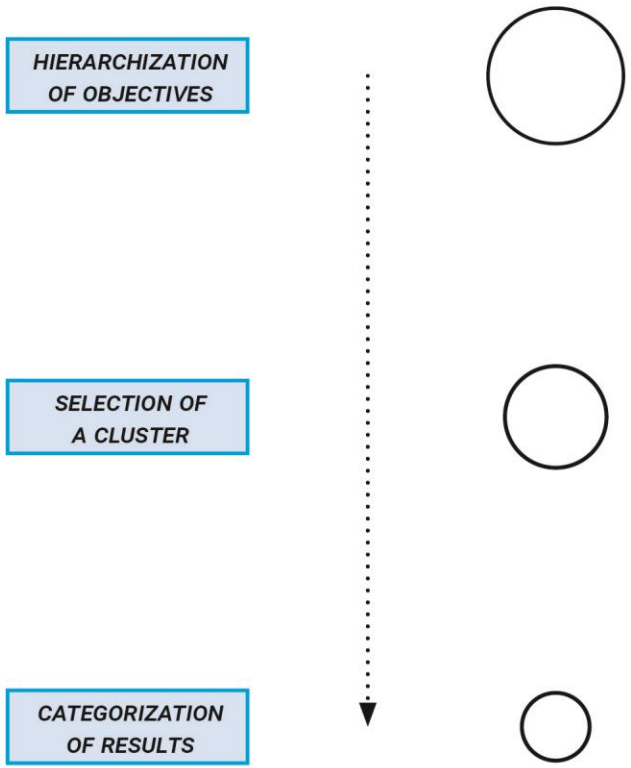
TRADE-OFF

EVALUATION OF CLUSTERS





TRADE-OFF


HIERARCHIZATION OF OBJECTIVES
SELECTION OF A CLUSTER
CATEGORIZATION OF RESULTS

TRADE-OFF

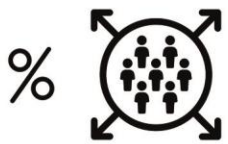
CATEGORIES AND HIERARCHY OF OBJECTIVES (EXAMPLE OF VALIDATION CASE)

MASS INCREMENT

- REDUCED
- E4 kg < E5 kg
- E5 kg < E6 kg
- > E6 kg

% C-VALUE > 9 cm

- 80% < 85%
- 85% < 90%
- 90% < 95%
- > 95%

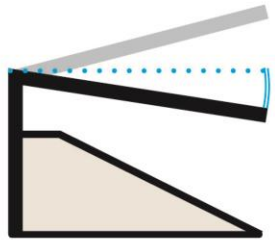


%CAPACITY INCREMENT

- > 20 %
- < 20 %

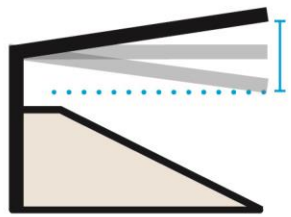
CAPACITY INCREMENT

- > 6500
- < 6500



ROOF INCLINATION

- OUTWARDS
- INWARDS



CLEAR HEIGHT ROOF

- 2 m < 4 m
- 0 m < 2 m
- 4 m < 6 m
- > 6 m

TRADE-OFF

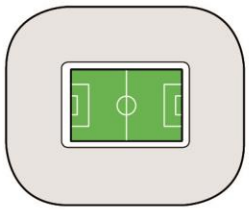
		ID	Algorithm	Phase	Clusters	Cluster1	Reduction Mass	Capacity higher than 20%	Viewing quality Higher than 90%
1	☐	758	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	90<95
2	☐	815	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	90<95
3	☑	830	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	>20	>95
4	☑	848	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	>20	>95
5	☐	853	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	85<90
6	☐	858	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	85<90
7	☐	869	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	90<95
8	☑	885	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	>20	>95
9	☐	894	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	90<95
10	☐	899	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	85<90
11	☐	909	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	85<90
12	☐	913	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	85<90
13	☐	926	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	85<90
14	☐	932	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	90<95
15	☐	935	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	85<90
16	☐	940	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	85<90
17	☐	942	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	90<95
18	☐	943	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	90<95
19	☐	945	NSGA2		CLUSTER_0	CLUSTER_0	Reduced	18<20	90<95
20	☐	0	NSGA2		CLUSTER_1	CLUSTER_4	E5<E6	18<20	85<90

VALIDATION CASE

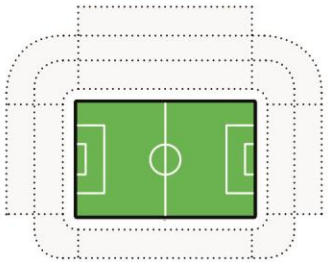
VALIDATION CASE

OLD TRAFFORD (MANCHESTER, UK)

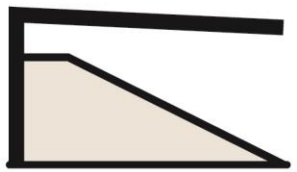
ROUNDED RECTANGLE LAYOUT GEOMETRY



STADIUM CONFIGURATION

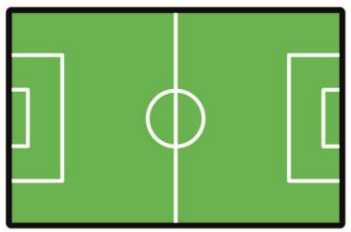


SIMPLE CANTILEVER STRUCTURAL SYSTEM



VALIDATION CASE (PLAYING AREA)

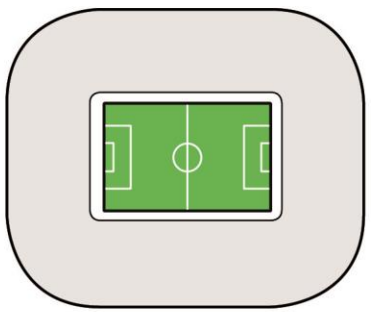
PITCH



PITCH DIMENSIONS

105 m x 68 m

ROUNDED RECTANGLE LAYOUT GEOMETRY



FIRST ROW DISTANCE X

7.2 m

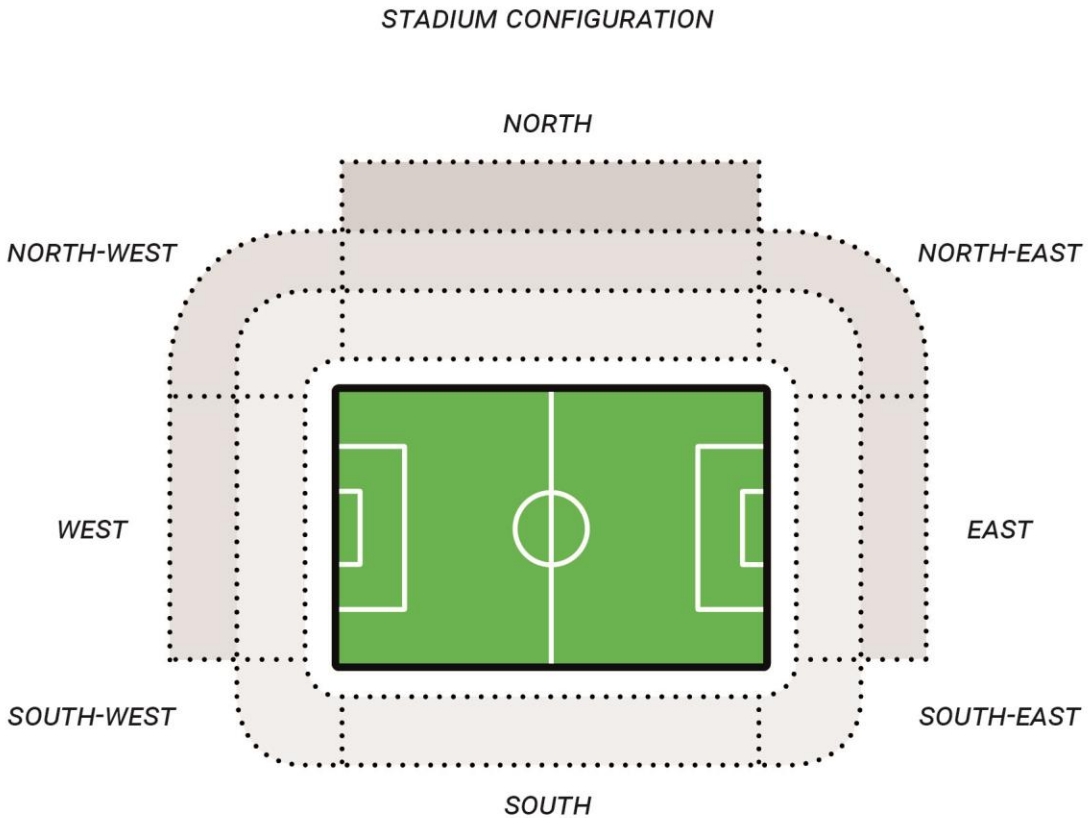
FIRST ROW DISTANCE Y

5,5 m

RADIUS CORNERS

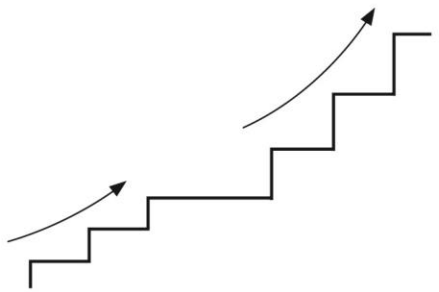
7,2 m

VALIDATION CASE (CONFIGURATION)

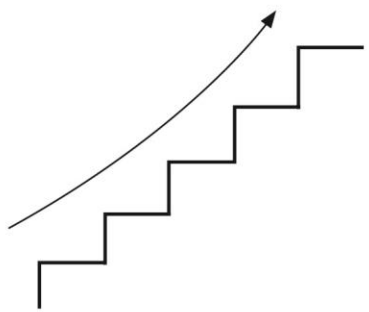


VALIDATION CASE (STAND TYPOLOGY)

DOUBLE PARABOLIC

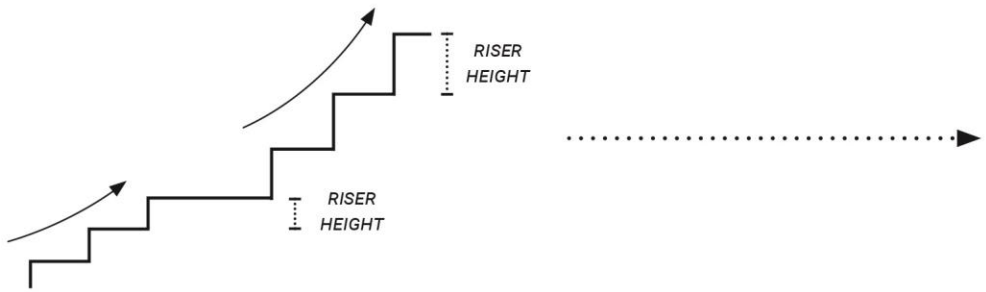


PARABOLIC

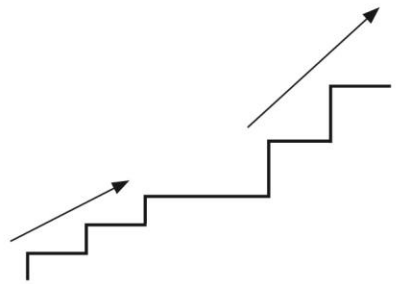


VALIDATION CASE (STAND TYPOLOGY)

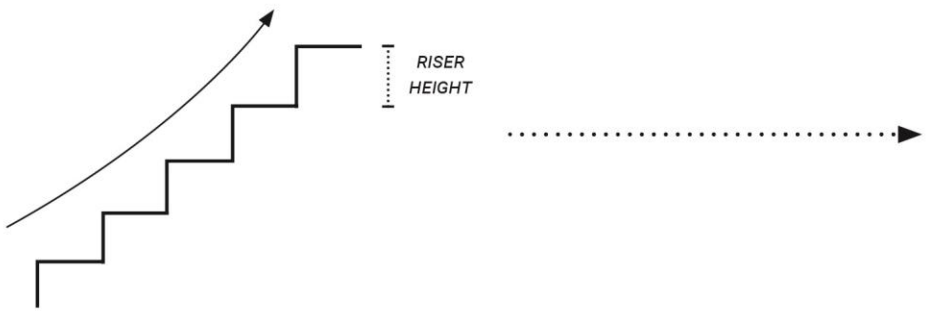
DOUBLE PARABOLIC



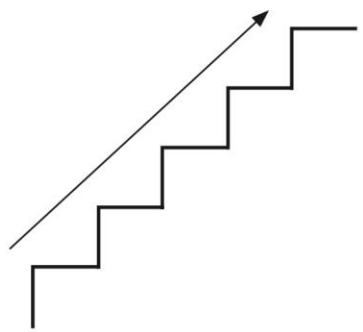
STAND TYPE TIER 1



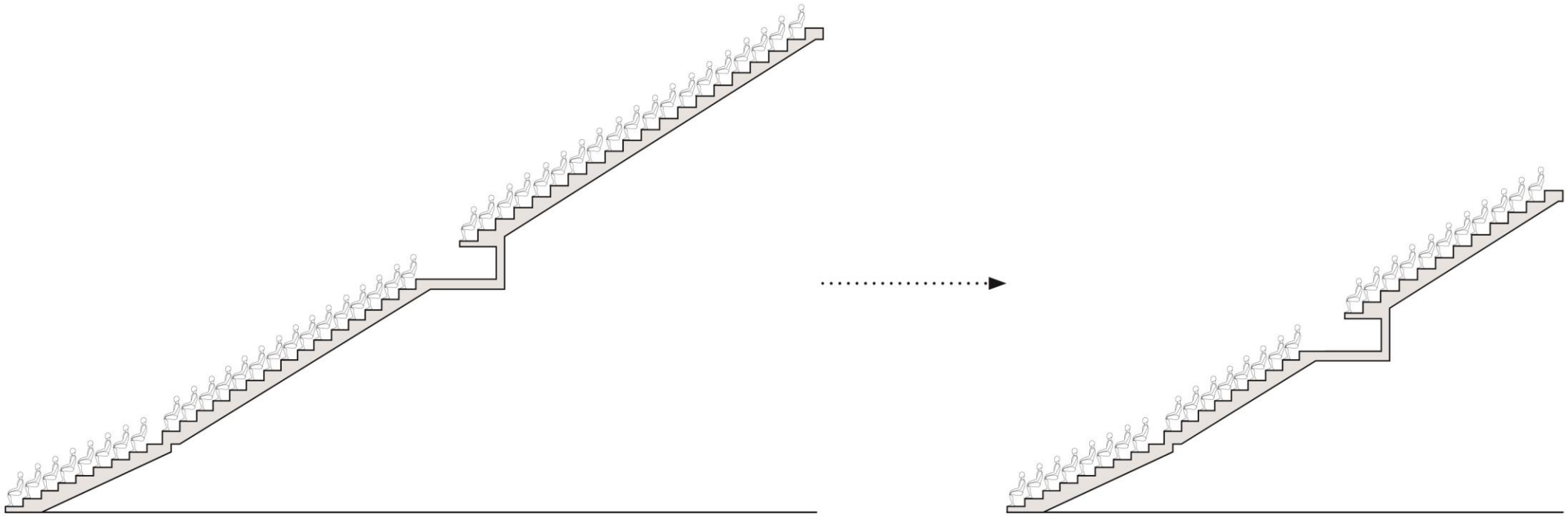
PARABOLIC



STAND TYPE TIER 2/3

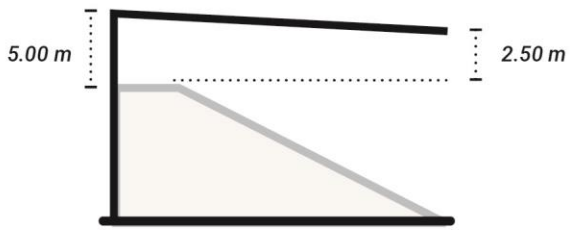


VALIDATION CASE (GEOMETRY)



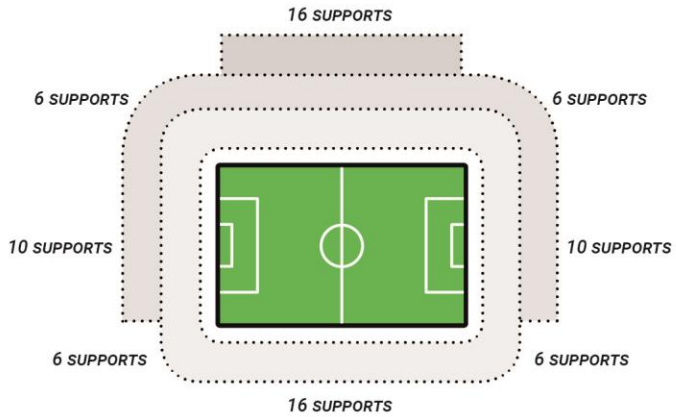
VALIDATION CASE (ROOF STRUCTURE)

SIMPLE CANTILEVER STRUCTURAL SYSTEM



NUMBER OF SUPPORTS

POSITION OF SUPPORTS

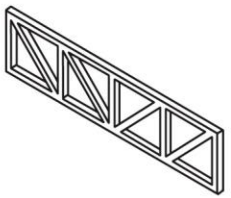


SUPPORT SET

MATERIAL

STEEL S235

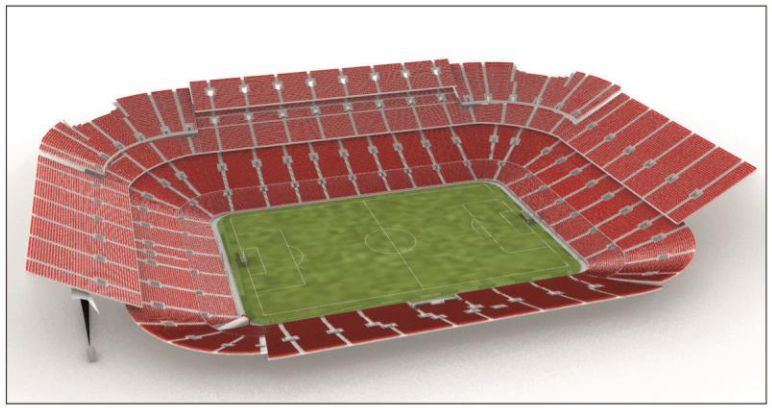
STRUCTURAL ELEMENTS

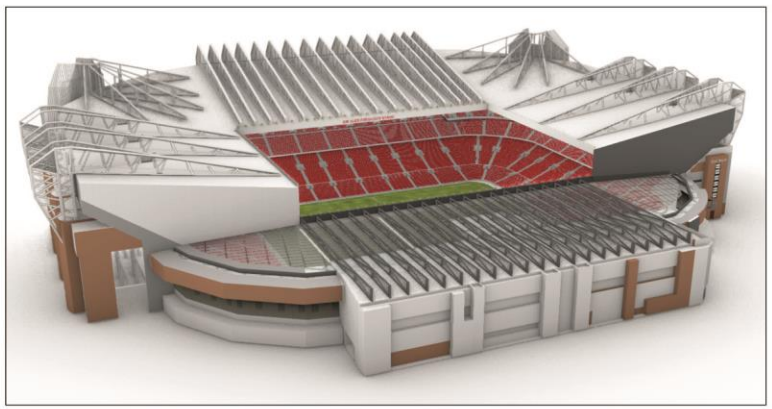


PILLARS AND CANTILEVERS

BRACINGS

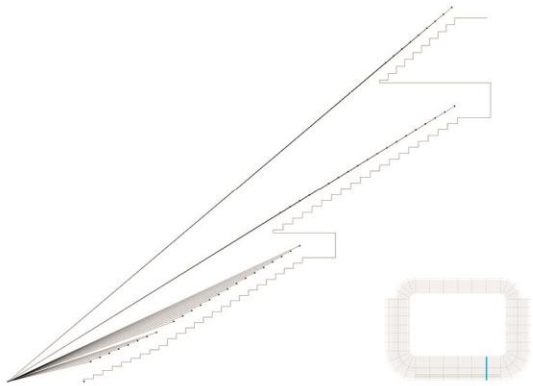
VALIDATION CASE



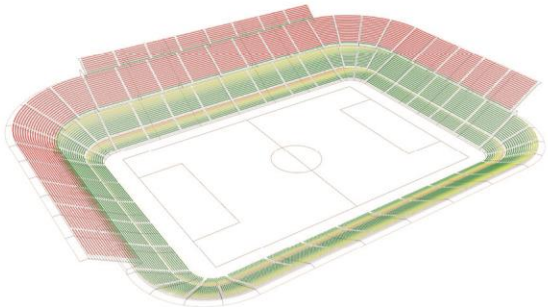


VIEWING QUALITY ASSESSMENT

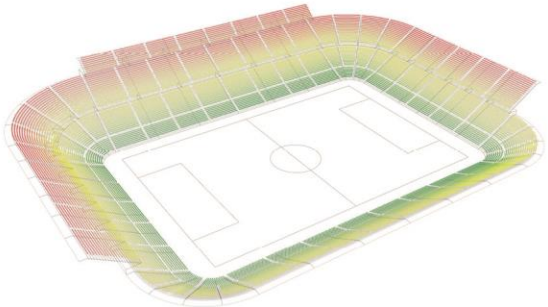
OUTPUTS	TIER 1	TIER 2	TIER 3	OVERALL
Capacity	19326	11846	1872	33044
% C-value > 6 cm	100%	4.88%	11.11%	39.14%
% C-value > 9 cm	90.02%	4.88%	11.11%	55.03%
% C-value 6 cm < X < 9 cm	-	-	-	5.83%
% C-value 9 cm < X < 12 cm	-	-	-	24.61%
% C-value > 12 cm	-	-	-	30.42%
Max Vertical Viewing Angle	-	-	-	40.2°
Min Vertical Viewing Angle	-	-	-	10.7°
Max Field of View	-	-	-	167.0°
Min Field of View	-	-	-	63.4°
% Field of View < 120°	-	-	-	63.95%
Max Viewing Distance	-	-	-	34.00 m
Min Viewing Distance	-	-	-	5.98 m
% Spectators within Max Distance	-	-	-	100%
Inclination	31.0°/23.8°	31.6°	39.8°	-



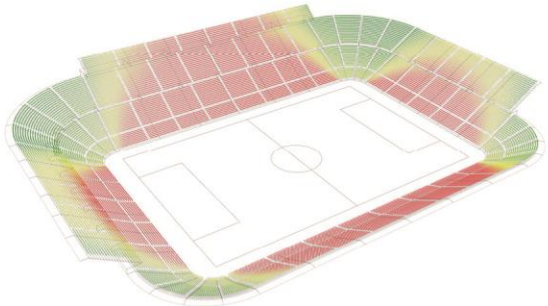
C-VALUE



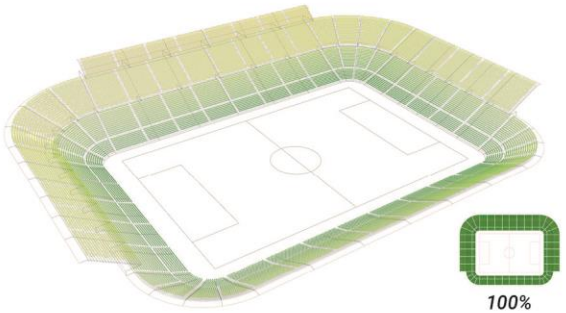
VERTICAL VIEWING ANGLE



FIELD OF VIEW



VIEWING DISTANCE

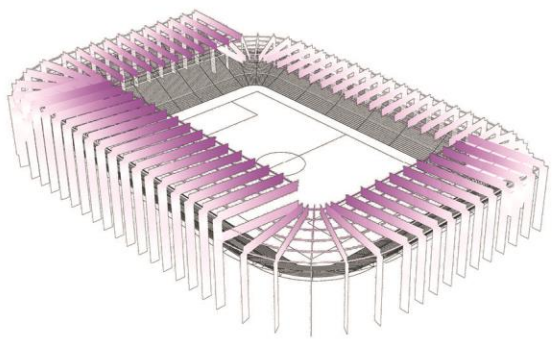


100%

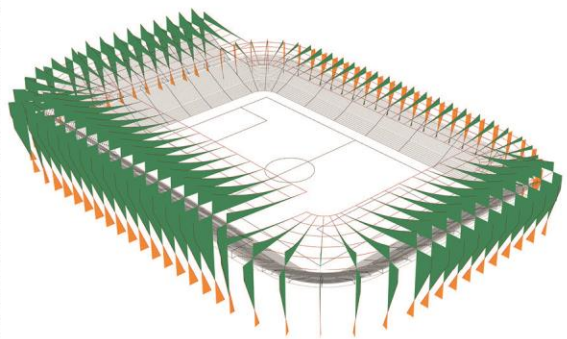
STRUCTURAL PERFORMANCE ASSESSMENT

OUTPUTS	PILLARS	CANTILEVERS	BRACINGS
Displacement Limit	10.4 cm	20.7 cm	3.3 cm
Max Displacement	0.8 cm	18.0 cm	1.9 cm
Stress Limit	235 Mpa	235 Mpa	235 Mpa
Max Stress	100.5 Mpa	100.5 Mpa	77.9 MPa

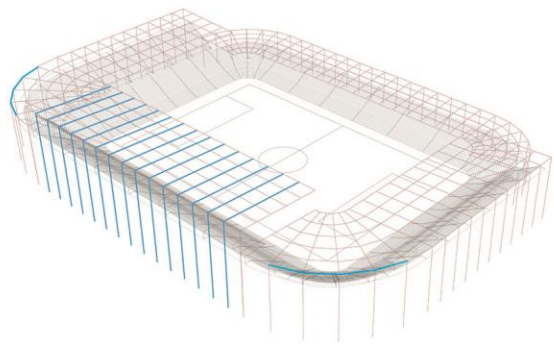
DISPLACEMENT



BENDING MOMENT

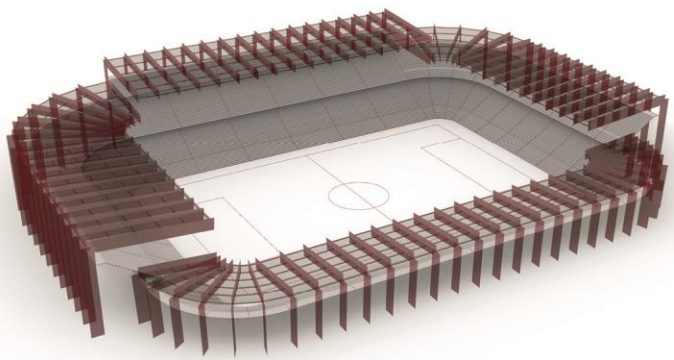


CRITICAL ELEMENTS



1ST RENOVATION APPROACH

OPTIMIZATION OF STAND TIER



1ST RENOVATION APPROACH

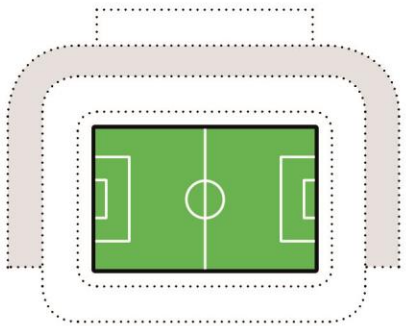
OPTIMIZATION OF STAND TIER

IMPROVE VIEWING QUALITY

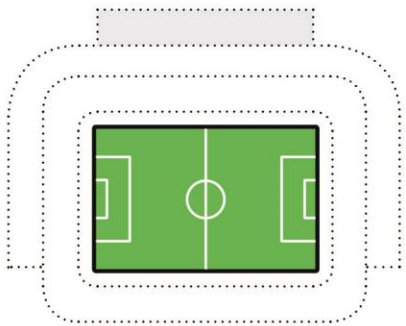
OPTIMIZE ROOF STRUCTURE

20 INPUTS

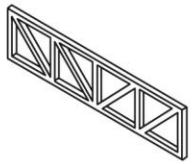
2ND TIER OF STANDS



3RD TIER OF STANDS

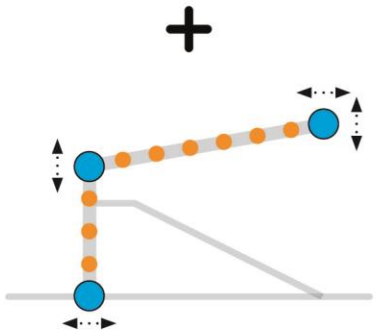


ROOF STRUCTURE



PILLARS AND CANTILEVERS

BRACINGS



1ST RENOVATION APPROACH

OPTIMIZATION OF STAND TIER

IMPROVE VIEWING QUALITY

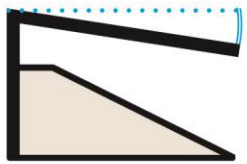
OPTIMIZE ROOF STRUCTURE

13 CONSTRAINTS

INCLINATION OF STANDS < 35°

STRESS > 0 MPa

%C-VALUE > 9 cm > 80%



INCLINATION OF ROOF > 1.5°

DISPLACEMENT > 0 cm

%C-VALUE > 6 cm = 0%

1ST RENOVATION APPROACH

OPTIMIZATION OF STAND TIER

IMPROVE VIEWING QUALITY

OPTIMIZE ROOF STRUCTURE

2 OBJECTIVES

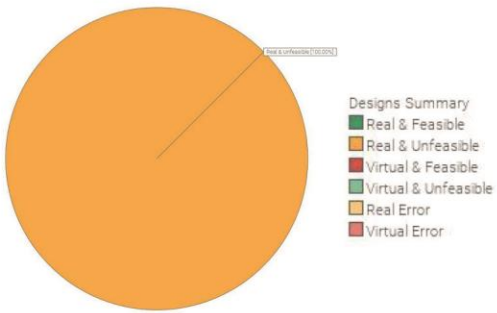
%

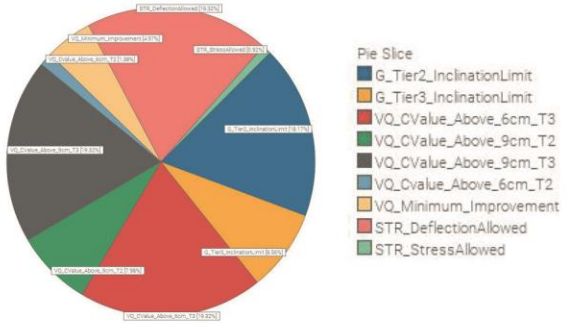
MAXIMIZE %C-VALUE > 9 cm

MINIMIZE MASS OF STRUCTURE

1ST OPTIMIZATION

OPTIMIZATION RUN	DESIGN PRODUCED	FEASIBLE	UNFEASIBLE
Run 1	167	0	167





1ST OPTIMIZATION

INPUTS

RISER HEIGHT

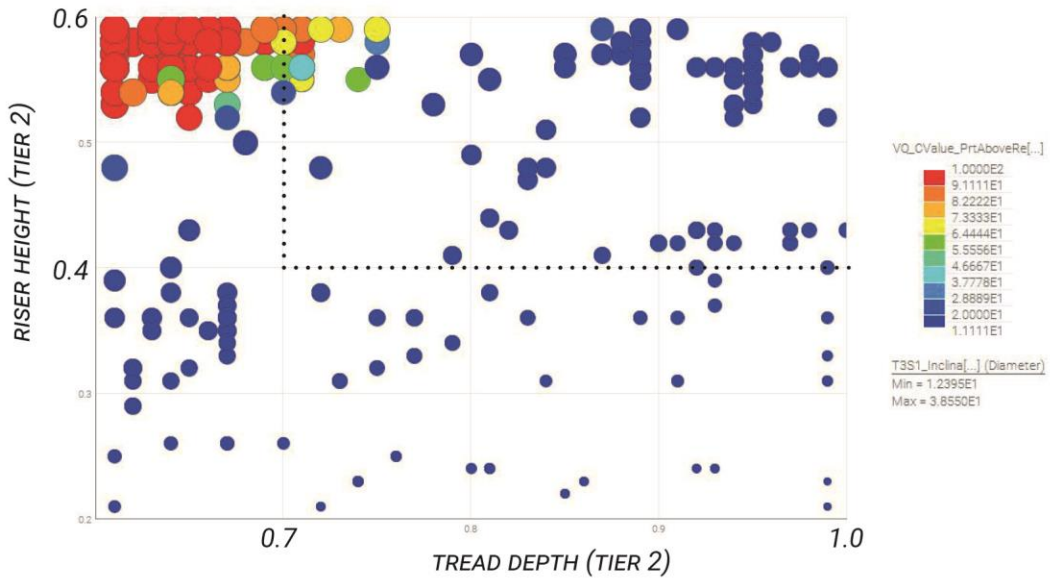
TREAD DEPTH

CONSTRAINTS

INCLINATION OF STANDS

%C-VALUE > 9 cm (TIERS)

BUBBLE DIAGRAM 4D TIER 2
(TREAD DEPTH VS RISER HEIGHT IN RELATION TO STAND INCLINATION AND %C-VALUE > 9 cm)



1ST OPTIMIZATION

INPUTS

RISER HEIGHT

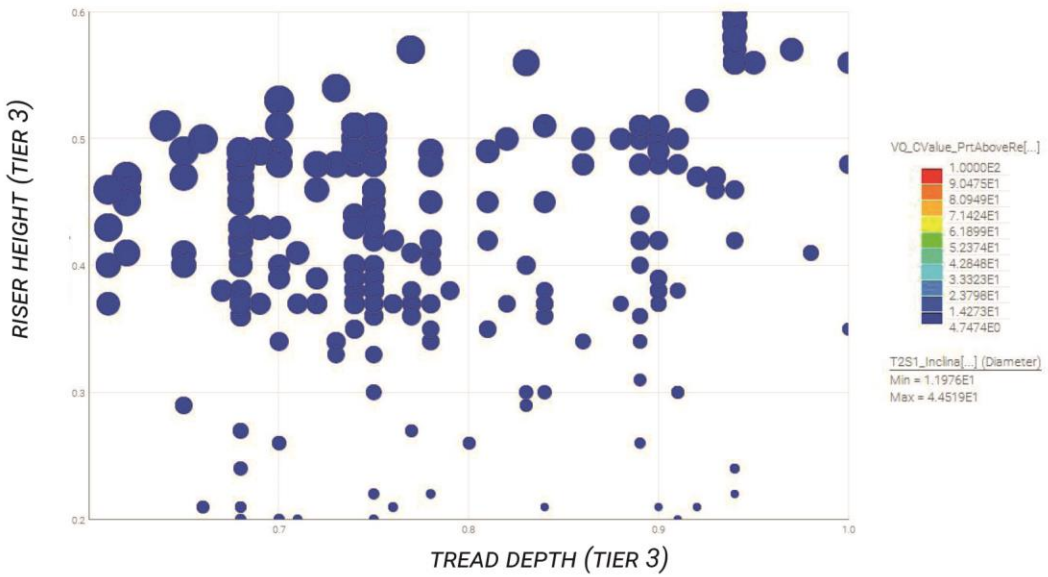
TREAD DEPTH

CONSTRAINTS

INCLINATION OF STANDS

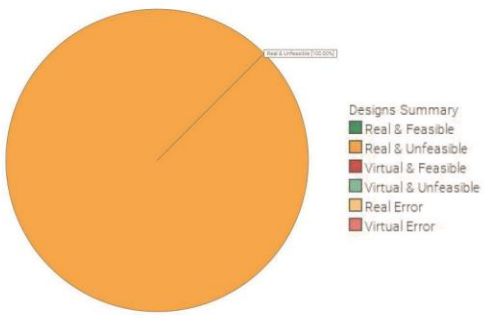
%C-VALUE > 9 cm (TIERS)

BUBBLE DIAGRAM 4D TIER 3
(TREAD DEPTH VS RISER HEIGHT IN RELATION TO STAND INCLINATION AND %C-VALUE > 9 cm)



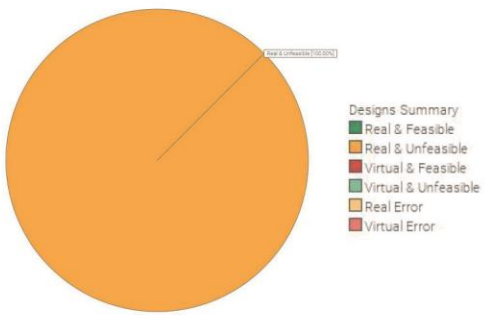
TOTAL OPTIMIZATION

OPTIMIZATION RUN	DESIGN PRODUCED	FEASIBLE	UNFEASIBLE
Run 1	167	0	167
Run 2	334	0	334
Run 3	358	0	358
Run 4	350	0	350
OVERALL	1209	0	1209

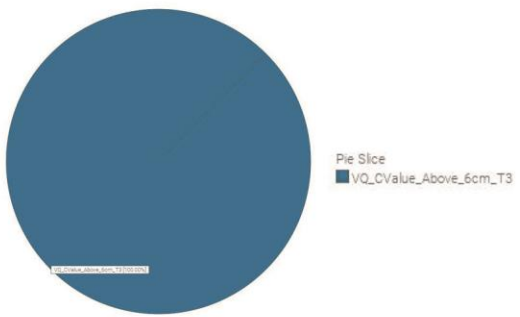


TOTAL OPTIMIZATION

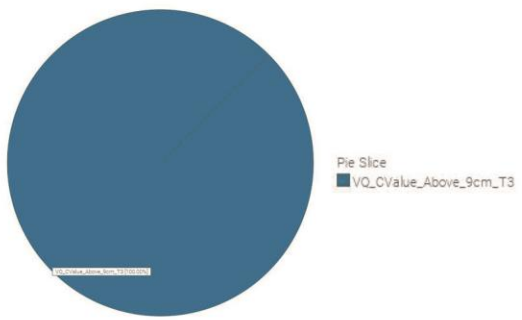
OPTIMIZATION RUN	DESIGN PRODUCED	FEASIBLE	UNFEASIBLE
Run 1	167	0	167
Run 2	334	0	334
Run 3	358	0	358
Run 4	350	0	350
OVERALL	1209	0	1209



%C-VALUE > 6 cm (TIER 3)



%C-VALUE > 9 cm (TIER 3)



TOTAL OPTIMIZATION

INPUTS

RISER HEIGHT

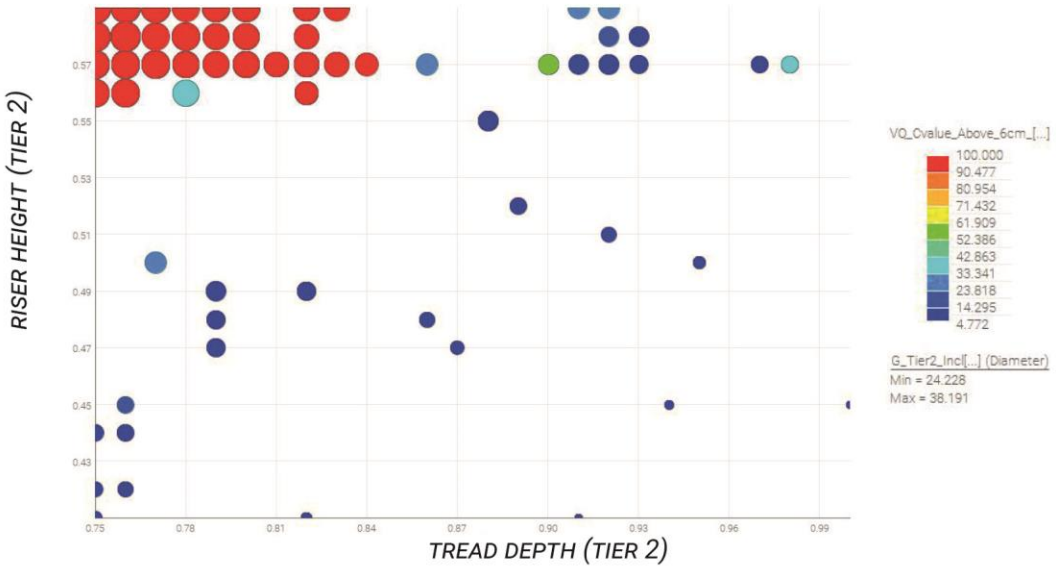
TREAD DEPTH

CONSTRAINTS

INCLINATION OF STANDS

%C-VALUE > 9 cm (TIERS)

BUBBLE DIAGRAM 4D TIER 2
(TREAD DEPTH VS RISER HEIGHT IN RELATION
TO STAND INCLINATION AND %C-VALUE > 9 cm)



TOTAL OPTIMIZATION

INPUTS

RISER HEIGHT

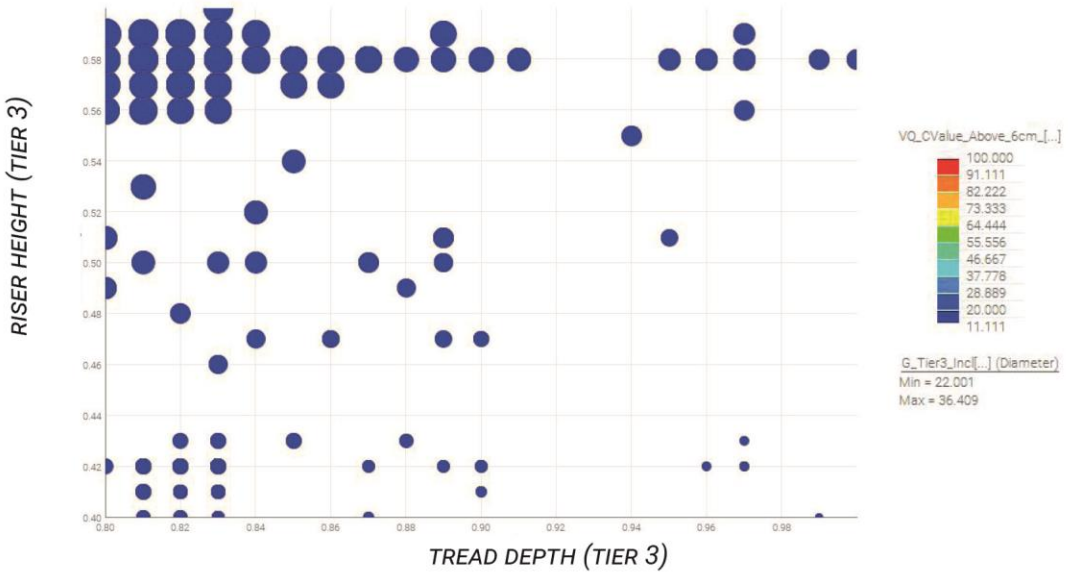
TREAD DEPTH

CONSTRAINTS

INCLINATION OF STANDS

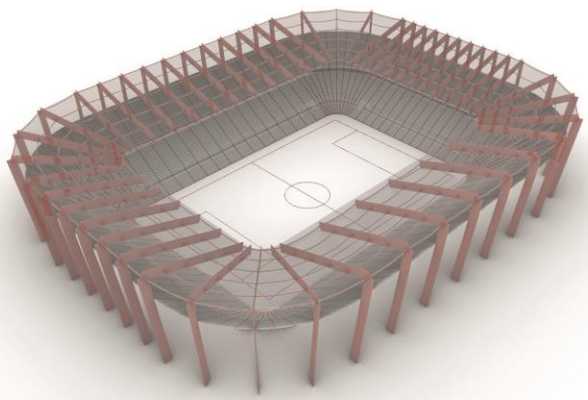
%C-VALUE > 9 cm (TIERS)

BUBBLE DIAGRAM 4D TIER 3
(TREAD DEPTH VS RISER HEIGHT IN RELATION
TO STAND INCLINATION AND %C-VALUE > 9 cm)



2ND RENOVATION APPROACH

ADDITION OF STAND/TIER



2ND RENOVATION APPROACH

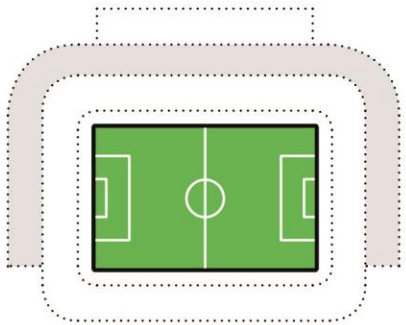
OPTIMIZATION OF STAND TIER

IMPROVE VIEWING QUALITY

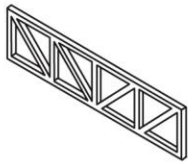
OPTIMIZE ROOF STRUCTURE

14 INPUTS

2ND TIER OF STANDS



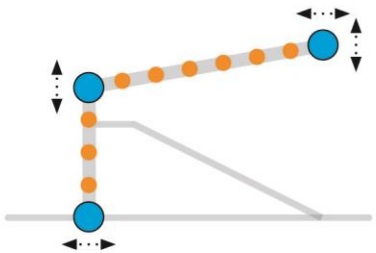
ROOF STRUCTURE



PILLARS AND CANTILEVERS

BRACINGS

+



2ND RENOVATION APPROACH

10 CONSTRAINTS

OPTIMIZATION OF STAND TIER

IMPROVE VIEWING QUALITY

OPTIMIZE ROOF STRUCTURE

INCLINATION OF STANDS < 35°

STRESS > 0 MPa

%C-VALUE > 9 cm > 80%

INCLINATION OF ROOF > 1.5°

DISPLACEMENT > 0 cm

%C-VALUE > 6 cm = 0%

2ND RENOVATION APPROACH

OPTIMIZATION OF STAND TIER

IMPROVE VIEWING QUALITY

OPTIMIZE ROOF STRUCTURE

3 OBJECTIVES

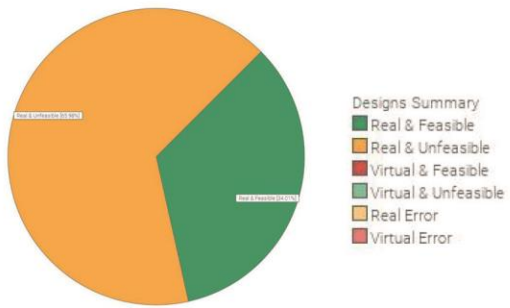
MAXIMIZE %C-VALUE > 9 cm

MINIMIZE MASS OF STRUCTURE

MAXIMIZE %CAPACITY

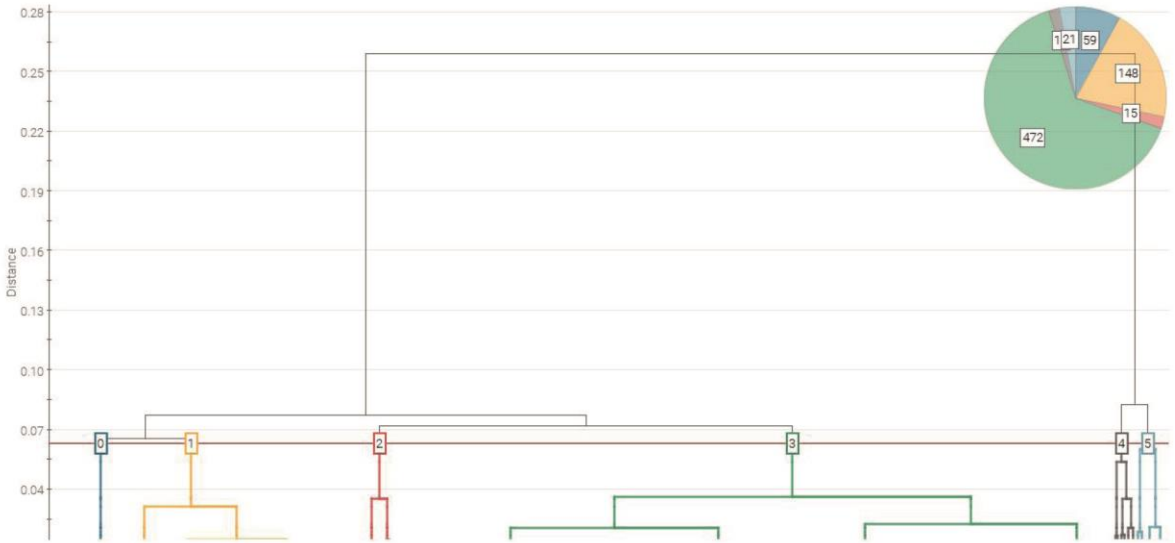
TOTAL OPTIMIZATION

OPTIMIZATION RUN	DESIGN PRODUCED	FEASIBLE	UNFEASIBLE
Run 1	161	29	132
Run 2	440	141	299
Run 3	374	146	228
Run 4	349	135	214
Run 5	411	140	271
Run 6	408	137	271
OVERALL	2143	728	1415



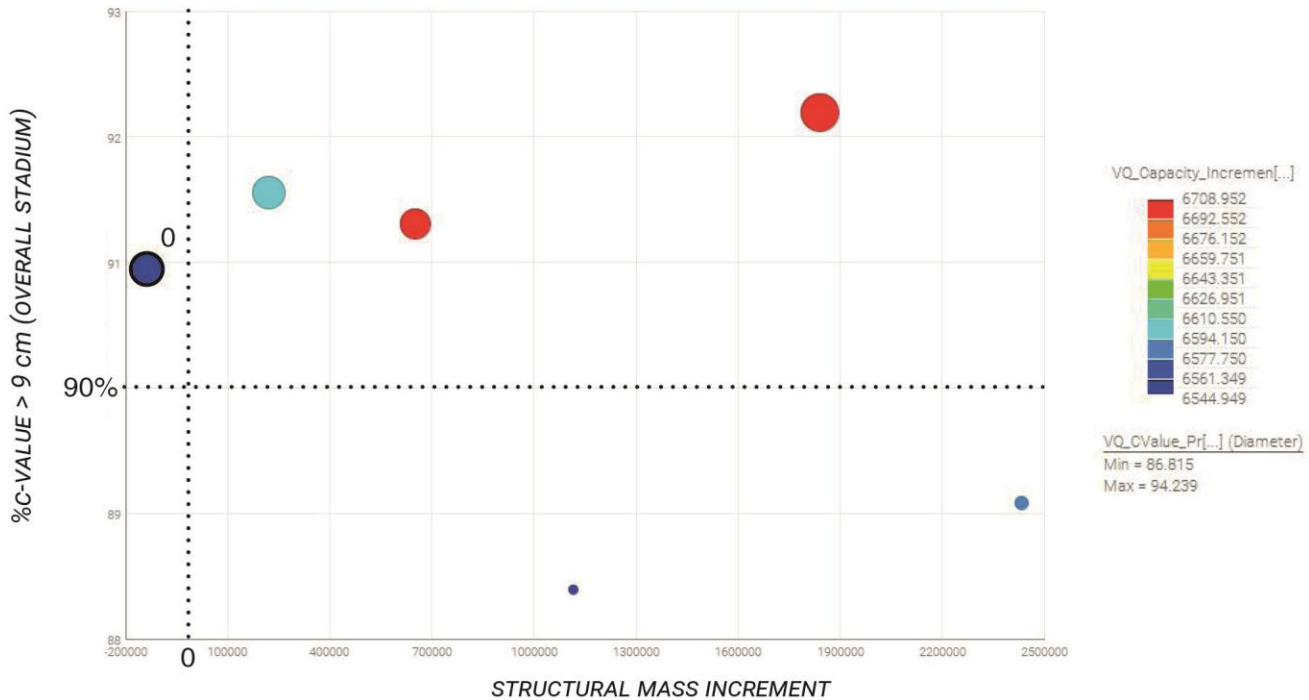
TRADE-OFF OF ALTERNATIVES

HIERARCHICAL CLUSTERING (CENTROID-LINKAGE)



TRADE-OFF OF ALTERNATIVES

(MASS INCREMENT VS %C-VALUE > 9 cm (OVERALL) IN RELATION TO %C-VALUE > 9 cm (TIER 2) AND THE CAPACITY INCREMENT)

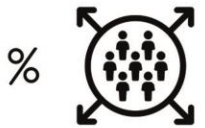


TRADE-OFF OF ALTERNATIVES

	↑	ID	Algorithm	Phase	Mass	% Capacity	%C-Value Higher 9 cm Overall	Inclination Roof	Round of Optimization	Capacity Increment	Height Above Spectators
1	☑	830	NSGA2		Reduced	>20	>95	Outwards	OPT_5	Higher_Than_6500	2_to_4
2	☑	885	NSGA2		Reduced	>20	>95	Outwards	OPT_5	Higher_Than_6500	2_to_4
3	☑	983	NSGA2		Reduced	>20	>95	Outwards	OPT_6	Higher_Than_6500	2_to_4
4	☑	1025	NSGA2		Reduced	>20	>95	Outwards	OPT_6	Higher_Than_6500	2_to_4
5	☑	1043	NSGA2		Reduced	>20	>95	Outwards	OPT_6	Higher_Than_6500	2_to_4
6	☑	1055	NSGA2		Reduced	>20	>95	Outwards	OPT_6	Higher_Than_6500	2_to_4
7	☑	1057	NSGA2		Reduced	>20	>95	Outwards	OPT_6	Higher_Than_6500	2_to_4

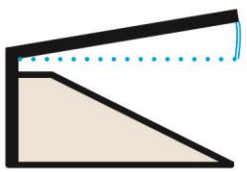
STRUCTURAL MASS ↓ *REDUCED*

%C-VALUE > 9cm ↑ *> 95%*

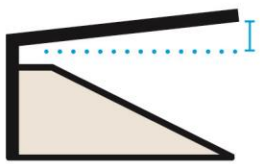


% INCREMENT CAPACITY ↑ *> 20%*

CAPACITY INCREMENT ↑ *> 6500*

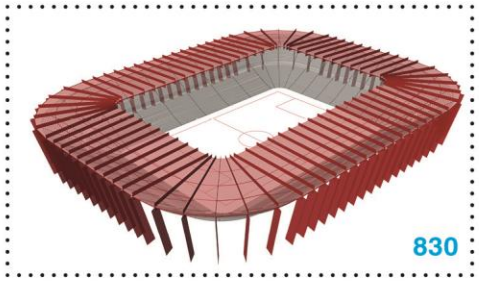


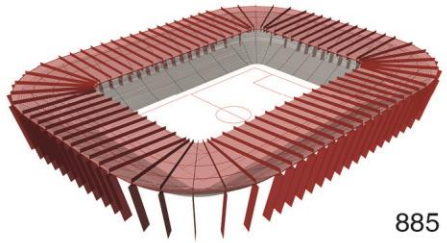
ROOF INCLINATION *OUTWARDS*

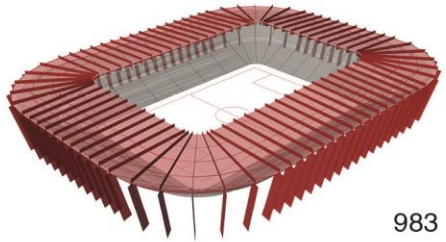


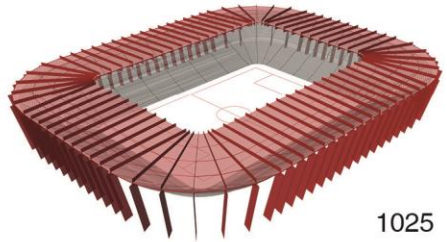
CLEAR HEIGHT OF ROOF *2 m < x < 4 m*

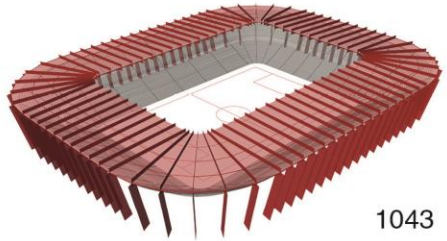
SELECTED DESIGN

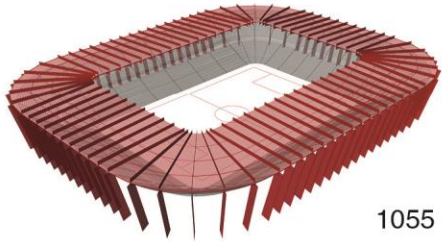


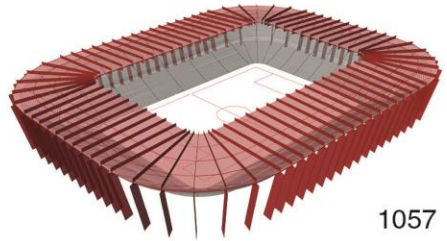










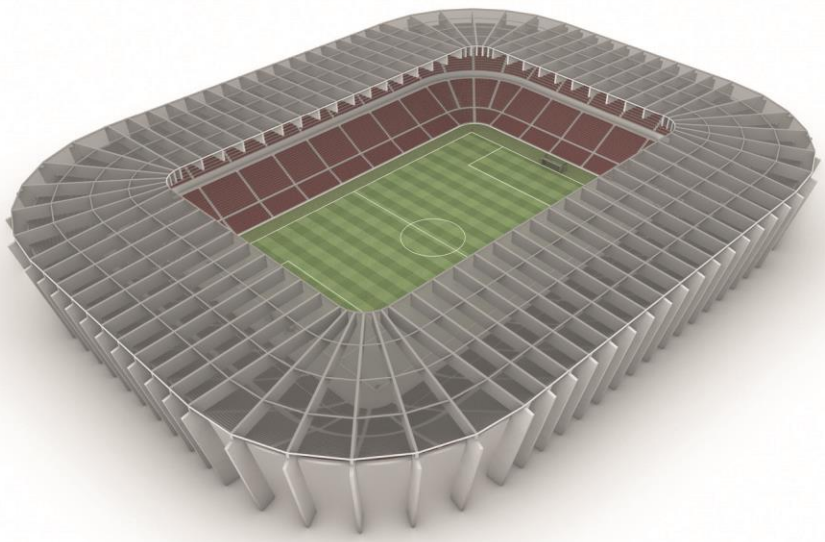


STRUCTURAL MASS ↓ - 1.08E5 Kg

%C-VALUE > 9cm ↑ + 40.15%

INCREMENT CAPACITY ↑ + 6712

SELECTED DESIGN



SELECTED DESIGN

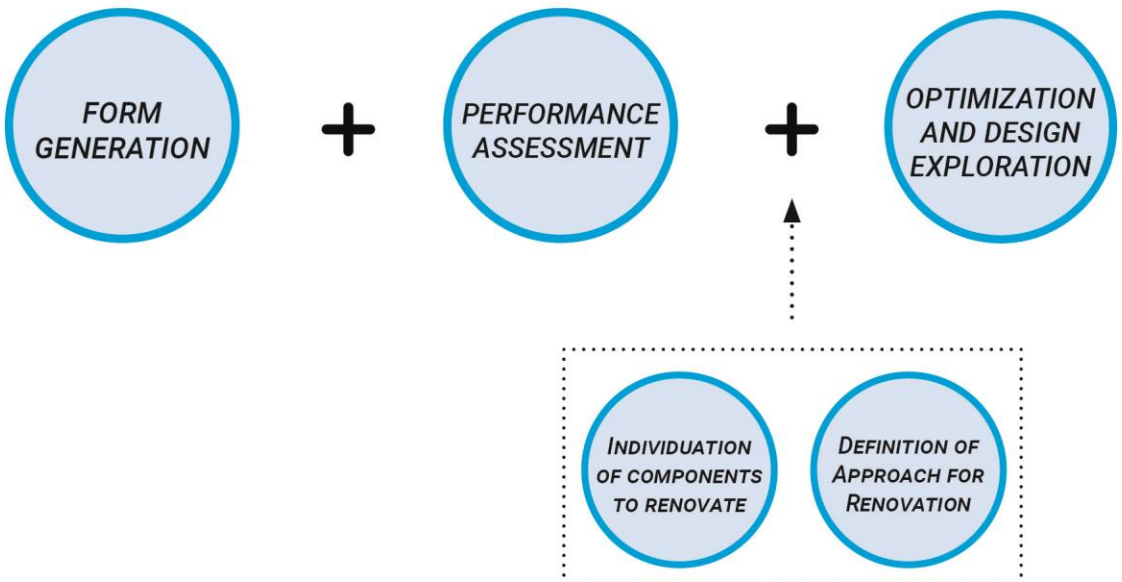
CONCLUSIONS

MAIN RESEARCH QUESTION

*How can a **COMPUTATIONAL METHOD** be designed for **STADIA RENOVATION PROCESS** to provide designers and engineers with an overview of the **CURRENT STRUCTURAL PERFORMANCE** of the **ROOF** structure and the **VIEWING QUALITY PERFORMANCE** of the **GRANDSTANDS**, while offering them the possibility to **OPTIMIZE** these **FEATURES JOINTLY**?*

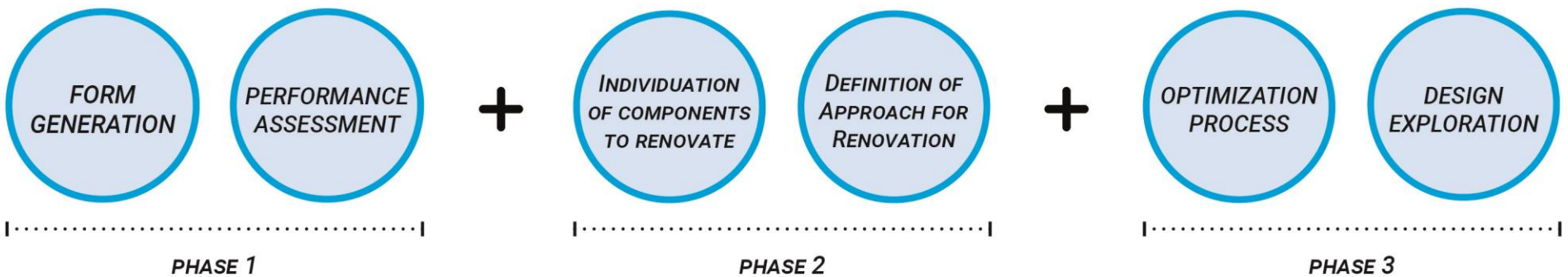
CONCLUSIONS

- *PERFORMANCES can constitute a BENCHMARK to determine the PORTIONS of the stadium TO BE RENOVATED*
  - *Only the INPUTS of THESE PORTIONS should be allowed to be ALTERED in the OPTIMIZATION*



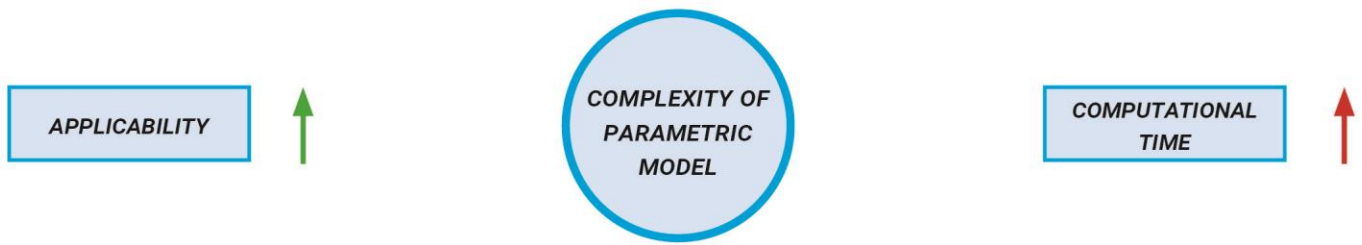
CONCLUSIONS

- *COMPLEX GEOMETRIES are produced and a LARGE AMOUNT OF DATA is generated during the assessment*
- *DATA STREAM should be kept in SAME COMPUTATIONAL ENVIRONMENT to MAINTAIN CONTROL over it*



CONCLUSIONS

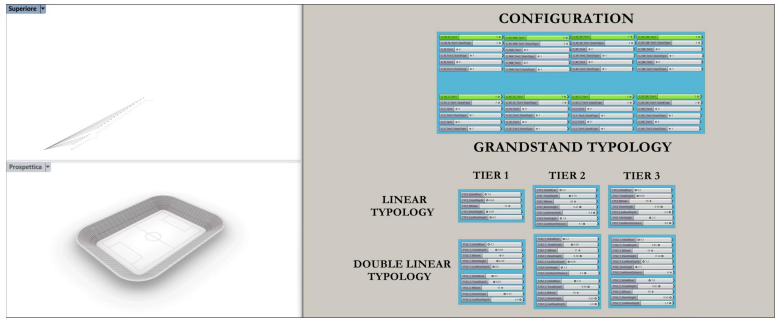
- *COMPLEXITY of model MORE RELEVANT for implementation of EXISTING STADIUMS rather than ALTERNATIVES*
  - *APPLICABILITY is limited to the STADIUMS THAT CAN BE GENERATED in parametric model*
- *Increasing COMPLEXITY can BENEFIT APPLICABILITY, but it AFFECTS COMPUTATIONAL TIME*

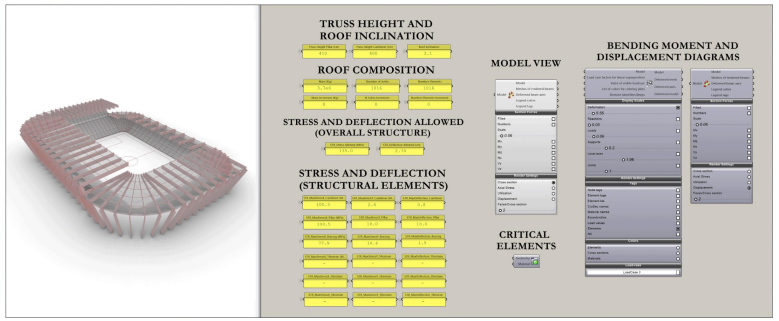


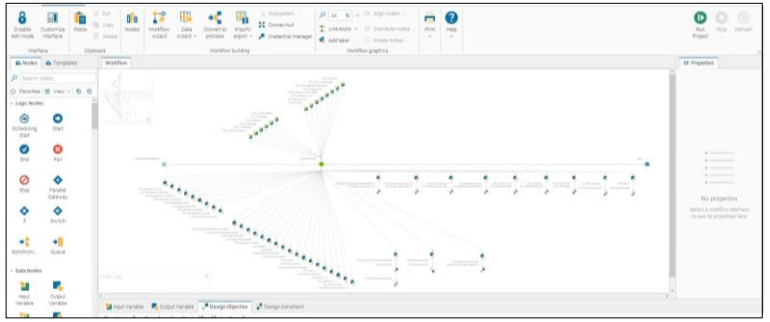
CONCLUSIONS

- *The USER INTERFACE should facilitate designer in NAVIGATING THE METHOD*

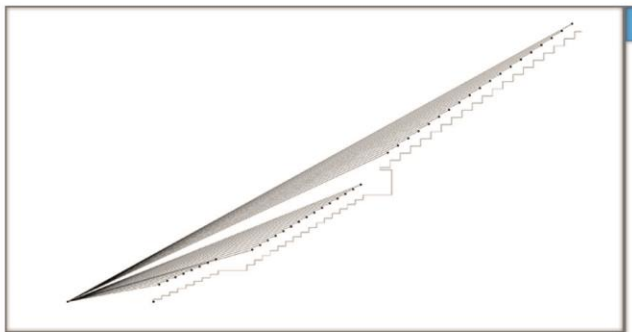
- *The designer should be provided with IMMEDIATE FEEDBACK to SUPPORT DECISION-MAKING*

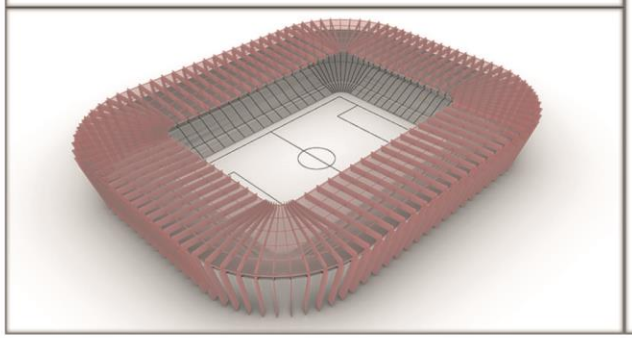






CONCLUSIONS





STADIUM GENERATION

PHASE

FORM GENERATION

PERFORMACE ASSESSMENT

OPTIMIZATION AND DESIGN EXPLORATION

Stadium Features

- [x] PLAYING AREA
- [x] CONFIGURATION
- [x] GRANDSTAND GEOMETRY
- [ ] SPECTATORS
- [ ] VERTICAL CIRCULATION
- [x] ROOF OUTLINE
- [ ] STRUCTURAL BOUNDARIES
- [x] STRUCTURAL ELEMENTS

PARAMETERS INFO

Tread Depth

The tread depth is the horizontal distance between one spectator's eye-point and the eye-point of the spectator seating exactly behind him. Extensively, it represents the depth of the seating/standing step of the grandstand.

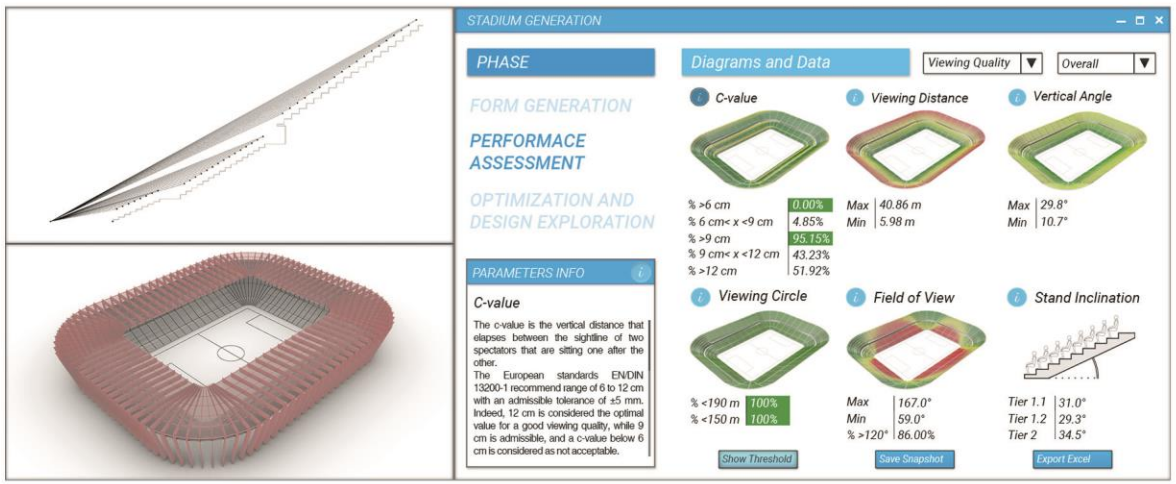
This parameter determines the seating comfort of the spectators. Therefore, the higher the value is, the more comfortable the user will be.

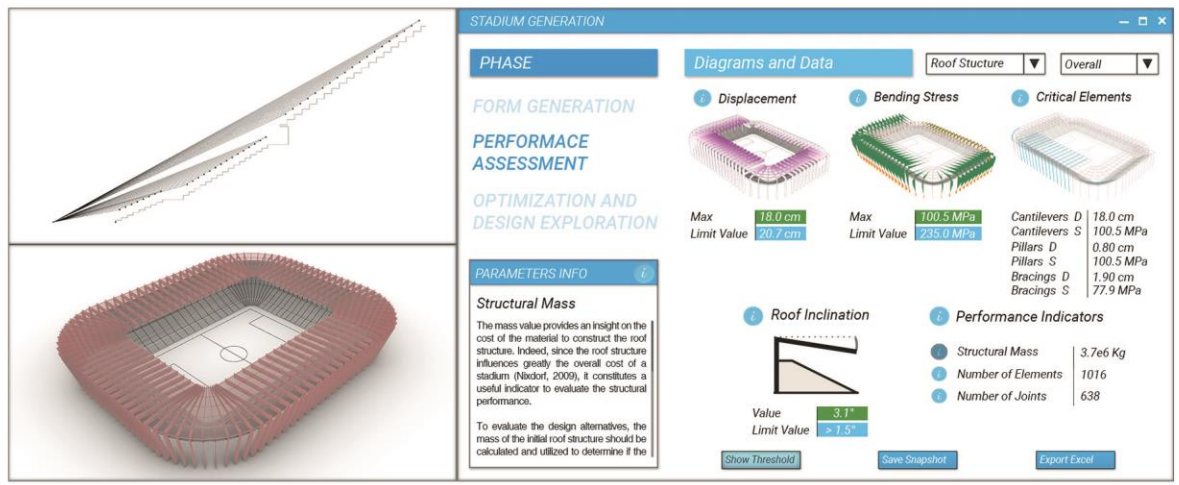
Input Parameters

Tier 2 ▼ Stand Type 1 ▼

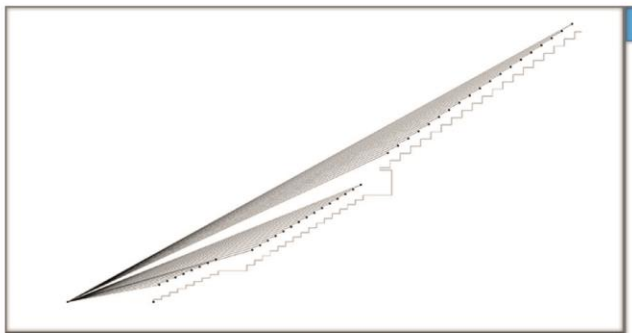
Initial Riser	0.2 cm	1.5 cm
Riser Height	0.2 cm	0.6 cm
Tread Depth	0.6 cm	1.0 cm
Number of Rows	01	30
Tier Height	1.8 m	3.0 m
Cantilever Distance	0.0 m	8.0 m

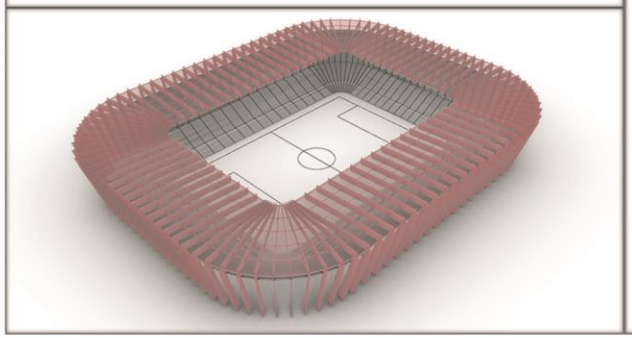
CONCLUSIONS





CONCLUSIONS





STADIUM GENERATION

PHASE

FORM GENERATION

PERFORMACE ASSESSMENT

OPTIMIZATION AND DESIGN EXPLORATION

PARAMETERS INFO

Structural Mass

The mass value provides an insight on the cost of the material to construct the roof structure. Indeed, since the roof structure influences greatly the overall cost of a stadium (Nixdorf, 2009), it constitutes a useful indicator to evaluate the structural performance.

To evaluate the design alternatives, the mass of the initial roof structure should be calculated and utilized to determine if the

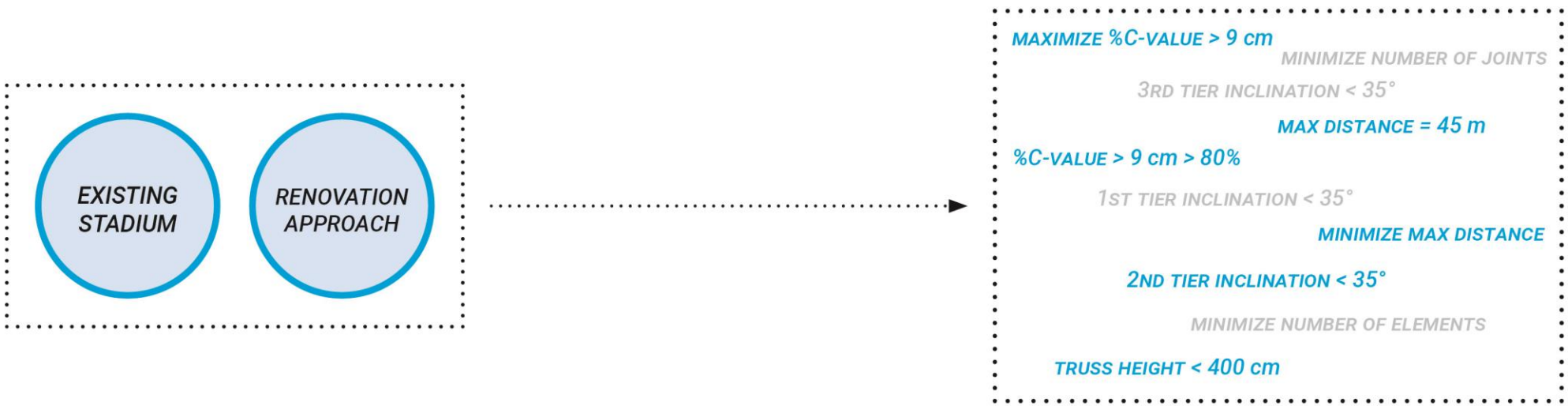
Performance Comparison — Design 830 — Overall Stadium

	INITIAL VALUE	NEW DESIGN	VARIATION
C-value % > 6 cm	54.15%	0.00%	- 54.15%
C-value % 6 cm < x < 9 cm	5.85%	4.85%	- 1.00%
C-value % > 9 cm	40.00%	95.15%	+ 55.15%
C-value % 9 cm < x < 12 cm	23.17%	32.15%	+ 8.98%
C-value % > 12 cm	16.83%	63.00%	+ 46.17%
Max Viewing Distance	39.2 m	40.5 m	+ 1.3 m
% Distance < 190 m	100%	100%	-
Max Vertical Angle	27.2°	30.2°	+ 3.0°
Max Field of View	167.0°	167.0°	-
Capacity	33044	39750	+ 6706
Max Displacement	18.0 cm	19.2 cm	+ 1.2 cm
Max Stress	100.5 MPa	143.5 MPa	+ 43.5 MPa
Structural Mass	3.7e6 Kg	3.2e6 Kg	- 5.0e5 Kg
Number of Elements	1016	938	- 78
Number of Joints	638	586	- 52

Show Threshold — Save Snapshot — Export Excel

CONCLUSIONS

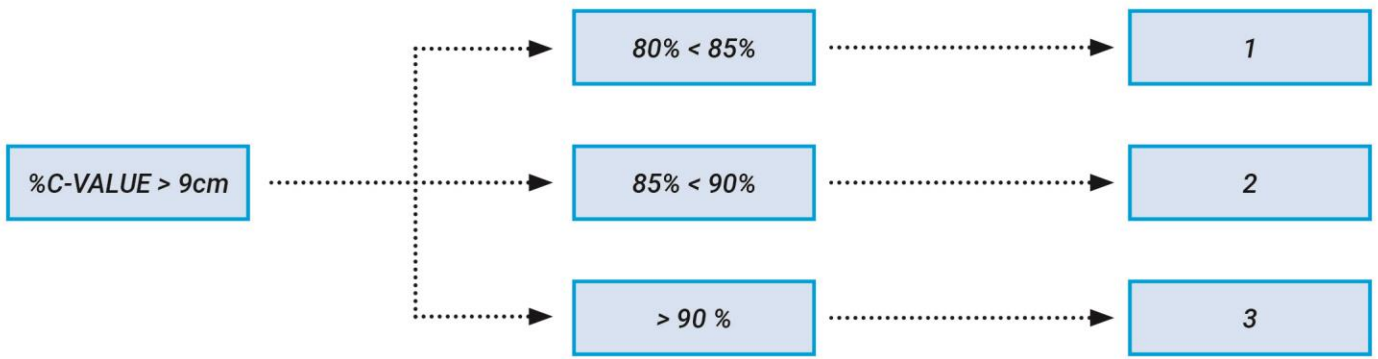
- *The method can SUPPORT DESIGNER in DEVELOPING CONCEPTS for the renovation*
- *The method PROVIDES OPTIONS for the OPTIMIZATION to the designer*
- *APPROACH and EXISTING STADIUM PERFORMANCES determines INPUTS, CONSTRAINTS and OBJECTIVES*



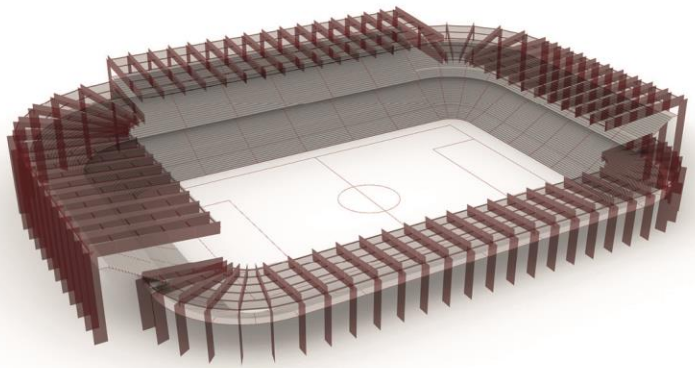
CONCLUSIONS

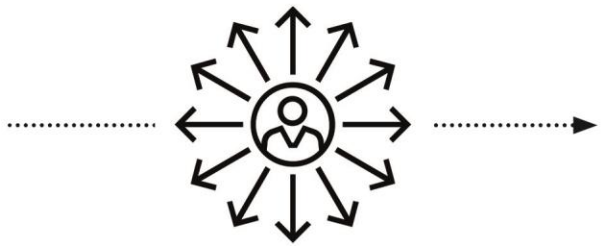
- *The DESIGNER should have CONTROL OVER the TRADE-OFF of the alternatives*
- *The designer should be able to give PRIORITY to different OBJECTIVES and TO INCLUDE AESTHETIC CRITERIA*
- *CATEGORIZATION can be effective, but it can be IMPLEMENTED in the PERFORMANCE ASSESSMENT*

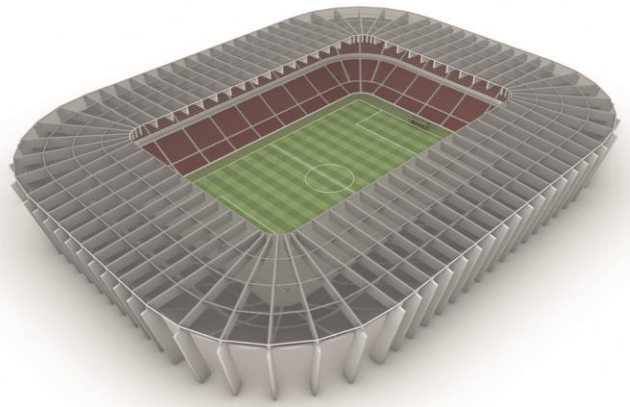
i.e. CATEGORIZATION IN PERFORMANCE ASSESSMENT



CONCLUSIONS







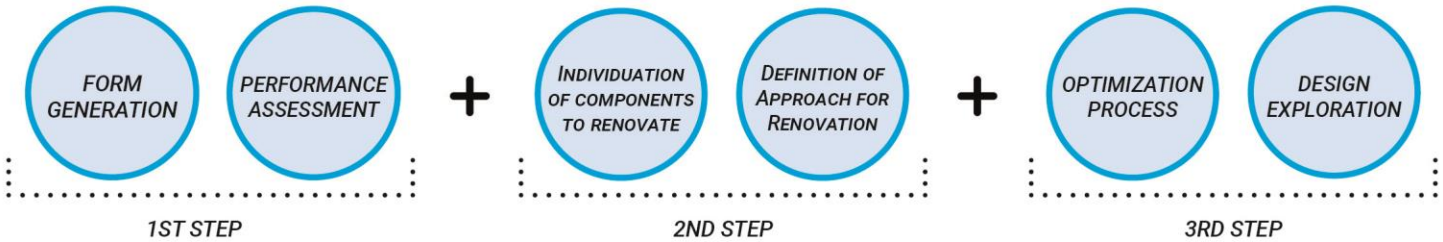
%C-VALUE > 9cm	↑	> 95%
STRUCTURAL MASS	↓	REDUCED
% INCREMENT CAPACITY	↑	+ 20%

CONCLUSIONS

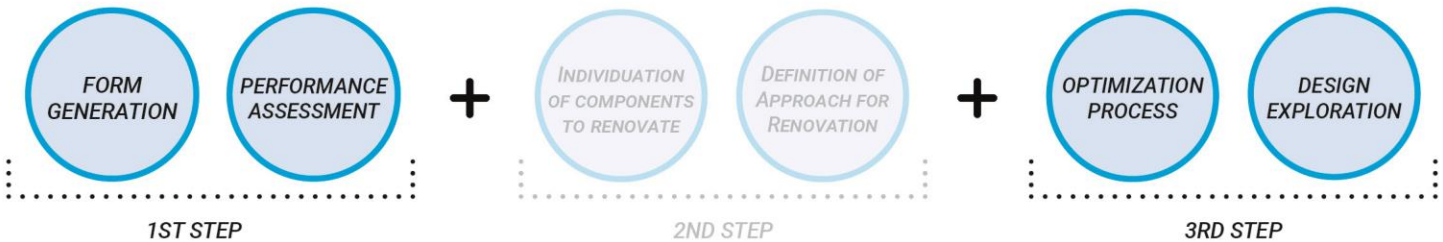
- *The method can be utilized to DEVELOP and to TEST CONCEPTS for renovation of stadiums*
  - *POTENTIAL to individuate and DISCARD INEFFICIENT DESIGNS*
- *The DESIGNS produced can constitute a BASIS for FURTHER DESIGN PHASES*
  - *POTENTIAL as a TOOL to generate NEW STADIUMS*

CONCLUSIONS

RENOVATION



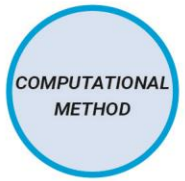
NEWLY BUILT STADIUMS



THANK YOU FOR YOUR ATTENTION!

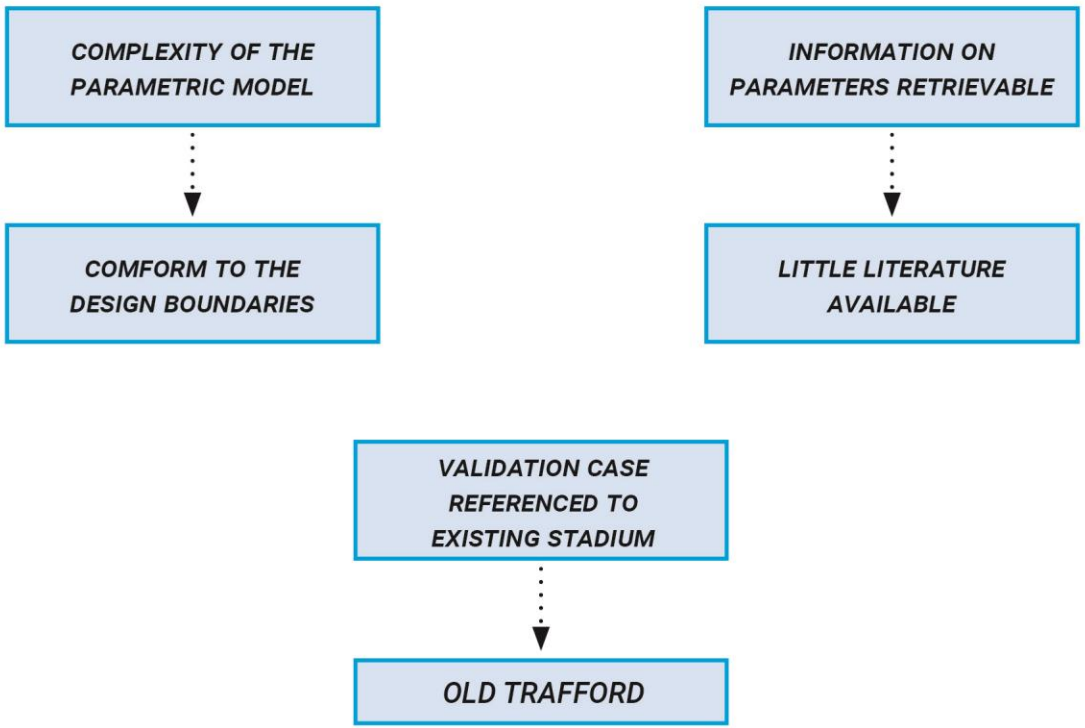
ANY QUESTIONS?

ADDITIONAL SLIDES



REFLECTIONS

- *The problematics encountered in the individuation of the validation case due to the lack of literature available on the necessary parameters can be solved by performing a lidar scan of the existing stadium.*
- *The developed method focuses on few aspects related to the renovation of football stadium, which are related mainly to the viewing quality, the structural performance of the roof and their related components. Indeed, the number of stadiums that can be implemented in the computational method is limited to the ones that have the same characteristics provided in the form generation.*
- *Even though the application on the validation case showed the potential of the computational method, it seems still premature to apply the proposed method in practice.*
- *Future research to refine the typologies of the implemented components can be performed to enhance the computational method for a practical application.*
- *A cost evaluation can be individuated as a crucial feature for future research in order to provide a further valuable criteria to determine the efficiency of the design alternatives.*

VALIDATION CASE

PROBLEMATICS