



COMPUTATIONAL METHOD FOR FOOTBALL STADIUM RENOVATION

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



BACKGROUND

Background and
Problem Statement

Research Structure

Form Generation

Performance
Assessment

Optimization and
Design Exploration

Validation Case

Conclusions



(Source: Foxsports.it)



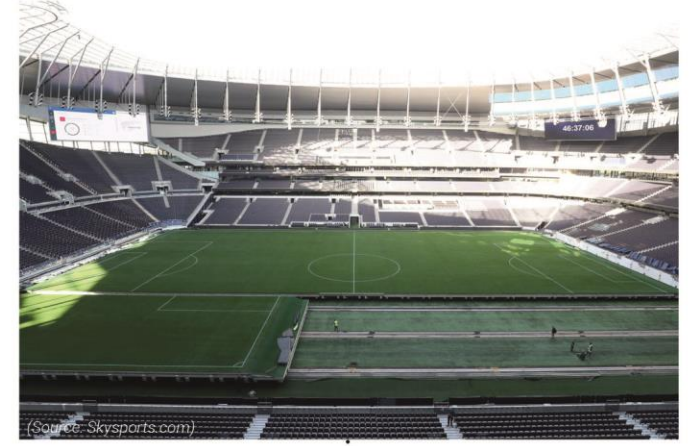




(Source: Foxsports.it)



(Source: korastats.org)



(Source: Skysports.com)



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.”

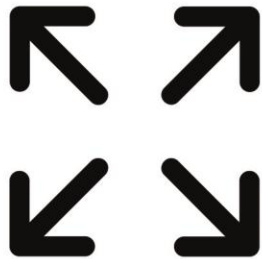
- TOM JONES, POPULOUS (2019)

*"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)

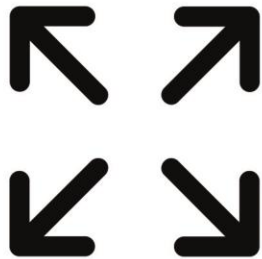
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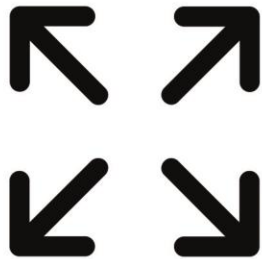
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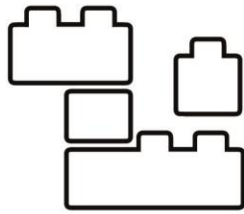
- UEFA (2011)





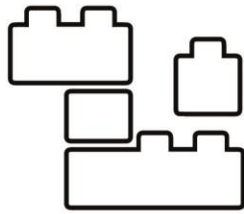
PROBLEM STATEMENT

STADIUM RENOVATION FEATURES



MULTIPLE COMPONENTS
TO BLEND TOGETHER

STADIUM RENOVATION FEATURES

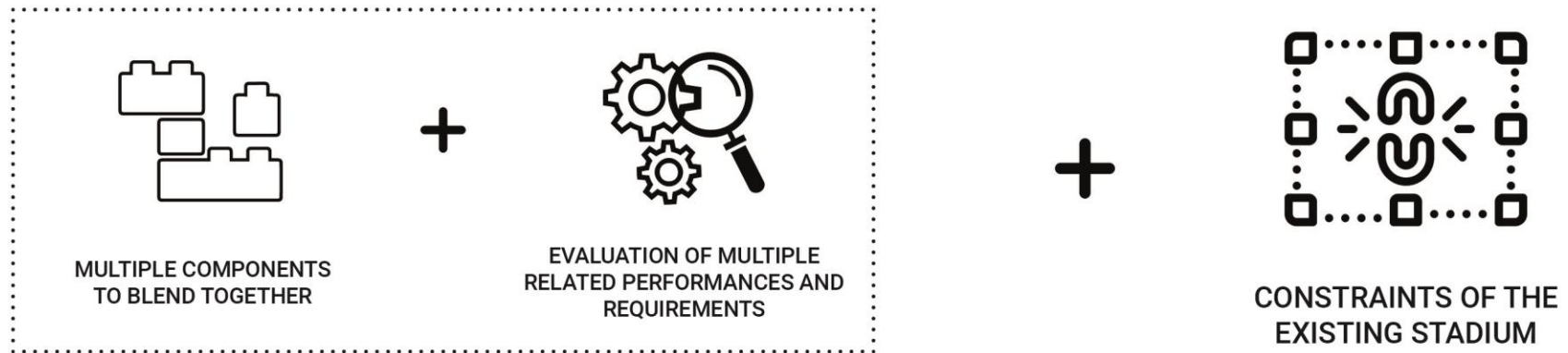


MULTIPLE COMPONENTS
TO BLEND TOGETHER



EVALUATION OF MULTIPLE
RELATED PERFORMANCES AND
REQUIREMENTS

STADIUM RENOVATION FEATURES



PROBLEMATICS



DIFFICULT
DECISION-MAKING

PROBLEMATICS



DIFFICULT
DECISION-MAKING

+



LONG PATH TOWARDS
AN OPTIMAL SOLUTION

PROBLEMATICS



SHIFT TOWARDS *PERFORMANCE ORIENTED DESIGN*

+

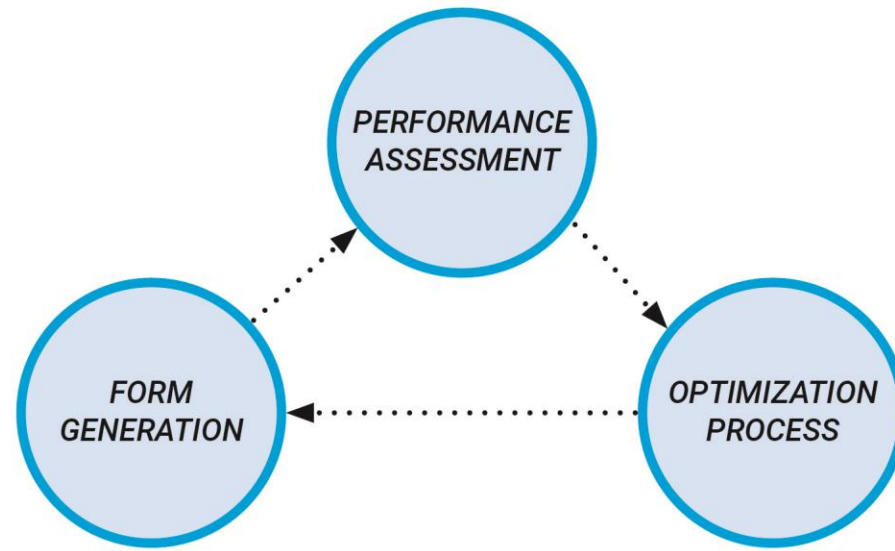
IMPLEMENTATION OF *COMPUTATIONAL METHODS*

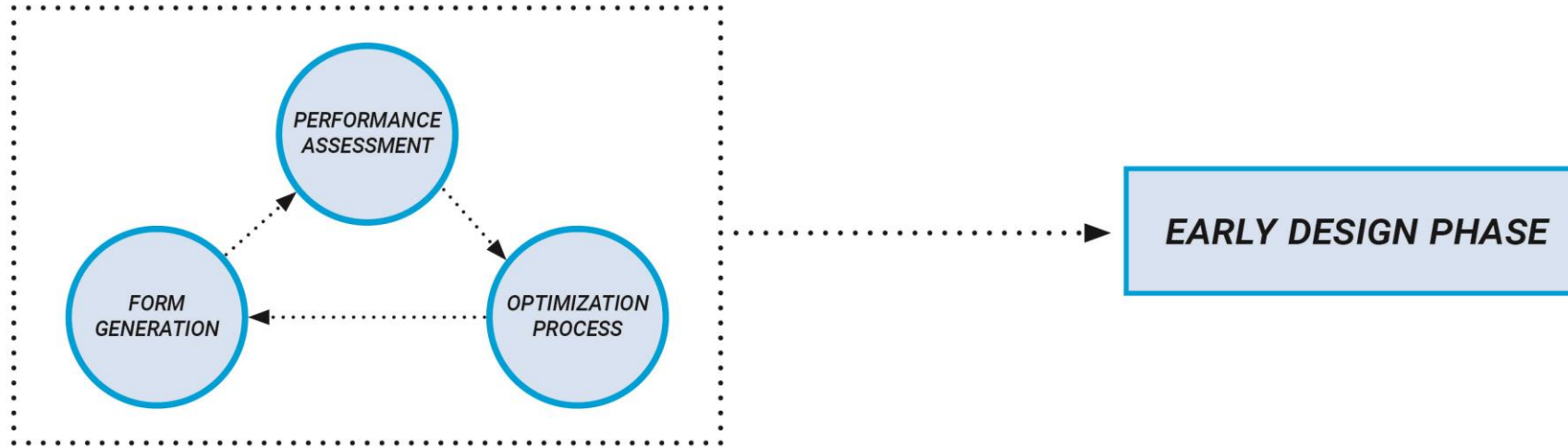
SHIFT TOWARDS **PERFORMANCE ORIENTED DESIGN**

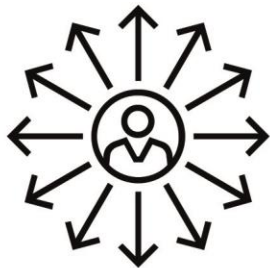
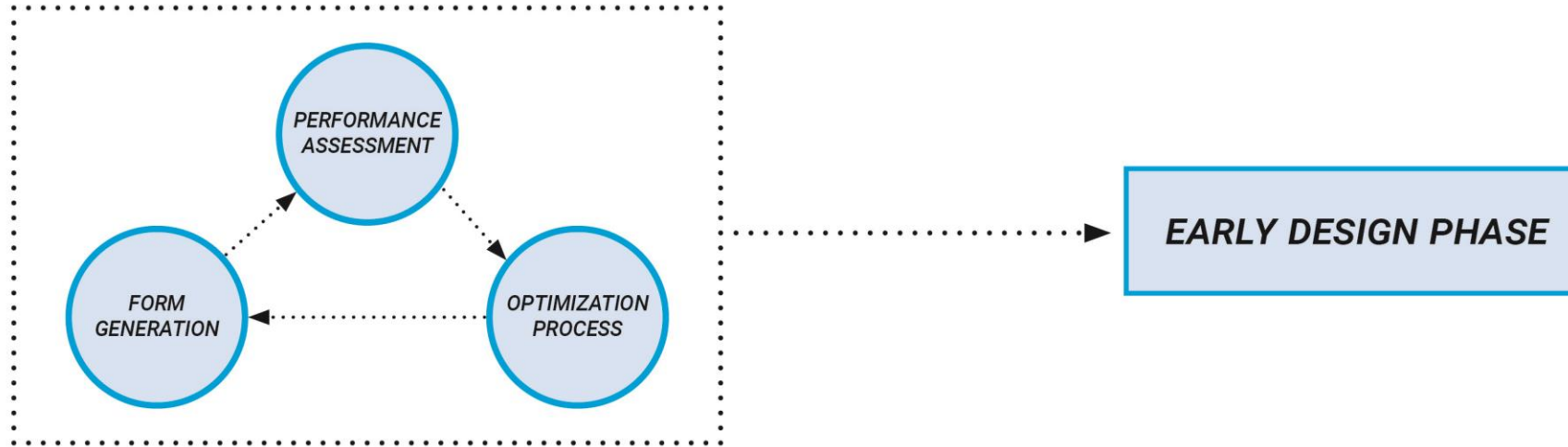
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IMPLEMENTATION OF **COMPUTATIONAL METHODS**

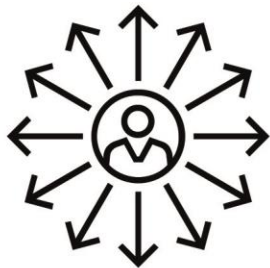
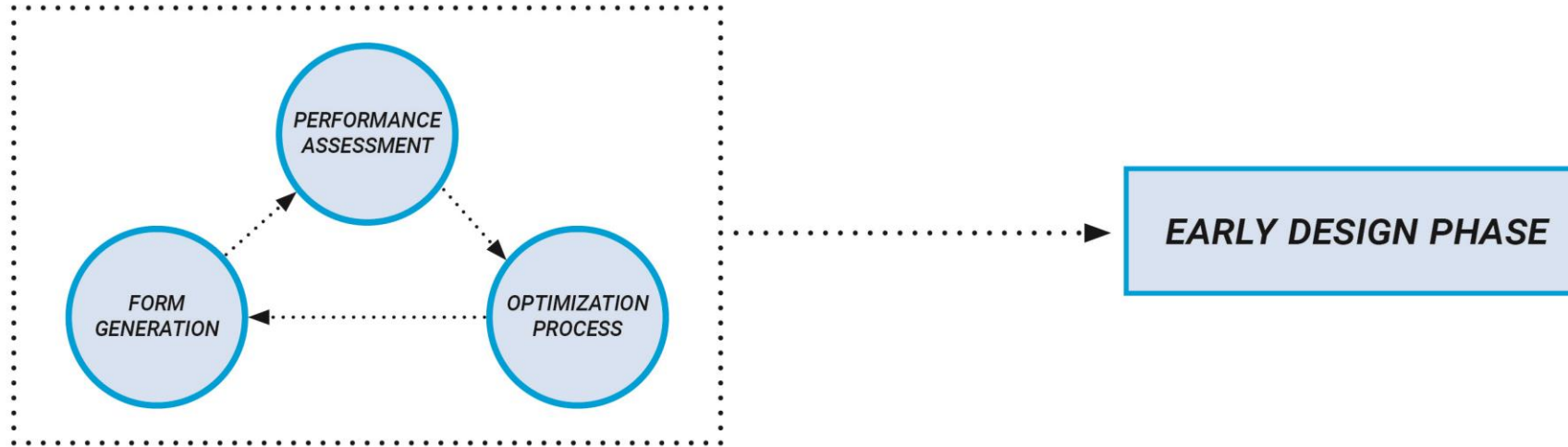
PERFORMATIVE COMPUTATIONAL ARCHITECTURE (PCA)







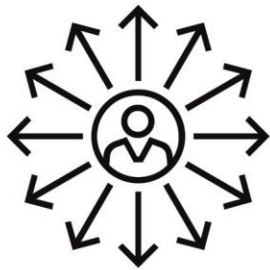
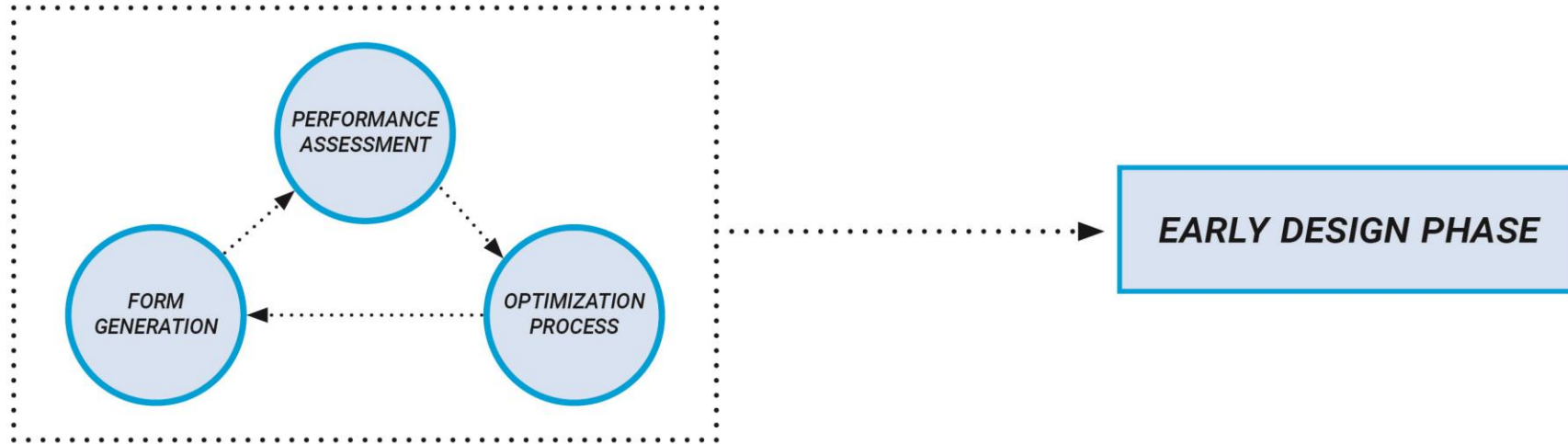
EXPLORE MULTIPLE ALTERNATIVES



EXPLORE MULTIPLE ALTERNATIVES

—		✓
—	✓	
—		✓
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—	✓	

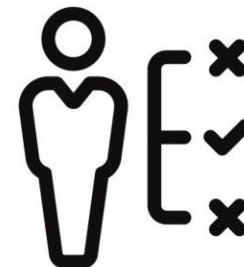
TRADE-OFF OF ALTERNATIVES



EXPLORE MULTIPLE ALTERNATIVES

—		✓
—	✓	
—		✓
—		✓
—	✓	

TRADE-OFF OF ALTERNATIVES



EASIER DECISION-MAKING

ENERGY

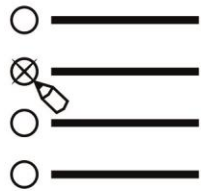
ACOUSTICS

DAYLIGHT

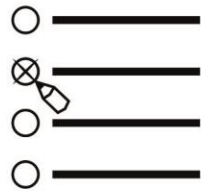
STRUCTURE

VIEWING

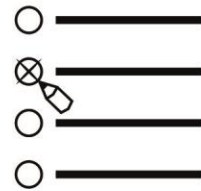
ENERGY



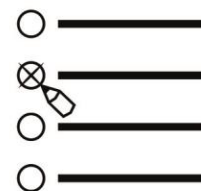
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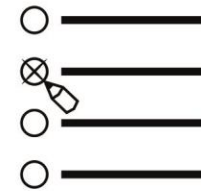
DAYLIGHT



STRUCTURE



VIEWING



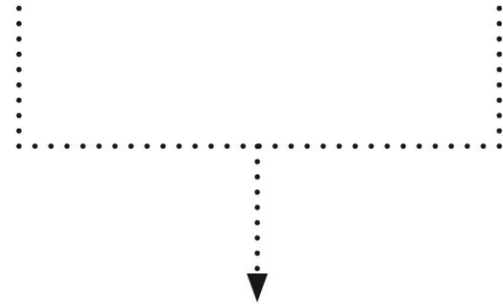
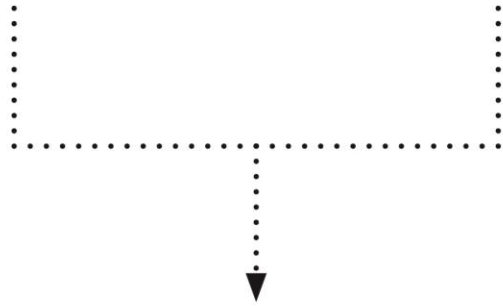
ENERGY

ACOUSTICS

DAYLIGHT

STRUCTURE

VIEWING



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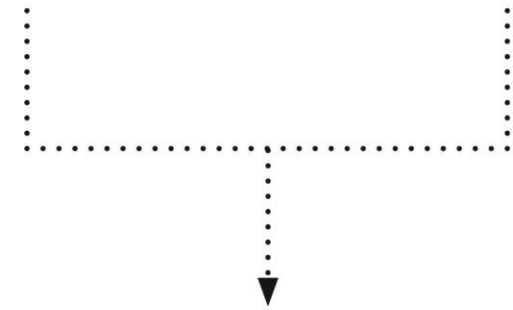
ENERGY

ACOUSTICS

DAYLIGHT

STRUCTURE

VIEWING



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ENERGY

ACOUSTICS

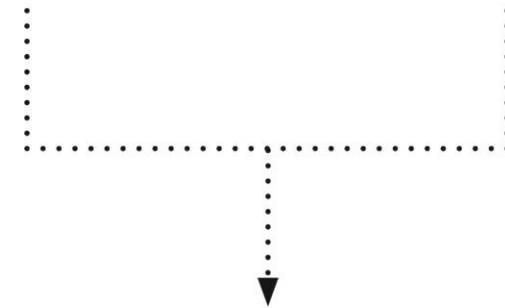
DAYLIGHT

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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- _____
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ENERGY

ACOUSTICS

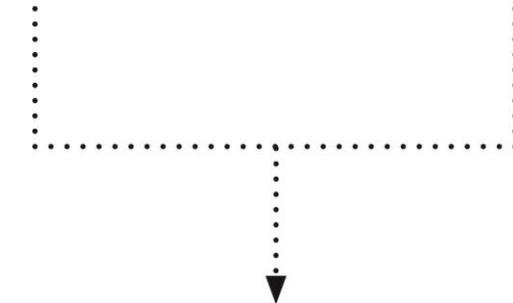
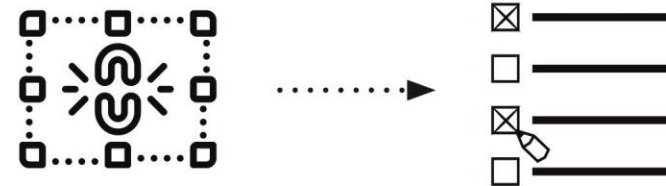
DAYLIGHT

STRUCTURE

VIEWING

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- PAN ET AL. (2019)



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

Background and
Problem Statement

Research Structure

Form Generation

Performance
Assessment

Optimization and
Design Exploration

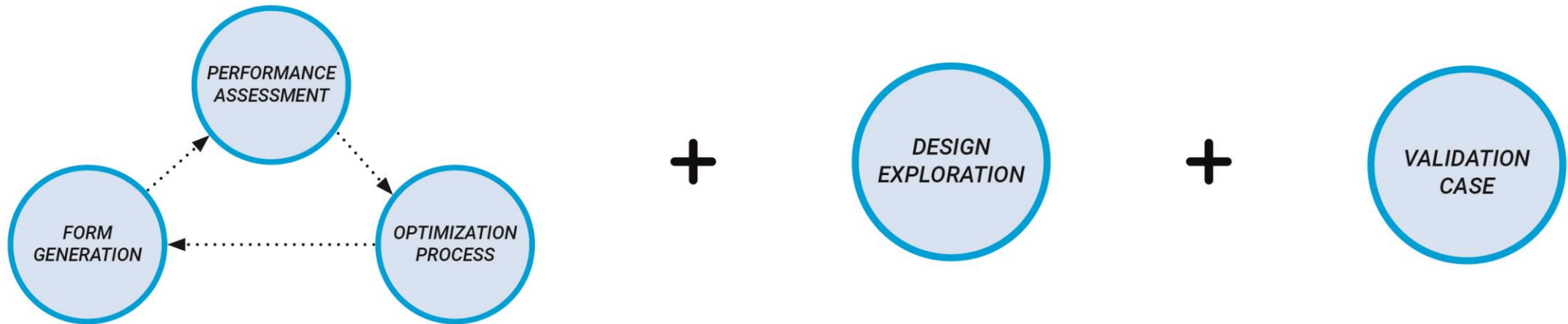
Validation Case

Conclusions

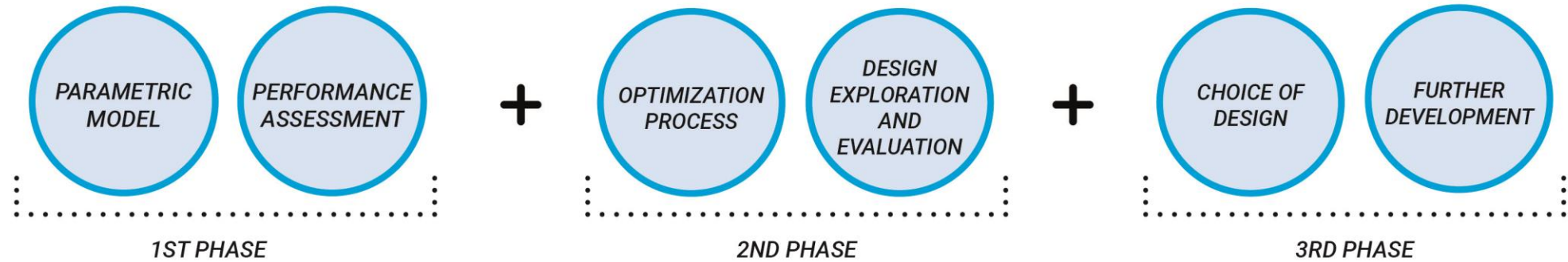
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INITIAL STRUCTURE OF THE COMPUTATIONAL METHOD

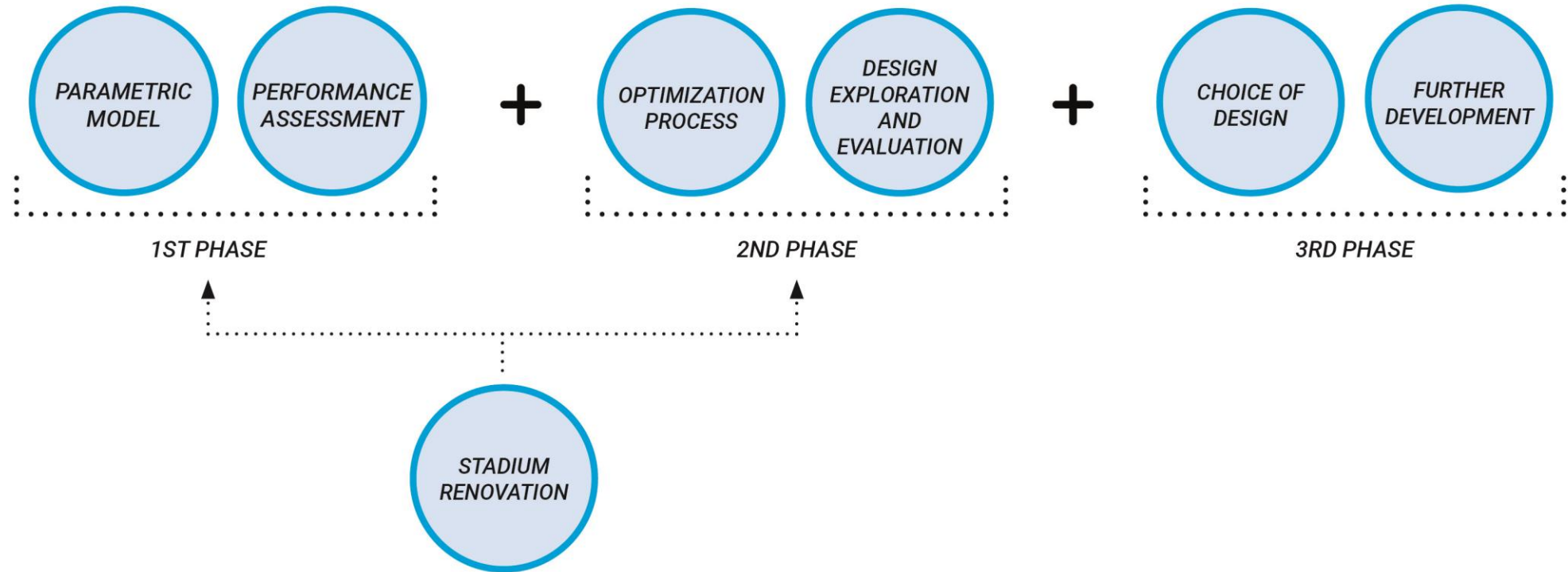
PERFORMATIVE COMPUTATIONAL ARCHITECTURE



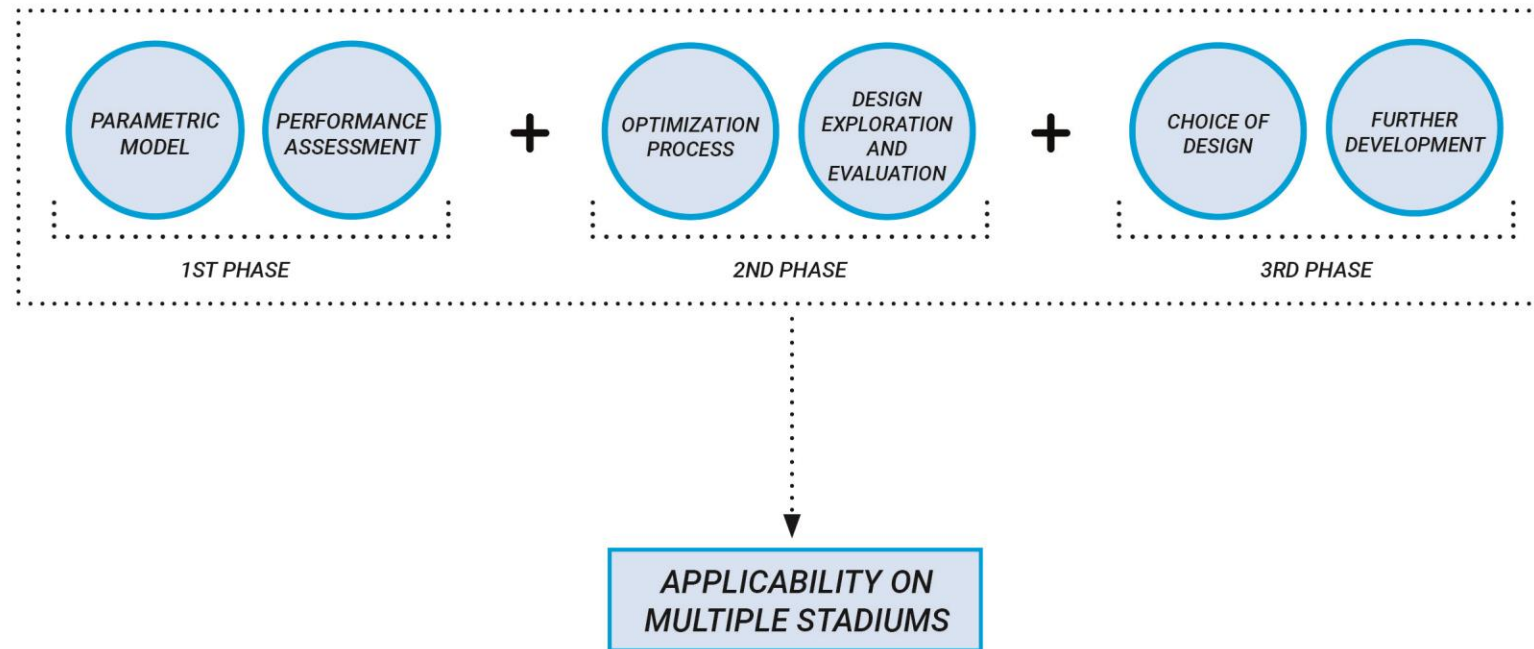
INITIAL STRUCTURE OF THE COMPUTATIONAL METHOD



INITIAL STRUCTURE OF THE COMPUTATIONAL METHOD



INITIAL STRUCTURE OF THE COMPUTATIONAL METHOD





FORM GENERATION

Background and
Problem Statement

Research Structure

Form Generation

Performance
Assessment

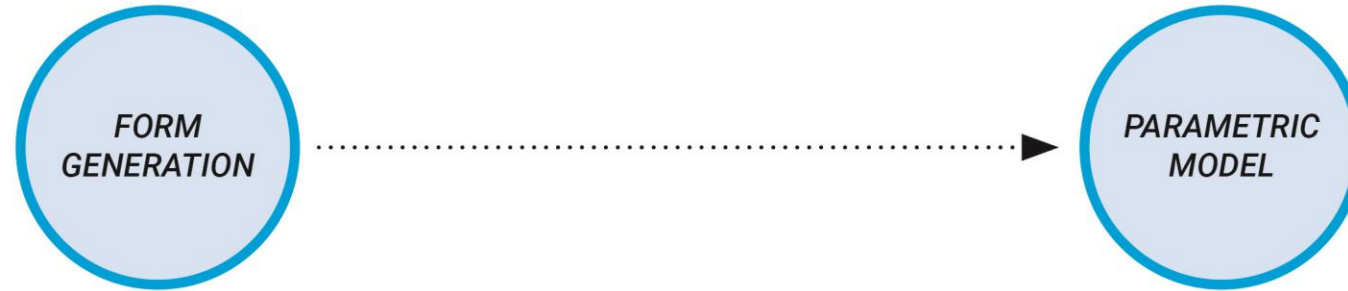
Optimization and
Design Exploration

Validation Case

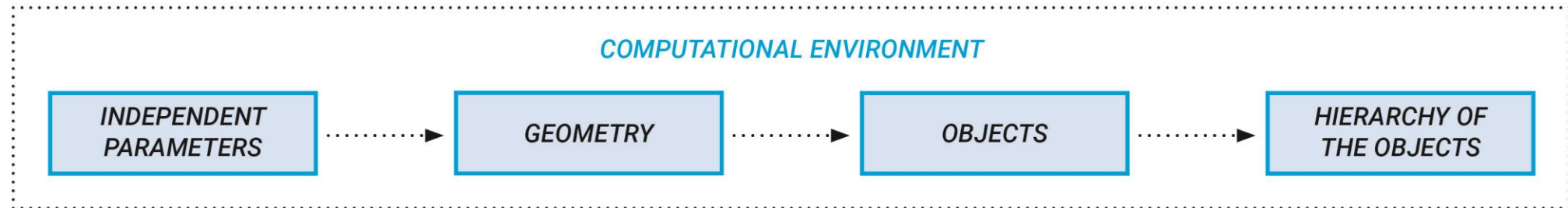
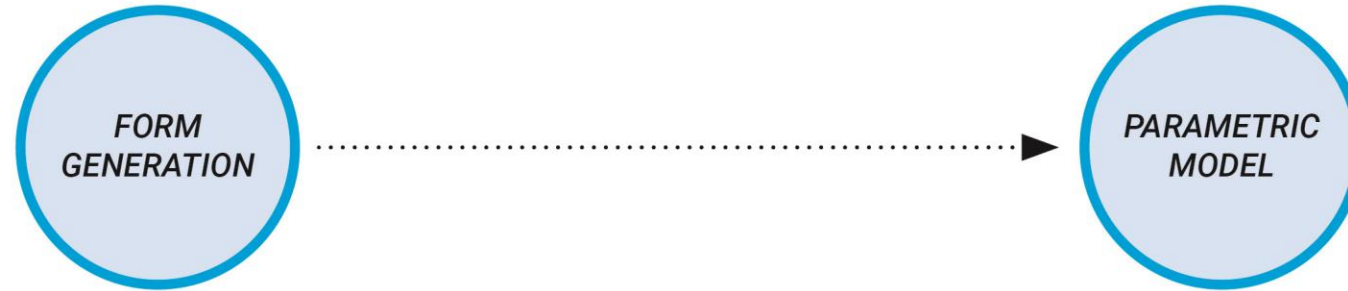
Conclusions

40

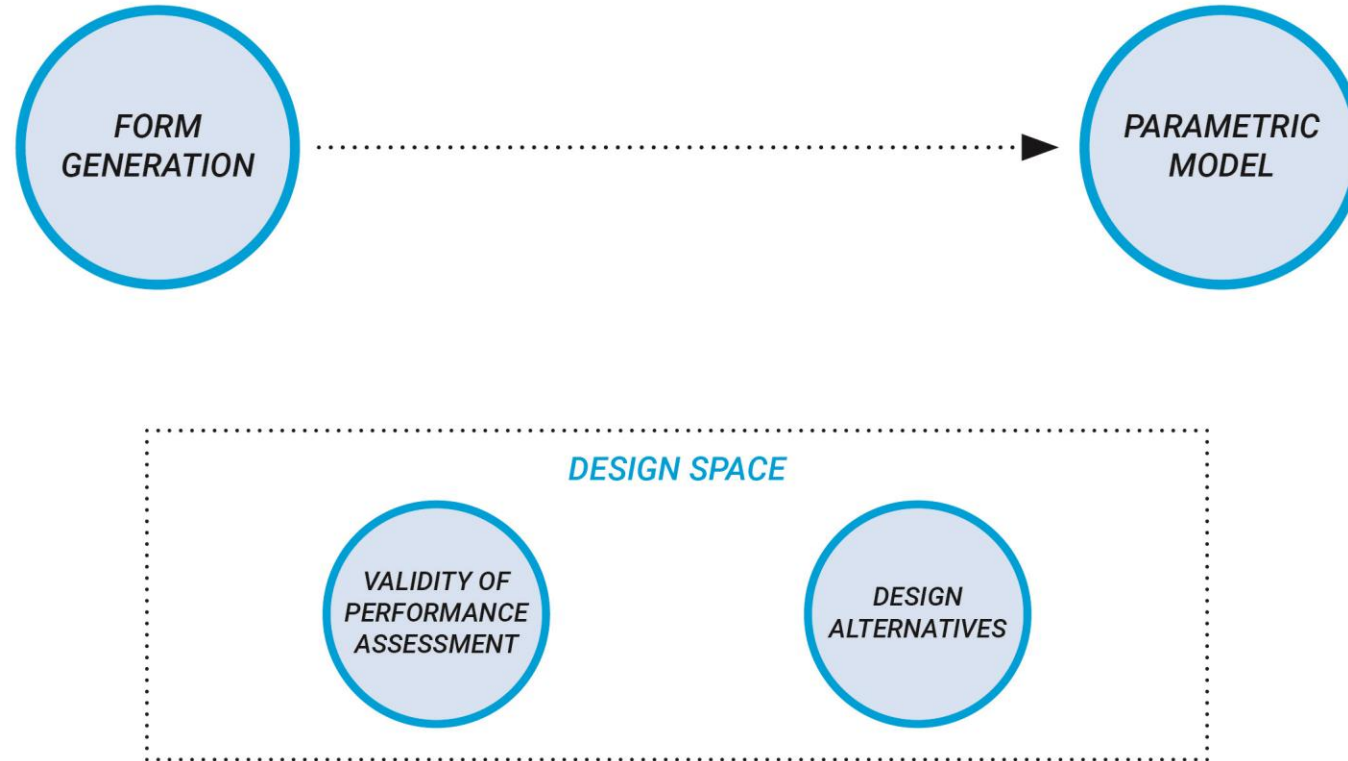
FORM GENERATION



FORM GENERATION

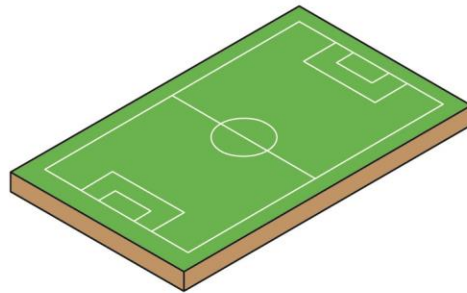


FORM GENERATION



STADIUM COMPONENTS

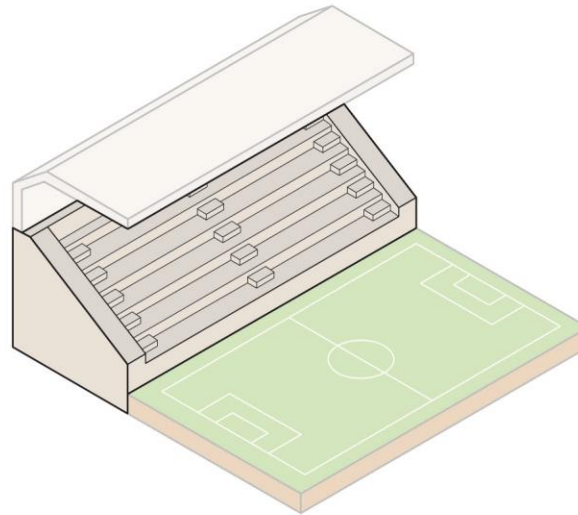
PLAYING AREA



FOCUS POINT
VIEWING QUALITY

+

GRANDSTAND



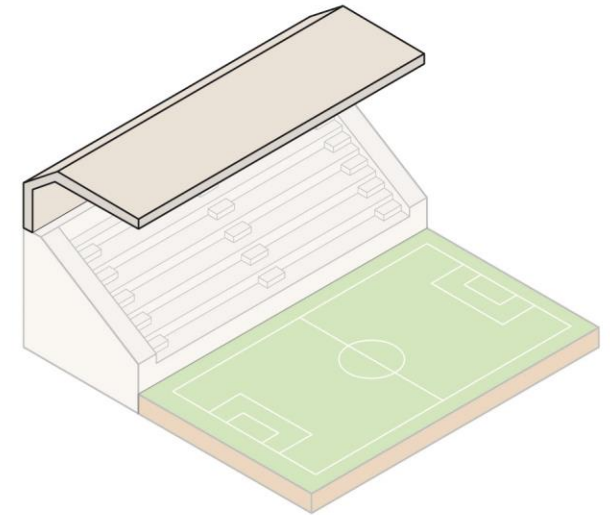
INFLUENCE ON
VIEWING QUALITY

INFLUENCE ON
ROOF OUTLINE

DETERMINES
CAPACITY

+

ROOF



STRUCTURAL
PERFORMANCE

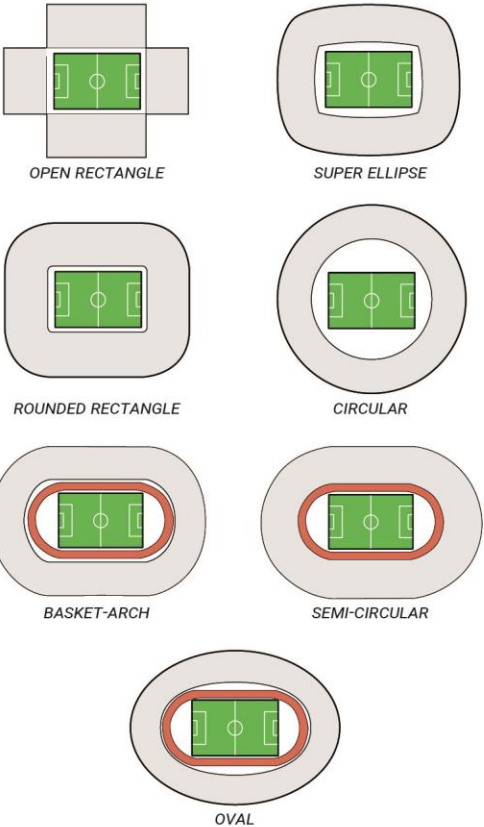
OBSTRUCTION OF
SPECTATORS' VIEW

COVER OF
GRANDSTAND

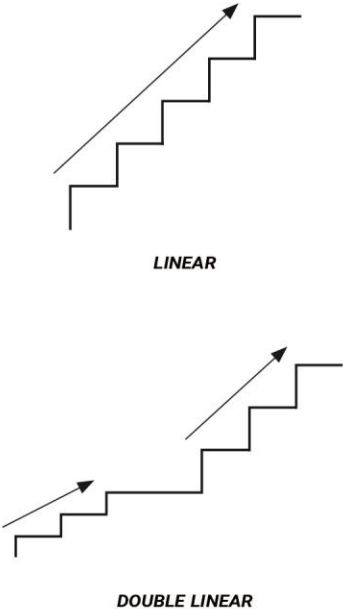
GREAT INFLUENCE
ON OVERALL COST

TYOLOGIES OF COMPONENTS

LAYOUT TYPOLOGIES



STAND TYPOLOGIES



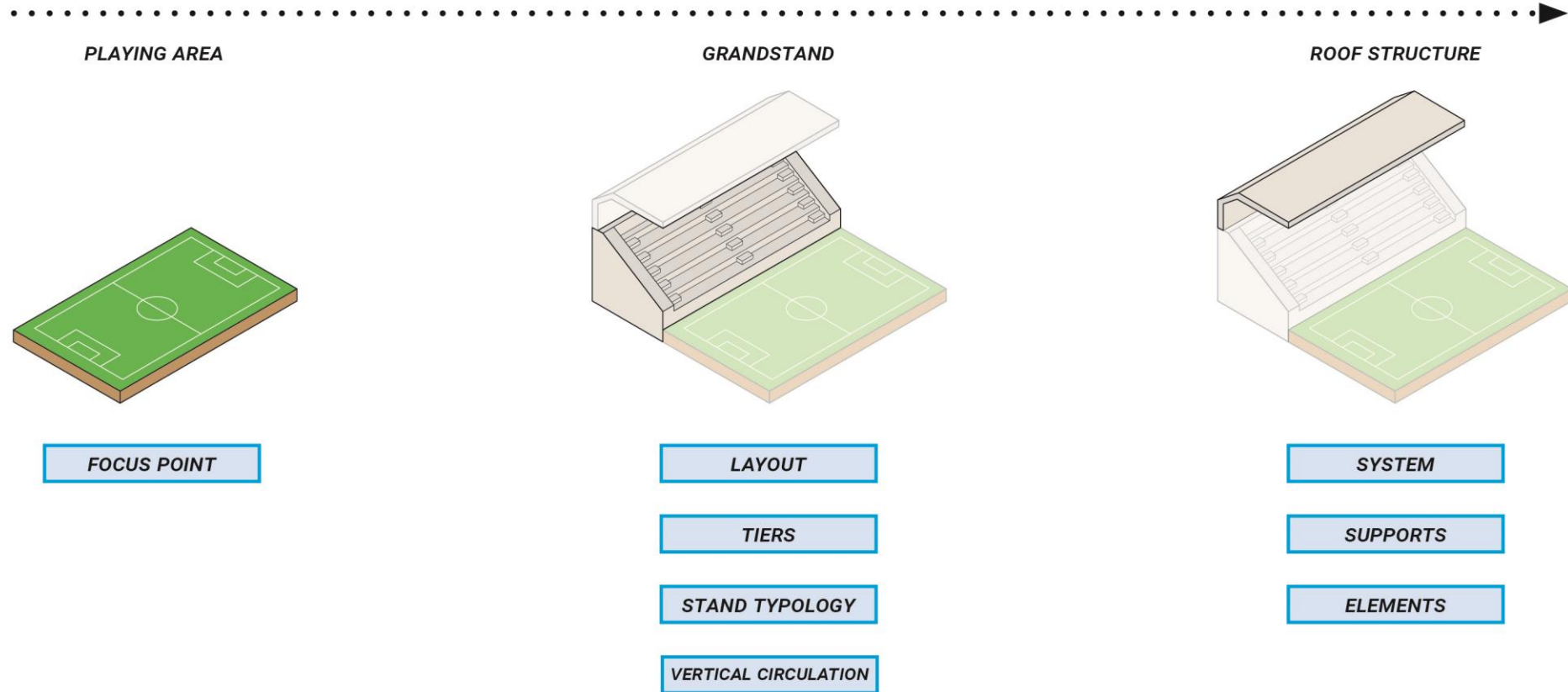
ROOF SYSTEMS



COMPUTATIONAL ENVIRONMENT

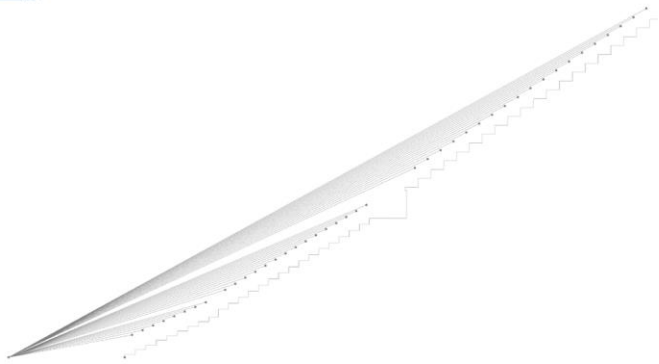


HIERARCHY OF THE OBJECTS

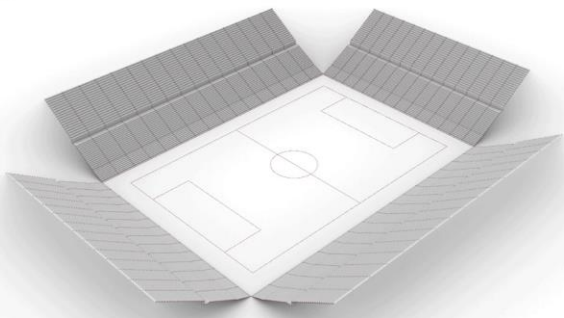


LAYOUT SELECTION

Superiore ▾



Prospettica ▾




LAYOUT TYPOLOGY

Layout_Typology: 0

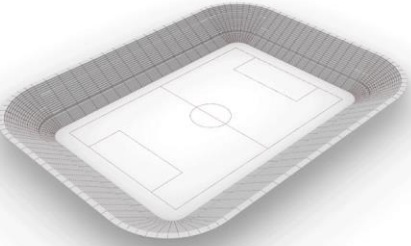
Layout Typology	Parameters	Attributes
Rectangle	Layout0_FRD.X: 7.5 Layout0_FRD.Y: 7.5 Layout0_Gap.X: 0 Layout0_Gap.Y: 0	Touchline Pitch First Row Distance X First Row Distance Y X Gap Y Gap
Super-Ellipse	Layout4_FRD.X: 7.5 Layout4_FRD.Y: 7.5 Layout4_Divergence_CP: 0.0 Layout4_Arc.Radius: 0.1	Touchline Pitch First Row Distance X First Row Distance Y Divergence CP Arc Radius
Circular	Layout2_Radius: 10.0	Touchline Corner Distance
Semi-Circular	Layout3_FRD: 6	Touchline Pitch Pitch Width Offset Track First Row Distance Athletic Track
Oval	Layout6_FRD: 6.0 Layout6_Arc.Radius: 5.0	Touchline Pitch Pitch Width Offset Track First Row Distance Arc Radius Athletic Track
Round Rect	Layout5_FRD: 7.5 Layout5_Divergence: 0	Touchline Pitch Pitch Width Offset Track First Row Distance Divergence Athletic Track
Rounded Rectangle	Layout1_FRD.X: 7.2 Layout1_FRD.Y: 5.5 Layout1_Radius: 7.2	Touchline Pitch First Row Distance X First Row Distance Y Radius

CONFIGURATION SET-UP

Superiore ▾



Prospettiva ▾



CONFIGURATION

G_85.N.Tier1	G_85.NW.Tier1	G_85.W.Tier1	G_85.SW.Tier1
G_85.N.Tier1.StandType	G_85.NW.Tier1.StandType	G_85.W.Tier1.StandType	G_85.SW.Tier1.StandType
G_N.Tier2	G_NNW.Tier2	G_W.Tier2	G_SW.Tier2
G_N.Tier2.StandType	G_NNW.Tier2.StandType	G_W.Tier2.StandType	G_SW.Tier2.StandType
G_N.Tier3	G_NNW.Tier3	G_W.Tier3	G_SW.Tier3
G_N.Tier3.StandType	G_NNW.Tier3.StandType	G_W.Tier3.StandType	G_SW.Tier3.StandType

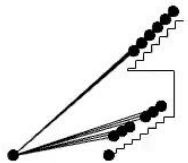
G_85.S.Tier1	G_85.SE.Tier1	G_85.E.Tier1	G_85.NE.Tier1
G_85.S.Tier1.StandType	G_85.SE.Tier1.StandType	G_85.E.Tier1.StandType	G_85.NE.Tier1.StandType
G_S.Tier2	G_SE.Tier2	G_E.Tier2	G_NE.Tier2
G_S.Tier2.StandType	G_SE.Tier2.StandType	G_E.Tier2.StandType	G_NE.Tier2.StandType
G_S.Tier3	G_SE.Tier3	G_E.Tier3	G_NE.Tier3
G_S.Tier3.StandType	G_SE.Tier3.StandType	G_E.Tier3.StandType	G_NE.Tier3.StandType

GRANDSTAND TYPOLOGY

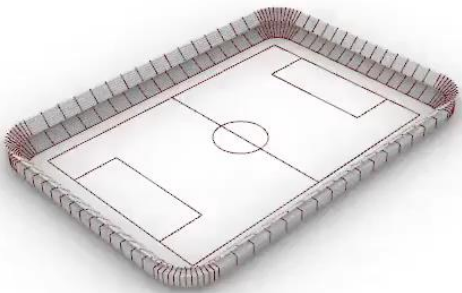
TIER 1	TIER 2	TIER 3
<p>LINEAR TYPOLOGY</p> <div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T1S1.Initialiser: 1.0 T1S1.TreadDepth: 0.60 T1S1.NRows: 15 T1S1.RowHeight: 0.20 T1S1.LastRowDepth: 0.6 </div> <div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T1S2.Initialiser: 0.2 T1S2.TreadDepth: 0.60 T1S2.NRows: 5 T1S2.RowHeight: 0.30 T1S2.LastRowDepth: 0.6 </div> <div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T1S2.2.Initialiser: 0.5 T1S2.2.TreadDepth: 0.65 T1S2.2.NRows: 16 T1S2.2.RowHeight: 0.39 T1S2.2.LastRowDepth: 2.4 </div>	<p>DOUBLE LINEAR TYPOLOGY</p> <div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T2S1.Initialiser: 0.2 T2S1.TreadDepth: 0.70 T2S1.NRows: 20 T2S1.RowHeight: 0.41 T2S1.LastRowDepth: 2.4 T2S1.TierHeight: 1.8 T2S1.CantileverDistance: 4.5 </div> <div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T2S2.Initialiser: 0.2 T2S2.TreadDepth: 0.60 T2S2.NRows: 11 T2S2.RowHeight: 0.40 T2S2.LastRowDepth: 0.60 T2S2.TierHeight: 2.5 T2S2.CantileverDistance: 4.5 </div> <div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T2S2.2.Initialiser: 1.0 T2S2.2.TreadDepth: 0.90 T2S2.2.NRows: 10 T2S2.2.RowHeight: 0.60 T2S2.2.LastRowDepth: 2.4 </div>	<div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T3S1.Initialiser: 0.2 T3S1.TreadDepth: 0.60 T3S1.NRows: 10 T3S1.RowHeight: 0.50 T3S1.LastRowDepth: 2.4 T3S1.TierHeight: 2.5 T3S1.CantileverDistance: 8.0 </div> <div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T3S2.1.Initialiser: 0.2 T3S2.1.TreadDepth: 0.85 T3S2.1.NRows: 10 T3S2.1.RowHeight: 0.50 T3S2.1.LastRowDepth: 1.2 T3S2.1.TierHeight: 2.5 T3S2.1.CantileverDistance: 8.0 </div> <div style="border: 1px solid #00aaff; padding: 5px; margin-bottom: 5px;"> T3S2.2.Initialiser: 1.0 T3S2.2.TreadDepth: 0.85 T3S2.2.NRows: 10 T3S2.2.RowHeight: 0.60 T3S2.2.LastRowDepth: 2.4 </div>

GRANDSTAND CONSTRUCTION

Superiore ▾



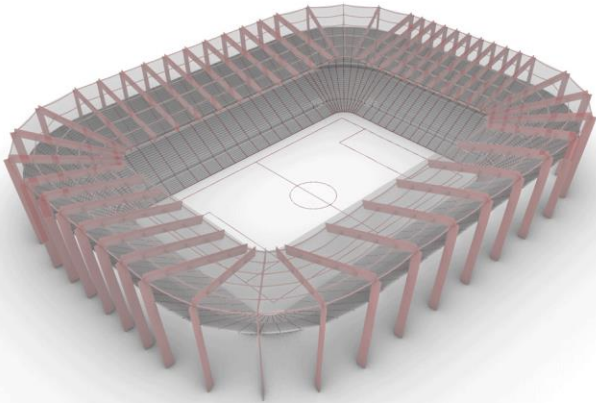
Prospettiva ▾



GRANDSTAND TYPOLOGY

	TIER 1	TIER 2	TIER 3
LINEAR TYPOLOGY	<ul style="list-style-type: none"> T1S1_InitialRiser: 1.2 T1S1_TreadDepth: 0.60 T1S1_NRows: 4 T1S1_RiserHeight: 0.20 T1S1_LastRowDepth: 0.6 	<ul style="list-style-type: none"> T2S1_InitialRiser: 0.2 T2S1_TreadDepth: 0.60 T2S1_NRows: 7 T2S1_RiserHeight: 0.60 T2S1_LastRowDepth: 0.6 T2S1_TierHeight: 3.5 T2S1_CantileverDistance: 3.5 	<ul style="list-style-type: none"> T3S1_InitialRiser: 0.2 T3S1_TreadDepth: 0.60 T3S1_NRows: 10 T3S1_RiserHeight: 0.50 T3S1_LastRowDepth: 2.4 T3S1_TierHeight: 2.5 T3S1_CantileverDistance: 8.0
DOUBLE LINEAR TYPOLOGY	<ul style="list-style-type: none"> T1S2_1_InitialRiser: 0.2 T1S2_1_TreadDepth: 0.60 T1S2_1_NRows: 4 T1S2_1_RiserHeight: 0.35 T1S2_1_LastRowDepth: 0.6 T1S2_2_InitialRiser: 0.4 T1S2_2_TreadDepth: 0.60 T1S2_2_NRows: 4 T1S2_2_RiserHeight: 0.42 T1S2_2_LastRowDepth: 0.8 	<ul style="list-style-type: none"> T2S2_1_InitialRiser: 0.2 T2S2_1_TreadDepth: 0.68 T2S2_1_NRows: 11 T2S2_1_RiserHeight: 0.40 T2S2_1_LastRowDepth: 0.68 T2S2_TierHeight: 2.5 T2S2_CantileverDistance: 4.5 T2S2_2_InitialRiser: 1.0 T2S2_2_TreadDepth: 0.90 T2S2_2_NRows: 10 T2S2_2_RiserHeight: 0.60 T2S2_2_LastRowDepth: 2.4 	<ul style="list-style-type: none"> T3S2_1_InitialRiser: 0.2 T3S2_1_TreadDepth: 0.85 T3S2_1_NRows: 10 T3S2_1_RiserHeight: 0.50 T3S2_1_LastRowDepth: 1.2 T3S2_TierHeight: 2.5 T3S2_CantileverDistance: 8 T3S2_2_InitialRiser: 1.0 T3S2_2_TreadDepth: 0.85 T3S2_2_NRows: 10 T3S2_2_RiserHeight: 0.60 T3S2_2_LastRowDepth: 2.4

STRUCTURAL SYSTEM



STRUCTURAL SYSTEM

STR_Structural_System 0
STR_Boundary_Conditions 2
Material 1

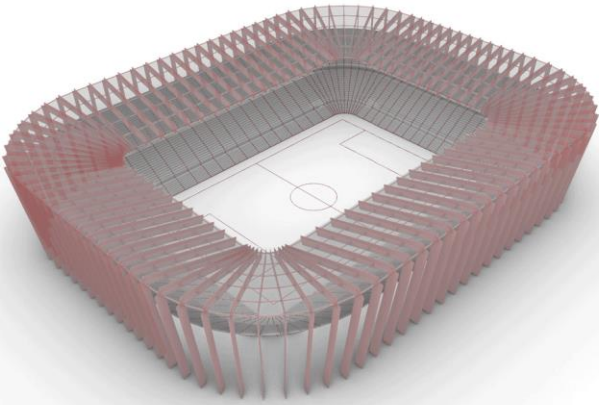
NUMBER AND POSITION OF SUPPORTS

STR_Support_0	10	STR_PosGroundSup_0	33.00
STR_Support_1	4	STR_PosGroundSup_1	33.00
STR_Support_2	6	STR_PosGroundSup_2	33.00
STR_Support_3	4	STR_PosGroundSup_3	33.00
STR_Support_4	6	STR_PosGroundSup_4	33.00
STR_Support_5	4	STR_PosGroundSup_5	33.00
STR_Support_6	10	STR_PosGroundSup_6	33.00
STR_Support_7	4	STR_PosGroundSup_7	33.00

ROOF OUTLINE

STR_Bracing	5
STR_ClearHeightAboveSpectator	0.0
STR_StartCantilever	10.0
STR_CantileverEnd_ZD	1
STR2_3_TieBack	10.0
STR3_ExtensionPillar	10.0
STR2_3_GroundSup	10.0
STR3_EndPos	-1

CONTROL POINTS MOVEMENTS



STRUCTURAL SYSTEM

STR_Structural_System

STR_Boundary_Conditions

Material

NUMBER AND POSITION OF SUPPORTS

STR_Support_0	<input type="text" value="16"/>	STR_PosGroundSup_0	<input type="text" value="32.00"/>
STR_Support_1	<input type="text" value="10"/>	STR_PosGroundSup_1	<input type="text" value="32.00"/>
STR_Support_2	<input type="text" value="12"/>	STR_PosGroundSup_2	<input type="text" value="32.00"/>
STR_Support_3	<input type="text" value="16"/>	STR_PosGroundSup_3	<input type="text" value="32.00"/>
STR_Support_4	<input type="text" value="12"/>	STR_PosGroundSup_4	<input type="text" value="32.00"/>
STR_Support_5	<input type="text" value="10"/>	STR_PosGroundSup_5	<input type="text" value="32.00"/>
STR_Support_6	<input type="text" value="10"/>	STR_PosGroundSup_6	<input type="text" value="32.00"/>
STR_Support_7	<input type="text" value="10"/>	STR_PosGroundSup_7	<input type="text" value="32.00"/>

ROOF OUTLINE

STR_Bracing	<input type="text" value="5"/>
STR_ClearHeightAboveSpectator	<input type="text" value="0.0"/>
STR_StartCantilever	<input type="text" value="10.0"/>
STR_CantileverEnd_2D	<input type="text" value="1"/>
STR2_3_TieBack	<input type="text" value="10.0"/>
STR3_ExtensionPillar	<input type="text" value="10.0"/>
STR2_3_GroundSup	<input type="text" value="10.0"/>
STR3_EndPos	<input type="text" value="-1"/>

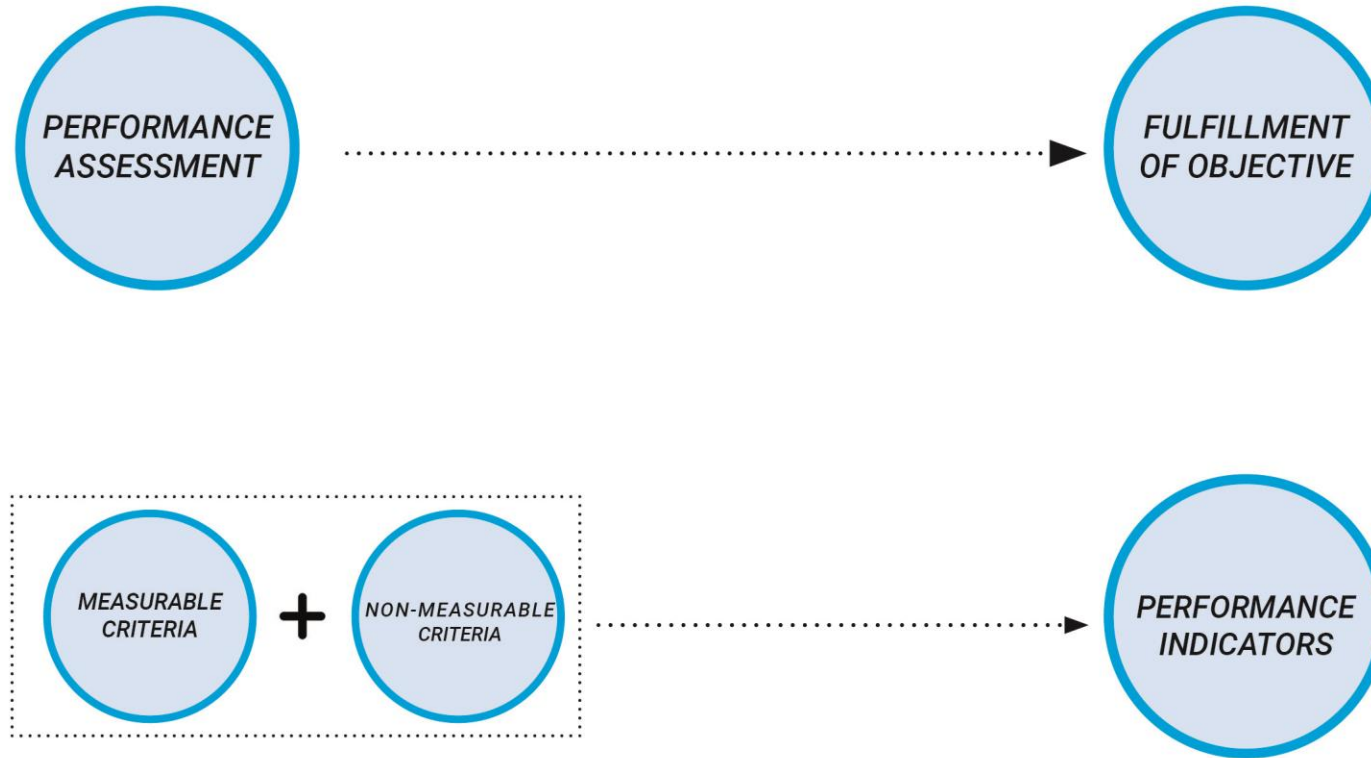


PERFORMANCE ASSESSMENT

PERFORMANCE ASSESSMENT



PERFORMANCE ASSESSMENT

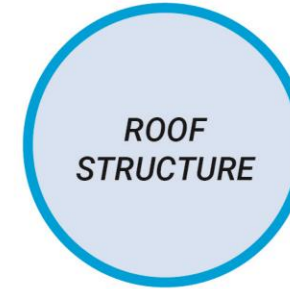


PERFORMANCE ASSESSMENT



COMFORT OF THE SPECTATORS IN **FOLLOWING** THE ACTIVITY

INDICATORS IN RELATION TO



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

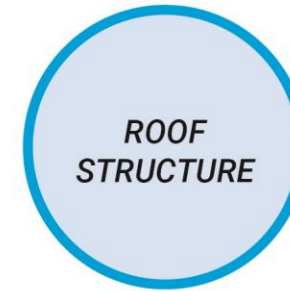
INDICATORS IN RELATION TO



PERFORMANCE ASSESSMENT



COMFORT OF THE SPECTATORS IN **FOLLOWING** THE ACTIVITY

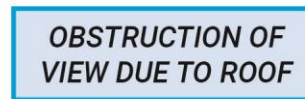


TRANSFER OF DEAD-WEIGHT AND EXTERNAL **LOADS** TO THE GROUND

INDICATORS IN RELATION TO



JOINT RELATION

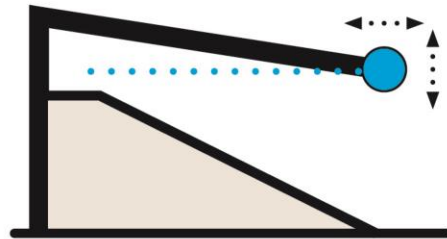


INDICATORS IN RELATION TO

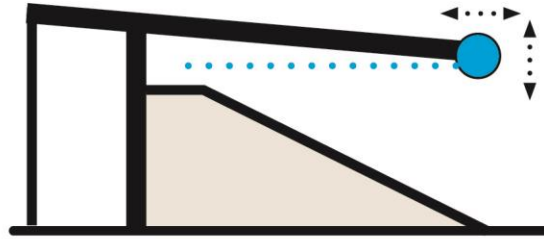


JOINT RELATION SOLUTION

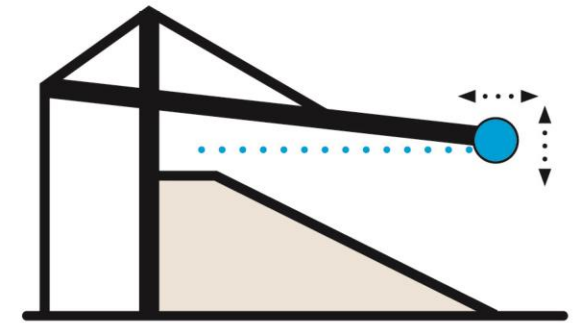
SIMPLE CANTILEVER



TIE-BACK CANTILEVER



RESTRAINED CANTILEVER



VIEW OBSTRUCTION
STAND COVERAGE

OPTIMIZATION
CONTROL OF
RANGE OF VALUES

SAVE
COMPUTATIONAL TIME

VIEWING QUALITY PERFORMANCES



C-VALUE

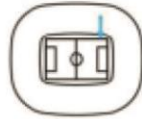
% > 6 cm

% 6 cm < X < 9 cm

% > 9 cm

% 9 cm < X < 12 cm

% > 12 cm



MAXIMUM DISTANCE

% SPECTATORS DISTANCE < 190 m

MAX DISTANCE

MIN DISTANCE

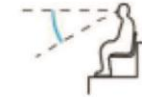


CAPACITY

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

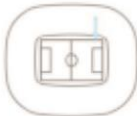
% > 6 cm

% 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

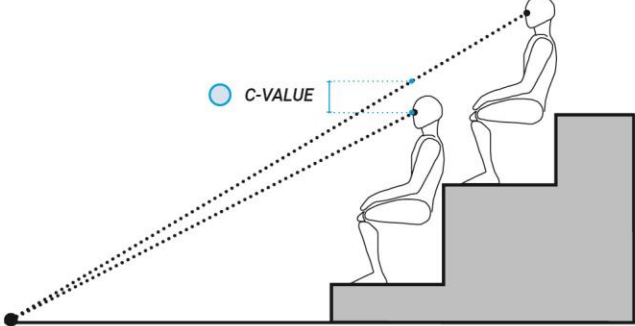
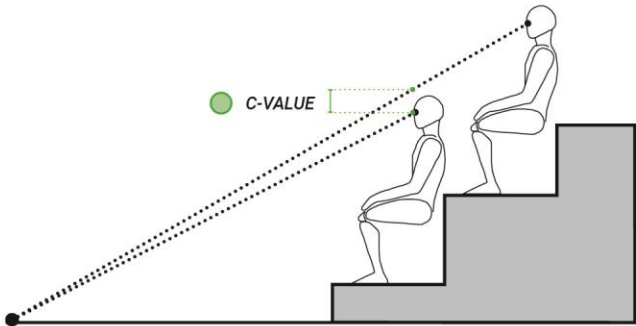
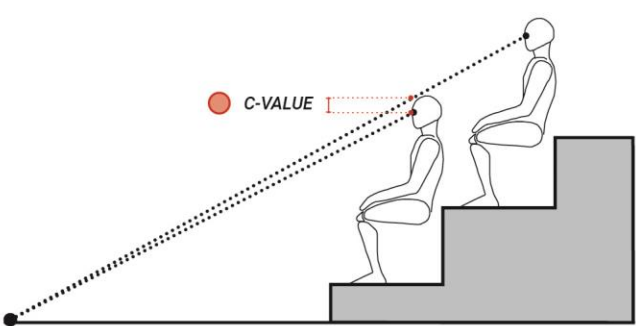
$\% > 6 \text{ cm}$

$\% 6 \text{ cm} < X < 9 \text{ cm}$

$\% > 9 \text{ cm}$

$\% 9 \text{ cm} < X < 12 \text{ cm}$

$\% > 12 \text{ cm}$



DESIGN ALTERNATIVES VS INITIAL SITUATION



C-VALUE

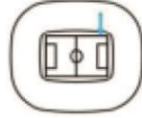
% > 6 cm

% 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

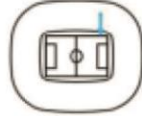
% > 6 cm

% 6 cm < X < 9 cm

% > 9 cm

% 9 cm < X < 12 cm

% > 12 cm



MAXIMUM DISTANCE

**% SPECTATORS
DISTANCE < 190 m**

MAX DISTANCE

MIN DISTANCE

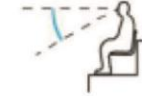


CAPACITY

CAPACITY

INCREMENT

% INCREMENT



VERTICAL VIEWING ANGLE

MAX ANGLE

MIN ANGLE



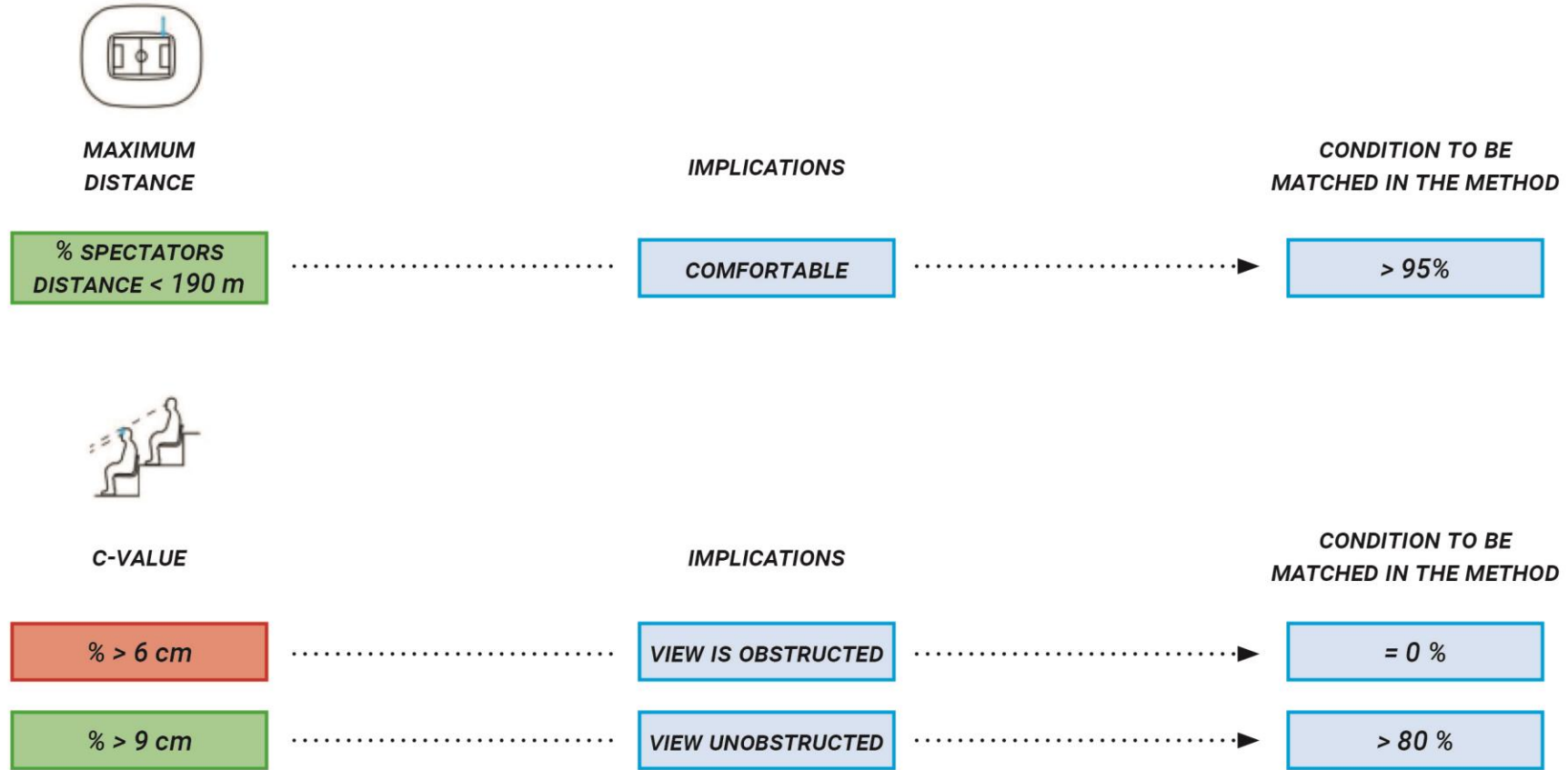
FIELD OF VIEW

MAX ANGLE

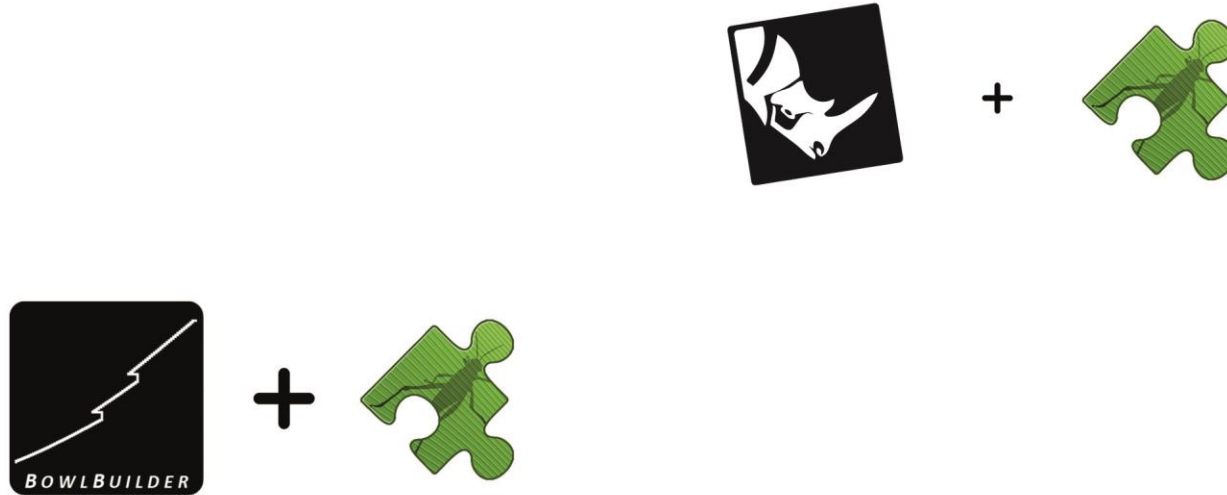
MIN ANGLE

**% SPECTATORS WITH
ANGLE < 120°**

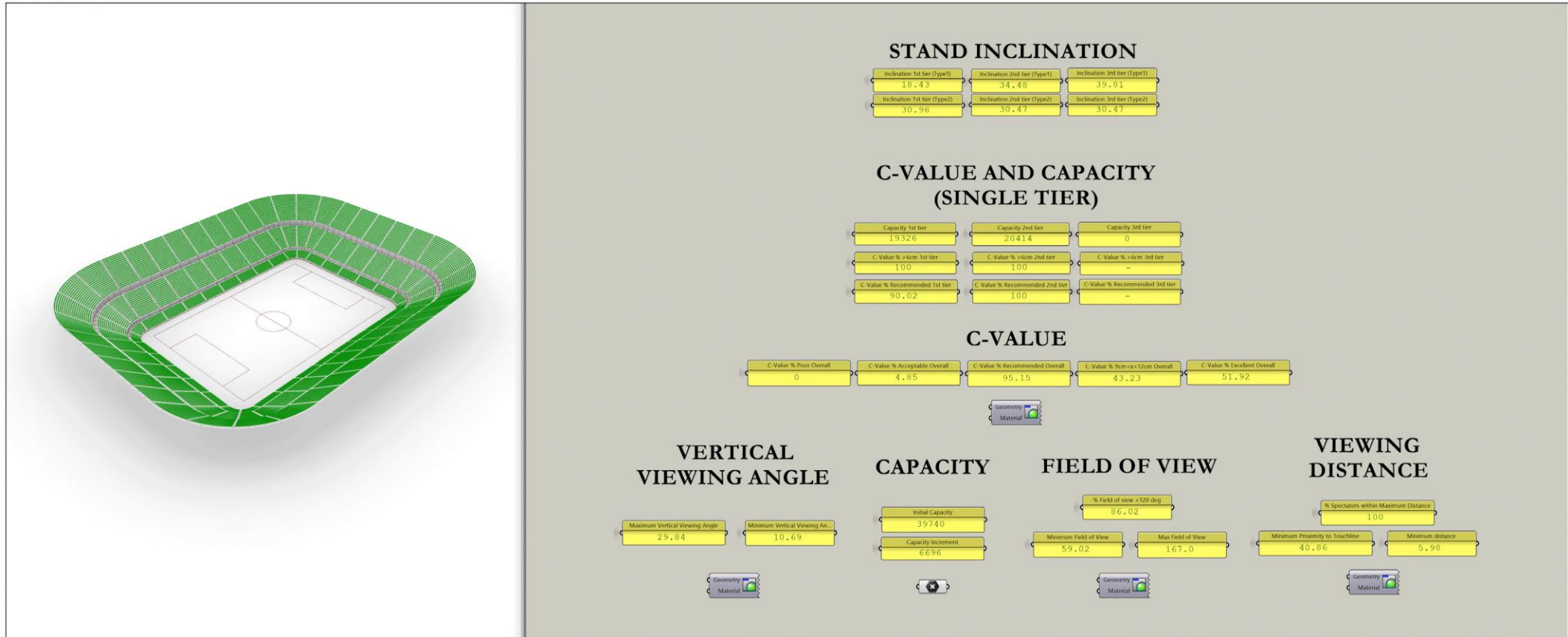
EVALUATE RENOVATION



COMPUTATIONAL ENVIRONMENT

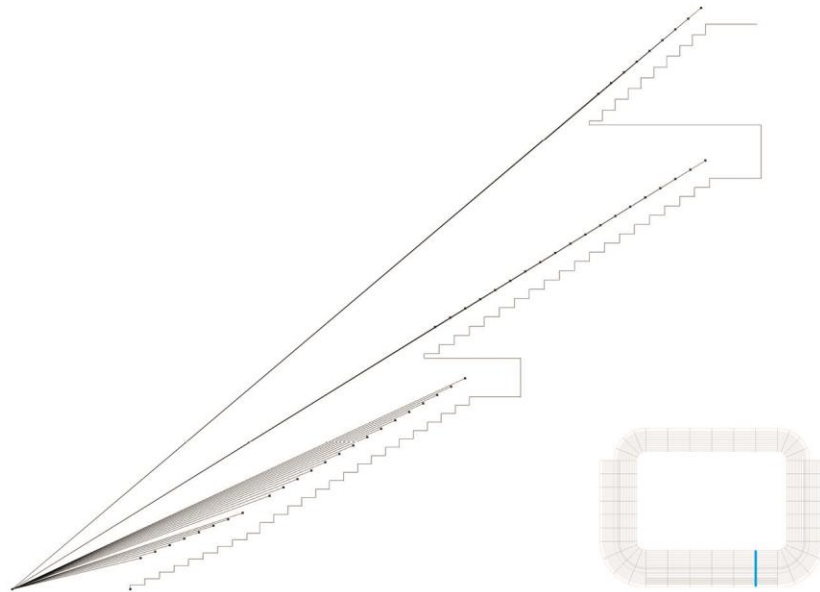


VISUALIZATION OF RESULTS

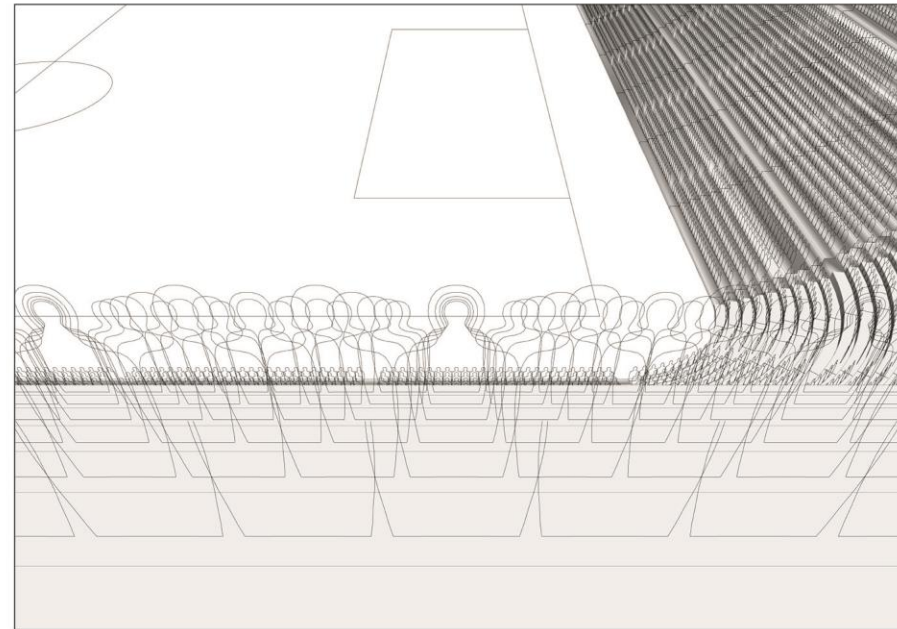


FURTHER DECISION-MAKING SUPPORT

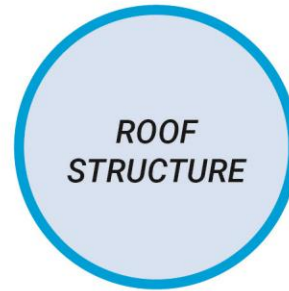
2D SECTION VISUALIZATION



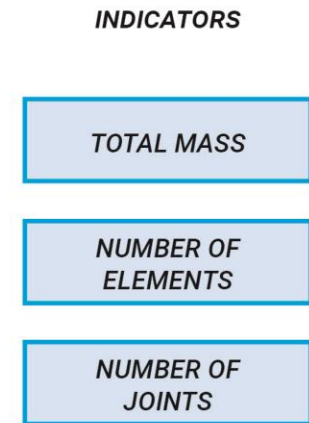
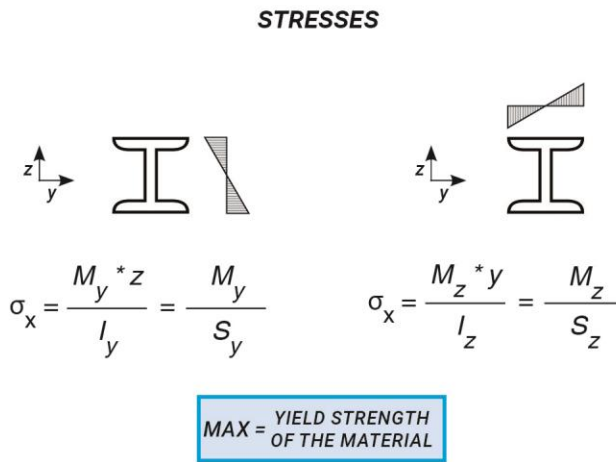
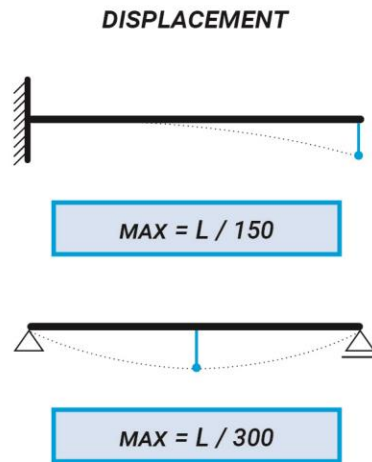
POINT OF VIEW VISUALIZATION



STRUCTURAL INDICATORS



TRANSFER OF DEAD-WEIGHT AND EXTERNAL LOADS TO THE GROUND



STRUCTURAL PERFORMANCES



DISPLACEMENT

MAX DISPLACEMENT

MAX DISPLACEMENT
(OVERALL)



STRESSES

MAX STRESS
(My-direction)

MAX STRESS
(Mz-direction)

MAX STRESS
(OVERALL)



MASS

TOTAL MASS

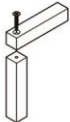
MASS INCREMENT



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

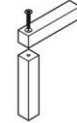


NUMBER OF
ELEMENTS

NUMBER OF
ELEMENTS

ELEMENT INCREMENT

OBJECTIVE



NUMBER OF
JOINTS

NUMBER OF
JOINTS

JOINTS INCREMENT

OBJECTIVE

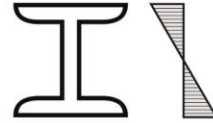
EVALUATION GROUP OF ELEMENTS



DISPLACEMENT

MAX DISPLACEMENT

MAX DISPLACEMENT
(OVERALL)



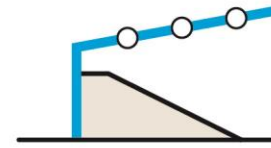
STRESSES

MAX STRESS
(My-direction)

MAX STRESS
(Mz-direction)

MAX STRESS
(OVERALL)

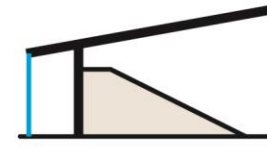
GROUPS OF STRUCTURAL ELEMENTS



PILLARS

CANTILEVERS

BRACINGS

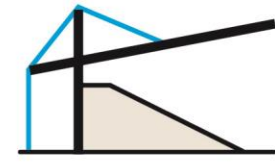


PILLARS

CANTILEVERS

BRACINGS

1-RESTRAIN



PILLARS

CANTILEVERS

BRACINGS

1-RESTRAIN

2-RESTRAIN

3-RESTRAIN

EVALUATION GROUP OF ELEMENTS



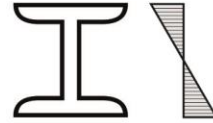
DISPLACEMENT

MAX DISPLACEMENT

MAX DISPLACEMENT
(OVERALL)



CONSTRAINT



STRESSES

MAX STRESS
(My-direction)

MAX STRESS
(Mz-direction)

MAX STRESS
(OVERALL)



CONSTRAINT



MASS

TOTAL MASS

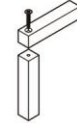
MASS INCREMENT



NUMBER OF
ELEMENTS

NUMBER OF
ELEMENTS

ELEMENT INCREMENT



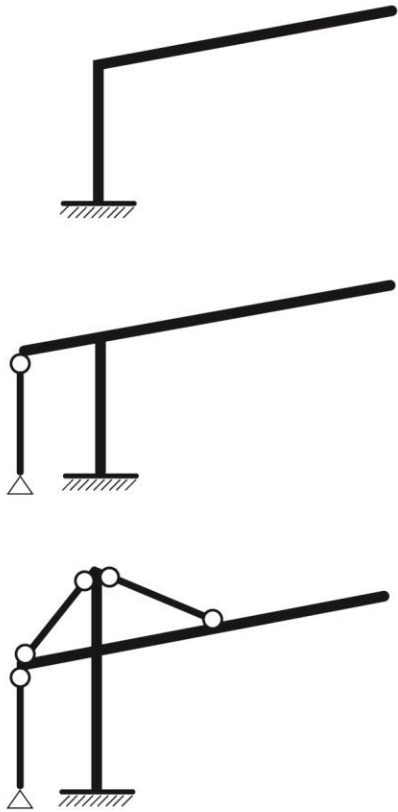
NUMBER OF
JOINTS

NUMBER OF
JOINTS

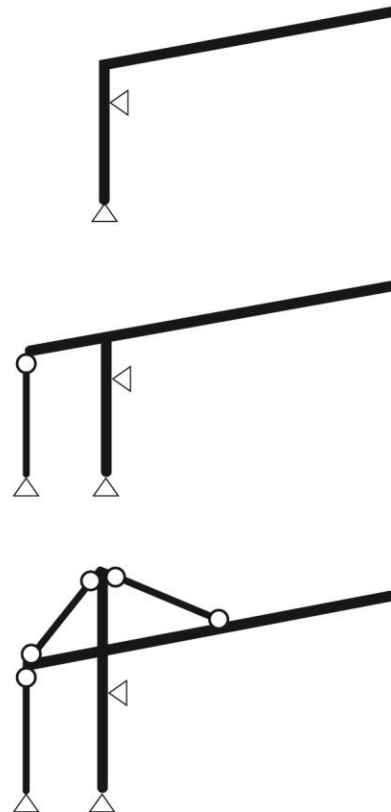
JOINTS INCREMENT

SUPPORT SETS

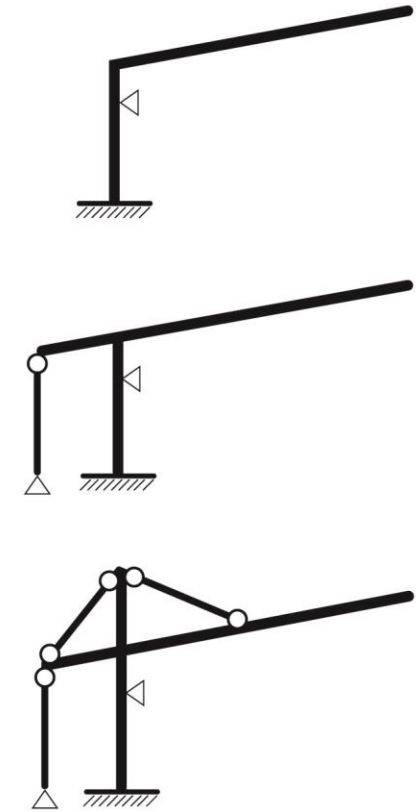
FIXED SUPPORT



HINGE + HINGE SUPPORT



FIXED + HINGE SUPPORT



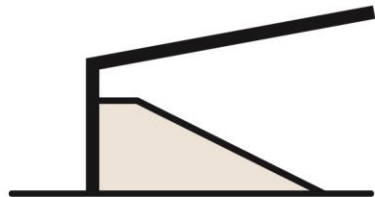
CONSIDERED ELEMENTS



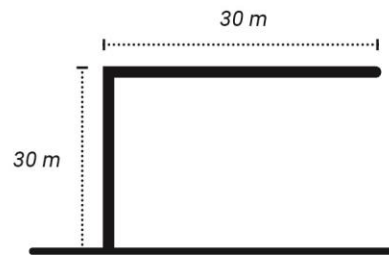
BEHAVIOUR OF SYSTEMS



MODEL SET-UP



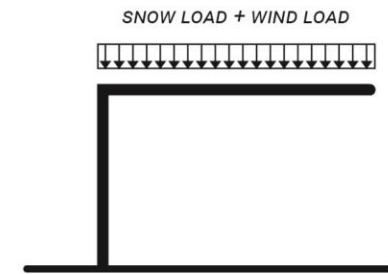
SIMPLE CANTILEVER



UK CHSC1016x30,0

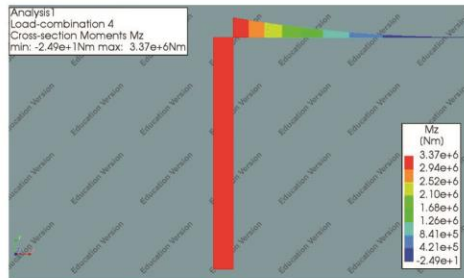
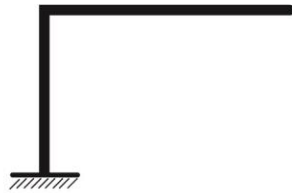


STEEL S235

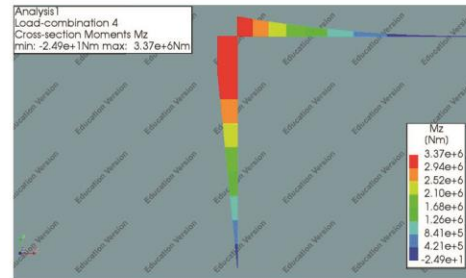


BEHAVIOUR OF SYSTEMS

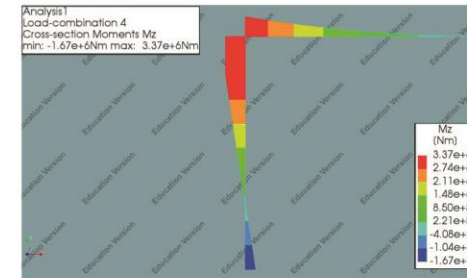
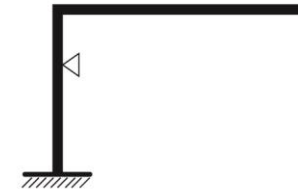
SUPPORT SET 0



SUPPORT SET 1

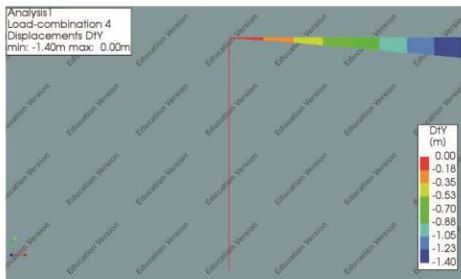
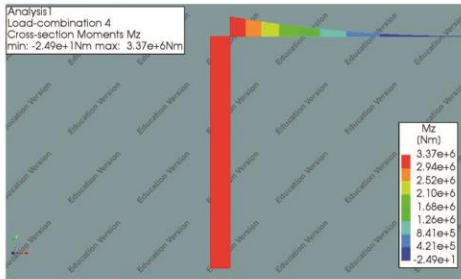


SUPPORT SET 2

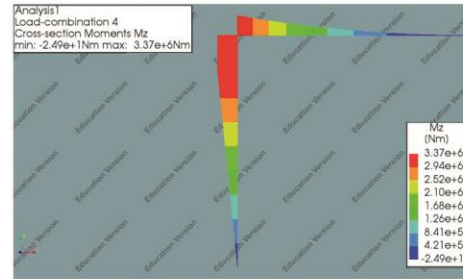


BEHAVIOUR OF SYSTEMS

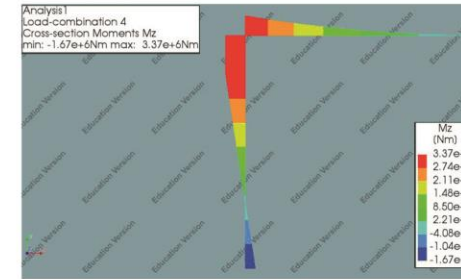
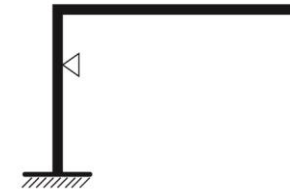
SUPPORT SET 0



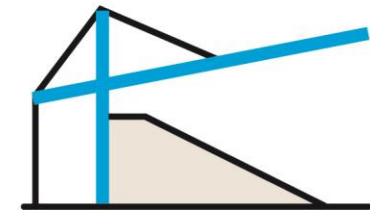
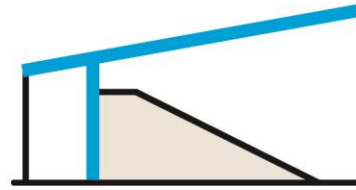
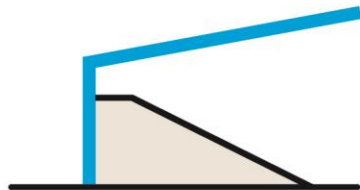
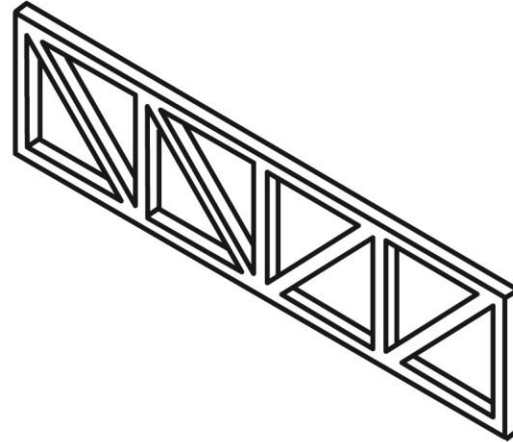
SUPPORT SET 1



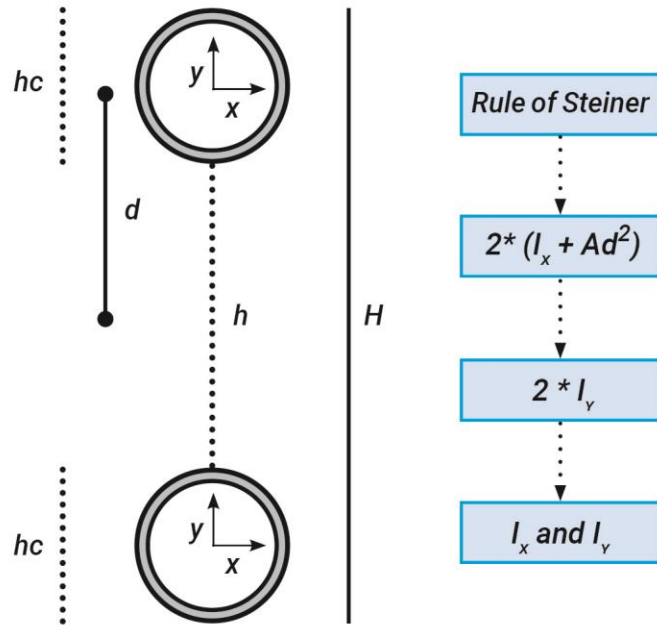
SUPPORT SET 2



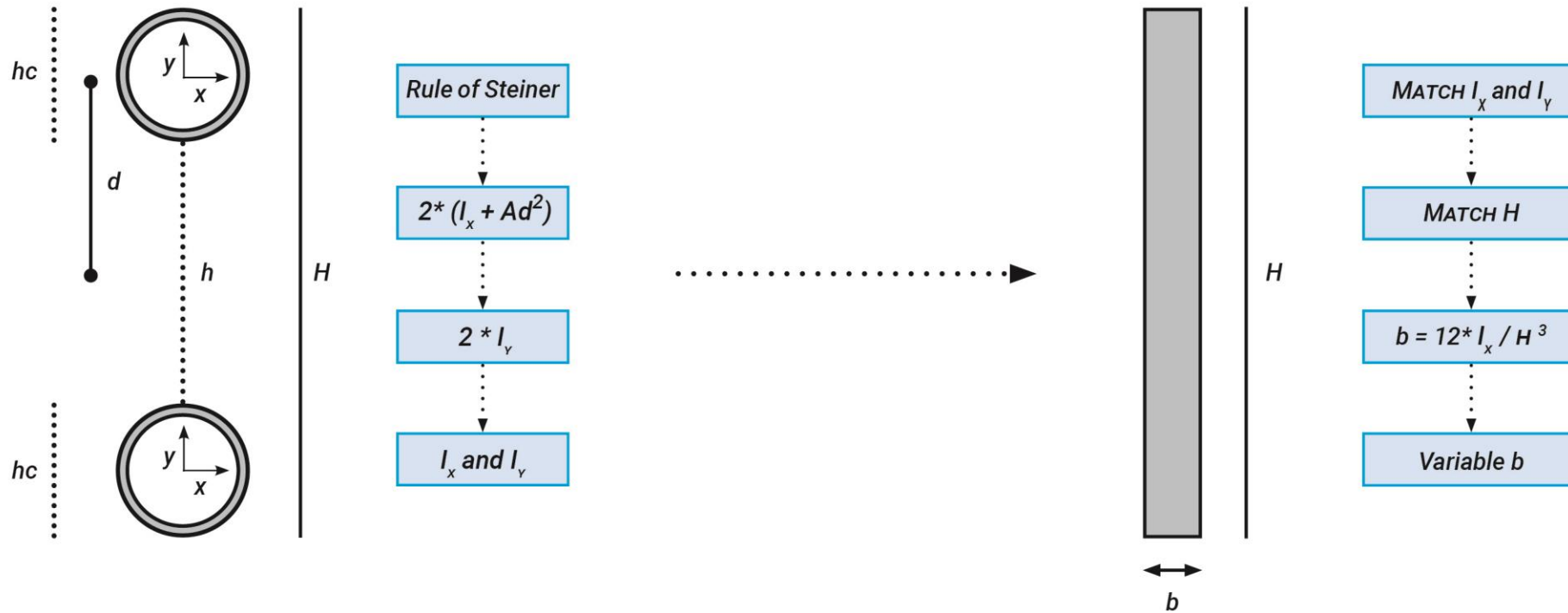
PARALLEL TRUSS IMPLEMENTATION



PARALLEL TRUSS IMPLEMENTATION



PARALLEL TRUSS IMPLEMENTATION



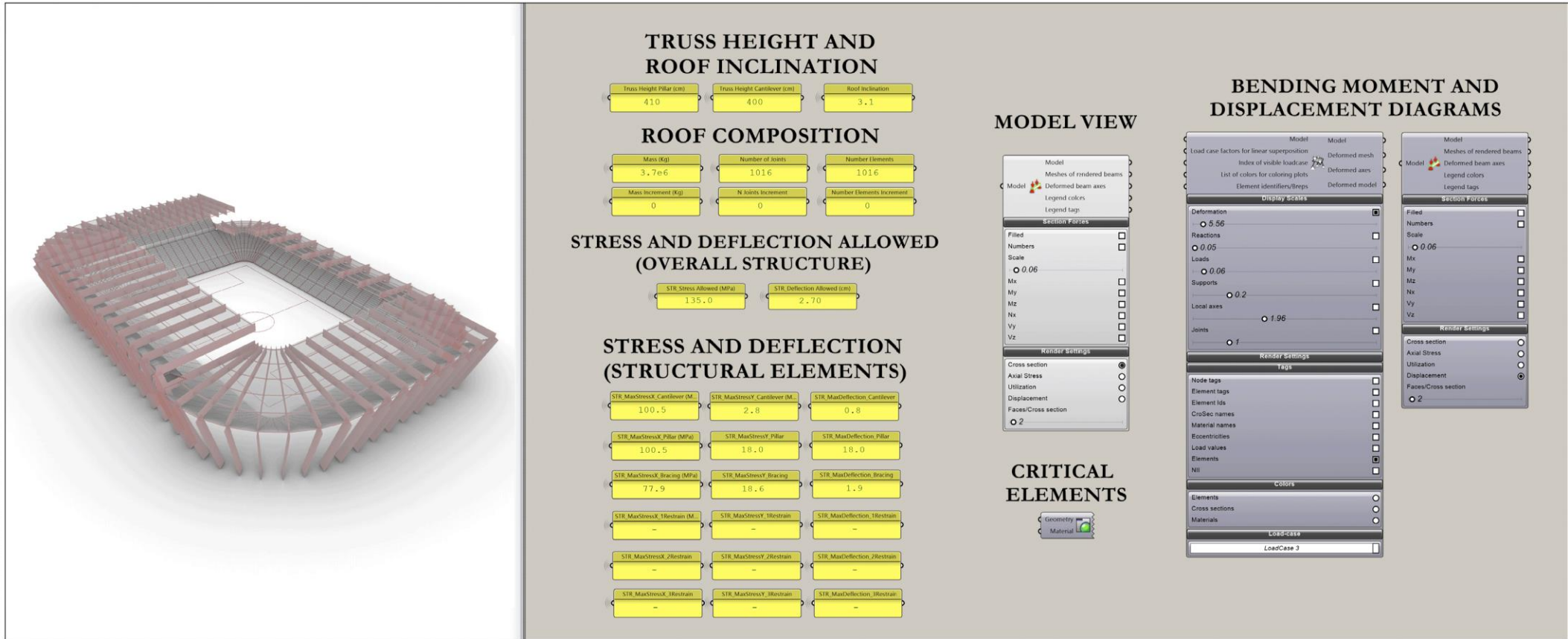
COMPUTATIONAL ENVIRONMENT



+

Karamba 3D

VISUALIZATION OF RESULTS

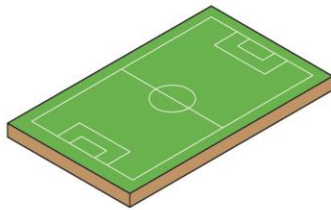




EXISTING STADIUM CONSTRAINTS

EXISTING STADIUM CONSTRAINTS

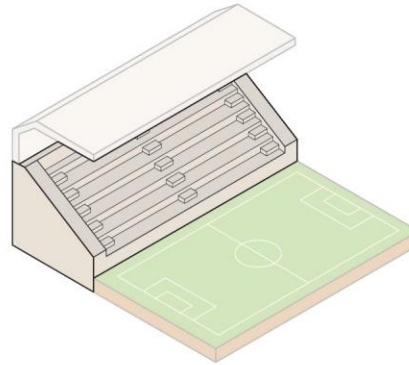
PLAYING AREA



FOCUS POINT

DIMENSIONS

GRANDSTAND



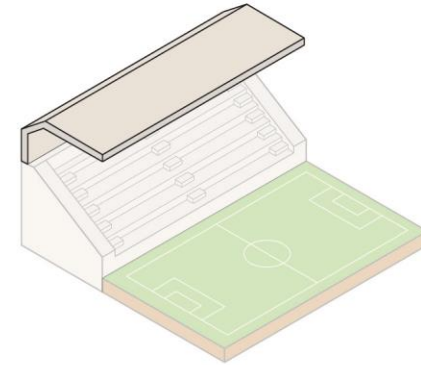
LAYOUT

% C-VALUE > 9 cm
> 80%

% C-VALUE > 6 cm
= 0%

% SPECTATORS WITH
MAX DISTANCE > 95%

ROOF STRUCTURE



POSITION OF
SUPPORTS

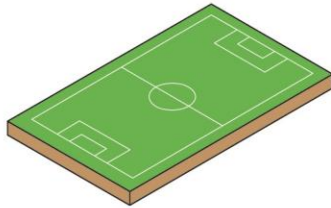
NUMBER OF
SUPPORTS

COVERAGE OF
GRANDSTANDS

CLEAR HEIGHT ABOVE
SPECTATOR'S SIGHT

EXISTING STADIUM CONSTRAINTS

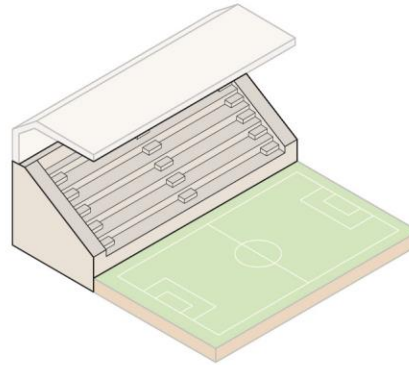
PLAYING AREA



FOCUS POINT

DIMENSIONS

GRANDSTAND



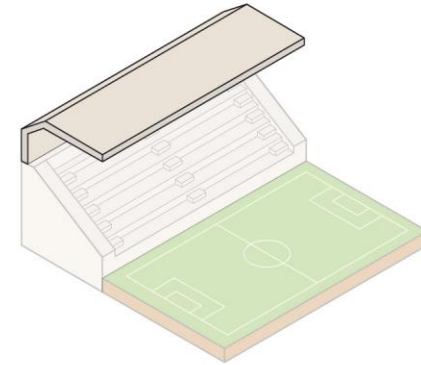
LAYOUT

% C-VALUE > 9 cm
> 80%

% C-VALUE > 6 cm
= 0%

% SPECTATORS WITH
MAX DISTANCE > 95%

ROOF STRUCTURE



POSITION OF
SUPPORTS

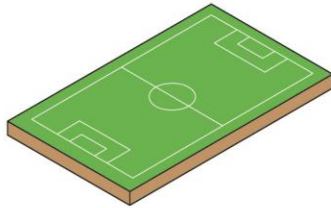
NUMBER OF
SUPPORTS

COVERAGE OF
GRANDSTANDS

CLEAR HEIGHT ABOVE
SPECTATOR'S SIGHT

EXISTING STADIUM CONSTRAINTS

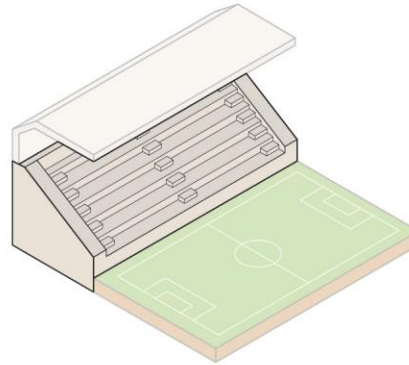
PLAYING AREA



FOCUS POINT

DIMENSIONS

GRANDSTAND



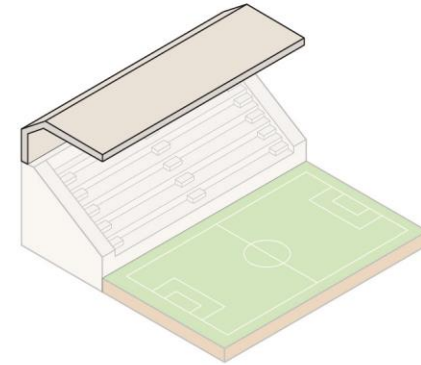
LAYOUT

% 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

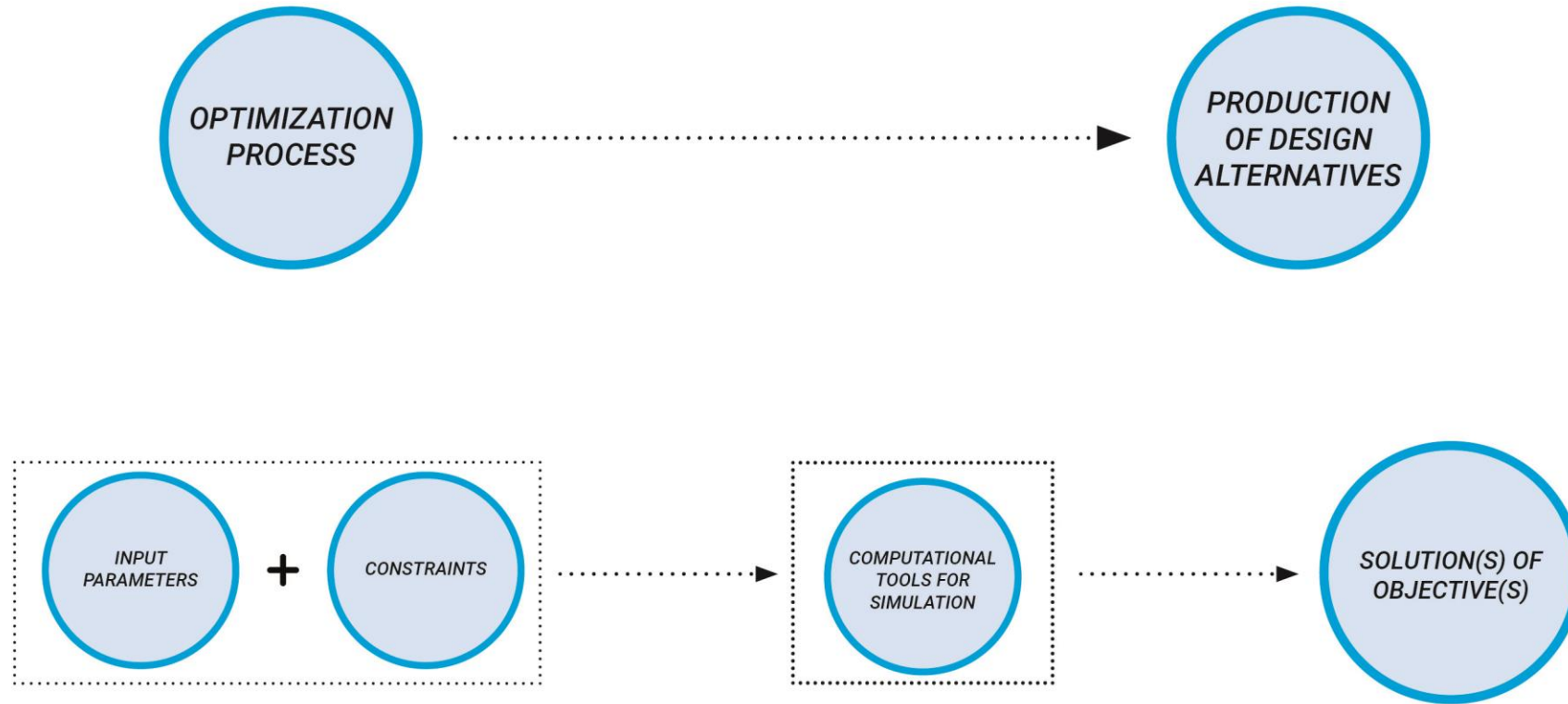


OPTIMIZATION AND DESIGN EXPLORATION

OPTIMIZATION PROCESS



OPTIMIZATION PROCESS



COMPUTATIONAL ENVIRONMENT



+

Karamba 3D



OPTIMIZATION SET-UP

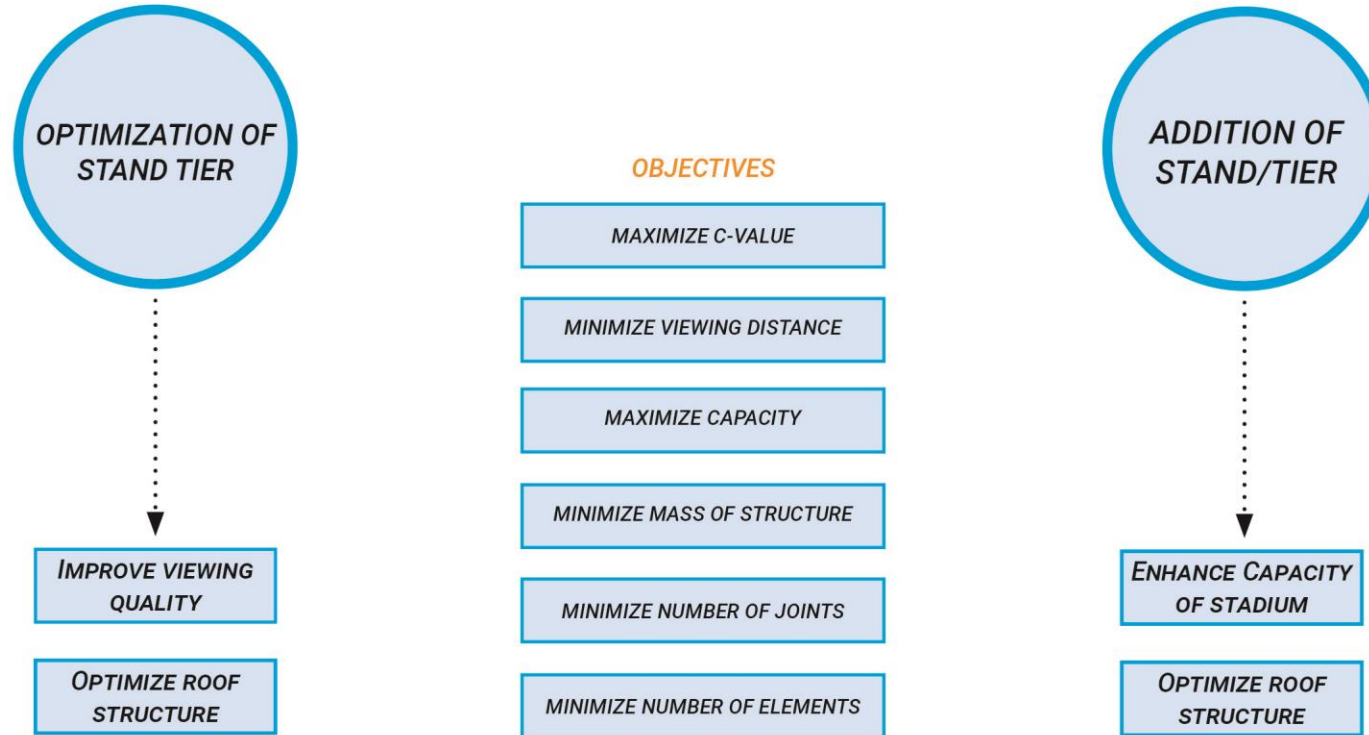
The screenshot displays a software interface for optimization set-up. The top menu bar includes HOME, WORKFLOW, PLANNER, RUN, and DESIGN SPACE. Below the menu is a toolbar with various icons for workflow building and graphics. The main workspace shows a complex workflow diagram with numerous nodes and connections. A 'Logic Log' window is open at the bottom, displaying a table of design objectives.

Enabled	Name	User Expression	Type	Format
<input checked="" type="checkbox"/>	VQ_Above_9cm	VQ_CValue_PrtAboveRecommended	Maximize	0.0000E0
<input checked="" type="checkbox"/>	STR_MassIncrement	STR_Mass_Increment	Minimize	0.0000E0
<input checked="" type="checkbox"/>	Capacity_Percentage_Increment	VQ_Capacity_PrtIncrement	Maximize	0.0000E0

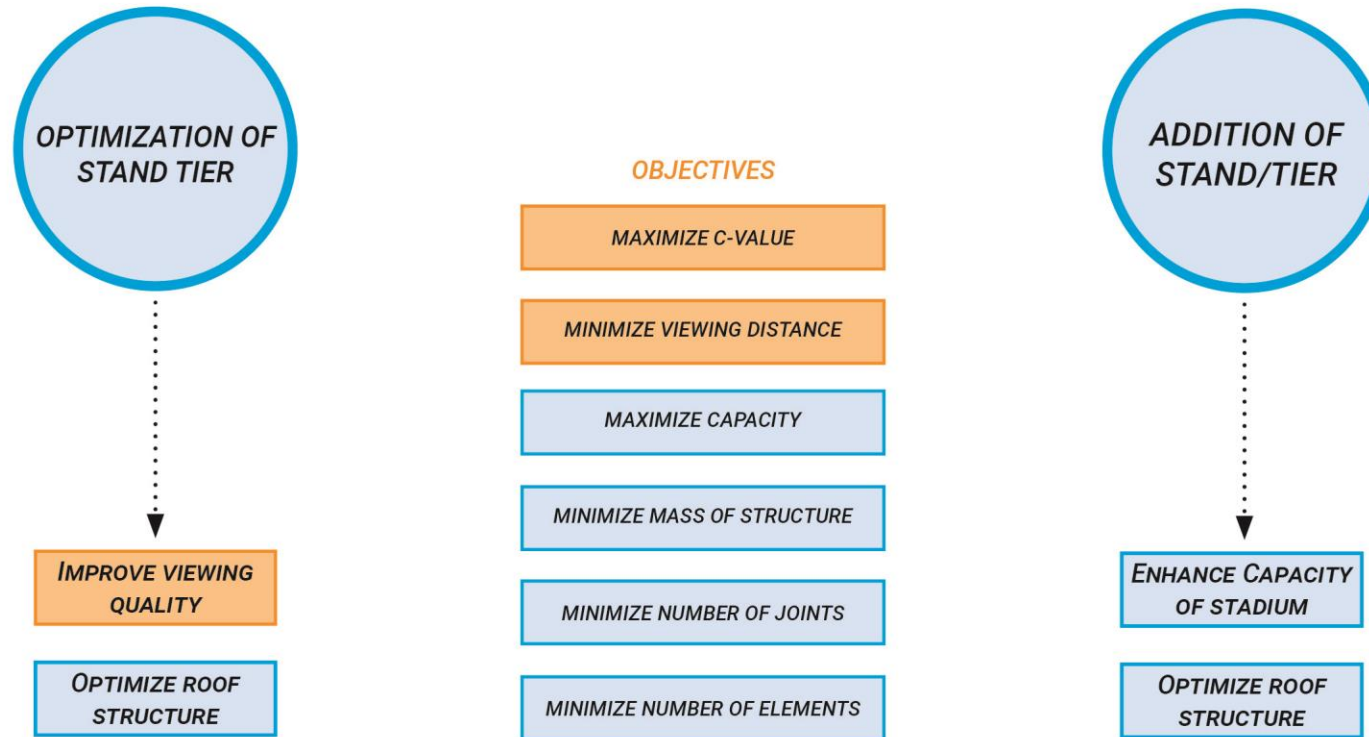
RENOVATION APPROACHES



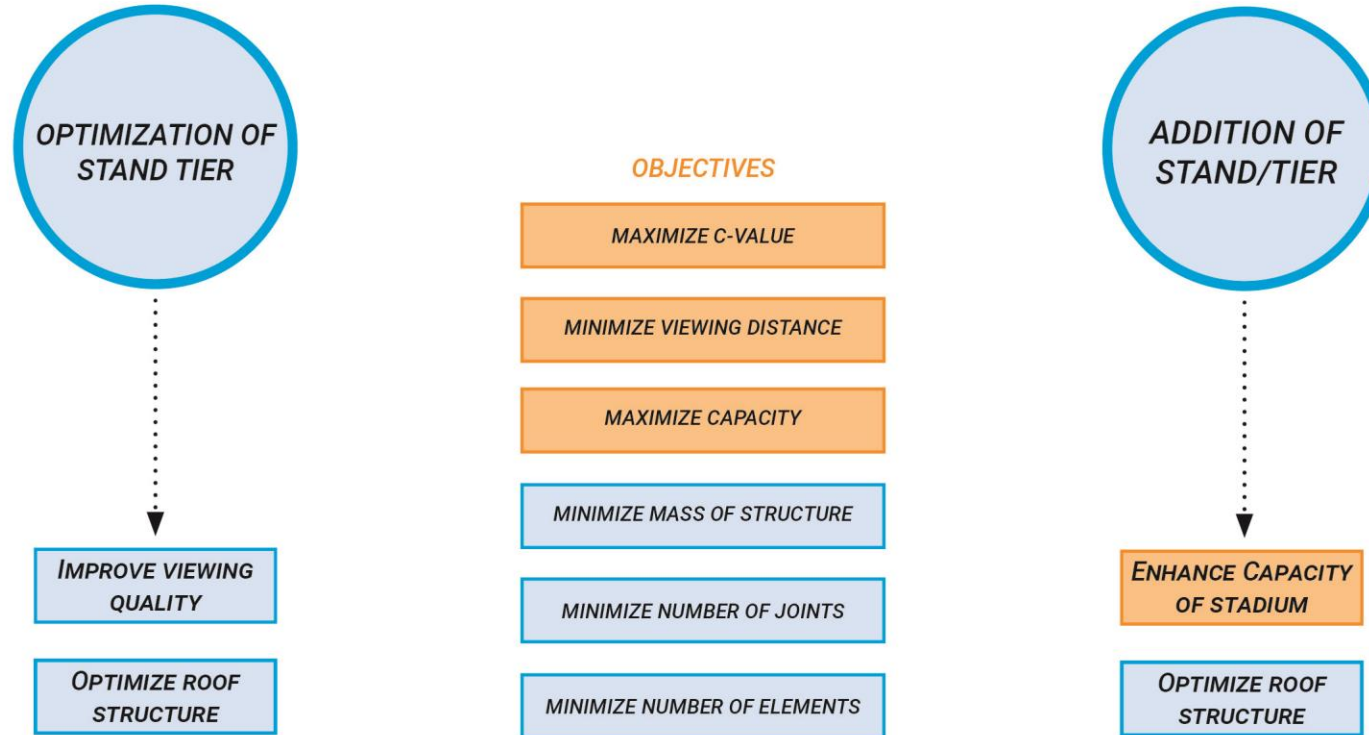
RENOVATION APPROACHES



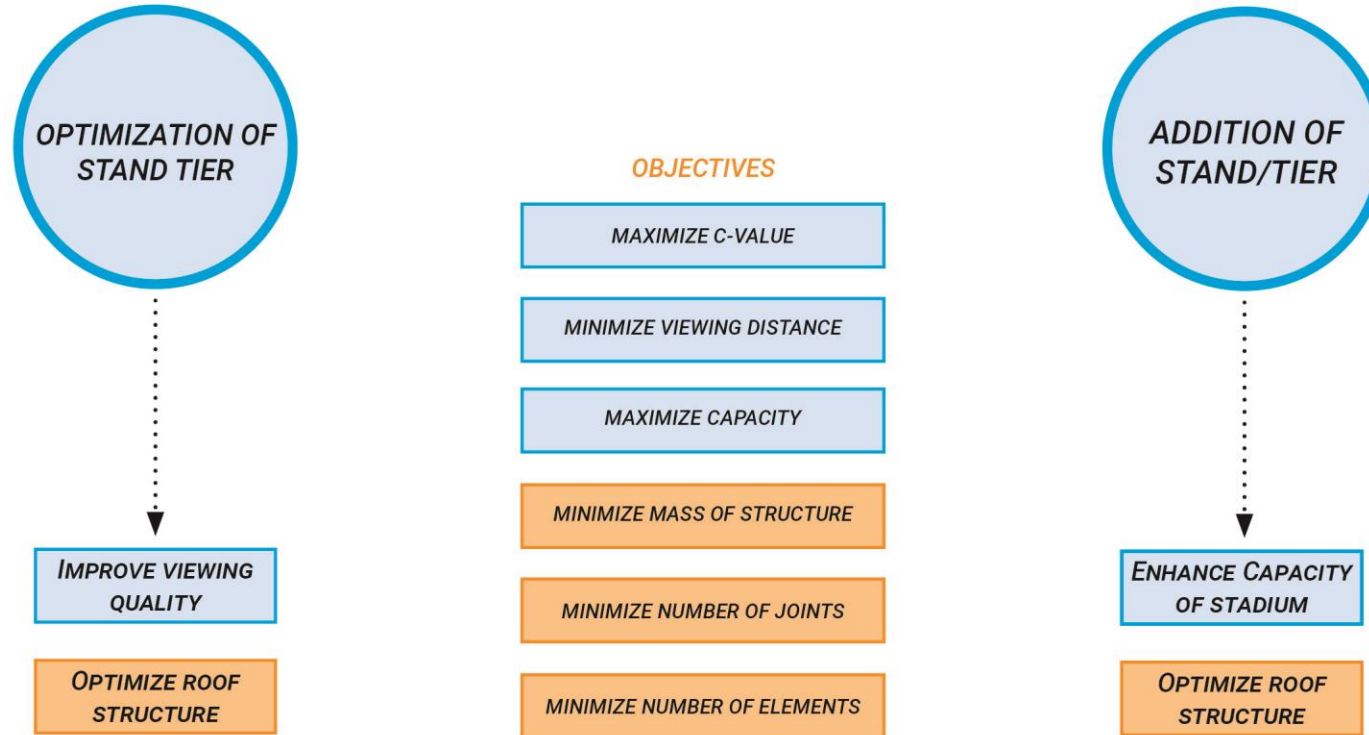
RENOVATION APPROACHES



RENOVATION APPROACHES



RENOVATION APPROACHES



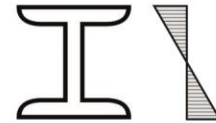
SET-UP MODEFRONTIER (CONSTRAINTS)

i.e. DESIGN CONSTRAINTS



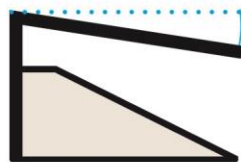
TIER INCLINATION

< 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

HOME WORKFLOW PLANNER RUN DESIGN SPACE Log In

Disable edit mode Customize interface Paste Cut Copy Delete Edit Import/export Filter Create Scale Filter Charts DOE Sensitivity Analysis RSM MVA MCDM Chart Graphics Arrange items Hide all Delete all Layout Report Help Run Project Stop Refresh

Explorer Charts Desktop

View

Tables (24)

- Cluster_0
- DOE_FIRST_OPT_NSGA-II
- DOE_SECOND_OPT_NSGA-II
- DOE_FOURTH_OPT_NSGA-II
- DOE_THIRD_OPT_NSGA-II
- DOE_thFIFTH_OPT_NSGA-II
- DOE_thSIXTH_OPT
- Last Batch of Designs
- Result First Round Opt
- Results Second Round Opt
- Results Third Round Opt
- Results tFourth Round Opt
- Results tffifft Round Opt
- Results tfsixth Round Opt
- Set-up_SECOND_OPT
- Set-up_TFOURTH_OPT
- Set-up_THIRD_OPT
- Set-up_thFIFTH_OPT
- Set-up_thSIXTH_OPT
- Total_Designs
- Total_Feasible_Designs

Clusters Tables (1)

- Clusters Table - HC_CENTRO_3

Hierarchical Tables (1)

- Hierarchical Total_Feasible_Designs_0

SOM Tables (2)

- SOM Table - SEQ_SOM_0
- SOM Table - SEQ_SOM_1

Charts (6)

ID	VQ_SpectatorsOptimumDistance	STR_MassIncrement	VQ_Above_9cm	G_Tier2_InclinationLimit	STR_DeflectionAllowed	STR_MaxTrussHeight	STR_PillarHeight	STR_RoofInclin
321	1.0000E2	8.4464E5	8.5685E1	3.4804E1	5.9372E-1	3.5200E2	3.6200E2	
322	1.0000E2	8.0004E5	8.5389E1	3.4624E1	-3.7032E-2	3.5200E2	3.6200E2	
323	1.0000E2	8.8713E5	9.5152E1	3.4624E1	5.8562E-1	3.5200E2	3.5700E2	
324	1.0000E2	-3.0720E5	8.7118E1	3.4992E1	-4.0876E0	3.1128E2	3.5200E2	
325	1.0000E2	1.2319E6	8.7118E1	3.4992E1	-1.7064E-1	3.5200E2	3.3200E2	
326	1.0000E2	1.0786E6	8.5389E1	3.4624E1	5.6893E-1	3.5200E2	3.9700E2	
327	1.0000E2	9.1517E5	8.7291E1	3.4624E1	6.0044E-1	3.5200E2	3.9200E2	
328	1.0000E2	8.6206E5	8.5389E1	3.4624E1	-3.2538E0	3.5200E2	3.4200E2	
329	1.0000E2	8.1497E5	9.1024E1	3.5272E1	5.8637E-1	3.5200E2	3.5200E2	
330	1.0000E2	8.9035E5	9.5141E1	3.5942E1	6.1062E-1	3.5200E2	3.5200E2	
331	1.0000E2	6.8849E5	7.9290E1	3.4624E1	5.7017E-1	3.5200E2	3.6200E2	
332	1.0000E2	5.9428E5	8.5389E1	3.4624E1	5.7930E-1	3.5200E2	3.6200E2	
333	1.0000E2	7.2367E5	8.7291E1	3.4624E1	5.8146E-1	3.5200E2	3.6200E2	
334	1.0000E2	8.9114E5	8.7291E1	3.4624E1	-5.8799E-1	3.5200E2	3.3200E2	
335	1.0000E2	7.5636E5	8.3254E1	3.3996E1	5.8488E-1	3.5200E2	3.7200E2	
336	1.0000E2	2.7614E6	4.7359E1	3.0793E1	-1.1746E1	3.5200E2	3.3200E2	
337	1.0000E2	1.0478E6	8.5389E1	3.4624E1	5.5017E-1	3.5200E2	3.6200E2	
338	1.0000E2	9.6696E5	8.5726E1	3.4308E1	5.6216E-1	3.5700E2	3.5700E2	
339	1.0000E2	7.6728E5	9.5152E1	3.4624E1	5.8235E-1	3.5200E2	3.6700E2	
340	1.0000E2	2.4639E6	8.5389E1	3.4624E1	-3.0475E0	3.5200E2	3.5200E2	
341	1.0000E2	1.3921E6	8.5389E1	3.4624E1	-3.8082E0	3.5200E2	3.5200E2	
342	1.0000E2	1.0977E6	9.5152E1	3.4624E1	5.3298E-1	3.5200E2	3.5200E2	
343	1.0000E2	5.3967E5	8.5726E1	3.4308E1	1.0655E-1	3.5700E2	3.4160E2	
344	1.0000E2	8.0831E5	8.5389E1	3.4624E1	6.2084E-1	3.5200E2	3.9200E2	
345	1.0000E2	6.4670E5	8.5389E1	3.4624E1	5.7916E-1	3.5200E2	3.6200E2	
346	1.0000E2	7.7422E5	8.9133E1	3.4624E1	5.7692E-1	3.5200E2	3.3200E2	
347	1.0000E2	5.4995E5	8.5389E1	3.4624E1	-1.0512E0	3.5200E2	3.3160E2	
348	1.0000E2	5.7610E5	8.7438E1	3.4765E1	-1.4633E0	3.5200E2	3.3160E2	
349	1.0000E2	7.8744E5	8.9133E1	3.4624E1	5.9056E-1	3.5200E2	3.6200E2	
350	1.0000E2							

Properties

General Information

Graphics

Virtual Designs Properties

Error Designs Properties

Unfeasible Designs Properties

Highlight Properties

Show/Hide Columns

Categories

Catalogues

+ Create

Algorithm

Phase

Catalogue: Algorithm

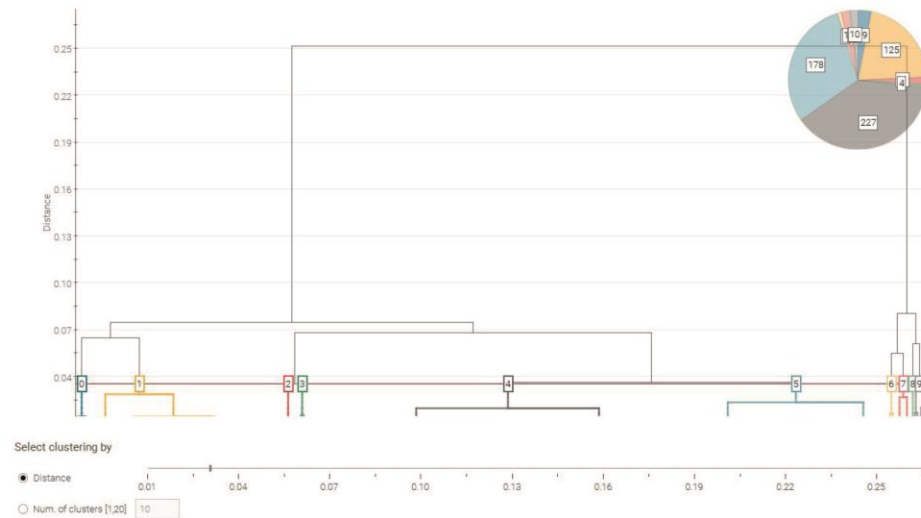
+ Create X Delete

Name	Visible
1 NSGA2	<input checked="" type="checkbox"/>

Ready Grid status: not available Mode: EDITOR v6.7.0 b20200302

TRADE-OFF

HIERARCHICAL CLUSTERING (CENTROID-LINKAGE)

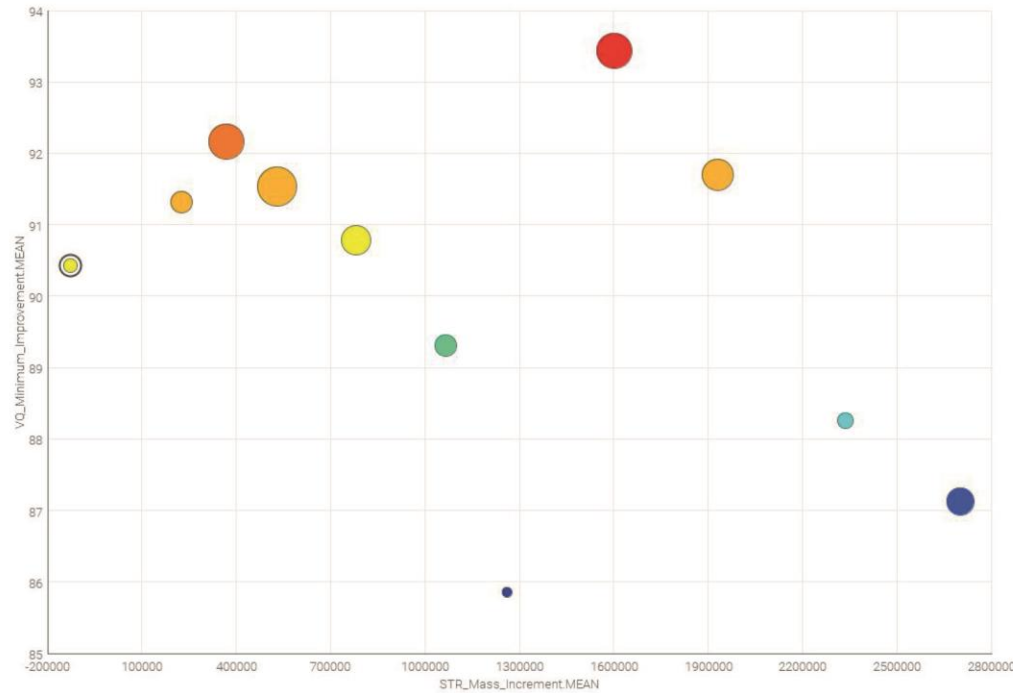


**GROUP SOLUTIONS
BASED ON DESIGN
SPACE LOCATION**

**CONTROL OVER
NUMBER OF GROUPS
TO BE CREATED**

TRADE-OFF

EVALUATION OF CLUSTERS

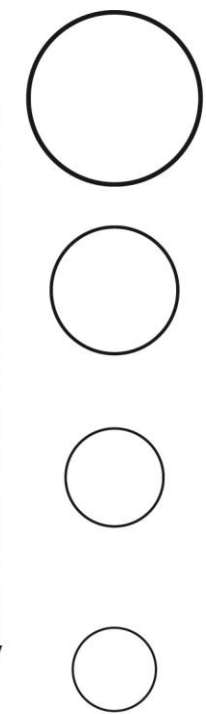


FEASIBLE DESIGNS

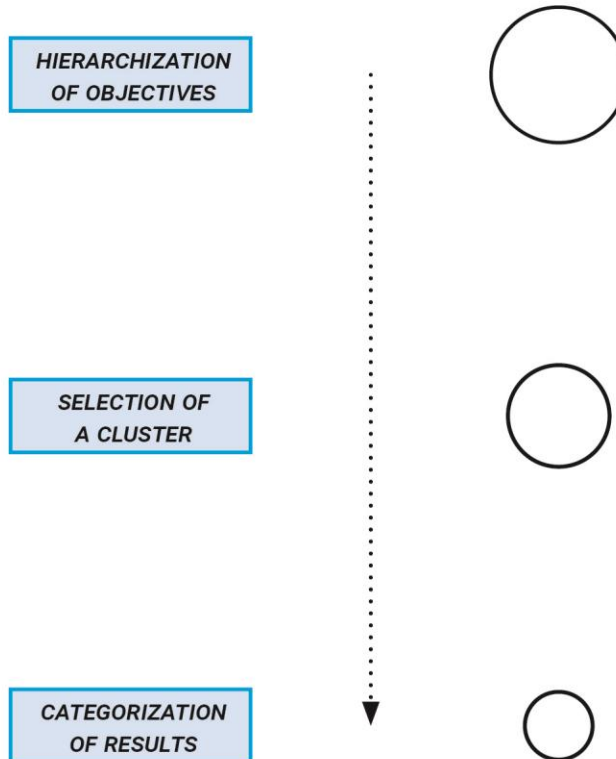
HIERARCHICAL CLUSTER

RESPONSE TOWARDS THE OBJECTIVES

SELECTION OF A CLUSTER



TRADE-OFF



TRADE-OFF

CATEGORIES AND HIERARCHY OF OBJECTIVES (EXAMPLE OF VALIDATION CASE)



MASS INCREMENT

REDUCED	●
€4 kg < €5 kg	●
€5 kg < €6 kg	●
> €6 kg	●



% C-VALUE > 9 cm

80% < 85%	●
85% < 90%	●
90% < 95%	●
> 95%	●



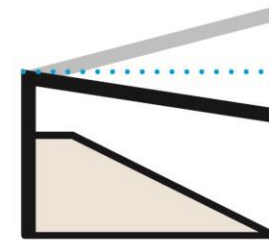
%CAPACITY INCREMENT

> 20 %	●
< 20 %	●



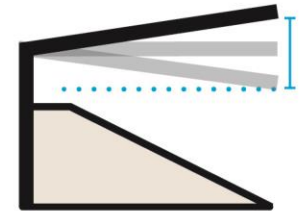
CAPACITY INCREMENT

> 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	<input type="checkbox"/> 758	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 90<95
2	<input type="checkbox"/> 815	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 90<95
3	<input checked="" type="checkbox"/> 830	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● >20	● >95
4	<input checked="" type="checkbox"/> 848	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● >20	● >95
5	<input type="checkbox"/> 853	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 85<90
6	<input type="checkbox"/> 858	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 85<90
7	<input type="checkbox"/> 869	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 90<95
8	<input checked="" type="checkbox"/> 885	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● >20	● >95
9	<input type="checkbox"/> 894	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 90<95
10	<input type="checkbox"/> 899	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 85<90
11	<input type="checkbox"/> 909	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 85<90
12	<input type="checkbox"/> 913	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 85<90
13	<input type="checkbox"/> 926	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 85<90
14	<input type="checkbox"/> 932	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 90<95
15	<input type="checkbox"/> 935	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 85<90
16	<input type="checkbox"/> 940	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 85<90
17	<input type="checkbox"/> 942	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 90<95
18	<input type="checkbox"/> 943	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 90<95
19	<input type="checkbox"/> 945	● NSGA2		■ CLUSTER_0	■ CLUSTER_0	● Reduced	● 18<20	● 90<95
20	<input type="checkbox"/> 0	● NSGA2		■ CLUSTER_1	■ CLUSTER_4	● E5<E6	● 18<20	● 85<90



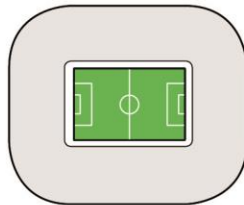
VALIDATION CASE

VALIDATION CASE

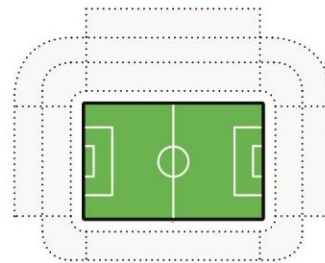
OLD TRAFFORD (MANCHESTER, UK)



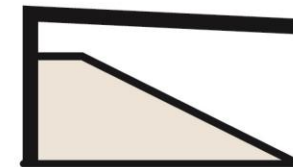
*ROUNDED RECTANGLE
LAYOUT GEOMETRY*



STADIUM CONFIGURATION

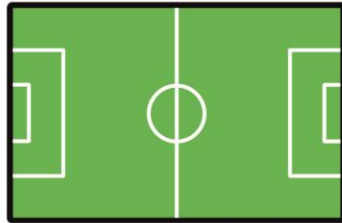


*SIMPLE CANTILEVER
STRUCTURAL SYSTEM*



VALIDATION CASE (PLAYING AREA)

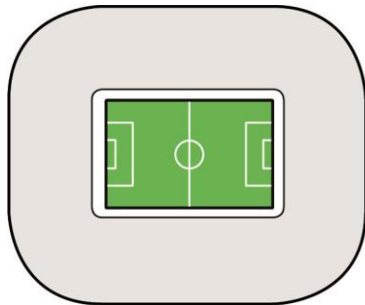
PITCH



PITCH DIMENSIONS

105 m x 68 m

ROUNDED RECTANGLE
LAYOUT GEOMETRY



FIRST ROW DISTANCE X

7.2 m

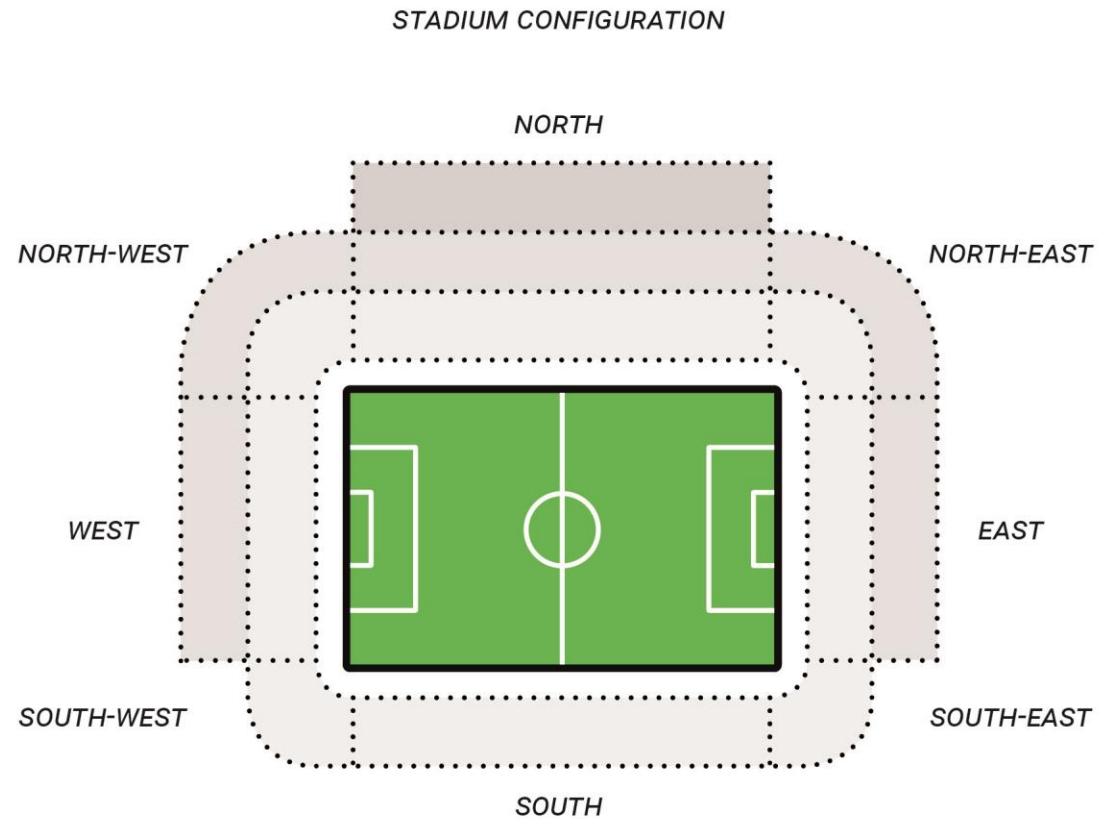
FIRST ROW DISTANCE Y

5,5 m

RADIUS CORNERS

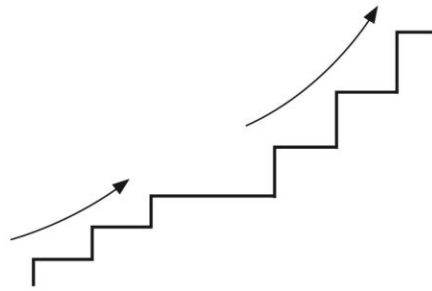
7,2 m

VALIDATION CASE (CONFIGURATION)

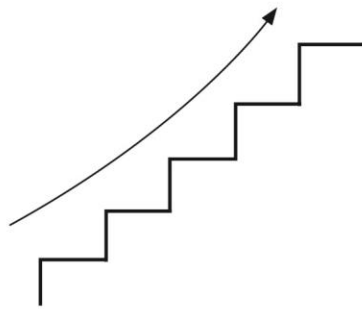


VALIDATION CASE (STAND TYPOLOGY)

DOUBLE PARABOLIC

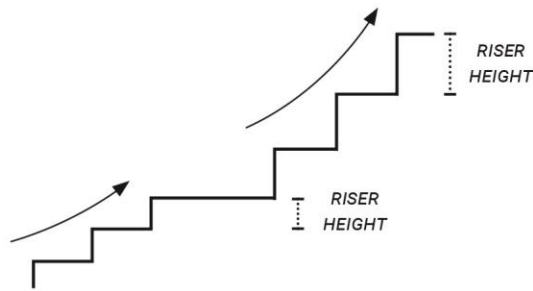


PARABOLIC

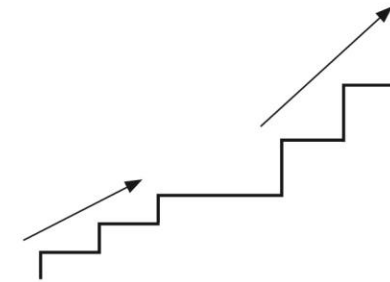


VALIDATION CASE (STAND TYPOLOGY)

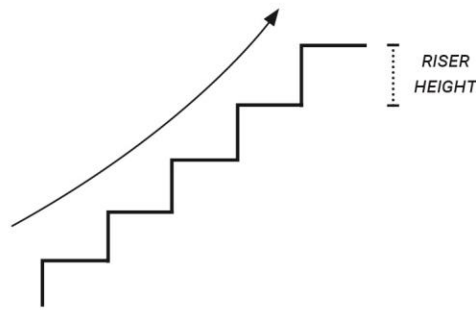
DOUBLE PARABOLIC



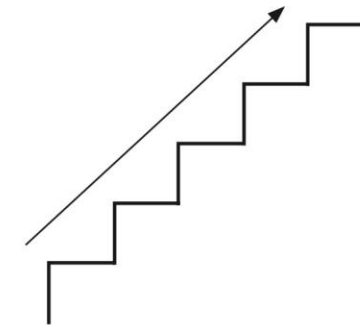
STAND TYPE TIER 1



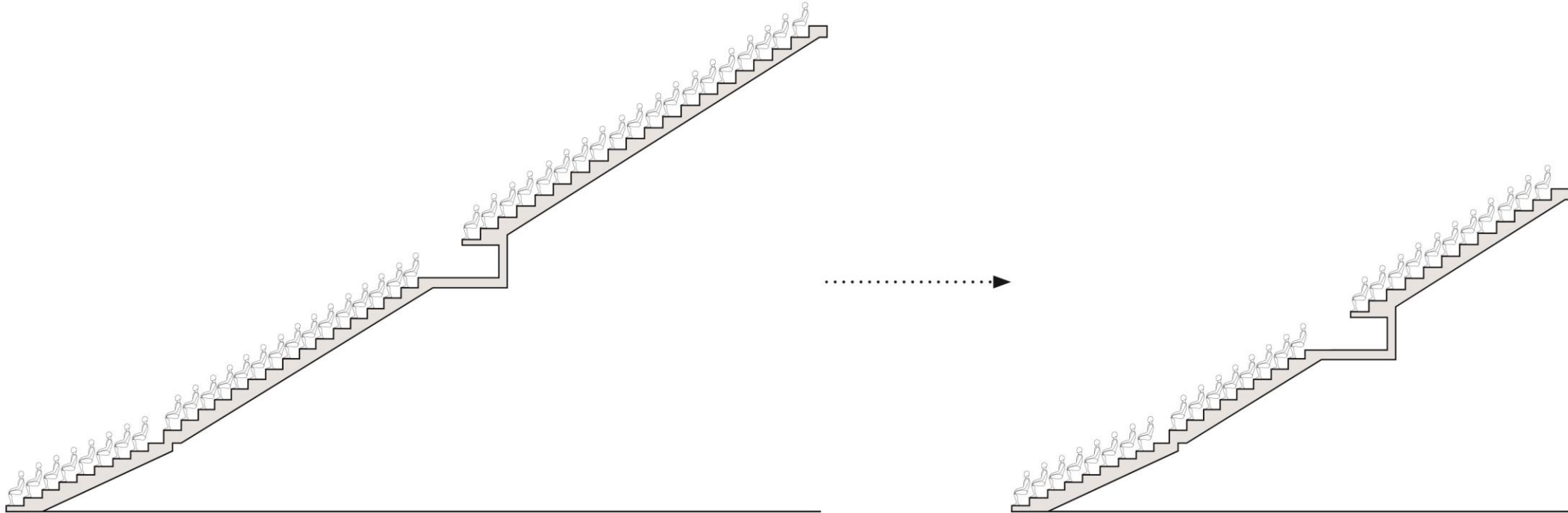
PARABOLIC



STAND TYPE TIER 2/3

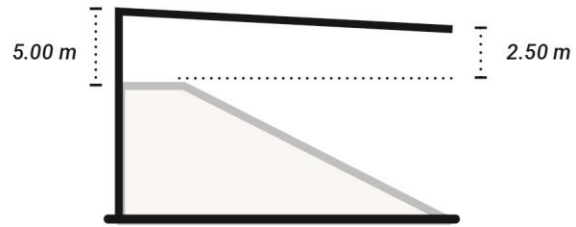


VALIDATION CASE (GEOMETRY)



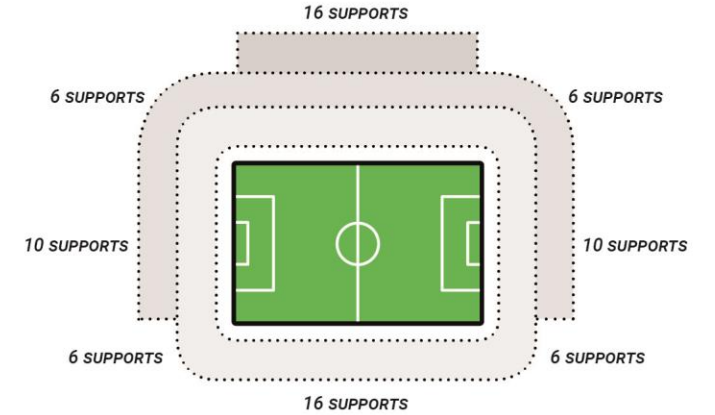
VALIDATION CASE (ROOF STRUCTURE)

SIMPLE CANTILEVER STRUCTURAL SYSTEM

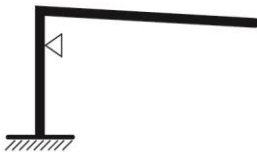


NUMBER OF SUPPORTS

POSITION OF SUPPORTS



SUPPORT SET

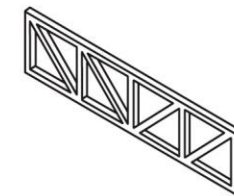


MATERIAL



STEEL S235

STRUCTURAL ELEMENTS

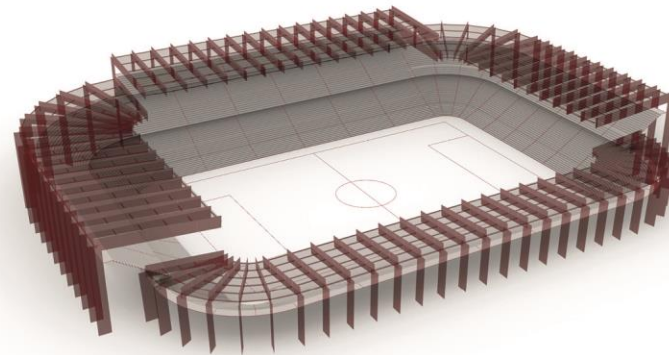
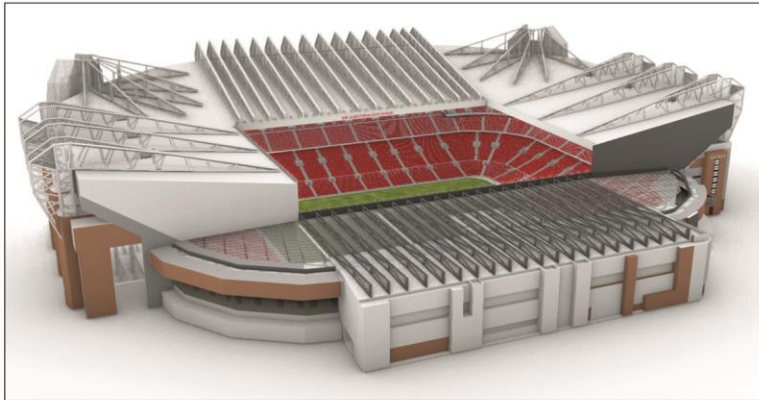


PILLARS AND CANTILEVERS



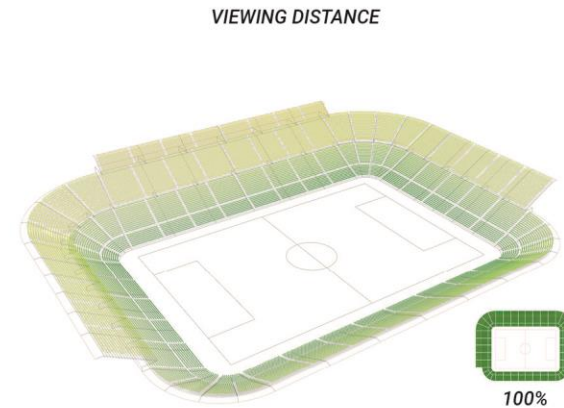
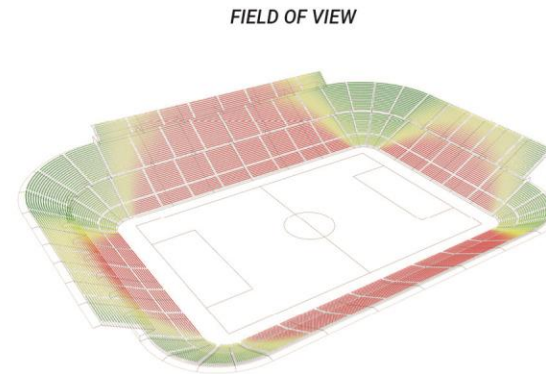
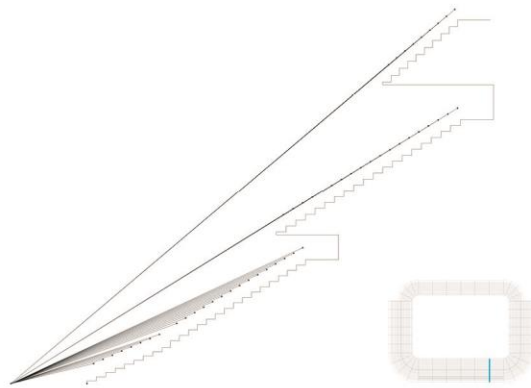
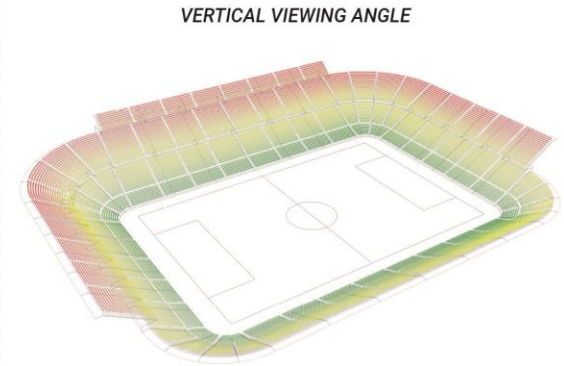
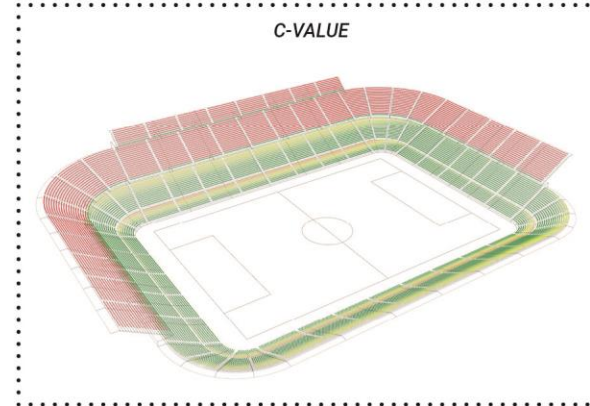
BRACINGS

VALIDATION CASE



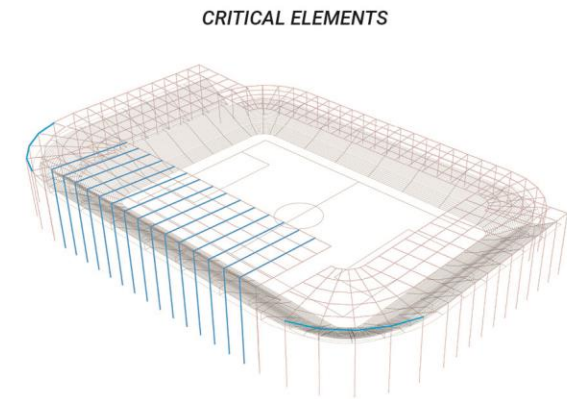
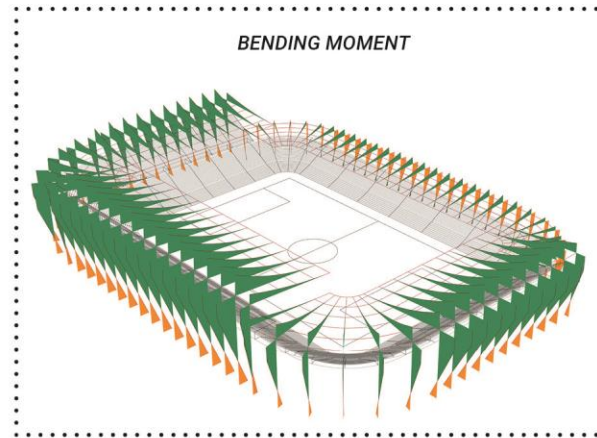
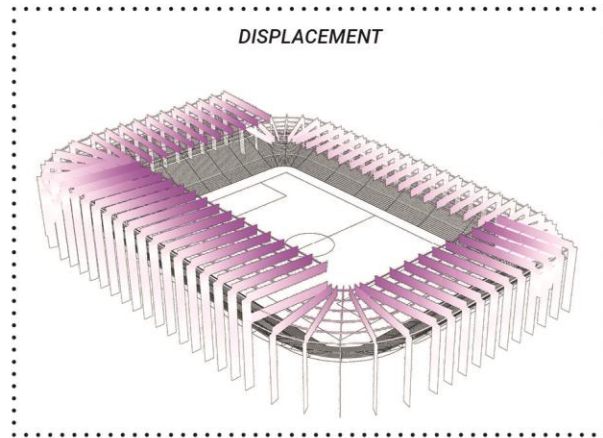
VIEWING QUALITY ASSESSMENT

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°	-



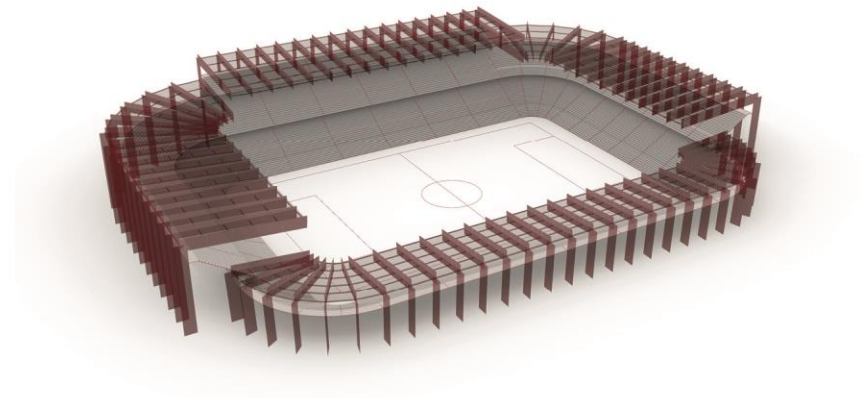
STRUCTURAL PERFORMANCE ASSESSMENT

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



1ST RENOVATION APPROACH

OPTIMIZATION OF
STAND TIER



1ST RENOVATION APPROACH

20 INPUTS



IMPROVE VIEWING QUALITY

OPTIMIZE ROOF STRUCTURE

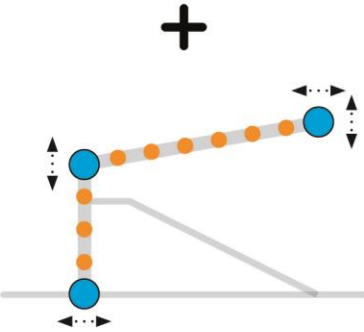
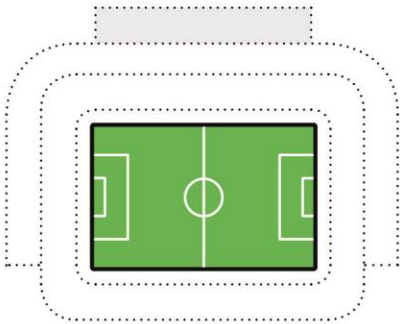
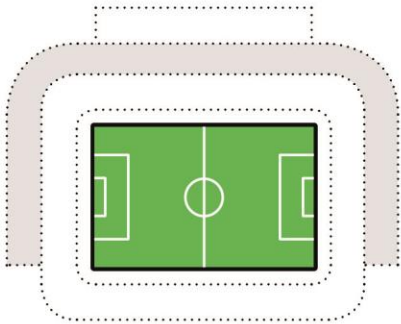
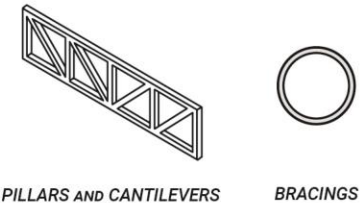
2ND TIER OF STANDS



3RD TIER OF STANDS



ROOF STRUCTURE



1ST RENOVATION APPROACH

13 CONSTRAINTS



IMPROVE VIEWING QUALITY

OPTIMIZE ROOF STRUCTURE



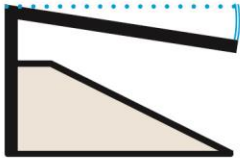
INCLINATION OF STANDS < 35°



STRESS > 0 MPa



%C-VALUE > 9 cm > 80%



INCLINATION OF ROOF > 1.5°



DISPLACEMENT > 0 cm



%C-VALUE > 6 cm = 0%

1ST RENOVATION APPROACH

2 OBJECTIVES



IMPROVE VIEWING QUALITY

OPTIMIZE ROOF STRUCTURE



MAXIMIZE %C-VALUE > 9 cm

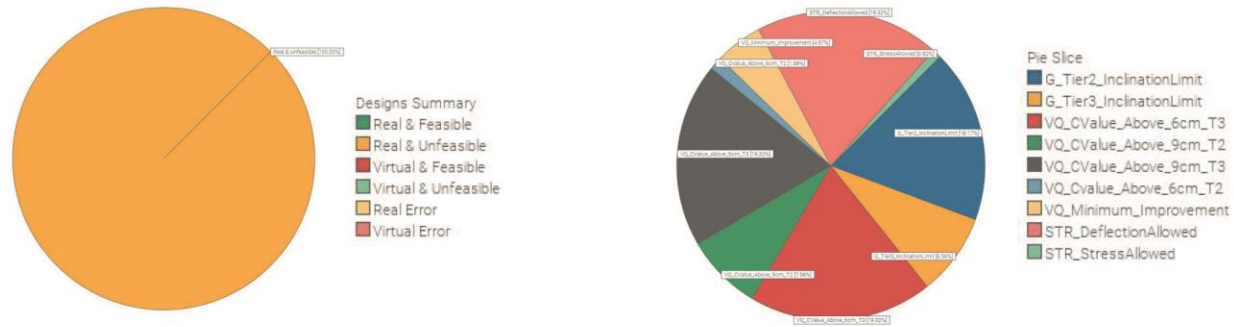


MINIMIZE MASS OF STRUCTURE

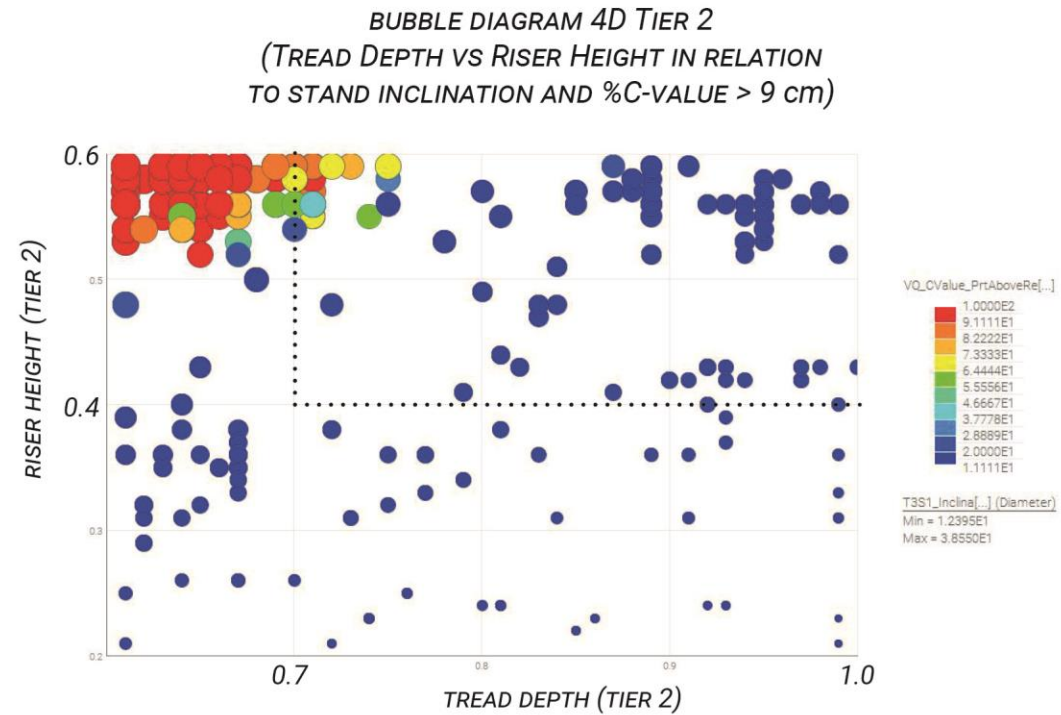
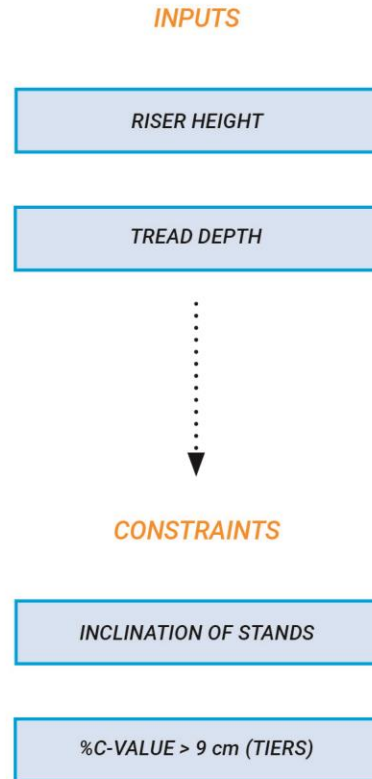


1ST OPTIMIZATION

OPTIMIZATION RUN	DESIGN PRODUCED	FEASIBLE	UNFEASIBLE
Run 1	167	0	167



1ST OPTIMIZATION



1ST OPTIMIZATION

INPUTS

RISER HEIGHT

TREAD DEPTH

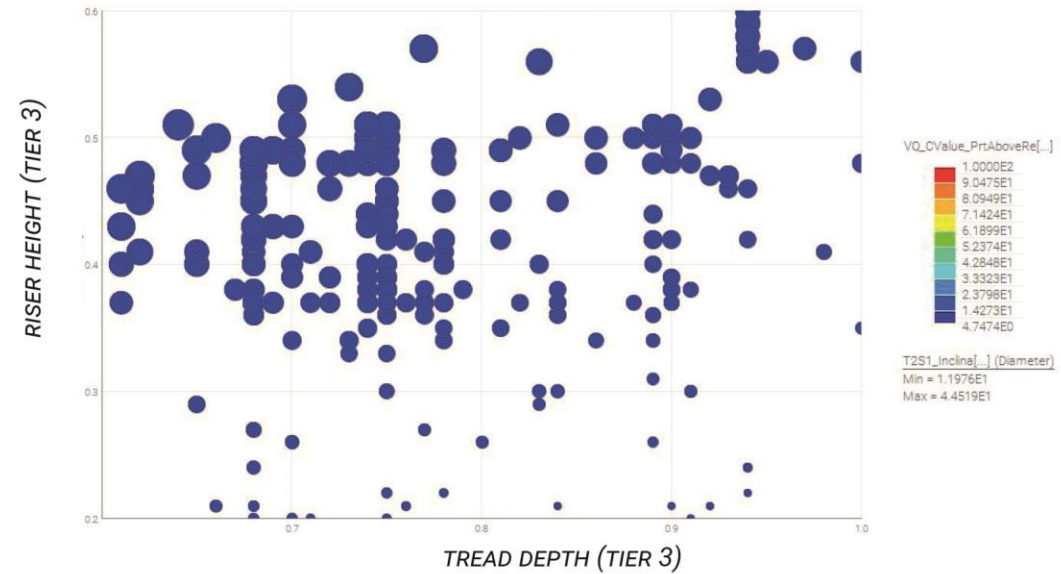


CONSTRAINTS

INCLINATION OF STANDS

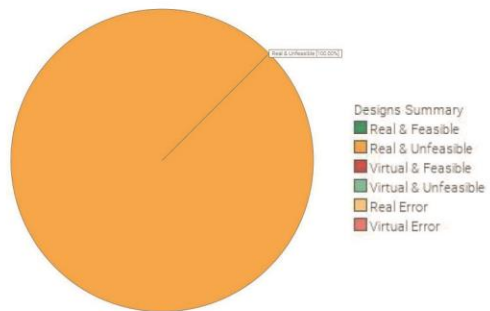
%C-VALUE > 9 cm (TIERS)

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



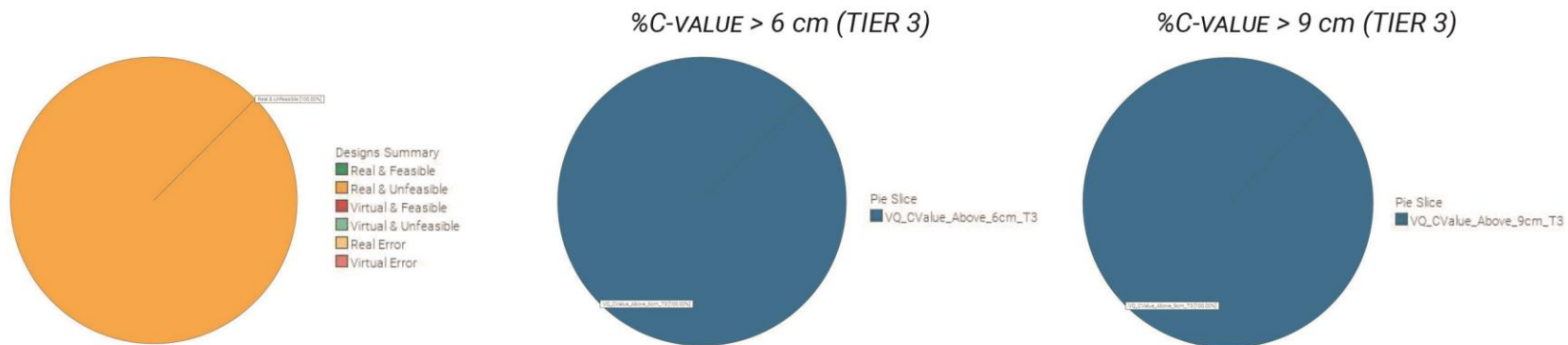
TOTAL OPTIMIZATION

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



TOTAL OPTIMIZATION

INPUTS

RISER HEIGHT

TREAD DEPTH

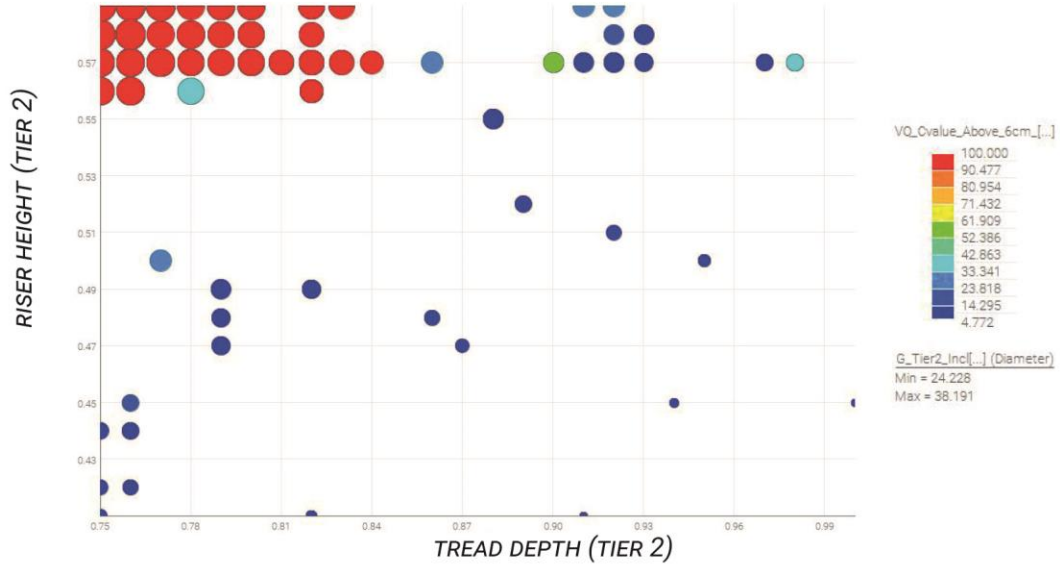


CONSTRAINTS

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

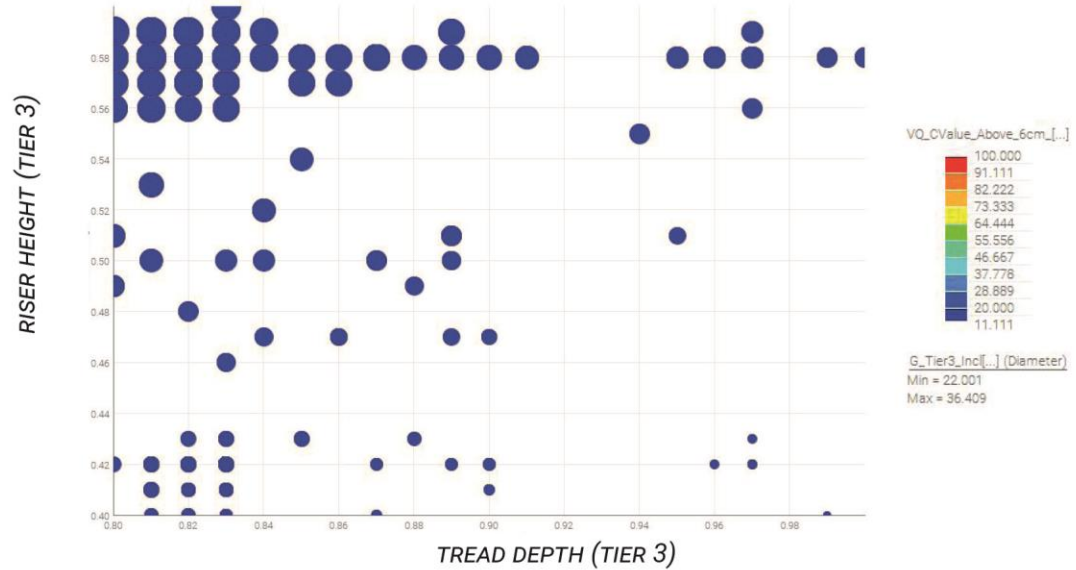


CONSTRAINTS

INCLINATION OF STANDS

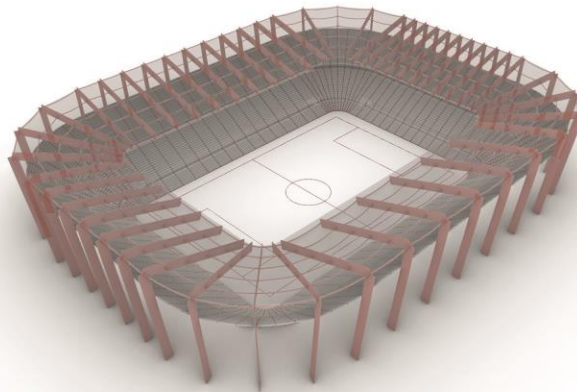
%C-VALUE > 9 cm (TIERS)

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



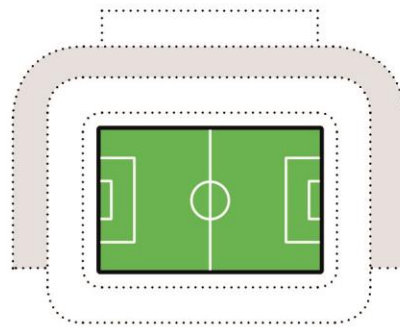
2ND RENOVATION APPROACH



IMPROVE VIEWING QUALITY

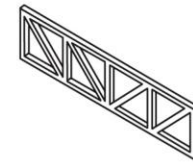
OPTIMIZE ROOF STRUCTURE

2ND TIER OF STANDS



14 INPUTS

ROOF STRUCTURE

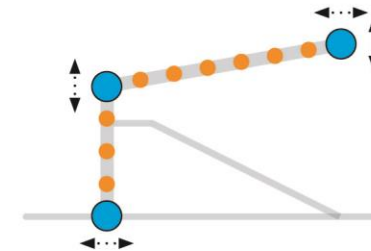


PILLARS AND CANTILEVERS



BRACINGS

+



2ND RENOVATION APPROACH

10 CONSTRAINTS



IMPROVE VIEWING QUALITY

OPTIMIZE ROOF STRUCTURE



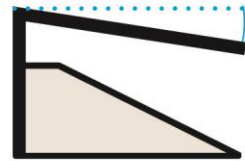
INCLINATION OF STANDS $< 35^\circ$



STRESS > 0 MPa



%C-VALUE > 9 cm $> 80\%$



INCLINATION OF ROOF $> 1.5^\circ$

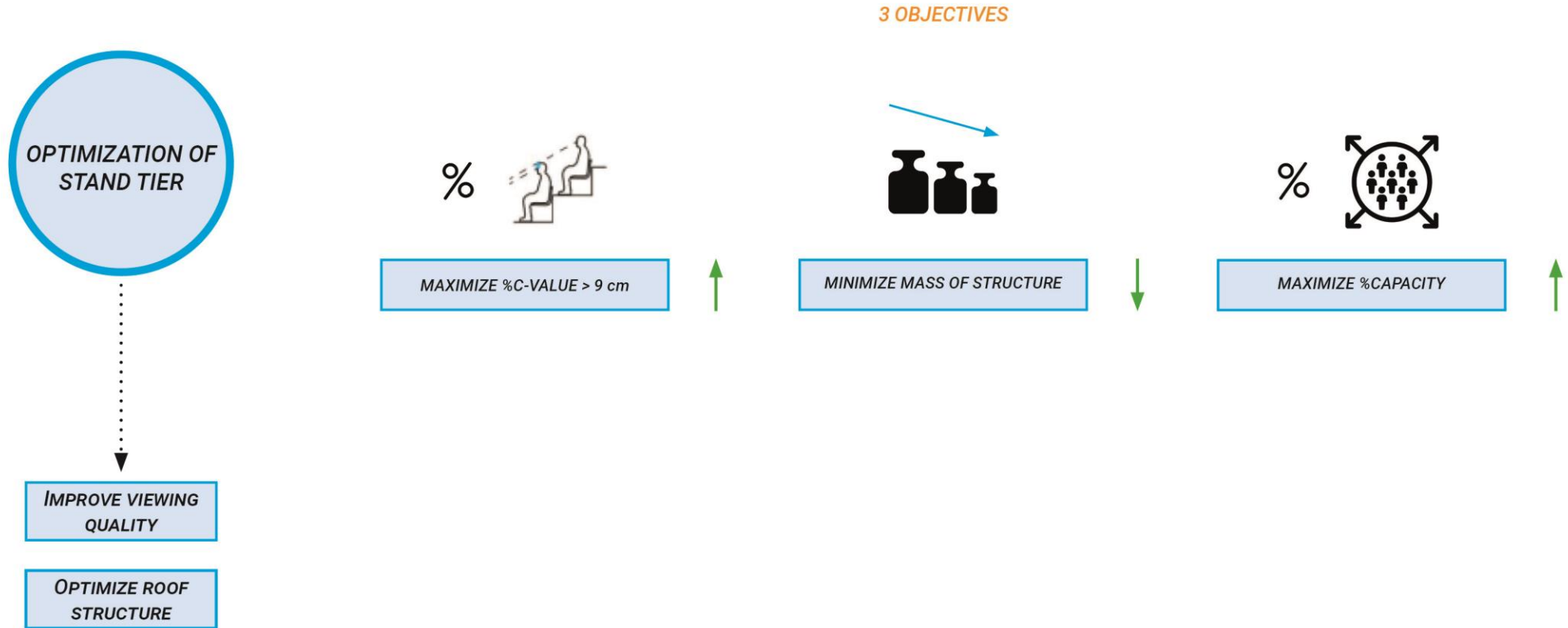


DISPLACEMENT > 0 cm



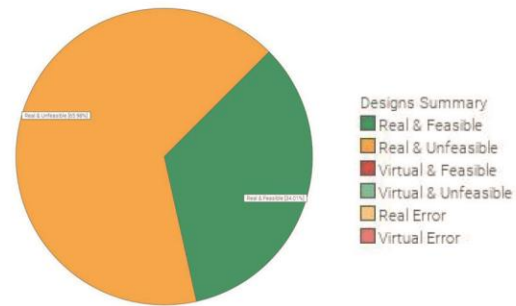
%C-VALUE > 6 cm = 0%

2ND RENOVATION APPROACH



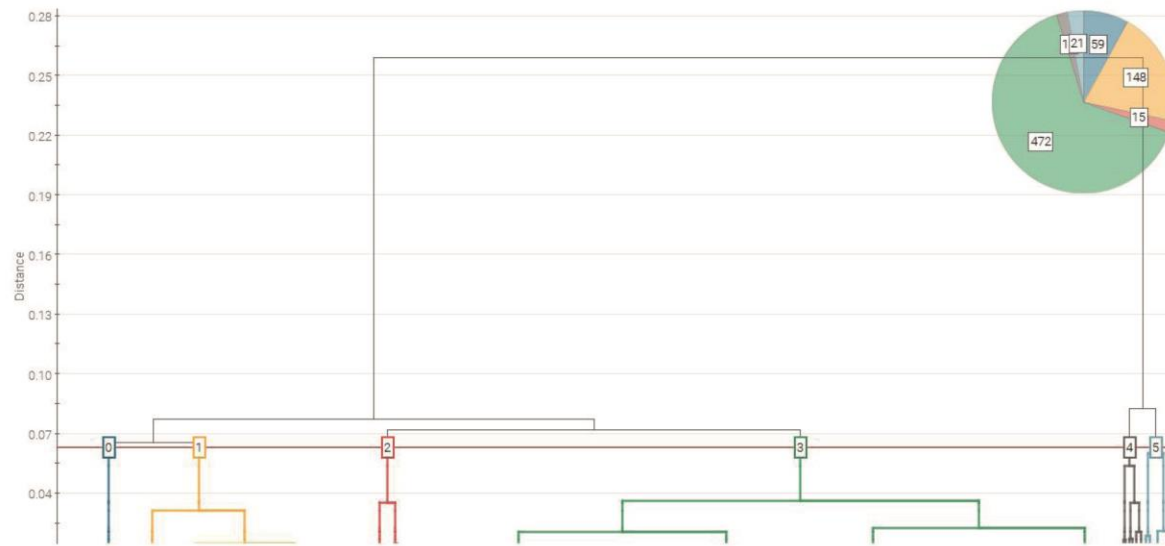
TOTAL OPTIMIZATION

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



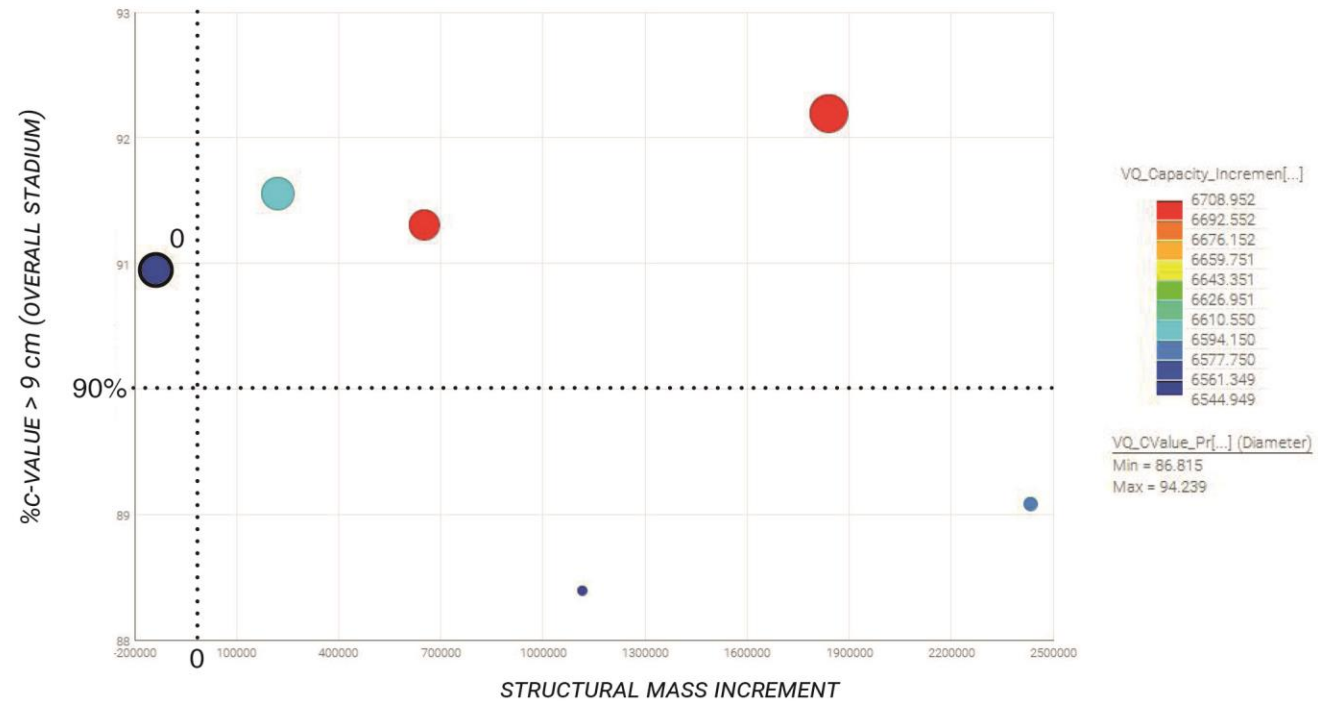
TRADE-OFF OF ALTERNATIVES

HIERARCHICAL CLUSTERING (CENTROID-LINKAGE)



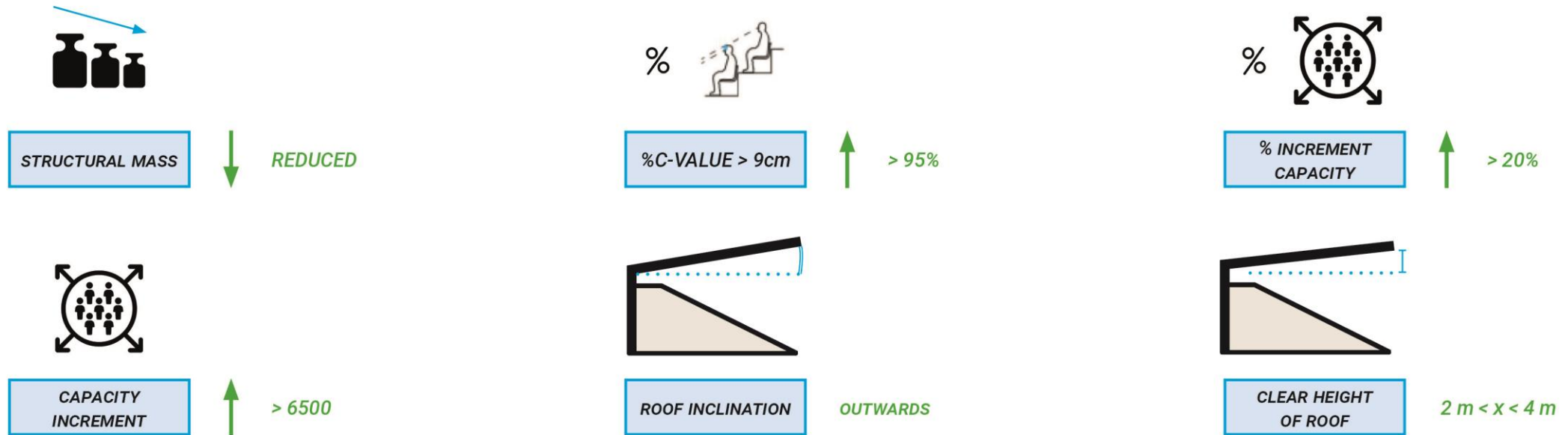
TRADE-OFF OF ALTERNATIVES

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

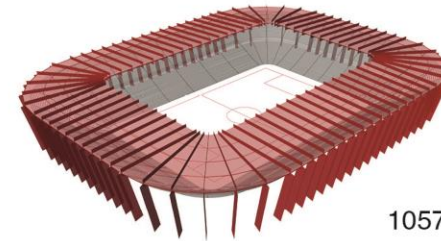
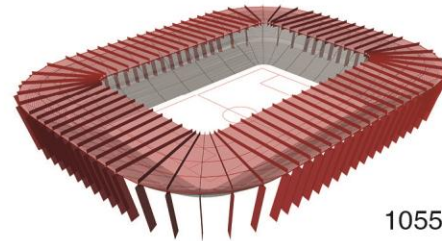
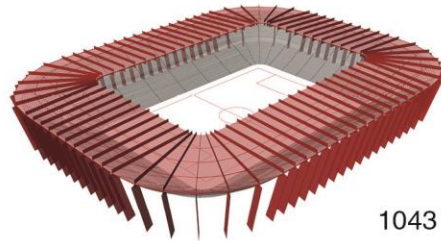
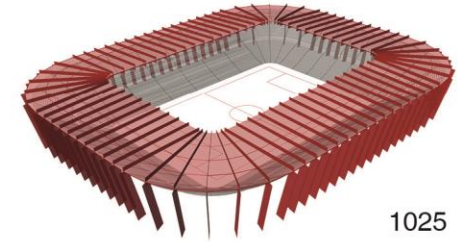
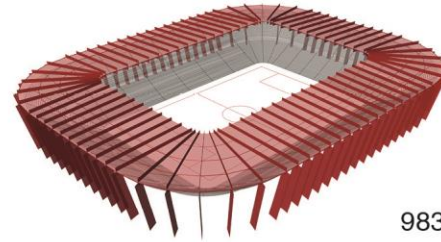
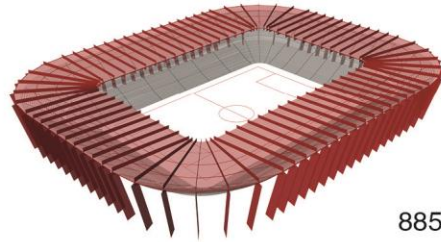
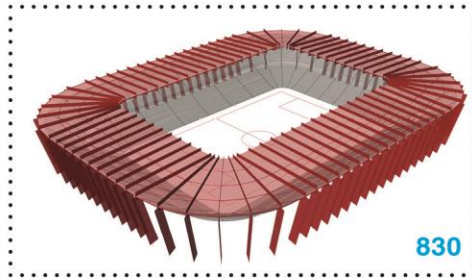


TRADE-OFF OF ALTERNATIVES

	↑	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



SELECTED DESIGN



STRUCTURAL MASS

↓ - 1.08E5 Kg

%



%C-VALUE > 9cm

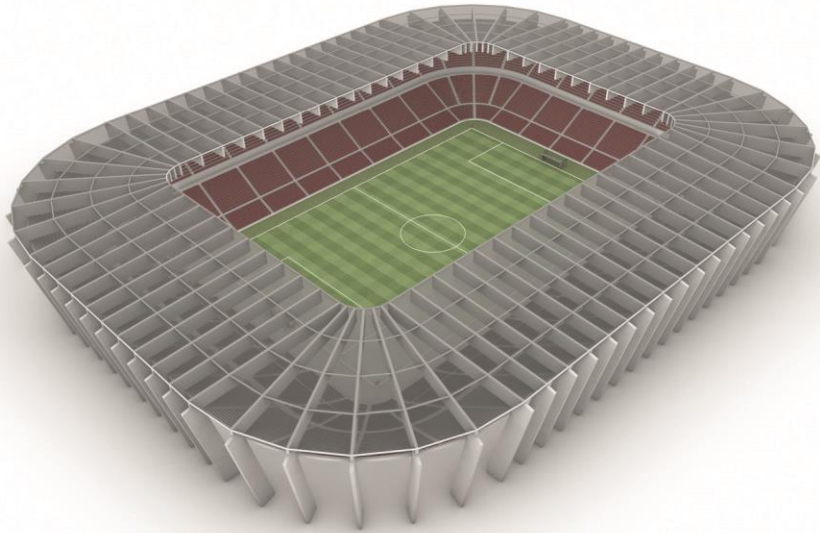
↑ + 40.15%



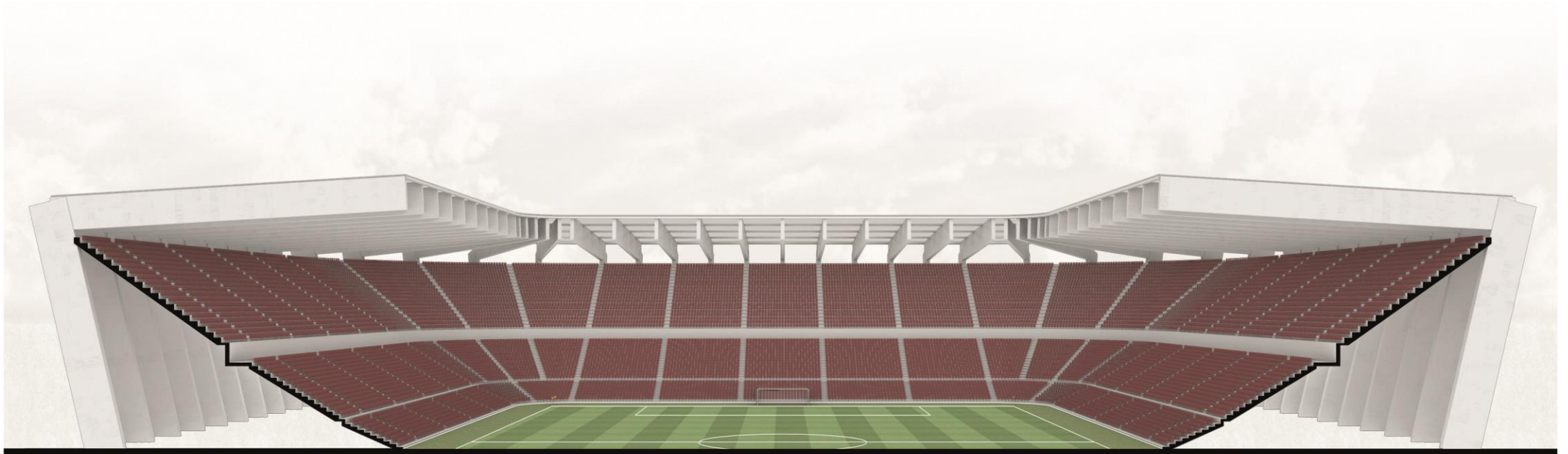
INCREMENT CAPACITY

↑ + 6712

SELECTED DESIGN



SELECTED DESIGN



A background network diagram consisting of numerous nodes (small circles) connected by thin lines, forming a complex web of connections. The nodes are colored in shades of grey and light blue. The overall structure is dense and interconnected, with some nodes having more connections than others.

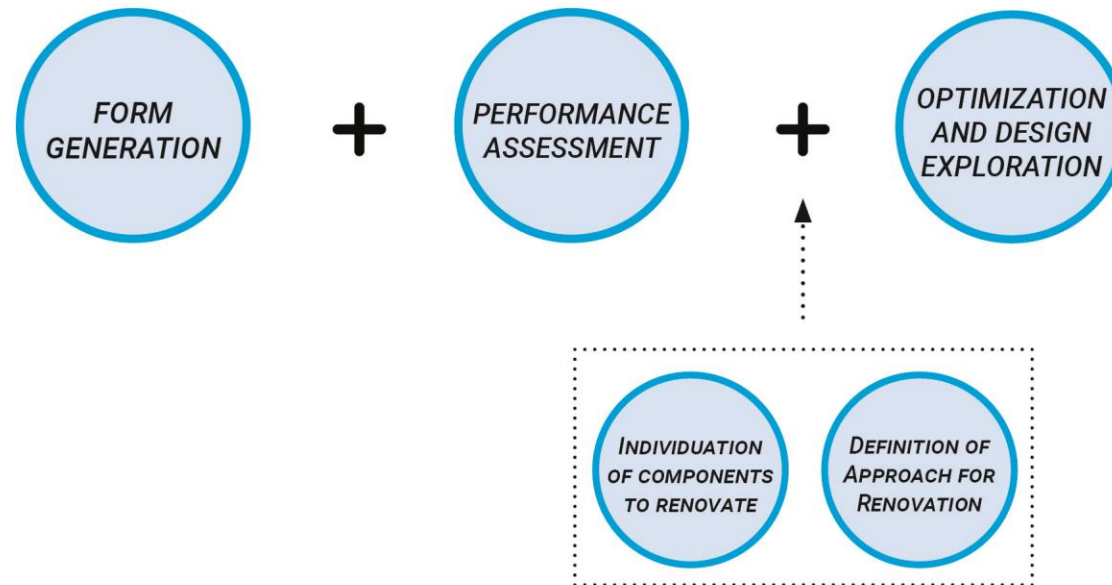
CONCLUSIONS

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**?

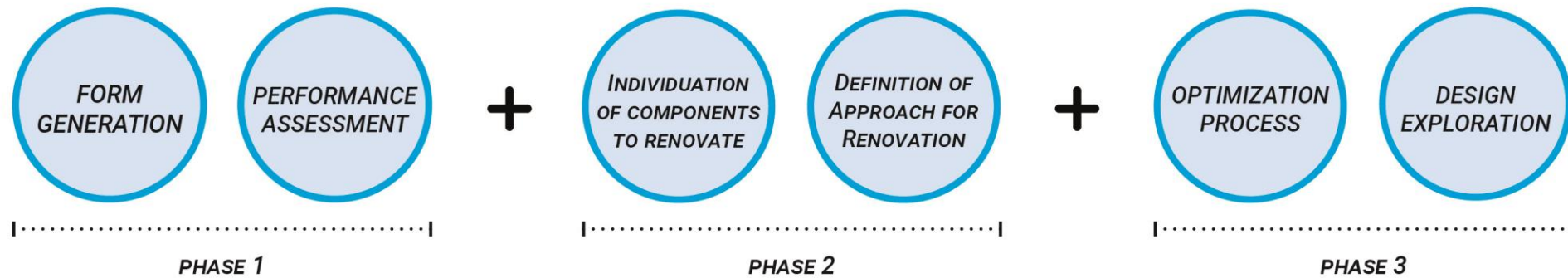
CONCLUSIONS

- *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*



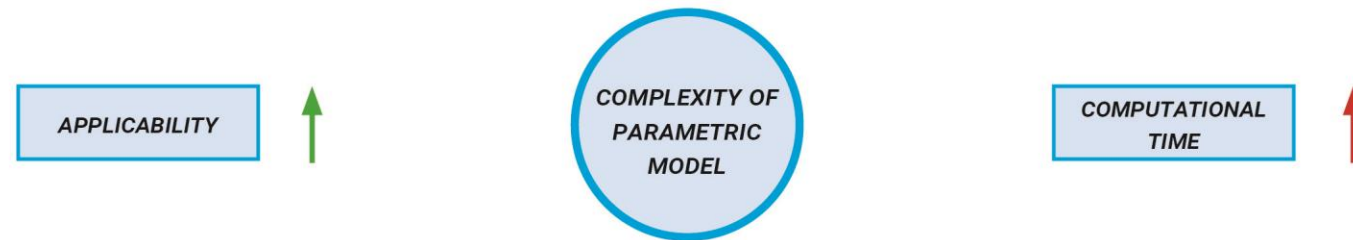
CONCLUSIONS

- **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



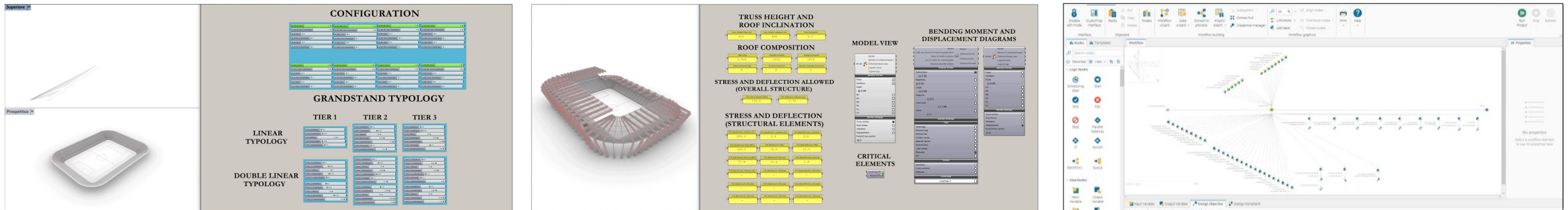
CONCLUSIONS

- **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

PERFORMANCE ASSESSMENT

OPTIMIZATION AND DESIGN EXPLORATION

Stadium Features

- PLAYING AREA**
- CONFIGURATION**
- GRANDSTAND GEOMETRY**
- SPECTATORS**
- VERTICAL CIRCULATION**
- ROOF OUTLINE**
- STRUCTURAL BOUNDARIES**
- 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.

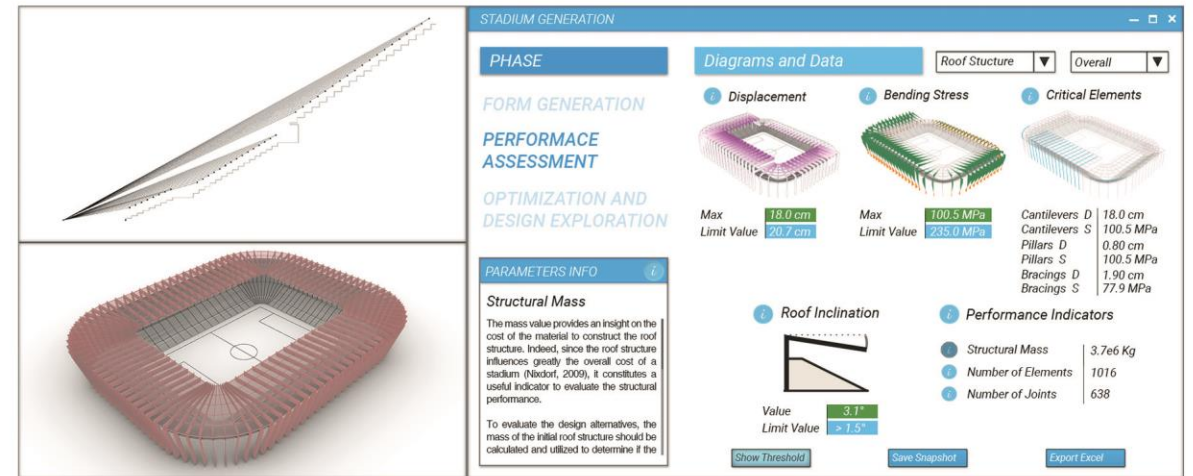
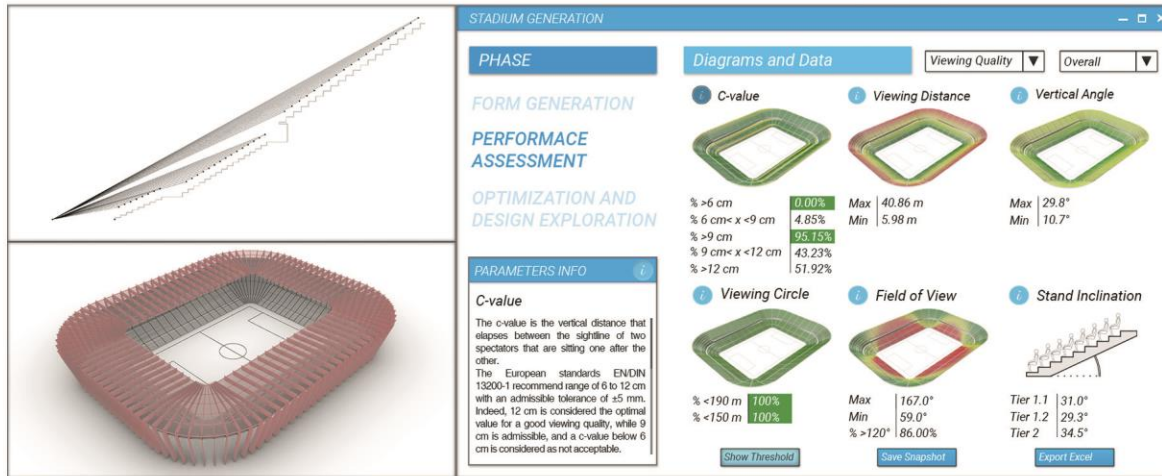
This parameter determines the seating comfort of the spectators. Therefore, the higher the value is, the more comfortable the user will be.

Input Parameters

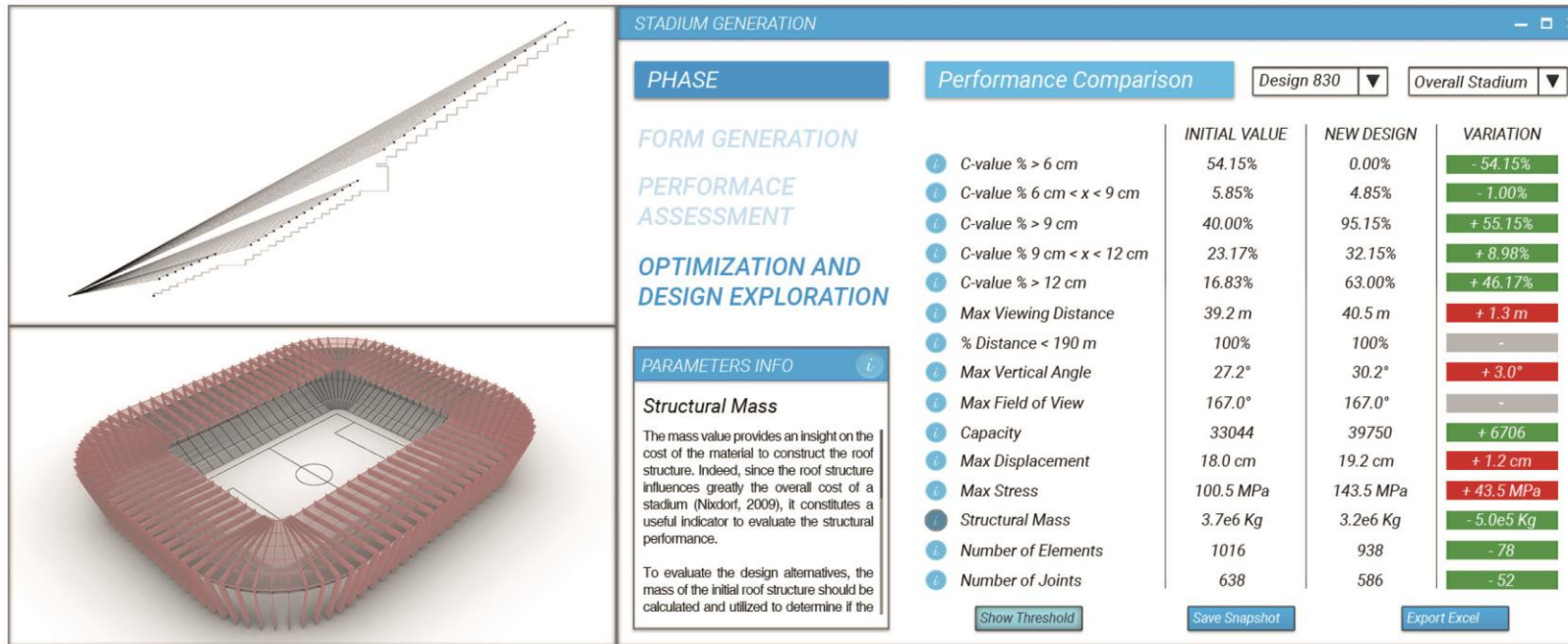
Tier 2 | Stand Type 1

- 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

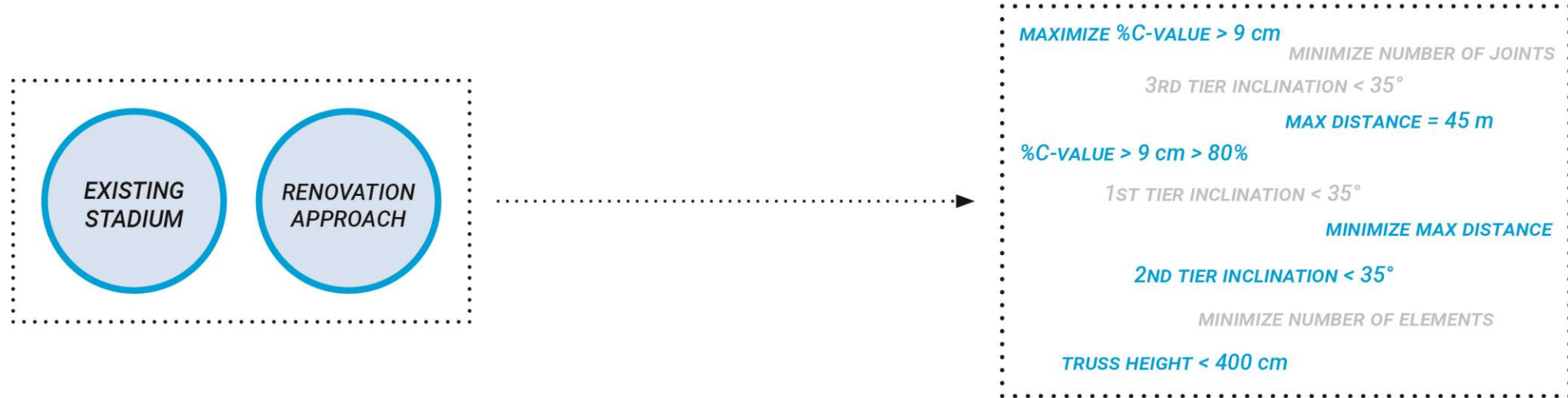


CONCLUSIONS



CONCLUSIONS

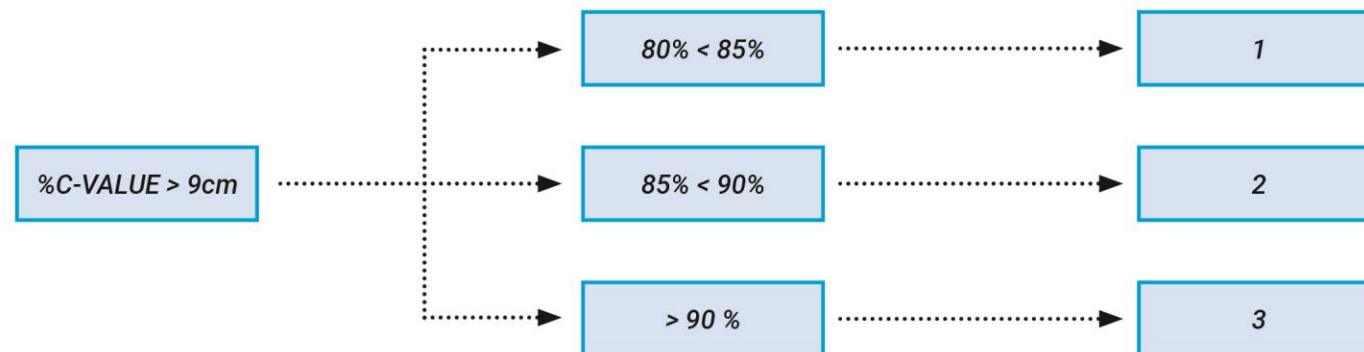
- The method can **SUPPORT DESIGNER** in **DEVELOPING CONCEPTS** for the renovation
 - The method **PROVIDES OPTIONS** for the **OPTIMIZATION** to the designer
- **APPROACH** and **EXISTING STADIUM PERFORMANCES** determines **INPUTS, CONSTRAINTS** and **OBJECTIVES**



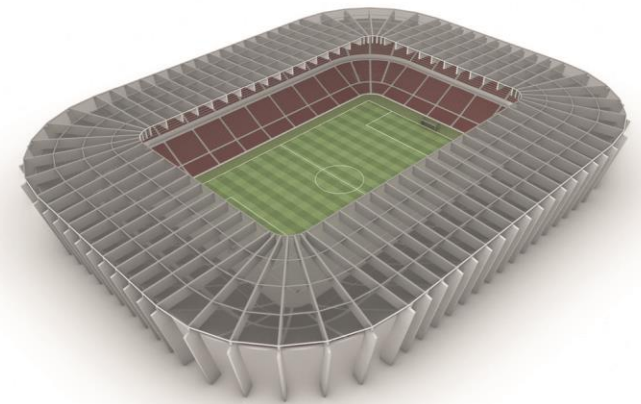
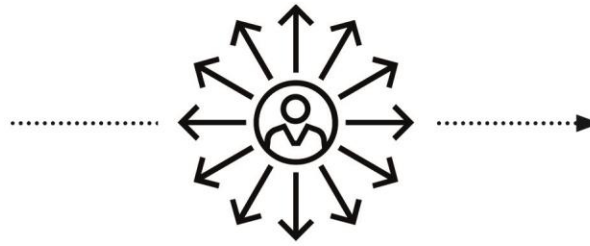
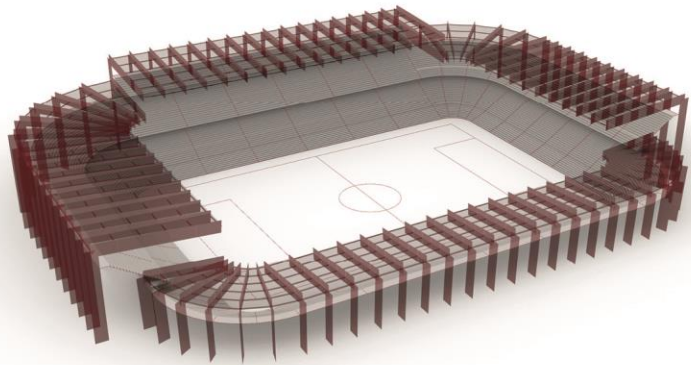
CONCLUSIONS

- 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

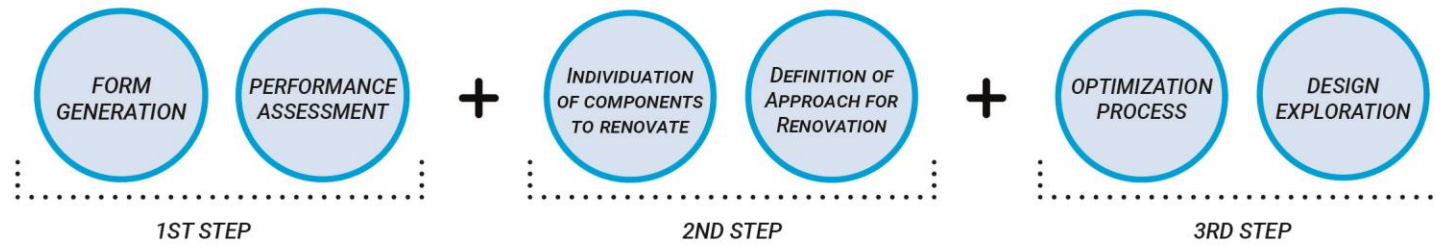
% INCREMENT CAPACITY ↑ + 20%

CONCLUSIONS

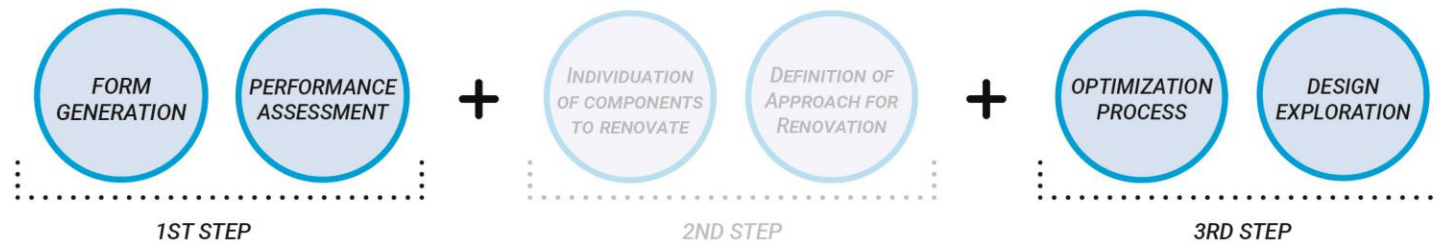
- The method can be utilized to *DEVELOP* and to *TEST CONCEPTS* for renovation of stadiums
 - *POTENTIAL* to individuate and *DISCARD INEFFICIENT DESIGNS*
- The *DESIGNS* produced can constitute a *BASIS* for *FURTHER DESIGN PHASES*
 - *POTENTIAL* as a *TOOL* to generate *NEW STADIUMS*

CONCLUSIONS

RENOVATION



NEWLY BUILT STADIUMS



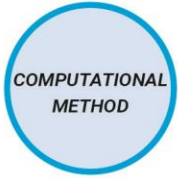
THANK YOU FOR YOUR ATTENTION!



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

