

Good design makes a difference "



Developing Open Systems and Methods for Collaborative Modeling

Volker Mueller, Bentley Systems, Incorporated



Developing Open Systems and Methods for Collaborative Modeling

- Learn why this problem is not yet solved.
- Learn why researchers are concerning themselves with it.
- Learn how to analyze data sharing needs.
- Learn how to map data.



open systems and methods

- agenda
 - beginnings
 - motivation
 - goals
 - relevance
 - activities
 - next steps
 - participation



beginnings



Home	Submissions	Programme	Local information	Registration	Contact
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Call	Submit a poster	Awards	Lodging	Scholarships	
Committees	Submit a workshop	Programme	Travel	Registration form	

Workshop 5

Open Systems and Methods for Collaborative Built Environment Modeling

4 July 2011
Half day PM
Stouffs Rudi, Chaszar Andre - Delf University of Technology
Tuncer Bige - ETH Zurich
Coenders Jeroen - ARUP
Boeykens Stefan - KU Leuven
Sart Tilman Campus
Building B37 - Institut de mathématiques



CAA futur 4 > 8 JULY Liège · BEL	es 2011				MIRCO.
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Open Systems and Methods for Collaborative Built Environment Modeling

Schedule 4 July 2011 Half day PM Chair Stouffs Rudi, Chaszar Andre - Delf University of Technology Tuncer Bige - ETH Zurich

Format

- Coenders Jeroen ARUF Boeykens Stefan - KU Leuven
- Sart Tilman Campus Building B37 Institut de mathématique Location

Objectives Current building and planning practices face the issue that, despite their increasing ability to support the collaborative deployment of project teams' and other stakeholders' distributed intelligence through concurrent as well as asynchronous processes, a early stages of the building process few tools are eary stages or the building process rew tools are available to predict and simulate performance in several key aspects of the project, though the early stages are most crucial in terms of decision making, Available tools that can asses, simulate or predict buildings' performances in various respects are buildings performances in various respects are currently only employed rather late in the design and planning process, due to their complexity and specificity, resulting in optimizing a given solution (post-rationalization) based on "educated quesses" rather than enabling the planning parties to make better-informed decisions beforehand. Anothe bottleneck while employing such tools is their incompatibility with the extremely dynamic nature of these early stages. Here, options would have to be evaluated quickly, but since the different software packages are not communicating in real-time with each other, designers and planners are not able to each other, designers and planners are not able to keep momentum while importing, exporting and converting large amounts of model data back and forth iteratively. Important methods and techniques that partially address these issues include tric-associative modeling, computationa parametric-associative modeling, computational intelligence, building information modeling, and file-to-factory techniques. The problem remains that these various techniques and methods only offer partial solutions towards integrated, performance-criented design and need further developments and oriented design and need further developments and non-prescriptive linkages in order to achieve the flexibility and fluidity which are necessary to support true design exploration, especially in the early stages where divergent rather than convergent thinking is prevalent, and standards and other conventions tend to be overly restrictive.

Workshop 5

In this workshop we aim to discuss these issue and possible approaches to overcome them, focusing on building design but considering the larger context within which buildings perform and upon which they have an impact. We aim to relate the need for detailed information modeling and exchange for design validation and documentation with modeling approaches that support the dynamic nature of design at the early stages and are able to leverage the strengths of rules and type as well as supporting "expandable rationality innovation and emergence. We aim to identify concrete R&D steps that can alleviate some of the issues identified above.

Expected output The workshop will bring together both invited and We aim to identify concrete R&D steps that can other interested researchers, practitioners and developers to brainstorm and discuss on the issues

alleviate some of the issues and help to achieve the objectives presented above. It is also the intention to publish the workshop results in a joint and objectives presented above, with the goal of and objectives presented adove, with the goal of identifying concrete RAD steps. Participants are invited to submit a position paper or a brief description of research results that can sheel light on these issues or suggest possible (partial) solutions. Some will be selected for short presentations. Papers and presentations will form the bases for discussion. publication, possibly a special journal issue.

Objectives

Current building and planning practices face the issue that, despite their increasing ability to support the collaborative deployment of project teams' and other stakeholders' distributed intelligence through concurrent as well as asynchronous processes, at early stages of the building process few tools are available to predict and simulate performance in several key aspects of the project, though the early stages are most crucial in terms of decision making. Available tools that can assess, simulate or predict buildings' performances in various respects are currently only employed rather late in the design and planning process, due to their complexity and specificity, resulting in optimizing a given solution (post-rationalization) based on "educated guesses" rather than enabling the planning parties to make better-informed decisions beforehand. Another bottleneck while employing such tools is their incompatibility with the extremely dynamic nature of these early stages. Here, options would have to be evaluated quickly, but since the different software packages are not communicating in real-time with each other, designers and planners are not able to keep momentum while importing, exporting and converting large amounts of model data back and forth iteratively. Important methods and techniques that partially address these issues include parametric-associative modeling, computational intelligence, building information modeling, and fileto-factory techniques. The problem remains that these various techniques and methods only offer partial solutions towards integrated, performanceoriented design and need further developments and

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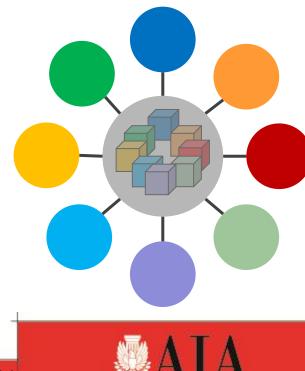
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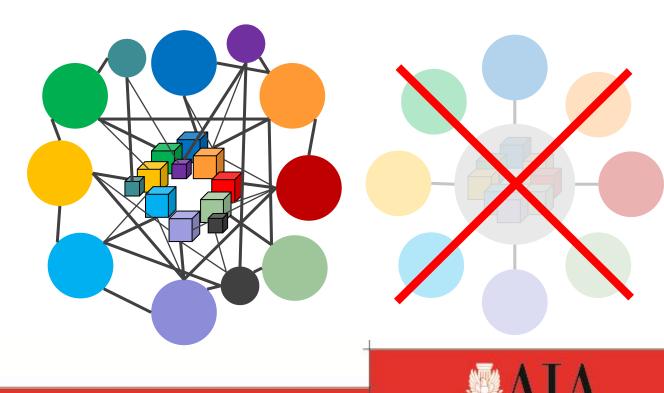


- the reality of AEC/O processes
 - collaborative
 - dynamic
 - asynchronous
 - content-rich
 - non-linear
 - multi-disciplinary
 - cross-disciplinary
 - trans-disciplinary

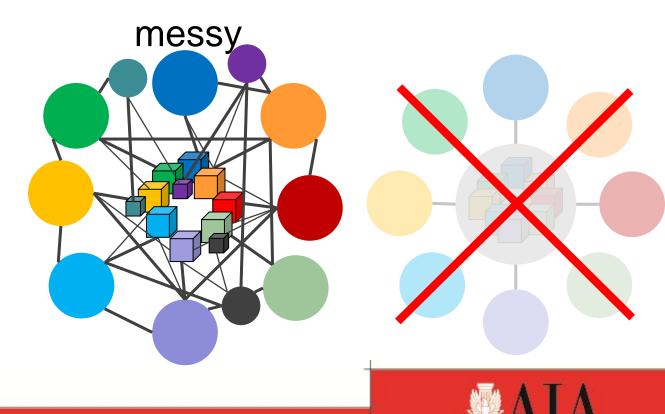


- the reality of AEC/O processes
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- the reality of AEC/O processes
 - one word:



- the reality of AEC/O processes
 - one word:



- desire of intelligent design
 - performance feedback
 - constructability feedback
 - any other parameter feedback



- requirement of freedom & flexibility
 - design data
 - design tools
 - analysis tools
 - any other data & tools in project lifecycle

goals

requirement of freedom & flexibility

– one word:

open systems and methods



goals

requirement of freedom & flexibility

- one word four words:

open systems and methods



goals

- requirement of freedom & flexibility
- desire of designing intelligently
 - one word four eight words:

open systems and methods for built environment modeling (BEM)

why the problem is not solved, yet:

- messy problem
 AND
- goal of open and flexible solution



why researchers are interested in this:

messy problem

AND

- goal of open and flexible solution
 AND
- desire of designing intelligently



relevance

- quality of design
- quality of design to construction process
- quality of construction
- quality of operation

relevance

- ability to react to project specifics
 - required disciplines >>> data
 - required methods >>> tools
 - design
 - analysis
 - representation
- other self-evident reasons
 - meet and discuss after the session
 - (or wait for participation information)



how to analyze data exchange needs:

- respond to specific project conditions
 - project goals
 - project partners
 - disciplines >>> data
 - methods >>> tools



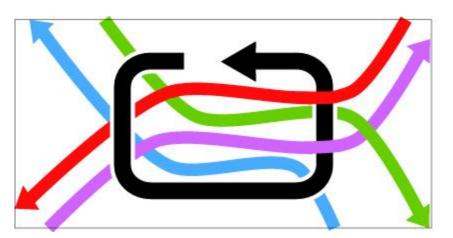
activities

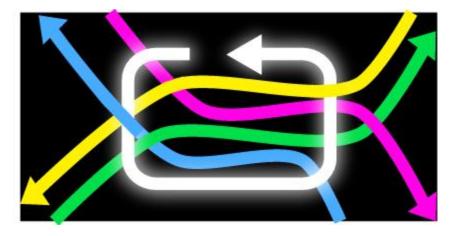
 workshop at CAAD Futures 2011 on July 4th, 2011



activities

- workshop at CAAD Futures 2011 on July 4th, 2011
- ongoing discussion on LinkedIn group
 Open Systems & Methods for Collaborative BEM







activities

- discussion topics
 - System implementation
 - MDO¹⁾ via Open Systems & Methods
 - MDO Interface Issues for Open Systems & Meth
 - Customized Digital Workflows (CDW)
 - Tool nodes
 - Mapping nodes
 - GUI nodes
 - etc.

1) MDO: multi-disciplinary optimization





next steps

- broaden the participation
- continue discussions
 - on LinkedIn
 - in workshops at various conferences
- work towards initial requirements
 - general system architecture
 - specific system components
- start prototype implementations



participation

- workshop chairs (5)
 - Rudi Stouffs, TU Delft
 - Andre Chaszar, TU Delft
 - Tuncer Bige, ETH Zurich
 - Jeroen Coenders, Arup
 - Stefan Boeykens, KU Leuven

publicly accessible information about workshop at: www.lucid.ulg.ac.be/conferences/caadfutures2011/Workshop5.html



participation

- workshop participants (11)
 - at workshop mostly from academia
 - international
 - Europe (7 participants, 4 countries)
 - Asia (3 participants, 2 countries)
 - Americas (1 participant, 1 country)



participation

- LinkedIn group:
 - Open Systems & Methods for Collaborative BEM
 - -24 Members (10-17-2011)
 - 15 Academic Researchers
 - 7 AEC Professionals
 - 2 Industry Researchers
 - 9 countries
 - 4 continents





how to map data:



how to map data: (impossible in remaining time)



how to map data: (impossible in remaining time) how to participate:



how to map data: (impossible in remaining time) how to participate:

• LinkedIn group:

- Open Systems & Methods for Collaborative BEM



Developing Open Systems and Methods for Collaborative Modeling

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Good design makes a difference " **Division of Capital Asset Management**



D·C·A·M

DESIGN MODEL VS. CONSTRUCTION MODEL

- Zahra Assar
- Luciana Burdi
- Laura Herbert
- Ethel Macleod
- Erik Sanford



Identify the differences between a design phase and construction phase BIM.

Explain methods for managing BIM expectations throughout the project.

 Understand the process of BIM development from design through construction.

Identify the potential impact of differences between the design and construction models.



SPRINGFIELD DATA CENTER PROJECT

- Tier III N+1 Data Center
 - Active backup facility
 - Redundant systems
 - Secure facility
- 145,000 sqft
- \$110 M Project Cost





SPRINGFIELD DATA CENTER PROJECT

- Groundbreaking on July 22, 2010
- Anticipated Completion
 in December 2012
- LEED Gold Anticipated



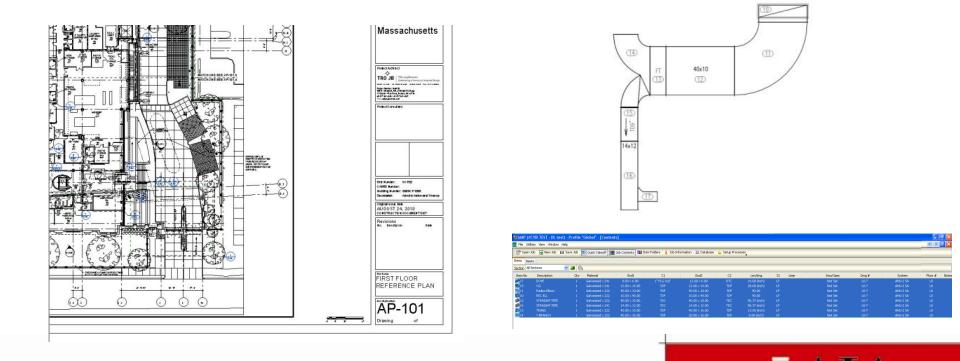




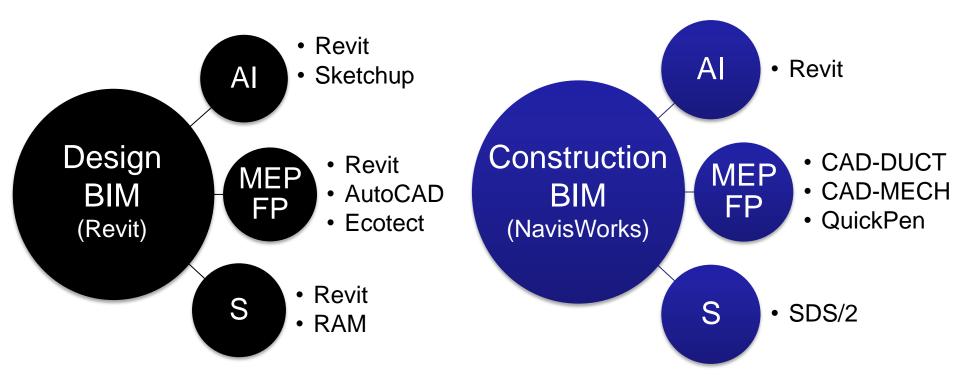
INHERENT DIFFERENCES - USES

- Design
 - Documentation
 - Visualization
 - Analysis

- Construction
 - Fabrication /Shop Drawings
 - Coordination
 - Scheduling



INHERENT DIFFERENCES – SOFTWARE USED





MANAGING EXPECTATIONS

- BIM Execution Plan
 - Identify BIM Goals and Uses

Priority (1-3)	Goal Description	Potential BIM Uses					
- Most Important	Value added objectives						
1	Address field conflicts	Spacial Coordination - 3D Construction Coordination					
3	FYI - Asses the value of using the BIM model for cost estimating	Quantities Take-offs					
2	Address logistic conflicts	To some degree - 4D modeling					
2	Look-ahead schedule for coordination with subcontractors	4D modeling - when needed					
3	Track progress during construction	4D modeling - if needed					
1	Identify concerns with construction sequences	4D modeling					
1	Facilitate the Commissioning Phase	Model and Tag Major Equipment					
2	Facilitate the construction phase coordination/shop drawing review	Live Coordination Meetings (With Model)					
1	3D Record Model for coordination with sub-contrators	Record Model (Navisworks)					
1	3D model to be used for Phase 2	Record Model (Revit)					
2	Provide or explore the option to produce an FM model	FM Model (?)					
2	3D Record of the site utilities	Site utilities Model (major civil)					
1	Pre-fabrication/On time deliveries	Subcontractors 3D Model					
2	Details on the existing building and its relation with the new addition	Existing Conditions Building Model					
1	Helping users to understand the project, thus accelate decision making	Develop Graphics for design presentations					
2	Improve safety on site	Safety Plan in BIM					
1	Address conflicts in design	Spacial Coordination - 3D Design Coordination					
1	Evaluate the lighting in the office space of the new addition	Lighting BIM analysis					



MANAGING EXPECTATIONS

- Model Element Worksheet
 - Assign Model Author
 - Establish LOD per phase
 - Describe workflow

PHASE		SCHEMATIC DESIGN		DESIGN DEVELOPMENT			CONTRACT DOCUMENTS			CONSTRUCTION			
File Format		SCHEWARIC DESIGN						CONTINUED DOCOMENTS			construction		
Application & Version								8					
MODEL ELEMENT BREAKDOWN (CSI Uniformat)		LOD	Party	Notes	LOD	Party	Notes	LOD	Party	Notes	LOD	Party	Notes
				Modeled placeholder by		1/5	Duplicated, EOS by A, construction by S, A to manage levels, S to add TOS level in their model and monitor difference. A+S to		N/6	Duplicated, EOS by A, construction by S, A to manage levels, S to add TOS level in their model and monitor difference. A+S to			CM - Changes made after
	Roof Construction	1	A/S	both	2	A/S	monitor slabs.	3	A/S	monitor slabs.	3	CM	consolidation set
	Canopy Construction Dunnage and Grating	0	S		1		Greater attention to detail in this are as design develops Modeled generically?	3	S		3		Steel Fabricator Steel Fabricator
	Misc. Metals	0	3			3	Modeled generically:	5	5		5		Misc Metals Sub to extent of
	Gusset Plates	0	S		1	S	Placeholder form for clash detection, details	1	S	Placeholder form for clash detection, details	3		Steel Fabricator
	Bracing	1	S		2	S		3	S		3	SUB	Steel Fabricator
	House keeping pads	1	E		2	E	S references A/E for generic locations and provides 2D detail			S references A/E for generic locations and provides 2D detail	3	SUB	Individual subs to model their required pads
B20 Exterior Enclosure						-							
	Exterior Walls	1	A		2	A		3	А		3		CM - Changes made after consolidation set
	Exterior Windows/Curtain wall	1	A		2	A		3	A		3	СМ	CM - Changes made after consolidation set
	Exterior Doors	1	A		2	A		3	A		3	СМ	CM - Changes made after consolidation set
	Veneer on Foundation Walls	1	A	Modeled as entire wall, duplicated w/struct	2	A	Modeled as wall on structural foundation	2	A	Modeled as wall on architectural placeholder foundation wall	2	СМ	CM - Changes made after consolidation set
	Veneer on Existing Walls	1	A		2	A		3	A	Modeled as separate wall	3	СМ	CM - Changes made after consolidation set
	Exterior Louver system	1	A	Built as Curtain wall	2	A		3	A	Built as solid wall	3		CM - Changes made after consolidation set, SUB - Operating Louvers



BIM LEVEL OF DEVELOPMENT



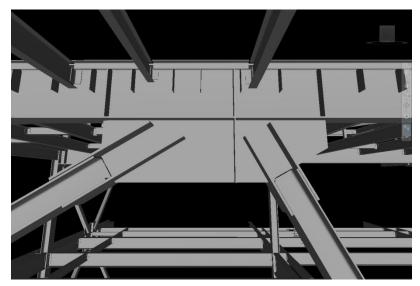
- Refer to AIA E202 for Guide
- Use Model Element Worksheet to Determine Uses
- LOD is NOT consistent across model
 - Walls = LOD 300
 - Wall Base = LOD 0 (not modeled)
- Warning: Elements may appear more accurate than designed



BIM DEVELOPMENT



Steel Framing – Design Model



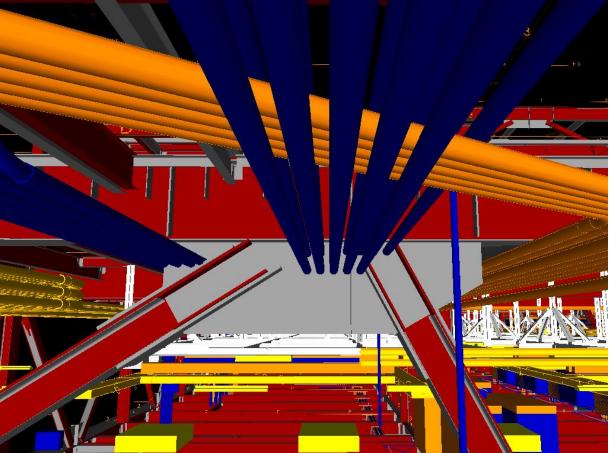
Steel Framing – Fabrication Model

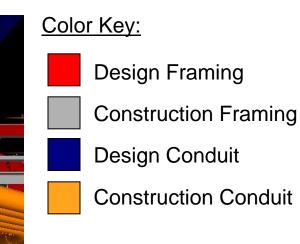
- Higher LOD in Construction Model
 - Fabrication models from subcontractors
- Current software and practice limitations prevent higher LOD in design model



POTENTIAL IMPACT

- Model Exclusions
 - Design model LOD limitations excludes content
 - Some components are 2D (details) only



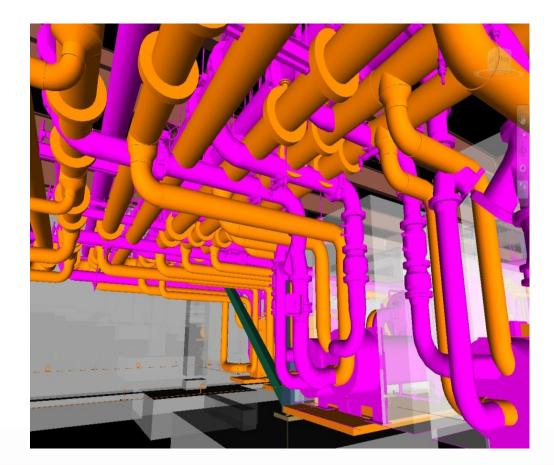






POTENTIAL IMPACT

- Modeling Differences
 - Design software is not accurate for fabrication



Color Key:



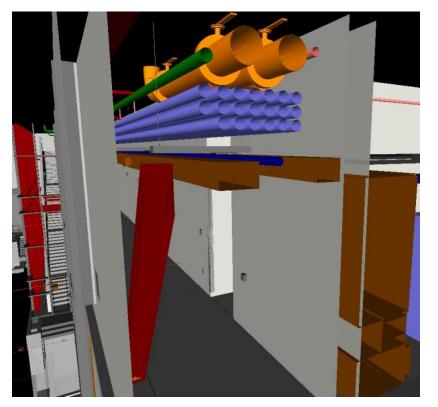
Design Piping

Construction Piping

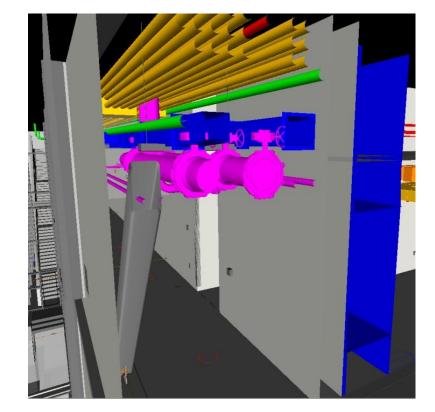


POTENTIAL IMPACT

- Constructability modifications
- Accessibility modifications



Design MEP/FP



Construction MEP/FP



LESSONS LEARNED

- Early involvement of the construction team
 - Improved understanding of design model content and limitations
 - Design assist possibilities
 - Right people / Right time modeling processes
- BIM Execution Plan use
 - Owner and contractor involvement needed
 - Tool for open communication
 - Defines Objectives
 - Manages Expectations



Division of Capital Asset Management



D·C·A·M

DESIGN MODEL VS. CONSTRUCTION MODEL

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- Luciana.Burdi@state.ma.us
- LHerbert@trojb.com
- Ethel_Macleod@gensler.com
- Erik.Sanford@skanska.com



Good design makes a difference "



"Cost-effective strategy to panelize a double curved surface"

LORENZO MARASSO Designer – Gensler Los Angeles

Ordine degli Architetti di Torino - Turin, Italy MArch – Yale University – New Haven – CT – USA BArch – Politecnico di Torino – Italy

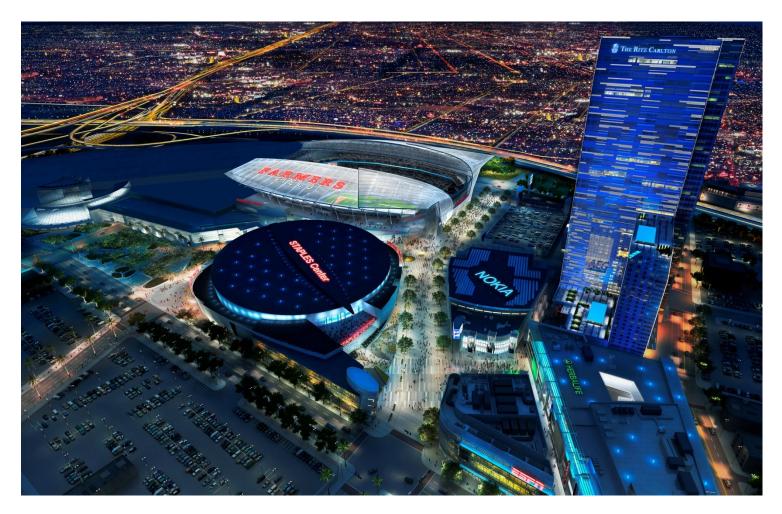
Prior experience: Greg Lynn FORM - Venice, California Office for Metropolitan Architecture – Rotterdam, The Netherlands; Asymptote Architecture - New York; Eisenman Architects - New York;





Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

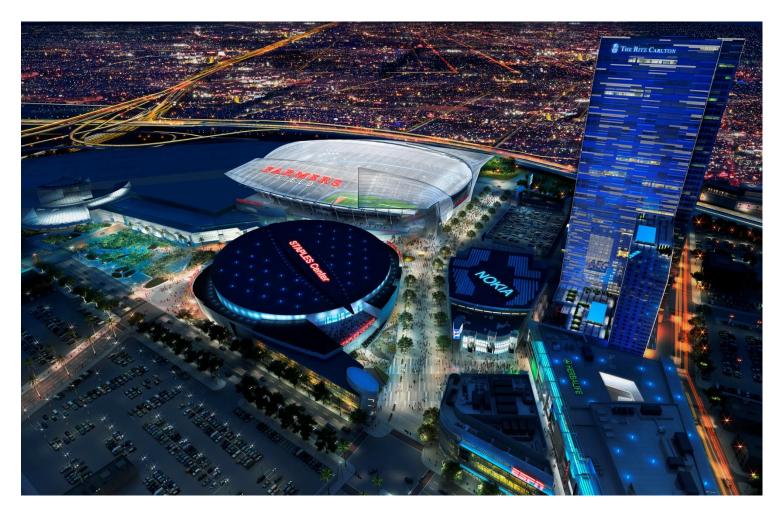




FARMERS FIELD NFL STADIUM DOWNTOWN LOS ANGELES

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





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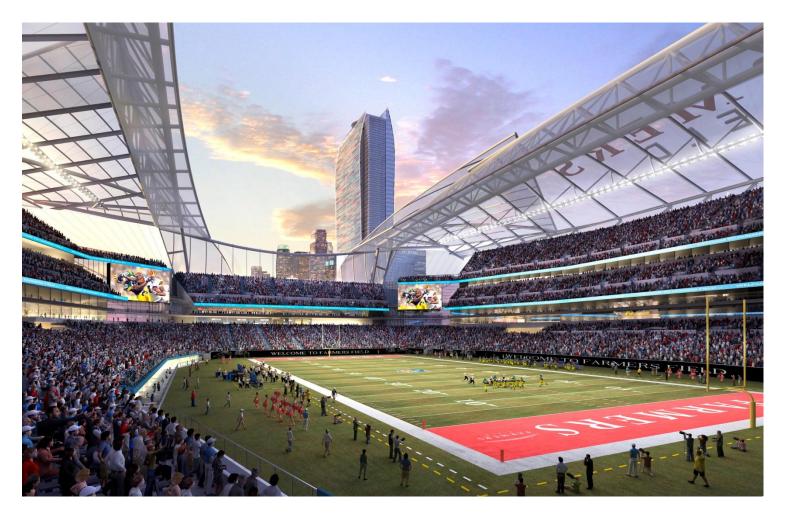




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AIA



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SHENBEI PERFORMING ARTS CENTER

DISTRICT OF SHENYANG - CHINA

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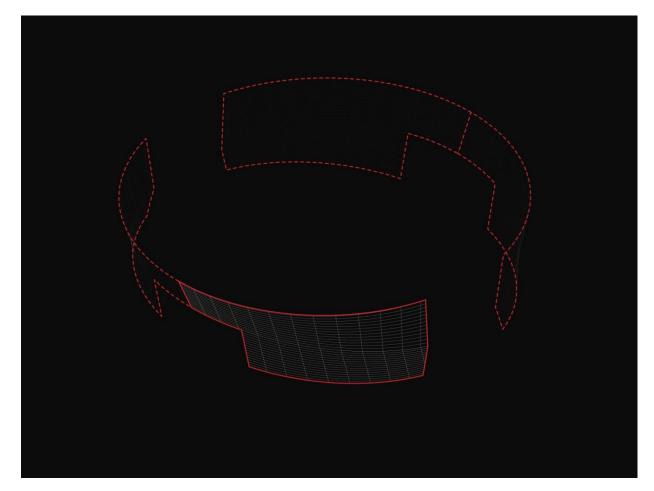




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TODAY'S LEARNING OBJECTIVES

Learning Objective #1:

To design and implement a cost-effective paneling solution using generative and computational tools.

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



TODAY'S LEARNING OBJECTIVES

Learning Objective #1:

To design and implement a cost-effective paneling solution using generative and computational tools.

Learning Objective #2:

How computational software can make your life easier in understanding these geometrical properties of your design and allow you to find an effective solution for them.

TAP Faster Forward 2011

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TODAY'S LEARNING OBJECTIVES

Learning Objective #1:

To design and implement a cost-effective paneling solution using generative and computational tools.

Learning Objective #2:

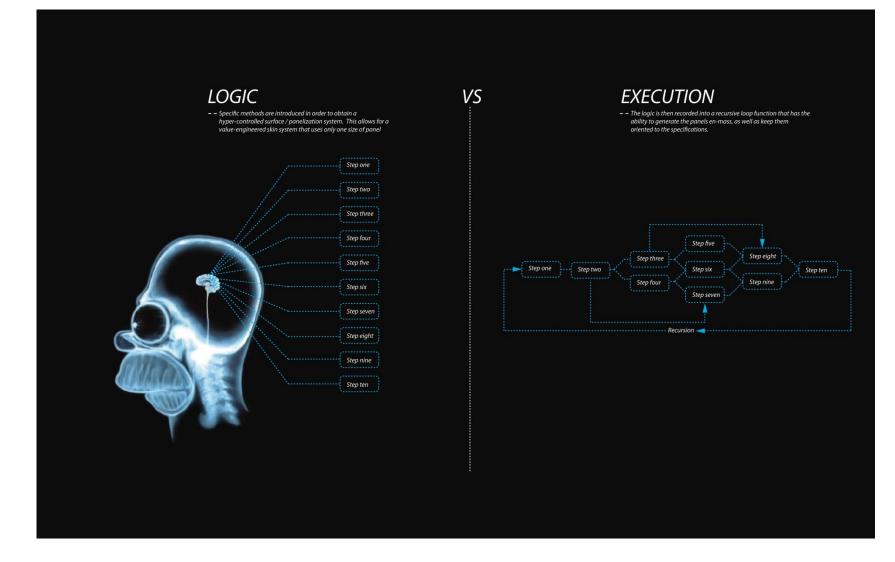
How computational software can make your life easier in understanding these geometrical properties of your design and allow you to find an effective solution for them.

Learning Objective #3:

Computational Tools don't solve problems "per se" but offers almost endless possibilities so it's up to the user to customize the tool in order to get the desired result.

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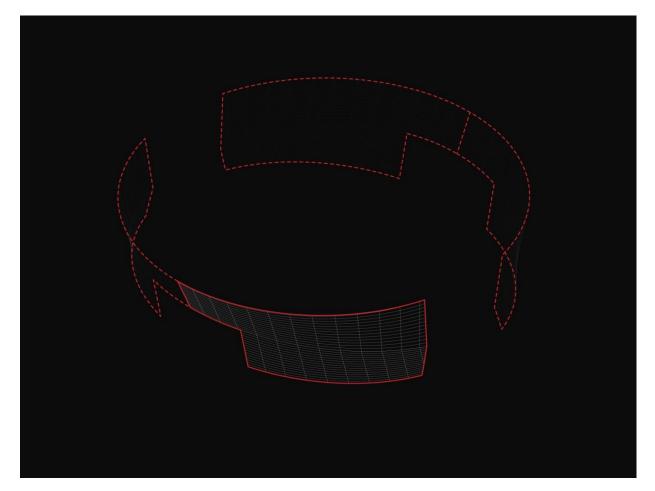
LOGIC vs EXECUTION



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THE PROJECT'S SURFACES ARE DOUBLE CURVED



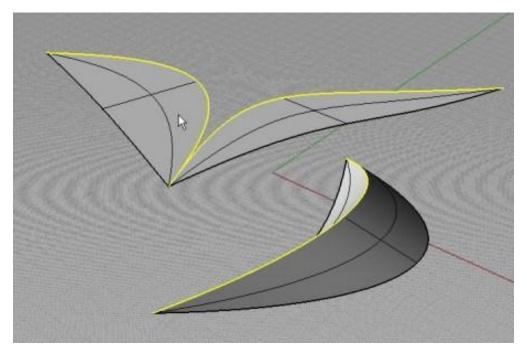
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UNDERSTANDING CURVATURE – SINGLE CURVATURE

1. The main problem is **geometrical**. *Single Curved Surfaces* can be flattened without stretching them and subdivide them in the 2D space and then transfer those information without data loss back to the 3D space.



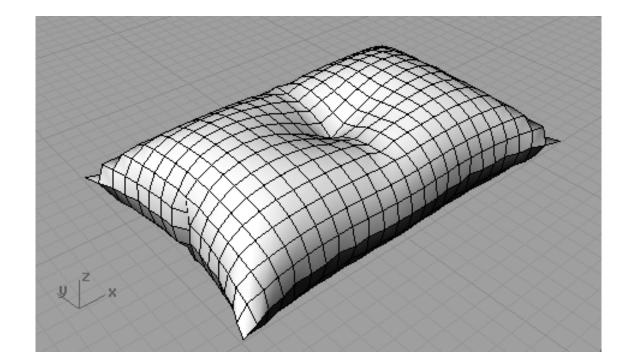
Example of "unrolling" a surface

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UNDERSTANDING CURVATURE – DOUBLE CURVATURE

2. The second main problem is that a *double curved-surface* can be subdivided into unique components but they will all result in different sizes which requires a high deal of customization and high costs.



Example of "doublecurved" components

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UNDERSTANDING CURVATURE – DOUBLE CURVATURE

2. The second main problem is that a *double curved-surface* can be subdivided into unique components but they will all result in different sizes which requires a high deal of customization and high costs.



Zaha Hadid Train Station Innsbruck, Austria

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AIA

UNDERSTANDING CURVATURE – DOUBLE CURVATURE

2. The second main problem is that a *double curved-surface* can be subdivided into unique components but they will all result in different sizes which requires a high deal of customization and high costs.



Gehry Partners *Deutsche Bank* Berlin, Germany

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SOLUTION: DESIGNING SINGLE CURVED SURFACES

3. Ideally we should be designing surfaces that can be "developed" or "unrolled" as they will conform to panels of the same size without stretching or tearing of the material.

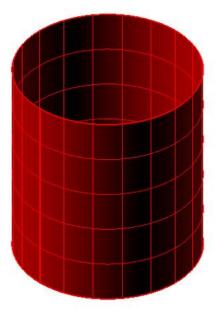


Gehry Partners *Disney Hall* Downtown Los Angeles

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TRANSLATION FROM SURFACE TO COMPONENT

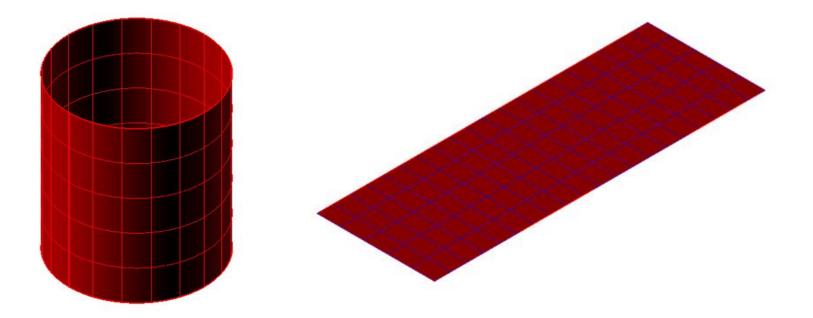


RULED and DEVELOPABLE SURFACE: CYLINDER

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TRANSLATION FROM SURFACE TO COMPONENT



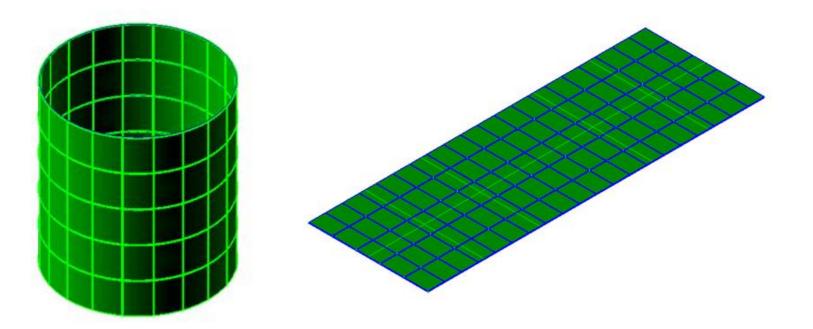
RULED and DEVELOPABLE SURFACE: CYLINDER

A cylinder can be unrolled and subdivded and all subdivisions result of the same size.

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TRANSLATION FROM SURFACE TO COMPONENT



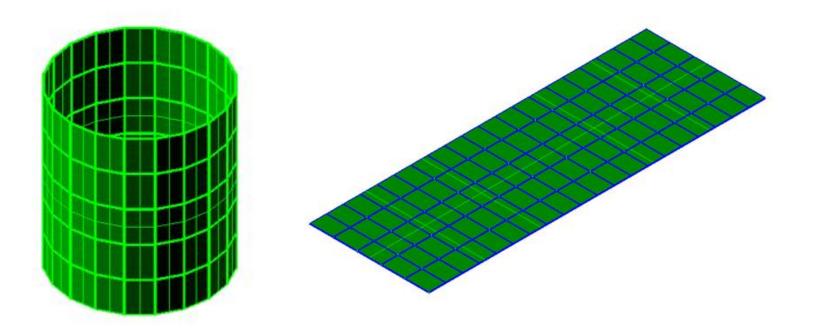
RULED and DEVELOPABLE SURFACE: CYLINDER

Panels can be rolled in one direction

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TRANSLATION FROM SURFACE TO COMPONENT



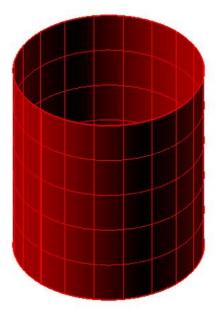
RULED and DEVELOPABLE SURFACE: CYLINDER

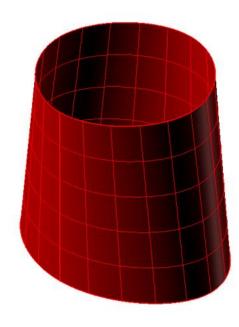
Panels can remain flat giving a "segmented" look to the surface

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TRANSLATION FROM SURFACE TO COMPONENT



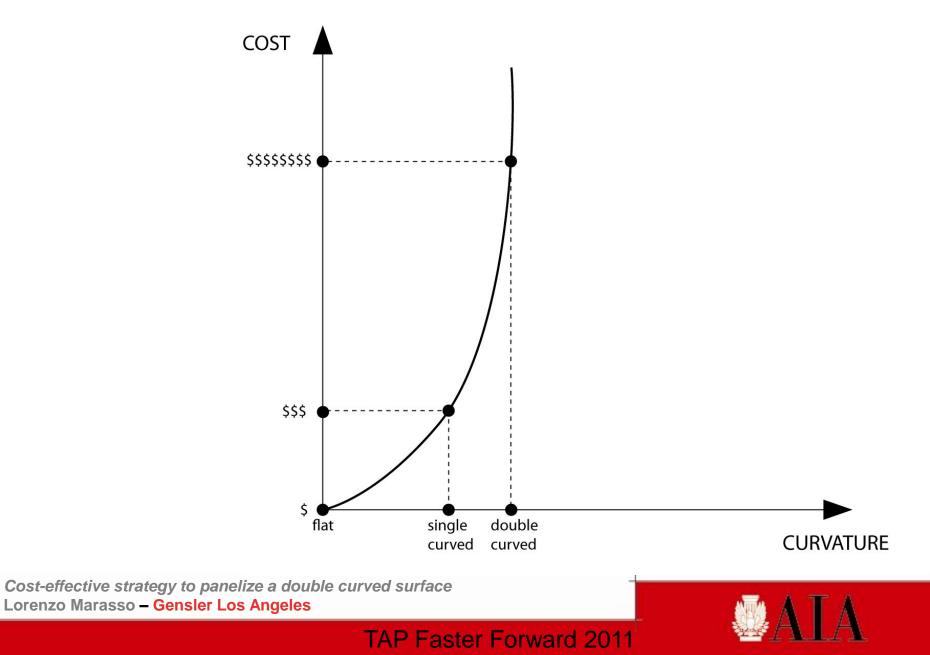


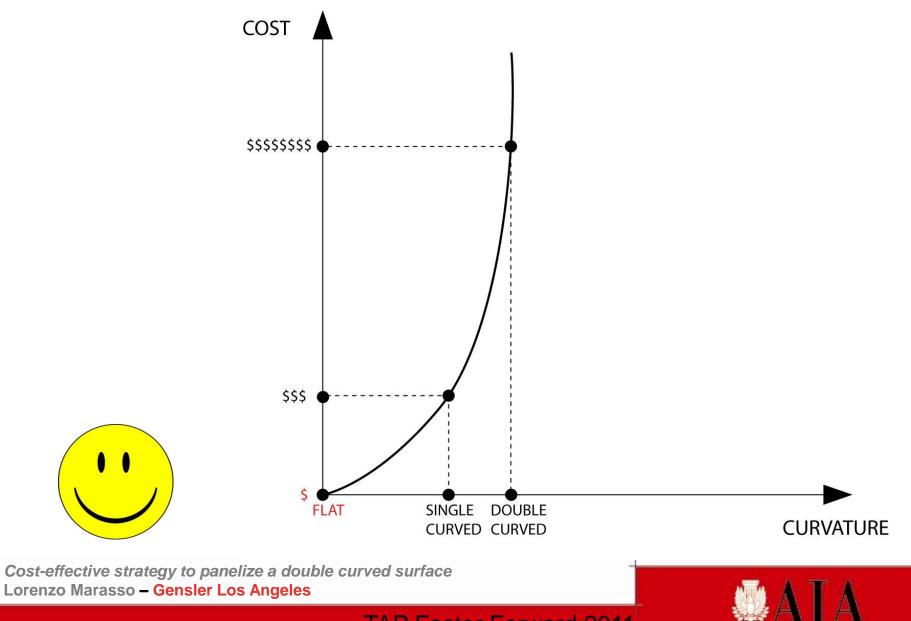
DEVELOPABLE SURFACE (also known as "single-curved surface") : All Panels are identical

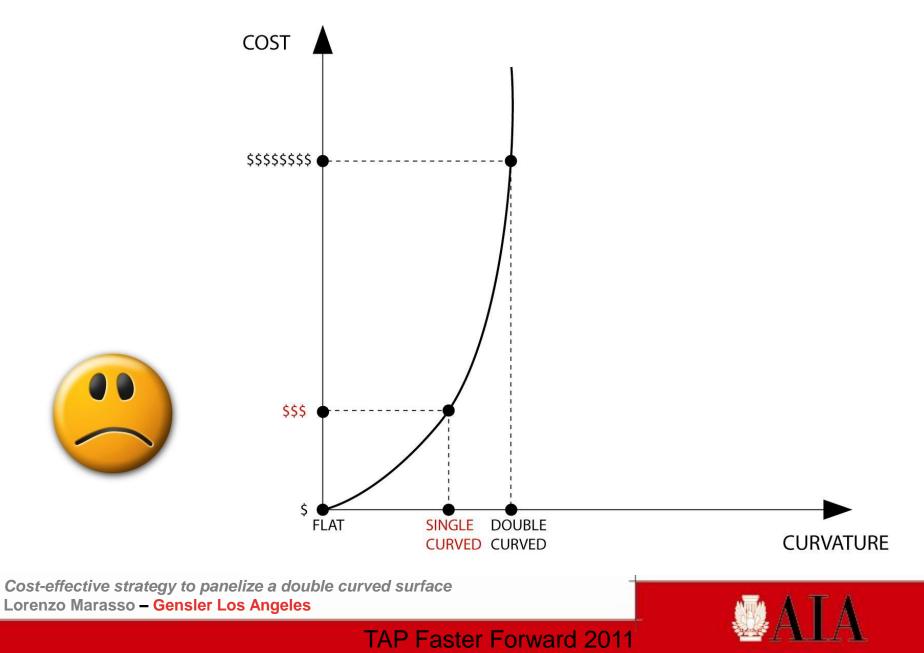
RULED LOFT (also known as a double-curved surface) : All panels are <u>unique</u>

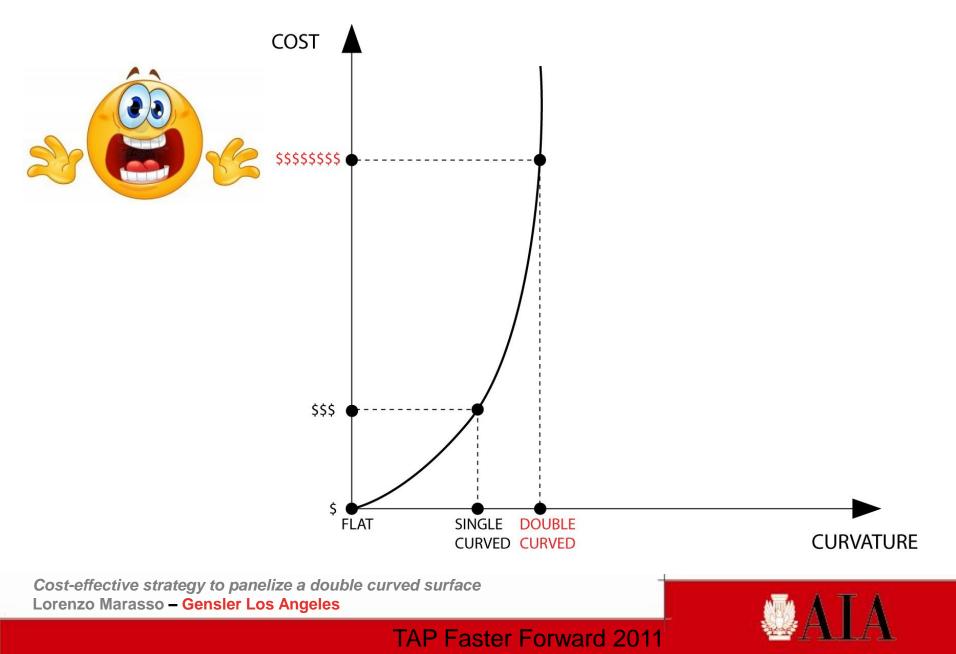
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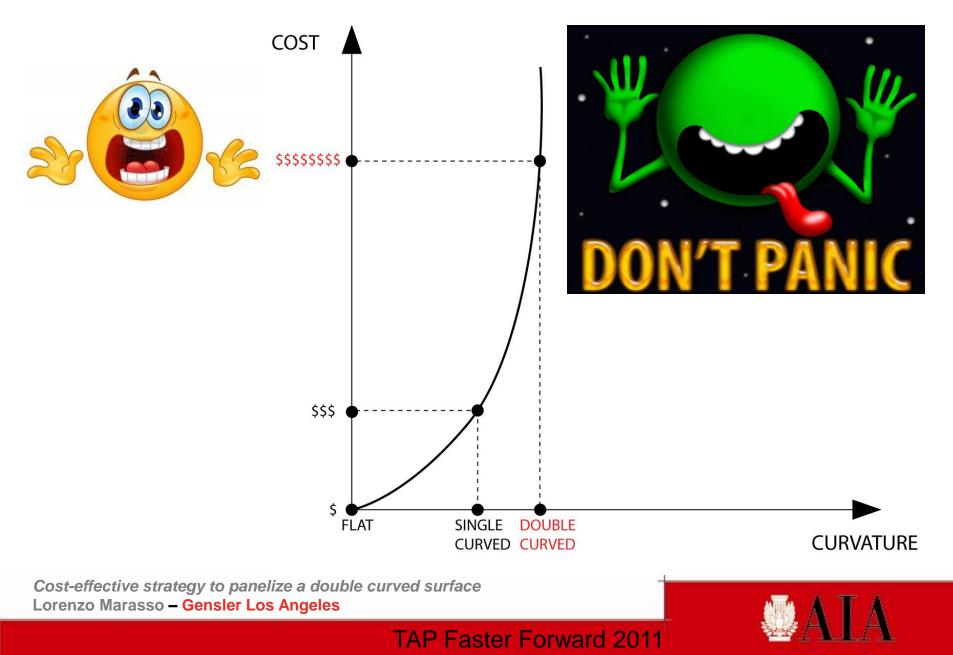




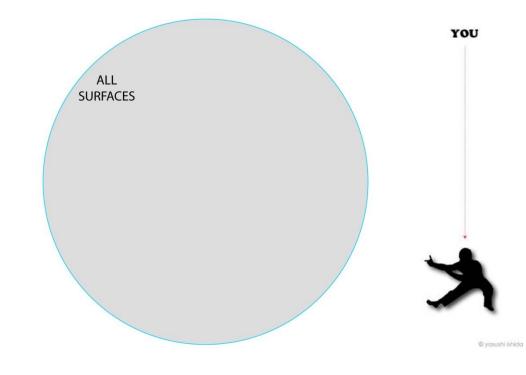








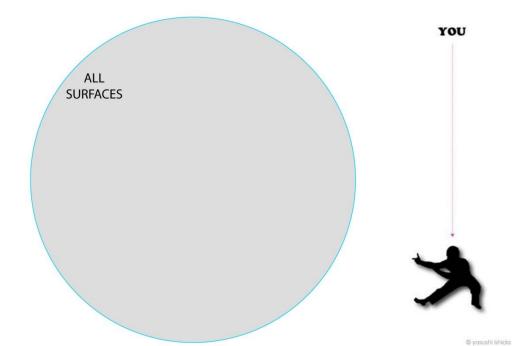
There are different categories of surfaces.



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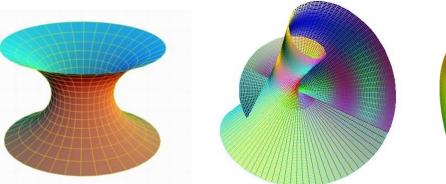
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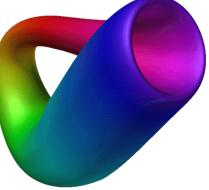
There are different categories of surfaces.



ALL SURFACES:

Surfaces with various configurations and different constructs

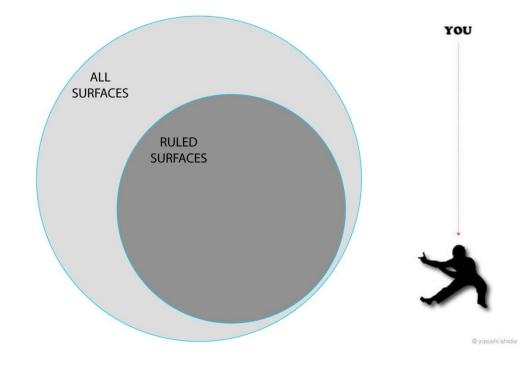




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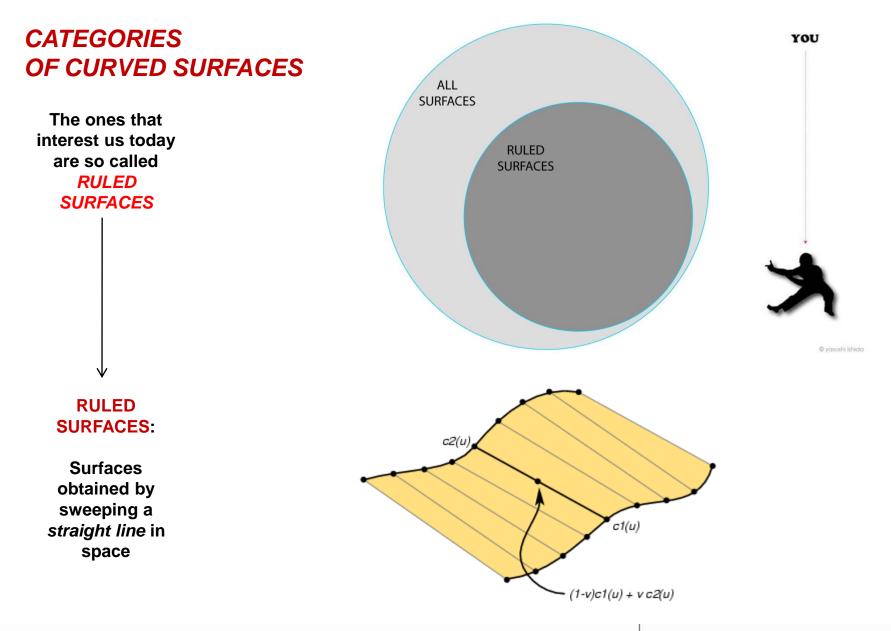
The ones that interest us today are so called *RULED SURFACES*



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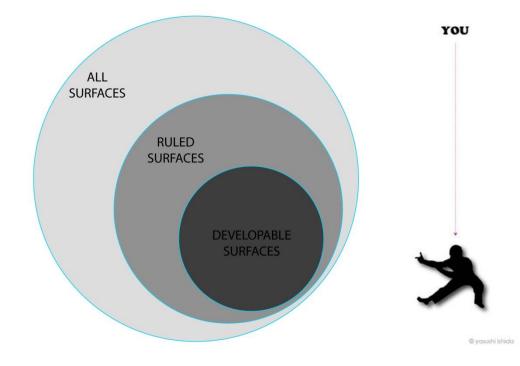
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A sub-category of *RULED SURFACES* are the *DEVELOPABLE SURFACES*



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A sub-category of RULED SURFACES are the DEVELOPABLE SURFACES

DEVELOPABLE SURFACES:

They are ruled surfaces except on every line there is a tangent plane with the same tangency in every point

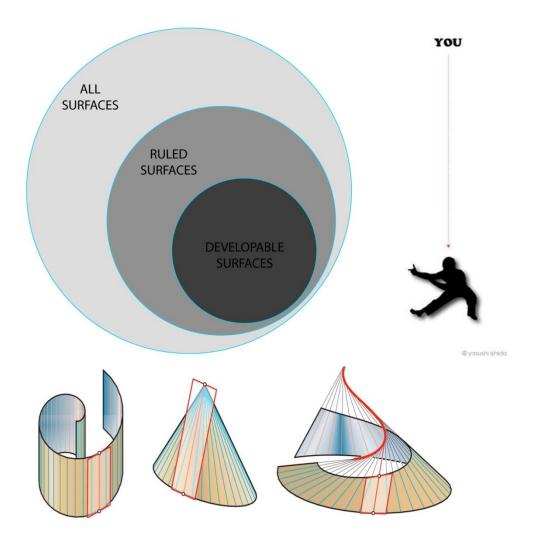
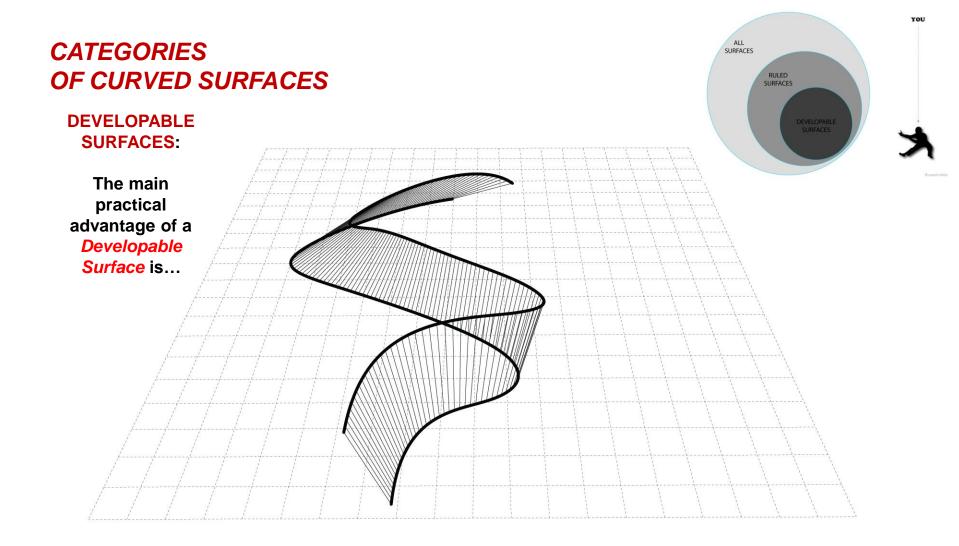


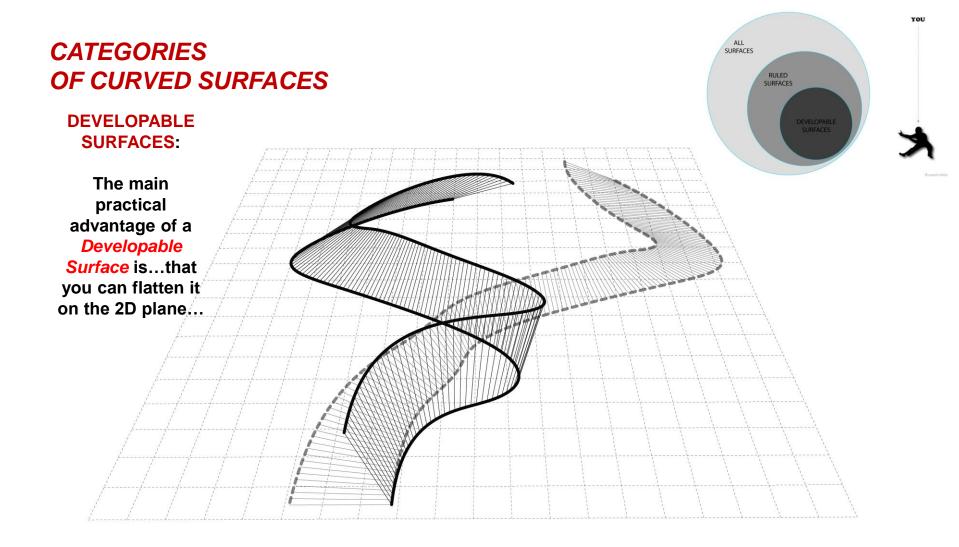
Figure 1: Three basic types of developable surfaces. (From left to right) General cylinder, general cone, tangent surface. Figure credits: (Pottmann et al., 2007).

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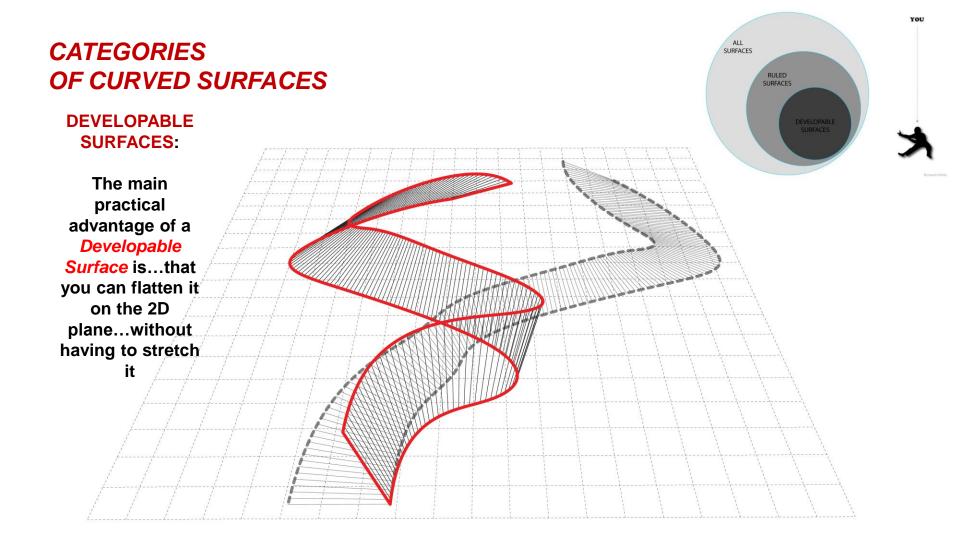




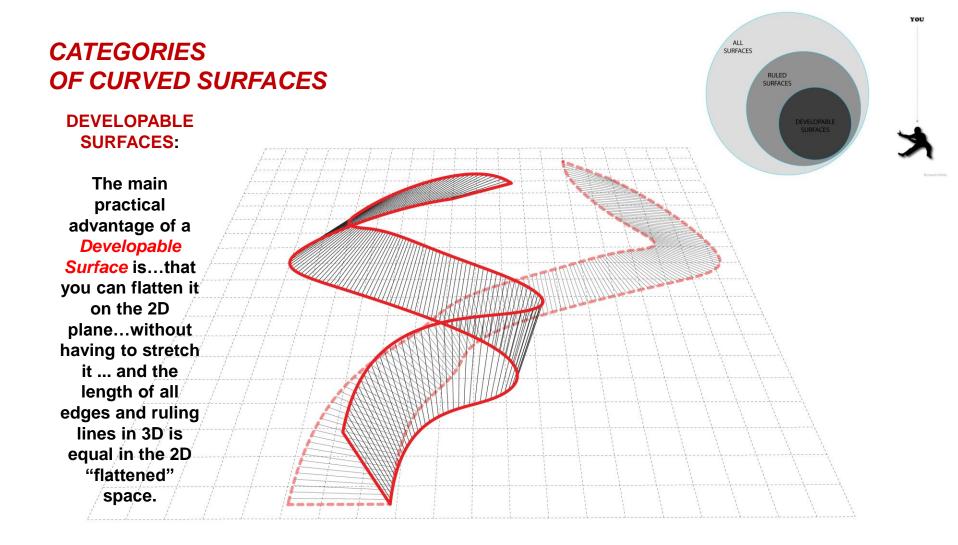
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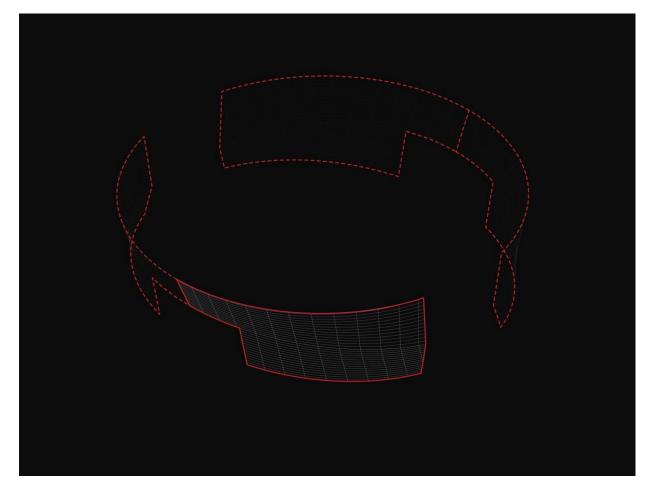


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THE PROJECT'S SURFACES ARE RULED BUT NOT DEVELOPABLE

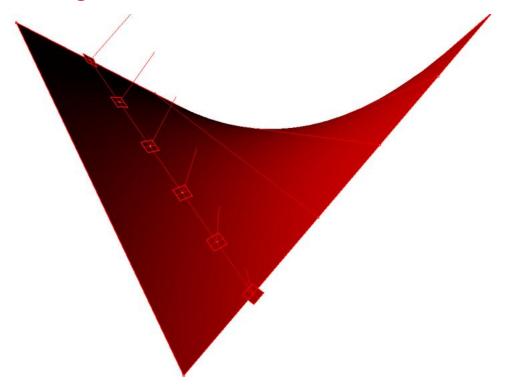


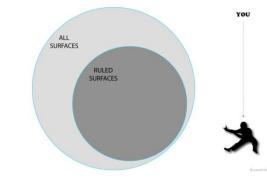
SHENBEI PERFORMING ARTS CENTER DISTRICT OF SHENYANG - CHINA

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



- Tangent Planes
- Angle between Normals



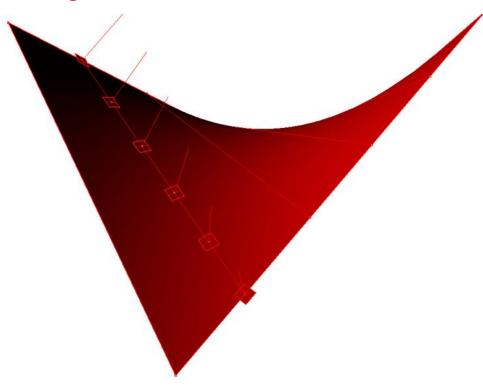


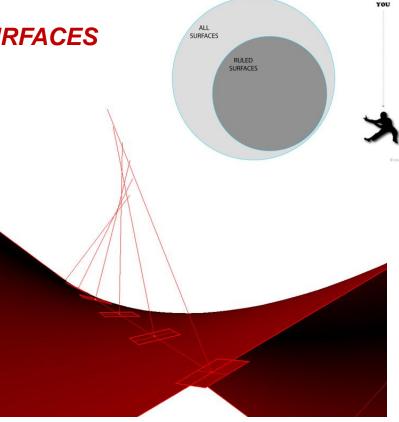
RULED SURFACE: HYPERBOLOID

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



- Tangent Planes
- Angle between Normals





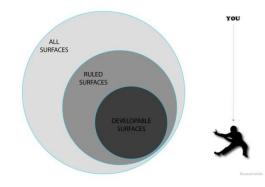
RULED SURFACE: HYPERBOLOID

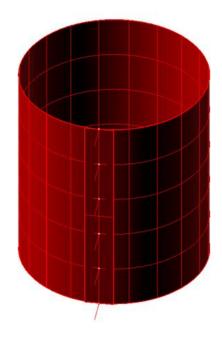
Tangent Plane is "tangent" in every point at all times except the normals are not parallel to each other

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



- Tangent Planes
- Angle between Normals



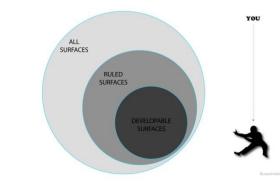


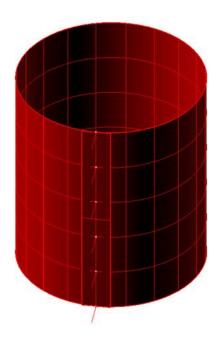
RULED and DEVELOPABLE SURFACE: CYLINDER

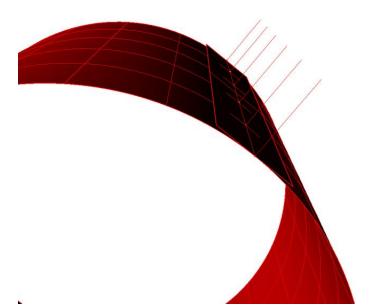
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



- Tangent Planes
- Angle between Normals







RULED and DEVELOPABLE SURFACE: CYLINDER

Tangent Plane is "tangent" in every point at all times except the normals are not parallel to each other

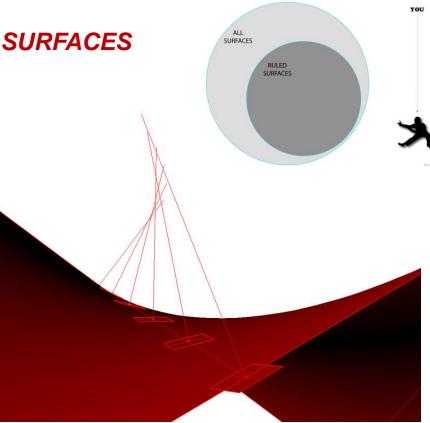
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

- Tangent Planes

- Angle between Normals

If the surface's tangent planes have the same tangency value the surface IS developable

If the surface angle between the normals is equal to zero the surface IS developable



RULED SURFACE: HYPERBOLOID

Tangent Plane is "tangent" in every point at all times except the normals are not parallel to each other

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- Tangent Planes

- Angle between Normals

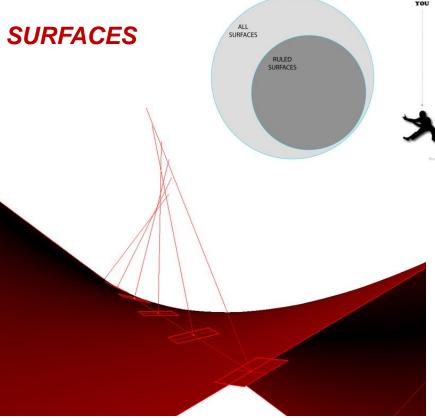
If the surface's tangent planes have the same tangency value the surface IS developable

If the surface angle between the normals is equal to zero the surface IS developable

If the surface's tangent planes numeric value is close from one another then the surface is very close in being developable

If the surface angle between the normals closer to zero then the surface is very close in being developable

RULED SURFACE: HYPERBOLOID

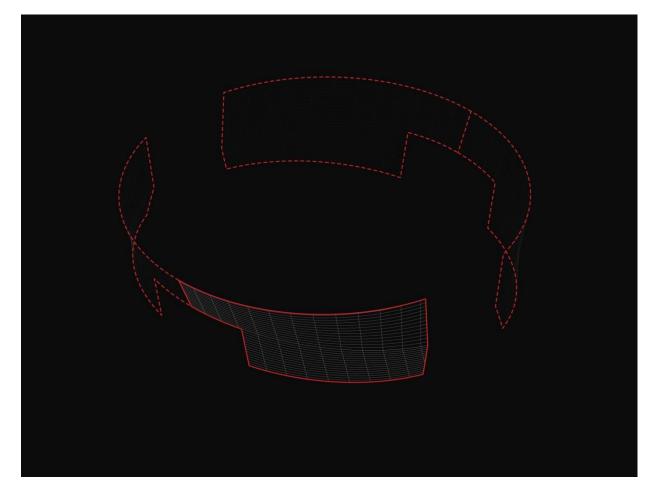


Tangent Plane is "tangent" in every point at all times except the normals are not parallel to each other

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THE PROJECT'S SURFACES ARE ALMOST DEVELOPABLE



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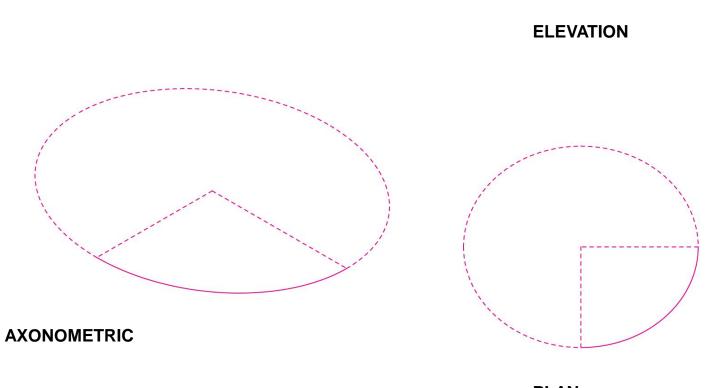




SHENBEI PERFORMING ARTS CENTER DISTRICT OF SHENYANG - CHINA

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

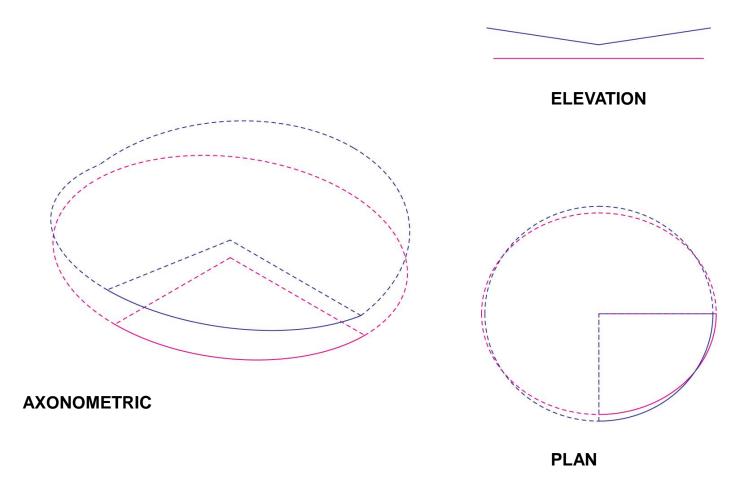




PLAN

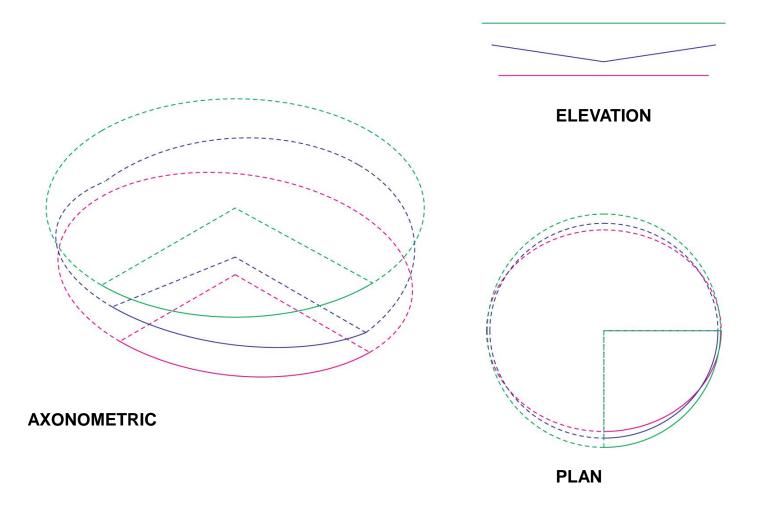
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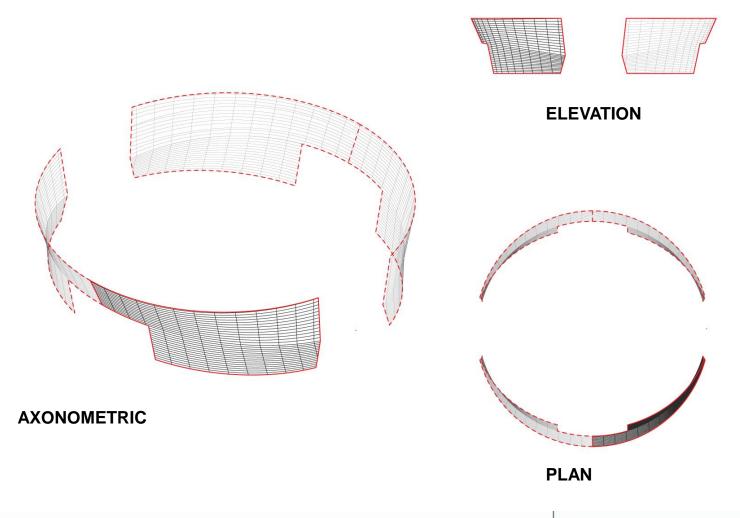
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





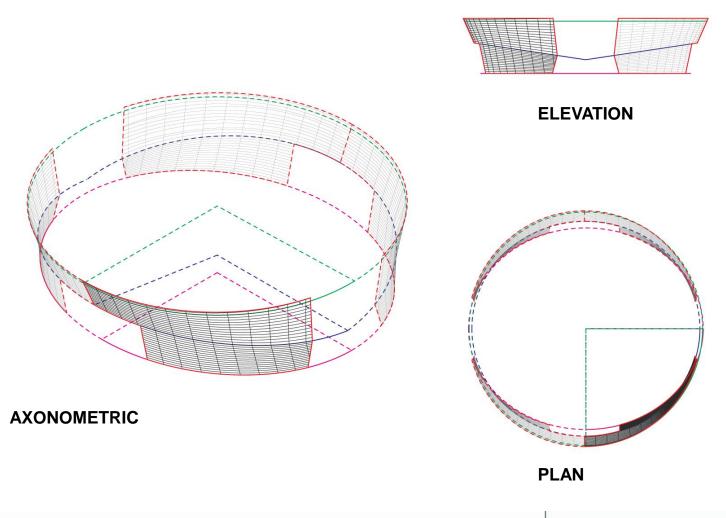
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

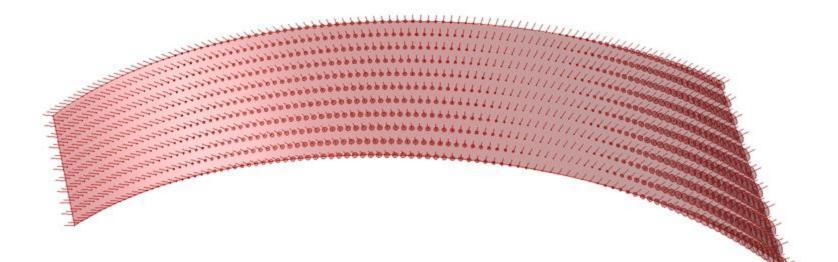




Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



HOW TO NUMERICALLY DETERMINE THAT THE SURFACE IS NOT *DEVELOPABLE*. Using parametric tools it is possible to determine in mathematical terms the amount of curvature at each point across a surface.

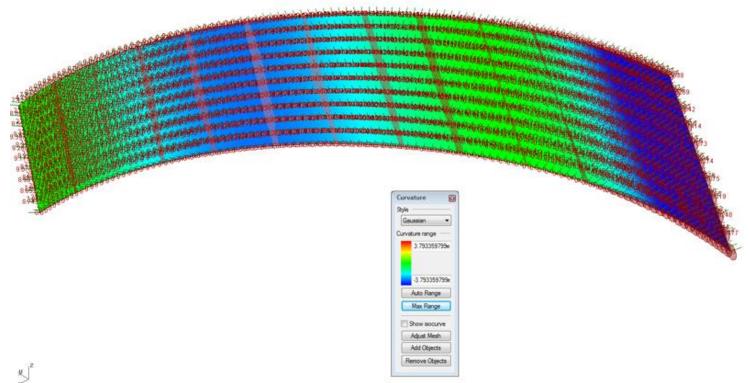


BY CALCULATING THE *MEAN CURVATURE* AT UV POINTS. The red circles are a visual datum that determines the amount of curvature in that spot.

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HOW TO NUMERICALLY DETERMINE THAT THE SURFACE IS NOT *DEVELOPABLE.* Using parametric tools it is possible to determine in mathematical terms the amount of curvature at each point across a surface.



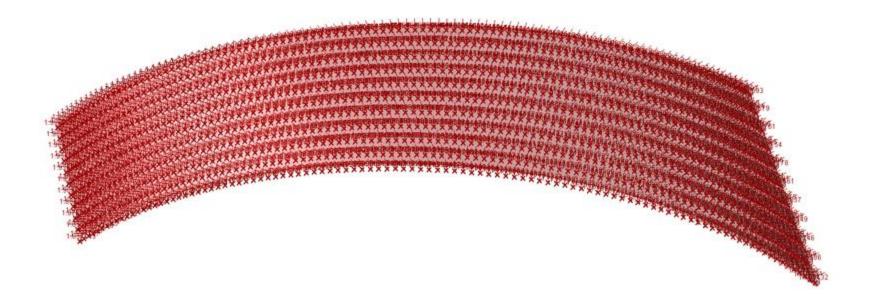
BY CALCULATING THE *GAUSSIAN CURVATURE* AT UV POINTS. Condition for Developable Surfaces is Gaussian Curvature to be equal to Zero in all points across the surface. The color coding reveals the amount of curvature.

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HOW TO NUMERICALLY DETERMINE THAT THE SURFACE IS NOT *DEVELOPABLE.* Using parametric tools it is possible to determine in mathematical terms the amount of curvature at each point across a surface.



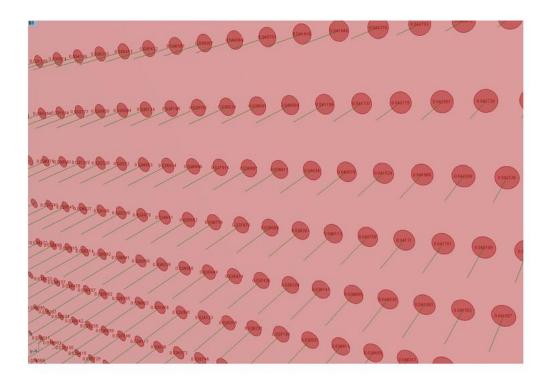
CALCULATION OF ANGLE BETWEEN NORMALS ON RULING LINES. If the angle between the normals is different from zero the surface is NOT developable.

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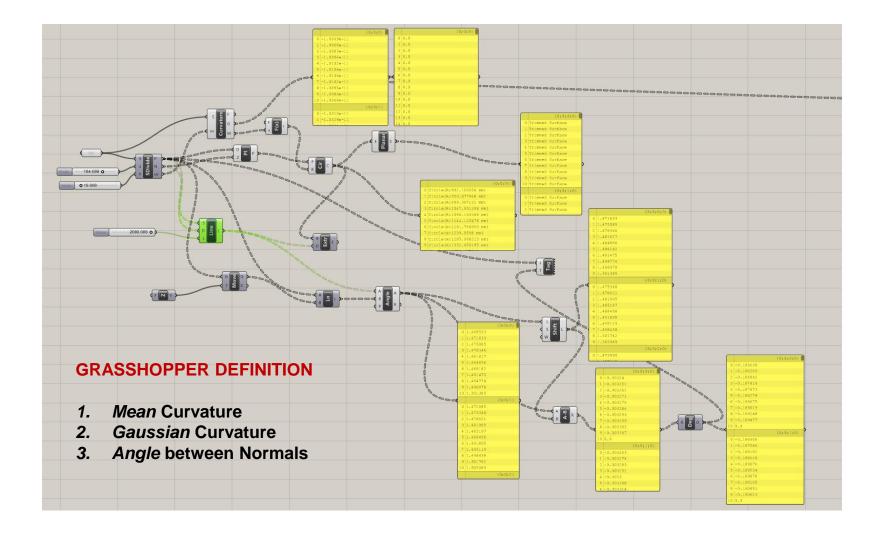
HOW TO NUMERICALLY DETERMINE THAT THE SURFACE IS NOT *DEVELOPABLE.* Using parametric tools it is possible to determine in mathematical terms the amount of curvature at each point across a surface.



CALCULATION OF ANGLE BETWEEN NORMALS ON RULING LINES. If the angle between the normals is different from zero the surface is NOT developable.

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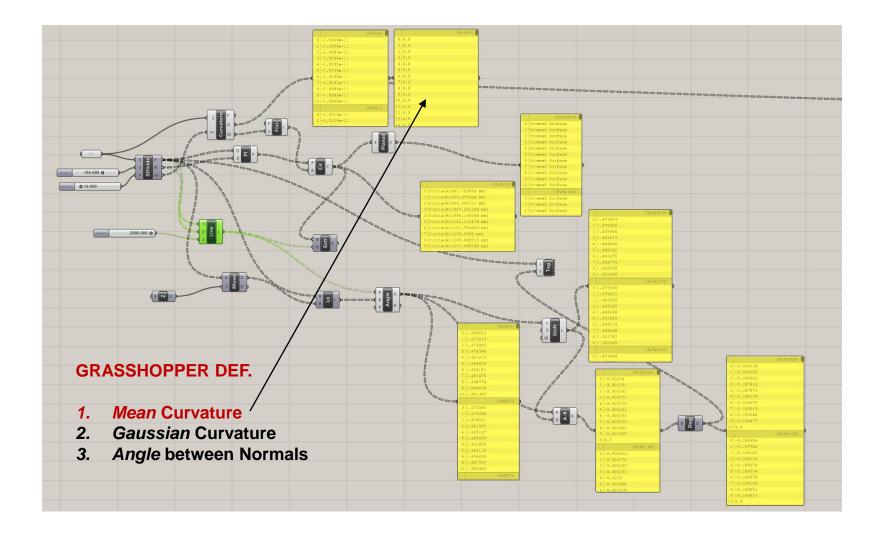




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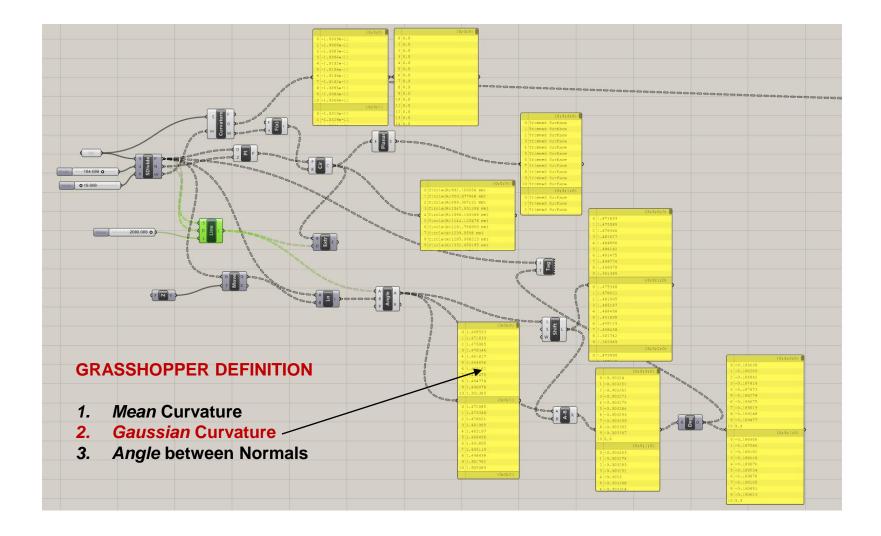
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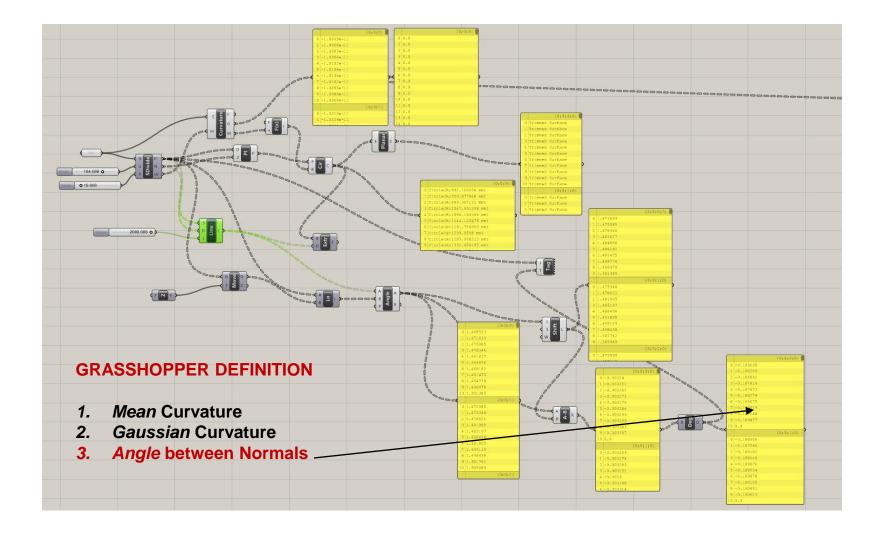
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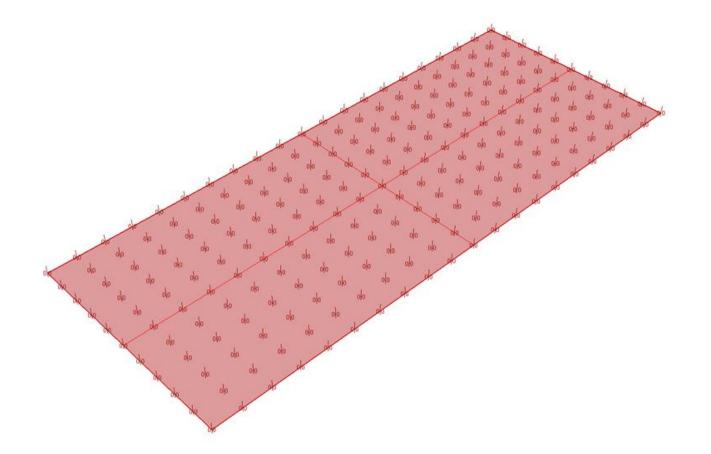




Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

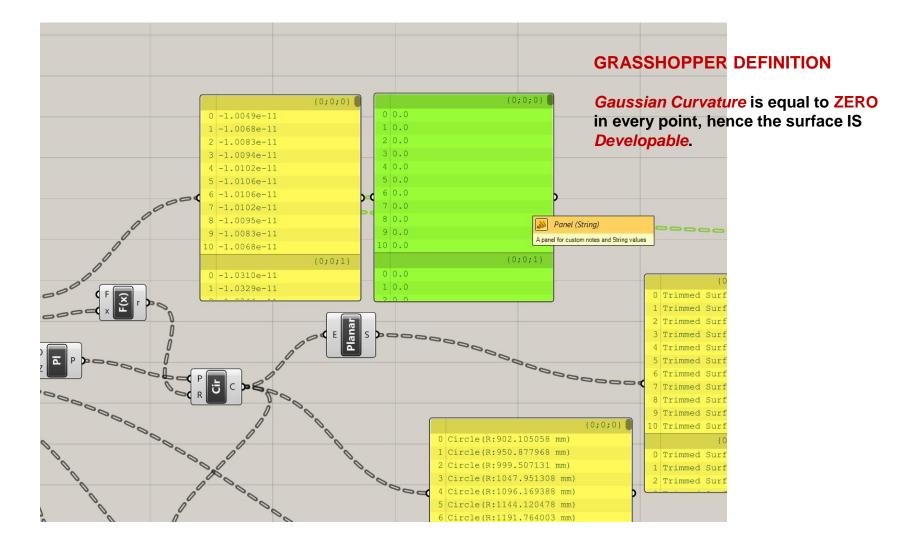


Application of Parametric Control to a Flat Surface



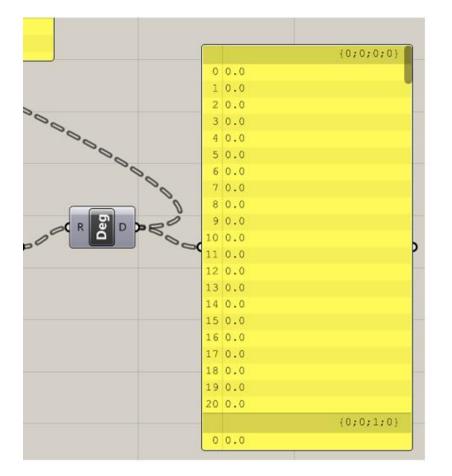
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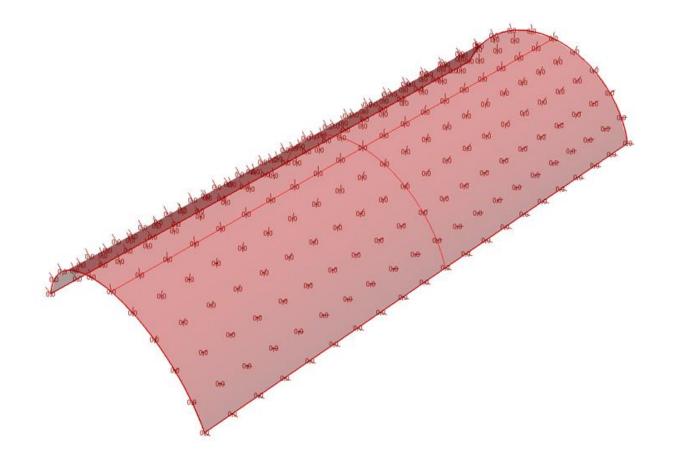
GRASSHOPPER DEFINITION

Angle between the normals is equal to ZERO, hence the surface IS *Developable*.

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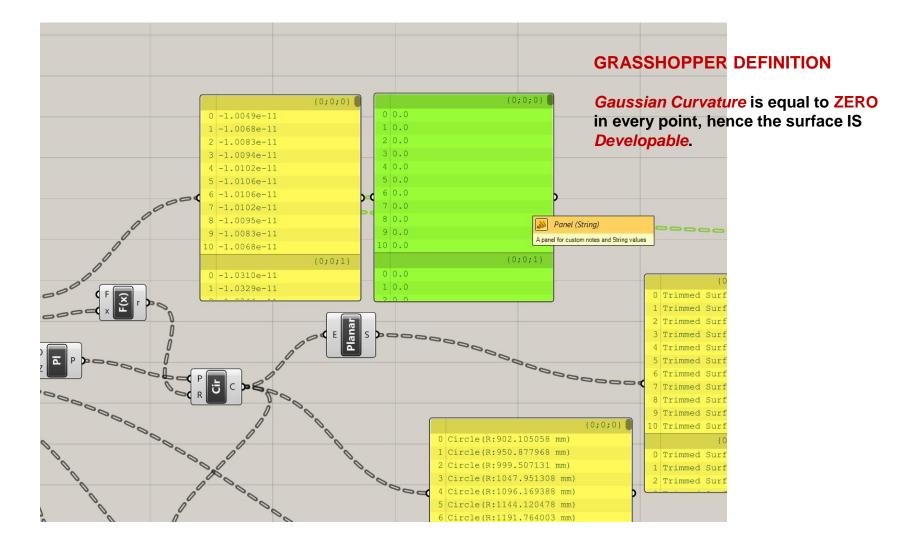


Application of Parametric Control to a Linear Extruded Surface



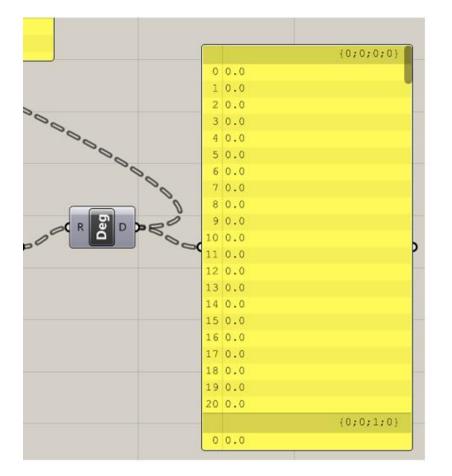
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GRASSHOPPER DEFINITION

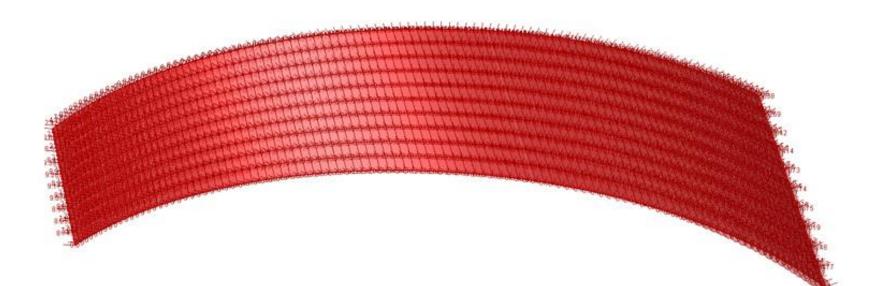
Angle between the normals is equal to ZERO, hence the surface IS *Developable*.

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PANELING DEFINITION – FROM SURFACE TO COMPONENT

GRASSHOPPER DEFINITION

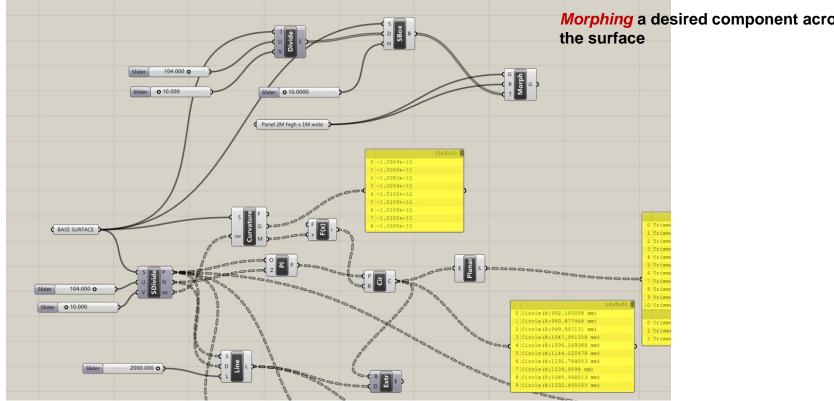


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PANELING DEFINITION

GRASSHOPPER DEFINITION



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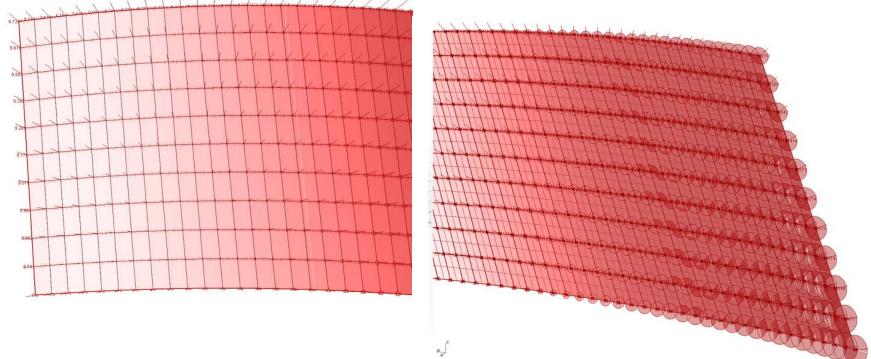
Morphing a desired component across

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PANELING DEFINITION

GRASSHOPPER DEFINITION

Morphing a desired component across the surface....results in unique panels that drift oblique when reaching one end



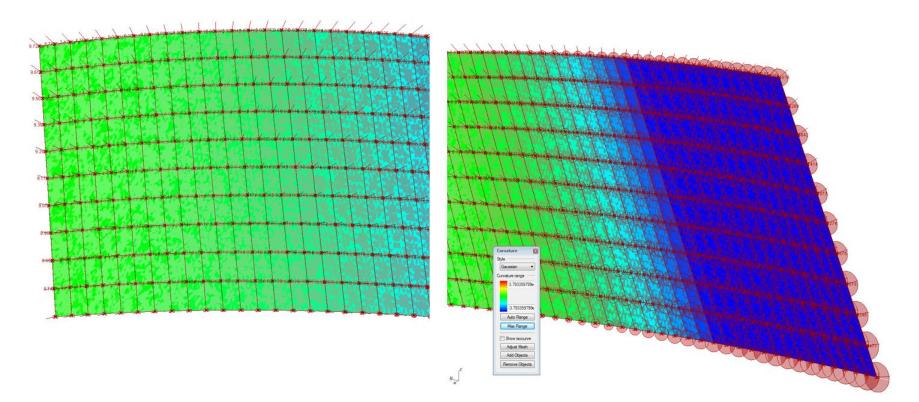
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PANELING DEFINITION

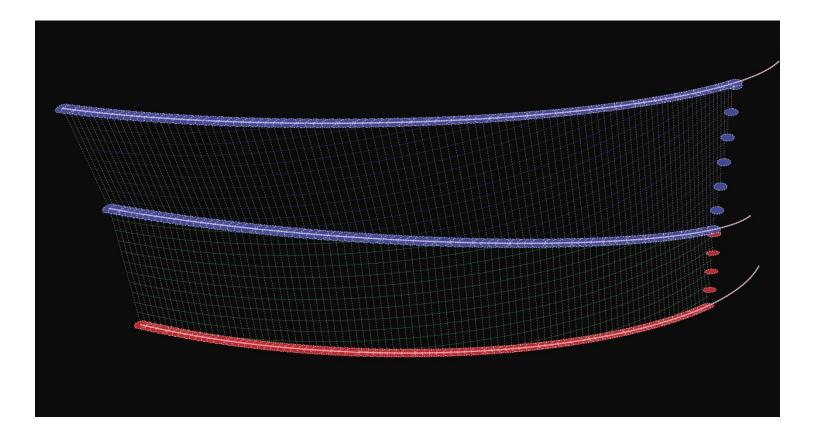
PARAMETRIC CONTROL

Gaussian Curvature visually colors different values of curvature



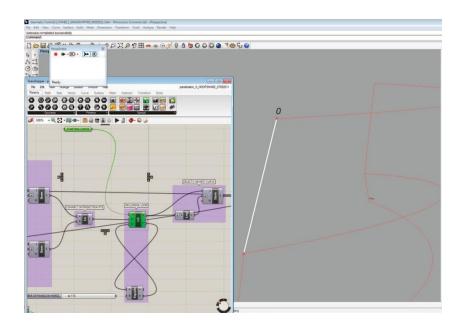
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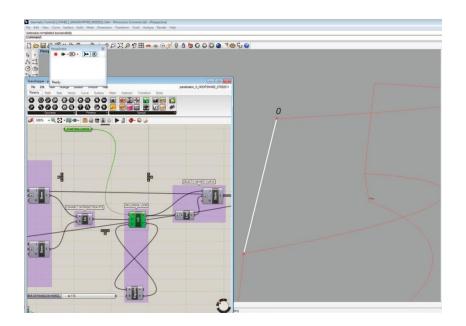




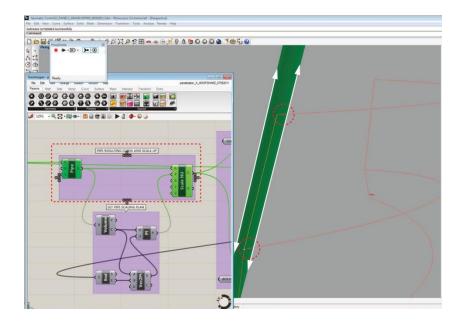
STEP 1: Start with edge curve from surface

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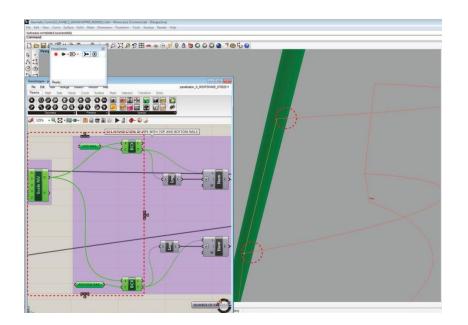
STEP 1: Start with edge curve from surface



STEP 2: Pipe curve and scale it up so that the surface intersects with the top and bottom rail curves

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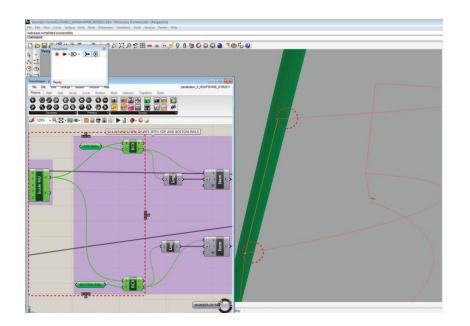




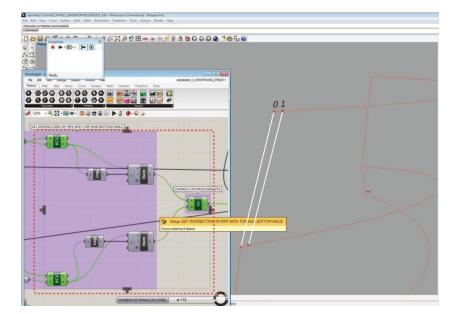
STEP 3: Get intersection points between top and bottom rail and pipe

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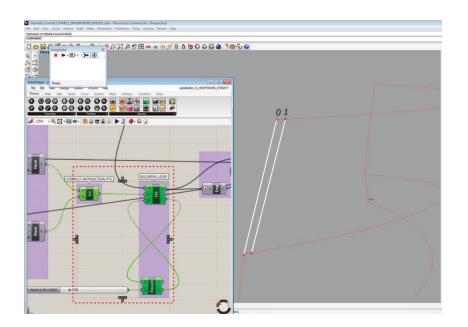
STEP 3: Get intersection points between top and bottom rail and pipe



STEP 4: Draw new curve between intersection points

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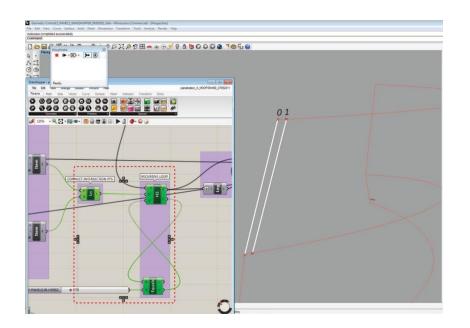




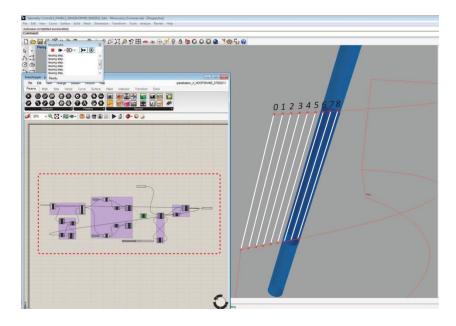
STEP 5: New curve goes into RECURSIVE LOOP function

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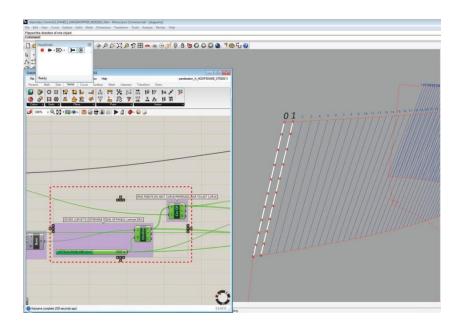
STEP 5: New curve goes into *RECURSIVE LOOP* function



STEP 6: REPEAT

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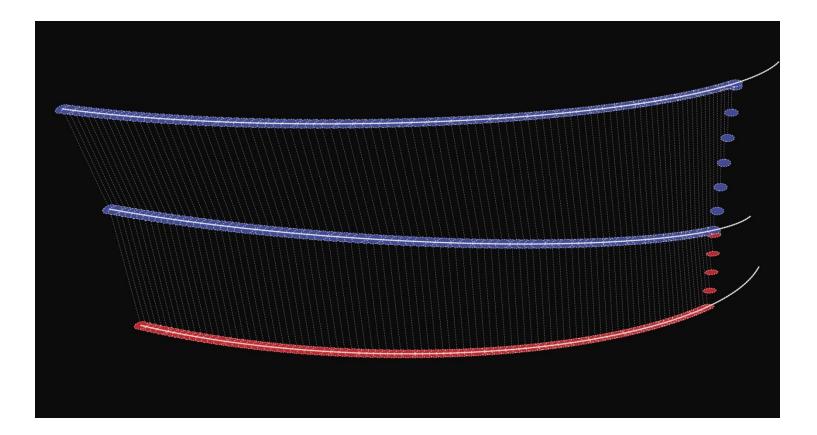




STEP 7: Use generated curves to begin paneling. The 1st crv is divide into 2000mm segments, then the closest point (perpendicular) on the next curve is found.

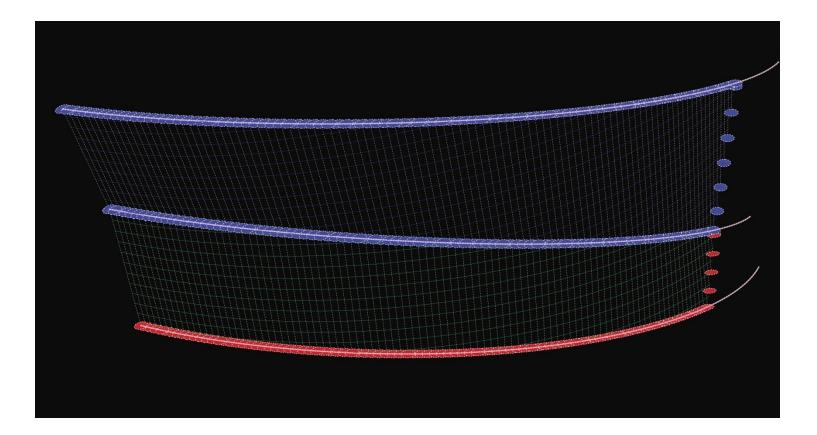
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





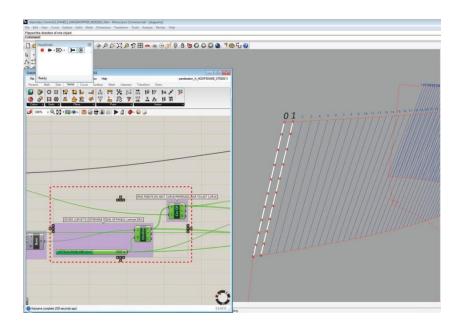
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

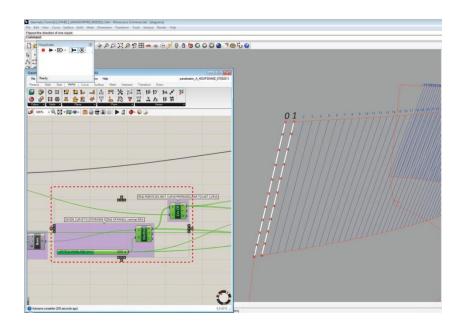




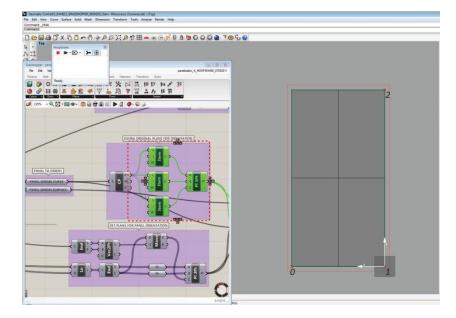
STEP 7: Use generated curves to begin paneling. The 1st crv is divide into 2000mm segments, then the closest point (perpendicular) on the next curve is found.

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

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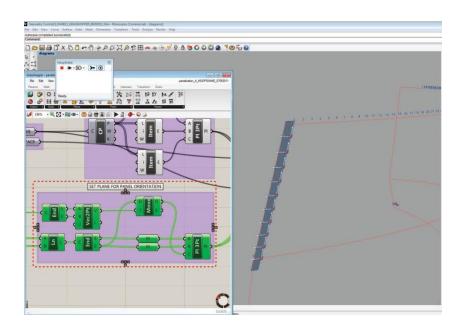
STEP 7: Use generated curves to begin paneling. The 1st crv is divide into 2000mm segments, then the closest point (perpendicular) on the next curve is found.



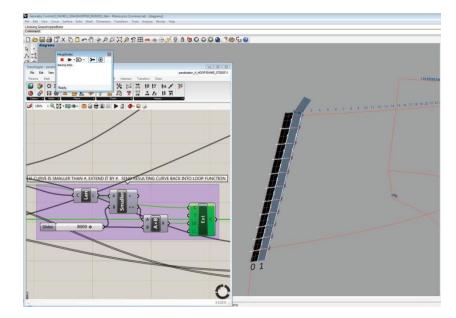
STEP 8: Define a reference plane to orient the panel from .

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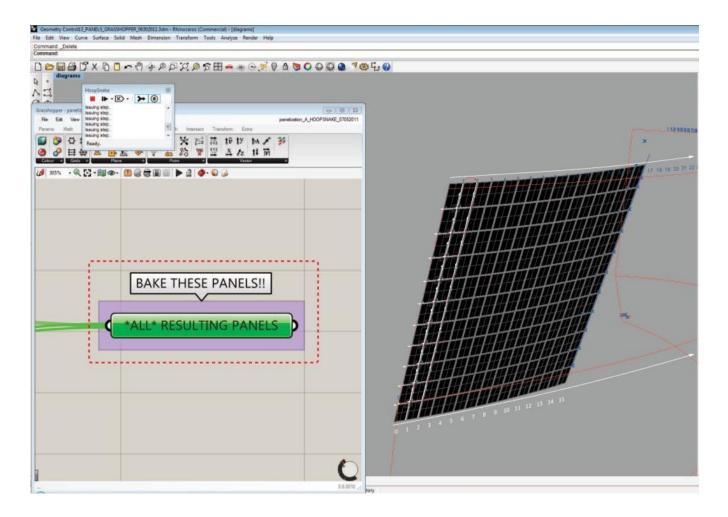
STEP 9: Orient panels to generated points. This ensures that each panel is perpendicular to its adjacent panels.



STEP 10: Take the last vertical curve and send it back to the *RECURSIVE LOOP*.

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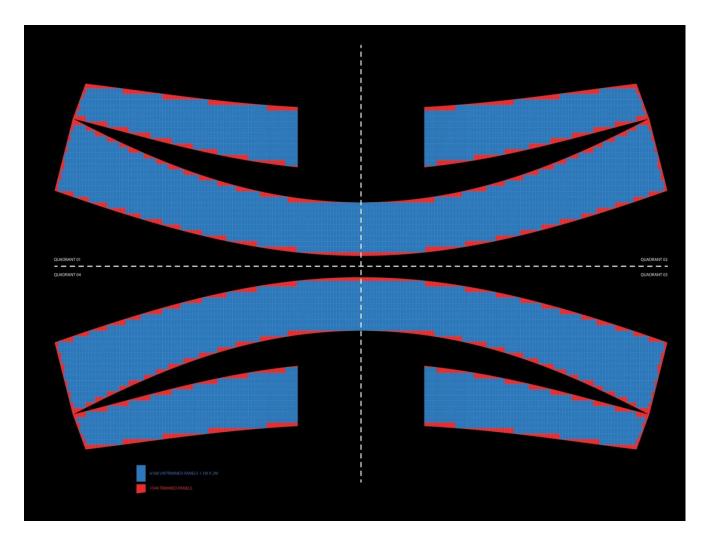


STEP 11: REPEAT until all panels are arrayed over the surface

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

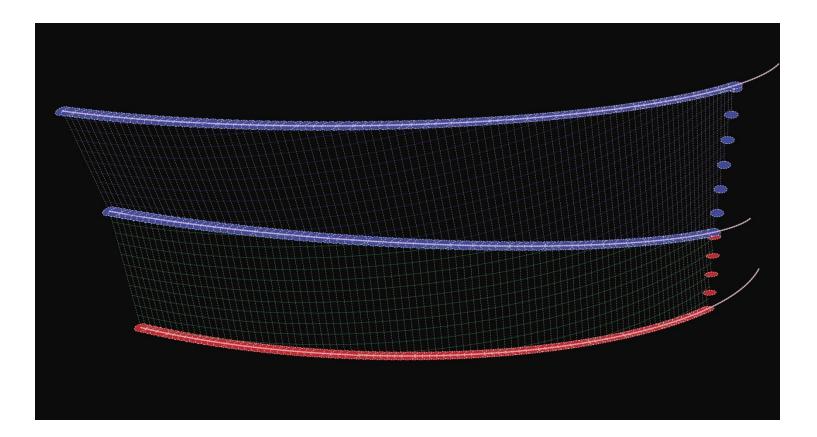


Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



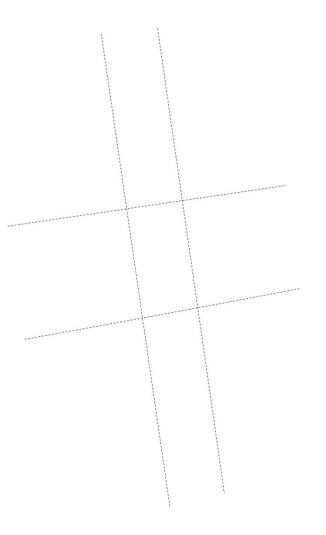
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





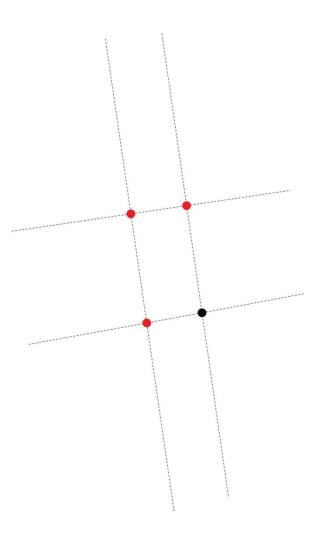
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





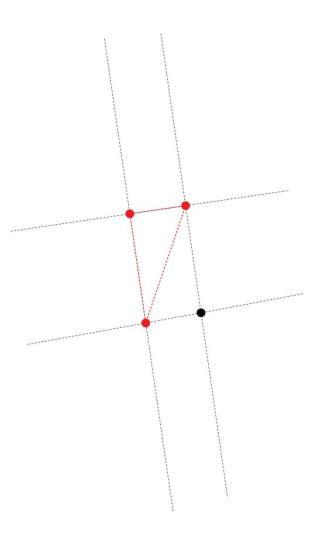
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





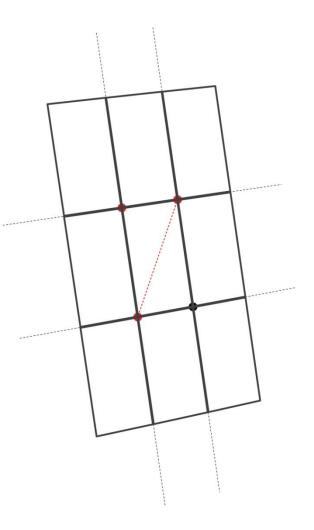
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





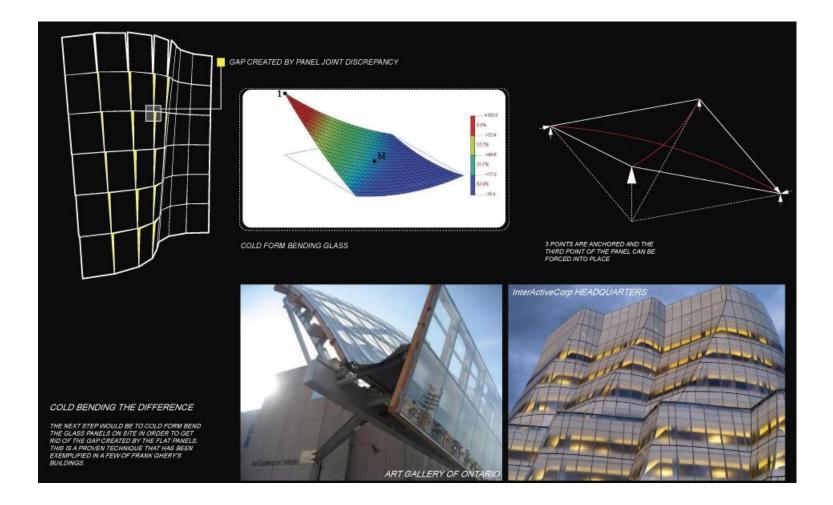
Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

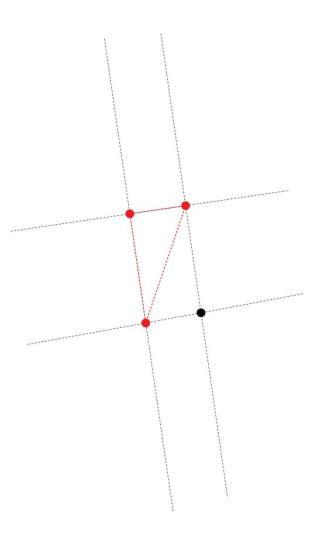




Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



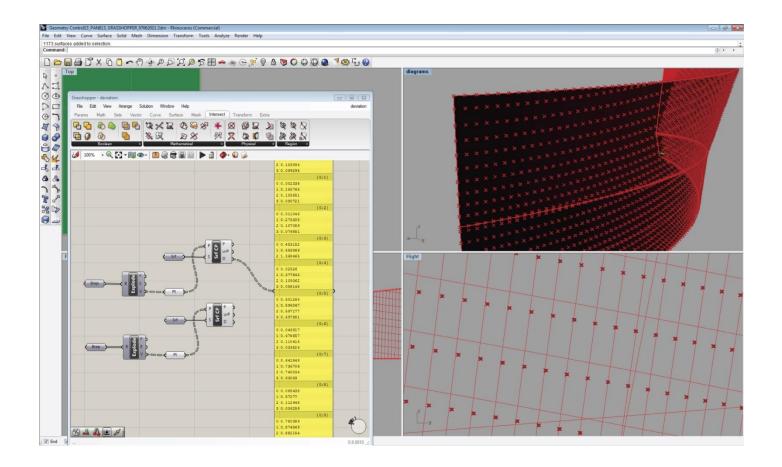
COLD BENDING



Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



COLD BENDING



Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles

AIA

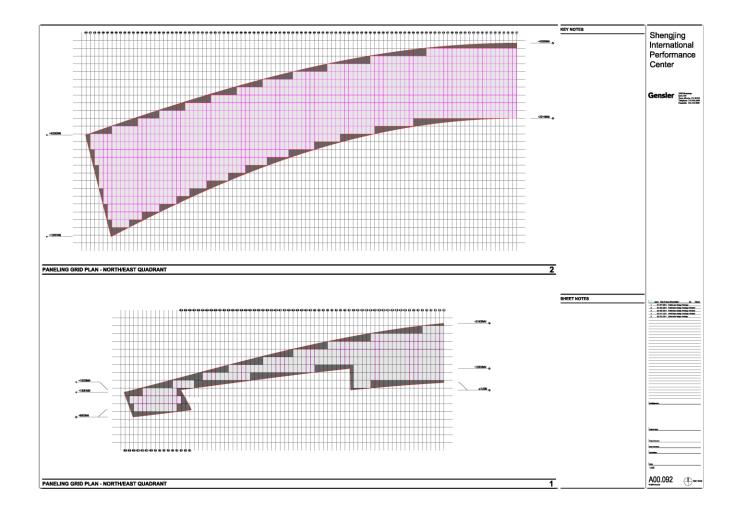
COLD BENDING

[0,0] 0, 1,2436		3.0.909395	1.2.274326		3.0.171197	0.0.338504		1. 5.463433			0. 1.179344	3. 4.232656	0. 16.314167	3.75.741874	79.211463	1.60.241334	0.81.068758 1.80.380023				1.47.969222 2.52.466913			3. 33.048891		1.11.703188
1.0.0558 2.0.1039	34 2. 1.569858	0.0.321577	3. 1.813904 (0;57)	1.8.793226 2.11.141791		3.0.205833	0.9.221132 1.1.956659	3.0.889968 (0;150)		0.2.6492	3. 1.470417	0.12.229548 1.4.09864	2.0.022663 3.13.485215	0. 121.270871 1. 113.494867 ((0;280) 0.29.421382	3.84.930575 (0;299)	2.50.69347 3.44.335846	1.64.291125 2.68.057756	0.67.578898 1.51.952705	(0;374) 0. 57.544848	3.56.820178 (0;393)	2.22.333074 3.34.900536	1.36.310019 2.35.682763	1.24.103241	0. 24.846379	3. 13.022182 (0;487)
3. 0.0992 (0;1, 0. 0.0023	1 [0:20]	2.0.113014 3.0.150778 (0:39)	0.2.075329 1.5.114233 2.6.769492	3.2.551295 [0;76] 0.4.42682	1.0.166785 2.0.190699 3.0.185219		3. 7.799304	0.7.051583 1.0.546015 2.0.125664	{0;169} 0.2.8956 1.9.513235	1.22.345805 2.21.303004 3.2.245454				2.87.462188 3.87.914679 (0:262)	. 0.443861		(0;318) 0.88.025612 1.84.017643	[0;337]	2.61.890211 3.71.641602 10:3561	2.36.014297	1.3.984241	(0;412) 0.20.49524 1.24.158645	(0;431)	2.33.005807 3.37.483865 (0:450)		1.8.461702
1.0.1657	51 2.0.119074	0.1.539747	3.2.011797 {0;58}	1.3.325537 2.0.161821	(0;95) 0. 0.92097	2.13.730319 3.2.774024	0.3.820596 1.6.769841	3. 5.331709 (0;151)	2.5.662672 3.0.628229	0.3.850457	2. 46.328846 3. 3.127545	(0;225) 0. 1.881745	3. 2.576194	0. 121.889911 1. 110.294243 ((0,281) 0.50.815407	{0;300}	2.61.280758 3.58.401756	2.16.511712	0.15.355483 1.25.379128	(0;375) 0. 62.674394		3. 16.094206	2. 39.350334	1.27.784516	0.26.642122	3. 14.673296 (0;488)
3. 0.0907. (0;2. 0. 0.0110	(0;21)	2.2.749017 3.0.75916 (0:40)	0.1.9217 1.2.051685 2.0.139824	3.4.062144 (0;77) 0.1.320411	1.8.672587 2.14.458463 3.1.439828			0.2.576204 1.1.49013 2.7.129539	(0;170) 0.1.649901 1.0.212551		(0;207) 0. 1.361954 1. 2.27578	1.0.946384 2.0.108697 3.0.146824	(0;244) 0.13.33292 1.4.747119	2.91.496255 3.95.923926 (0-263)	. 26.62852	1. 57.53782	(0:319) 0. 91.633527 1. 84.448337	3.34.774704 [0;338] 0.49.687169	3. 39.698601	1.58.496855 2.44.915394 3.42.852476	0. 32.898628 1. 15.971074 2. 22.33975	0. 30.320862	(0:432)	2.37.429364 3.40.565178 (0-451)		0.9.580652 1.0.401227 2.5.546677
1.0.2733	89 2. 1.701552	0.0.25611	3. 1.684746 (0;59)	1.8.00437 2.11.184123			0.7.897313 1.1.527549	3. 0.538672 (0;152)		(0;189) 0. 3.665698	2.0.083798 3.1.302022	(0,226) 0. 2.031621	3. 9.832829	0.118.654214 1.103.38675 0	(0;282) 0,69.342675	3. 12.857778 {0;301}	2.68.502234 3.68.958564	1.28.012017 2.34.812547	0.32.479642 1.39.255231	(0;376) 0.65.255563	3.34.202191 {0;395}	2.7.652543 3.0.111316	1.2.277432 2.2.017914		0.27.240964	3. 10.874952 (0;489)
3. 0.0766 (0;3 0. 0.4531	[0;22]	3.0.060315	0.1.716312 1.4.768285 2.6.89075	3.2.077806 (0;78) 0.4.171066	1.3.284467 2.0.164478 3.5.912905		3.6.387206	0.5.424142	(0;171) 0.4.920763 1.12 509099	1.24.731217 2.23.348153 3.1.749545	(0;208) 0. 1.785489 1. 43.997378	2.54.228658		2.91.66805 3.99.922248 (0-264)	49.930432	1.71.566256		[0;339]		2.51.237006	0.41.813067 1.26.462694 2.34.198397	0. 37.843764	(0;433)	2.17.940581 3.26.644676 (0-452)		1.4.670962
1.0.4533 2.1.3684	59 1.0.972235 55 2.0.118752	0.1.408232	3. 1.700353 (0;60)	1.2.96127 2.0.15684	(0;97) 0. 2.288266	2.0.156966 3.7.079541	0. 6.148394 1. 3.620024	3. 3.674194 (0;153)	2.7.165942 3.0.523217	(0;190) 0.2.63783	2.48.84359 3.2.017744	(0,227) 0. 11.55649	2.77.239034 3.8.938151	0.111.71261 1.92.917864	(0;283) 0.84.874256	3. 12.813862 (0;302)	2.72.498655 3.76.150502	1.42.424233 2.50.806288	0.46.327829 1.50.000872	(0;377) 0.65.416293	3.44.342686 (0;396)	2. 19.07107 3. 13.848974	1. 6.669368 2. 12.334321	0. 15.231256	(0;471)	3. 15.569264 (0;490)
(0;4) 0.0.0252 1.0.3778	5 (0;23)	3.0.583438	0.1.792379 1.1.806928 2.0.135859	3. 3.738275 (0;79) 0. 0.490398	1.7.120632 2.14.279212 3.0.846885	(0;116) 0.1.389708 1.14.392325	3. 0.469259	0.5.088261 1.2.346529 2.5.442443	[0;172] 0.7.458466 1.1.564429	1.2.28076 2.0.082756 3.1.517468		1.6.216675 2.0.020289 3.10.516621	4.0.266882 (0;246) 0.85.362467	2.88.124024	70.221199			3.64.377746 (0;340) 0.71.600172	3. 5.590299		0.49.033697 1.35.361235 2.44.323955	0. 43.190426		2.5.651318 3.12.416718	1.0.344979 2.5.336522 3.11.782689	0.5.006233 1.5.046426 2.33.59577
2.0.1093 3.0.0581	52 1. 1.635025 45 2. 1.830493	0.0.16566	3. 1.511235 (0;61)	1.7.12985 2.11.208069	(0;98) 0, 6.019697	2.17.876994 3.2.511153	0. 6.483635 1. 1.134957	3.0.269282 (0;154)	2.0.217546 3.0.096834	(0;191) 0.4.215316	2.0.096997 3.0.740295	(0;228) 0, 6.948308	1.92.882452 2.19.158346	0.101.210571 1.79.029638	(0;284) 0. 7.98123	3. 34.352498 (0;303)	2.73.407245 3.80.11832	1.54.556526 2.64.375671	0. 57.046532 1. 57.758707	(0;378) 0.63.280559	3. 52.646461 {0;397}	2.28.274588 3.25.247661	1. 14.617798 2. 21.521672	0.21.727122	(0;472) 0. 15.492215	3. 38.891617 (0;491)
(0;5) 0, 0,5012 1, 0,5960	54 [0;24]		0.1.299826 1.4.357943 2.7.001013	3. 1.584459 (0;80) 0.3.846527	1.2.815973 2.0.156589 3.5.219698		3, 4.890213	0.3.765777 1.0.149877 2.0.119903	4.5.809178 [0;173] 0.0.223609	1.26.650222 2.25.400916 3.1.123802	0.0.240342	1.37.40265 2.53.297082 3.22.901384	0. 9.669464	2.81.007402 3.96.481344 (0:266)	43.308603		0.83.774941				1. 42.565167			3.0.143722	1.5.653492 2.11.753754 3.17.472672	1.8.673513
2.0.5971 3.0.4978	77 1.0.977374 81 2.0.119864	0.1.240249	3. 1.361515 {0;62}	1.2.583107 2.0.150986	(0;99) 0. 3.720717	2.0.148979 3.5.982814	0.8.422505 1.0.508639	3.2.002009 (0;155)	1.0.056124 2.0.336319	(0;192) 0. 1.614978	2.50.433434 3.27.535336	4.0.815841 {0;229}	2.0.069521 3.5.461199	0.49.744902 1.18.217107	(0;285) 0,34,690549	3.51.914222 (0;304)	2.71.361659 3.80.999233	1.15.159952 2.41.27407	0.64.778398 1.62.667518	(0;379) 0.22.221055	3. 59.004909 (0;398)	2.35.38396 3.34.432232	1.21.483575	0.26.548871	(0;473) 0. 19.520742	3.28.794871 (0;492)
[0;6 0.0.0439 1.0.4786	17 [0;25]	2.2.939666 3.0.381935 (0:44)	0.1.618626 1.1.54148 2.0.132236	3.3.342936 (0;81) 0.0.413713	1.5.488987 2.13.263579 3.8.031298		3. 2.176638	0.7.427852	3.0.330029 (0;174) 0.6.620639	2.0.089193	4.0.767649 (0;211) 0.55.258879	1. 62.544627	0.0.281996	2.22.911239	13.055805	1.91.355692			3. 37.697743		0.13.381026 1.19.756969 2.17.908001	0.47.840179	(0;436)	2. 13.530952 3. 10.293162 (0.455)		1.11.221505
2.0.1104 3.0.0338	15 1. 1.693377	0.1.992244	2.0.132236 3.1.288258 (0;63)		4.0.255516	2.17.247755	(0:137)	3. 4.05148 4. 0.086513	1.15.180015 2.8.79201	(0;193)	0. 55.258879 1. 56.1059 2. 33.971093	[0;230]	2.95.269692		(0;286)	3. 65.652041	2. 13.553949	1.32.665644	0. 69.662191	(0;380)	3. 30.911829		1.27.178915	0.29.80812	[0;474]	3. 20.035618 (0;493)
(0;7) 0.0.6418 1.0.7367	19 [0;26]	2.3.156819 3.0.15486 4.1.937696	0.0.824128 1.3.881711 2.7.100047	3. 1.073464 (0;82) 0. 3.450455	0. 16.888534 1. 17.618567 2. 12.359257			(0;156) 0. 4.002085 1. 4.122969	3.7.698154 4.0.305201 (0:175)	1.28.093281 2.27.527095 3.9.968001		1.5.156366 2.0.038073 3.8.826976	(0;249) 0. 5.285935 1. 1.697762	2.48.26323 1 3.70.400778 2 (0:268) 3	. 12.732605	1.91.016647		(0;343)		2.21.703453	0.26.166461 1.29.956798 2.1.189165	0.47.375596	(0;437)		1.14.376921 2.22.310229 3.26.341679	1. 12.78615
2.0.7400.	1. 0.968326 3 2. 0.119392	[0;45] 0.0.0492	3.0.996352 {0 ,6 4}	1.2.191048 2.0.144587	(0;101) 0. 5.325263	2.0.142376 3.4.781617	0.4.985108 1.0.784195	2.4.325106 (0;157)	0.10.011115	4.0.366043 (0;194)	2.0.059959 3.0.029805	(0;231) 0. 3.681976	2. 0.095763 3. 0.331162	0.87.290146 1.61.860652	[0;287] 0.74.87051	3.75.715764 (0;306)	2.33.691133 3.51.347174	1,46.719019 2,4.847203	0.71.832776 1.64.473661	(0;381) 0. 44.27557	3.11.441337 (0;400)	2. 43.783884 3. 46.638425	1. 31.612441 2. 41.413921	0.31.612306	[0;475] 0.25.226282	3. 12.510498 (0;494)
(0;8 0.0.0684 1.0.5727	38 (0;27)	2.0.123936	0.1.39532 1.1.256997 2.0.127436	3. 2.871168 (0;83) 0. 1.390235	1.2.346547 2.0.149667 3.4.427766	(0;120) 0.2.745594 1.9.156749	3. 3.318506	0.2.092986 1.0.043024 2.0.117625	2.9.556235 (0;176) 0.5.900862	0.30.640124 1.30.574881 2.13.963935	(0;213)	1.56.185496 2.64.705929 3.5.480513	(0;250) 0. 9.140359 1. 70.339791	2.70.458113 1	. 34.217249	1.87.449242		3.9.024887 (0;344)	3. 57.761599	1.27.473655	0.36.344027 1.37.681694 2.12.889821	0.21.446518	(0;438)	2.26.262358		1. 13.459158
2.0.1124	16 1. 1.732431	[0;46]	2.0.127436 3.1.012785 (0;65)	0. 1.390235 1. 5.125909 2. 11.196222	(0;102)	1.9.156749 2.16.581063 3.1.267324	0.0.448044	3. 0.3342	1.1.287252	(0;195)	0.0.620647 1.0.430641 2.0.149758	(0;232)	2.97.620972	0:269) 3 0.17.607555 1.36.10958	(0;288)	3.82.251896	1.43.243563 2.51.377191 3.66.483746	1.57.4691	0.71.421104	(0;382)	3.5.254298		1. 14.038285	0.32.064769	(0;476)	2.5.531109 3.6.120274 (0;495)
(0;9) 0. 0.7803 1. 0.8745	89 [0;28]	1.0.831864 2.2.954441 3.3.323139	0.0.287615 1.3.337813	3. 0.547599 (0;84) 0. 2.977856	1.15.072419 2.17.327946 3.3.158344			1.0.360279	3.4.329795 (0;177) 0.1564401	2.0.097272	3.0.171298 (0:214) 0.4.049884	1. 4.003217 2. 0.056691		2.35.137832 3.61.802922	. 51.555965	1.80.791706	0.75.379911	(0;345)		2.46.494938	1.43.061425		(0;439)	2.30.472883	2.29.296265	1. 13.328312
2.0.8821	54 1.0.941455 15 2.0.119146	4.0.154643	2.7.187152 3.0.606065 (0;66)	1. 1.787541 2. 0.137949	[0;103] 0.4.531991	1.1.309839 2.0.13488 3.3.480232	0.3.412001 1.0.476882	2.2.164615 3.0.200785 (0;159)	0.1.364401 1.13.370396 2.11.724384	(0;196) 0.3.379285	1.55.355951 2.58.832488	3. 6.564591 (0,233) 0. 1.936802	2.7.40657 3.0.015223	0.44.536568 1.58.437256		3.85.403566 (0;308)	1.56.832269 2.66.491958 3.78.926884	1.65.061183 2.37.095527	0.68.554217	0.58.968405	3.19.311022 (0;402)	2.22.208958	1.20.971741	0.11.687417	0.0.96639	3. 0.769736 (0;496)
(0;1 0. 0.0961	83 (0;29)	0.5.953926 1.6.006151	0.1.119464 1.0.953169	3. 2.318157 (0;85)	1. 1.881055 2. 0. 142343	0.4.845918	3. 1.680993	0.9.618201 1.0.511373	3. 1.475952 (0;178)	1.32.657365 2.32.868921 3.2.827144		2.66.845595		2.4.734687 3.26.641665	. 64.90366	0.88.519805 1.71.178607	0.8.758722	[0;346]		2.55.968506	1.46.221651	0. 36.133827	(0;440)	3. 12.356351	2.42.83306	0.18.04117 1.12.477586
1.0.6608. 2.0.1139 3.0.0253	13 1. 1.750403	(0;48)	2.0.122702 3.0.679039 (0:67)	0.2.436933 1.4.002032 2.10.164142	3. 3.535771 (0;104) 0. 1.098642	1.6.478339 2.15.875282 3.0.692282	0. 3.014861	2. 1.56396 3. 0.118086 4. 7.894783	0.4.422218 1.1.17762 2.0.099492	(0;197)	0. 5.469574 1. 4.893278 2. 0.040849	3. 3.643115 (0;234) 0. 6.421332	0.0.14311 1.0.02073 2.0.516662	(0;271) 3 0.66.824982 1.76.28855 0	(0;290)	3.85.310459	1.22.710305 2.35.050127 3.56.582283	1.69.636787	0.21.567288	(0;384)	2.33.652225 3.30.860807 (0.403)		. 26.063289	0. 17.392899	(0;478)	2.2.427653 3.3.632407 (0:497)
(0;1 0.0.9154	97 [0:30]	2.0.152962	0.0.310608 1.2.726122	4. 0.009686	1. 13.159569 2. 17.002703	0.3.57789		0.0.424858	3. 2.95848 {0;179}	1.34.144738 2.35.165002	(0:216)	1.2.759265 2.0.077543	3. 0.530115 (0;253)		74.412177	1.5.733176	0.30.27289	{0;347}		2.33.021569	1.47.283951	0.41.418177	(0;441)	2.12.334025 3.19.127802	2.31.925121	0. 17.184095 1. 10.987257
1. 1.0080 2. 1.0229 3. 0.8719	1. 0.897814	(0;49)	2.6.953916 3.4.926132 4.0.192169	(0;86) 0. 13.971853 1. 14.90604	3. 2.518044 (0;105) 0. 3.638605	1.0.890474 2.0.128584 3.2.07989	0. 1.773199	1.0.115933 2.0.277832 3.0.265315	0.3.377791 1.16.357494 2.13.497514	(0;198)	0. 1.611986 1. 34.267809 2. 41.006341	(0;235)		(0;272) 3 0.84.637969 1.89.825885 0	0;291) (0;291) 106,753591	3. 31.91586	1.40.475783 2.9.803232 3.27.422997	1.71.333612	0. 34.939752	(0:385)	2.40.587716 3.40.031652 (0.404)		. 29.428257	0.22.285899	3. 37.781603 (0;479) 0. 13.281606	2.5.198416 3.7.173628 (0:498)
(0;1. 0.0.1279	2) 3.0.299258 55 (0;31)	1.5.895646 2.6.178491	(0;68) 0. 10.634919	2. 5.14307 (0;87)	1.1.421194 2.0.134742	(0;124) 0.6.948567	2.0.119688 3.0.010851	(0;161) 0.2.559356	3. 1.247608 (0;180)	1.0.877749 2.0.106096	3. 3.069527 (0;217)	1. 46.890416 2. 67.65758	3. 38.572394 4. 1.027255	2.42.330723 3.29.451643	. 80.230181	0.51.253992 1.25.896429	(0;329) 0. 48.006328	3.55.6459 (0;348)	2.20.547053 3.35.430642	1.25.746005 2.12.949841	0. 53.591381 1. 46.365863	(0;423) 0.45.199536	3. 14.935998 (0;442)	2. 19.098143 3. 24.955177	1. 12.39178 2. 22.520665	0.15.688058 1.8.934025
1.0.7402 2.0.1148 3.0.0600	1. 1.74458	{0;50}		0.2.423916 1.1.375123 2.0.131825		1.3.781867 2.13.610152 3.6.367744	0. 5.494625	1.4.529822 2.0.171467 3.0.002508	1.0.989118	(0;199)	0.5.246786 1.4.072702 2.0.055273		(0;254) 0. 102.406844 1. 108.40103-		[0;292]	3. 51.405441	1.54.61446 2.11.652989 3.2.208872	1.70.285522	0. 46.434477	(0;386)	2.45.387543 3.46.947596 (0.405)		1.31.177803	0.26.285667		2.7.271554 3.9.937694 (0:499)
(0;1 0, 1.0461;	58 [0;32]	2.0.150984	0.0.785234 1.0.632493	3. 1.678834 [0;88]	1.11.159695 2.16.6437			(0;162) 0. 7.986903	3. 1.721322 [0;181]	1.3.802358 2.0.758562	3. 4.721711 {0;218}	0.74.880086 1.75.976543	2.49.970824 (0;255)	2.59.314515 3.50.710281	. 92.95081 . 82.503071	0.66.414884 1.43.605603	(0;330) 0.62.11395	3.63.866747 (0;349)	2.35,446097 3.48.327358	1.36.214837 2.4.172363	1.43.580935	0.3.738094	{0;443}	2.24.917252 3.29.754146	2. 14.512436	
1. 1.1360 2. 1.1622 3. 0.9776	8 1.0.83611	3. 1.977489 {0;51} 0. 2.829423	2.0.117935 3.0.282471 (0:70)	0.2.735271 1.12.793838 2.14.834828	3.1.884734 (0;107) 0.2.64298	0.16.251539 1.17.676249 2.9.704606	0. 10.156874	1.0.177254 2.0.115008 3.6.262699	0.4.801804 1.18.953009 2.15.282105		0. 1.456458 1. 32.185702 2. 42.797674	2.63.732784 (0,237) 0.3.537579		0.107.484473	(0;293)	3. 68.178598	1.65.277735 2.29.470724 3.19.215543				2.48.167928 3.51.728744 (0.406)			0.29.307941	3. 17.494996 (0;481) 0. 20.222441	2.8.723767 3.12.004771 (0:500)
(0;1 0.0.1629	54 [0;33]	1.5.785533 2.6.341456	0.3.360961 1.10.108028	3. 3.191218 (0;89)	1.0.970199 2.0.127487	0.2.17592		(0;163) 0. 4.935149	[0;182]	1.0.057229	3. 1.628039 (0;219)	2.0.09981	(0;256)	2.72.142195 3.67.657065	.81.372896	1.58.740838	0.72.747153	[0;350]		2. 18.483856	0.22.120741	(0;425) 0. 15.388285	3. 31.074664 (0;444)	2.29.707 3.33.436839		1.3.492738
1.0.8097 2.0.1157 3.0.0965	1. 1.712611	(0:52)	2.10.999602 3.3.429134 (0:71)	0. 1.783559 1. 0.95684 2. 0.125749	3. 1.443344 (0;108) 0. 2.297414	2.0.122293	(0;145)	1.7.690087 2.1.060355 3.0.099707		3.0.284537	0.4.602103 1.3.157465 2.0.069452	3. 0.164397 (0;238) 0. 5.950734		(0;275) 3 0.112.833974 1.106.133909.0	(0;294)	3. 82.108763	1.72.613407 2.43.798798 3.37.002433	1.60.470812		(0;388)	2.10.528462 3.22.494218 (0.407)		. 30.254854	0.31.264842	[0;482]	2.0.706543 3.5.408779 (0:501)
(0;1 0. 1.1710	9 (0;34)	2.0.149077	0, 4.75748 1. 3.238106	3. 0.949554 (0;90)	1.9.082938 2.16.251341	0.0.923848		0.6.354362	3. 0.6501 (0;183)	1.35.096557	3. 3.619297 {0;220}	2.78.282133	(0;257)	2.80.967516 3.80.448676	. 76.978298	1. 30.846735	0.80.053725	(0;351)	2.59.074636 3.67.618099		0.31.328969 1.15.907448	(0;426) 0.24.779622	3. 36.597391 (0;445)	2.33.379499 3.35.911754	1. 17.653577	1.0.112648
1. 1.2569 2. 1.3000 3. 1.0712	75 1.0.756127	(0:53)	2.0.609989 3.0.172576 4.4.511392	0.1.595606 1.11.515022 2.14.736543	3. 1.262782 (0;109) 0. 1.543201	1.13.103602 2.16.766529 3.2.072644	(0;146)	1.0.292466 2.0.113154 3.4.647778	0.5.822253 1.21.146147 2.17.352566	2.37.459058 3.1.106577 (0:202)	1.29.492869	3. 6.788561 (0;239) 0. 18.654233	0.77.158612 1.86.203672 2.29.666525	(0;276) 3 0.114.339745 1.103.979424 0	(0;295)	3. 50.021105	1.76.765601 2.54.782577 3.51.300617	1.3.469121	0.8.844991		2.22.494616 3.32.980297 (0.408)	2.2.799871	1.0.955122	0.3.64161		2.5.37234 3.9.668217 (0:502)
(0;1 0. 0.1996	6) 3.0.260783 79 (0;35)	1.5.620444 2.6.494525	(0;72) 0. 0.388098	3. 2.615595 (0;91)	1.0.531814 2.0.120794	(0;128) 0, 10.448424	1. 1.797813 2. 8.293257	(0;165) 0. 7.064266	3.11.120541 4.0.425502	0.0.678511 1.3.551493	3. 1.026298 4. 0.045213	1.7.199621 2.6.772759	3. 12.672842 (0;258)	2.85.941185 3.89.238871	. 1.885499	0. 38.620876 1. 48.777752	(0:333) 0.84.177782	3. 18.786857 [0;352]	2.28.044168 3.44.900918	1.52.272044 2.39.210539	0.39.08663 1.25.101959	(0;427) 0. 32.039432	3. 12.554436 (0;446)	2.20.84379 3.28.963457	1.17.37936 2.2.14602	0.11.082337 1.3.428447
1.0.8688 2.0.1171 3.0.1333	1. 1.652016	(0;54)	1.0.320787 2.0.114459 3.0.10783	1.0.534674			4.0.162441	1. 10.588026 2. 2.296908 3. 0.101302			(0;221) 0.46.73398 1.50.258751			(0;277) 3 0.112.151777 1.98.276853 ((0;296)	3.20.409527	1.77.874718 2.62.563907 3.62.255455	1.13.366635	0.25.526924	(0;390)	2.32.968073 3.41.876871 (0.409)		1.6.690791	0.11.261755	(0;484)	2.9.62837 3.13.451532 (0:503)
(0;1 0, 1,2887	7) 3. 1.034532 58 [0;36]	1.2.475521 2.0.145961	(0;73) 0.2.755756	3.0.127122 (0;92)	1, 6.939887 2, 15.825682	4.9.121471 (0;129)	0.9.549515 1.10.38585	(0;166) 0.4.739266	2.14.038872 (0;185)	0.1.564729 1.35.515188	2.7.840532 (0;222)	0.6.1435e-4 1.3.7083e-4	3. 38.2806 (0;259)	2.87.21075 3.94.178355	23.976577	0.56.518285 1.62.90846	(0;334) 0.85.259716	3.35.358267 (0;353)	2.7.485978 3.21.10287	1. 52.937555 2. 45.883897	0.45.295528 1.32.845142	(0;428) 0. 37.29079	3. 20.494561 (0;447)	2.9.20523 3.15.555105	1.16.240746	0.2.741753
1. 1.3692 2. 1.4360 3. 1.1511	5 1.0.657676	(0;55)	1.9.494133 2.11.079885 3.3.002362	0.0.375402 1.10.139503 2.14.61102	3.0.65662 {0;111} 0.9.066081	0.0.680628 1.0.258269 2.0.189157	(0;148)	1.0.338387 2.0.112778 3.3.071456	0.5.220144 1.3.188525 2.0.422433	3.1.155473	0.3.492551 1.2.151257 2.0.086835	2.0.525432 3.0.526063 (0:241)		2 (0;278) 3 2.0.106.416684 1.89.169362 ((0;297)	3. 5.082798	1.76.077401 2.67.281055 3.70.008783		0. 39.108993		3.49.082316				3, 7,129627 {0;485} 0, 21,174717	2.34.757809 3.39.424707 (0:504)
(0;1 0.0.2367	8) 3.0.216311 29 (0;37)	1.5.397297 2.6.637102	(0;74) 0. 4.621323	3. 2.030618 (0:93)	1.2.647569 2.3.690296	3.0.173152 (0;130)	1.0.828842 2.0.130113	(0;167) 0.6.208493	3.0.073963 4.3.757391	(0;204) 0. 42.821611	3. 2.016314 (0;223)	0.1.163106 1.64.243148	3.59.249958 (0;260)	2.84.920515	43.469403	0.70.616368	(0;335) 0.83.436158	3. 49.76799 (0:354)	2.9.949443 3.0.571892	1.51.46433 2.50.262894	0. 49.853746 1. 39.038781	(0;429) 0. 40.652567	3. 27.355322 (0;448)	2.0.763132 3.3.931333	1. 14.321859 2. 8.055251	0.6.834434 1.5.402585
1.0.9165 2.0.1176 3.0.1704				0.7.129358 1.3.309747 2.4.015864		0.1.457288 1.9.93709 2.15.815517		1.4.176332 2.0.505241 (0:168)	[0;186] 0.0.747525 1.0.255502	1.43.807528 2.6.241877 (0:205)	0.2235856 1.44.27814 2.52.251269	2.80.558998 3.4.750776 (0:242)	0.116.64499. 1.112.83979 2.79.416257	2 (0:279) 3 1 0.97.277627 1.76.796612 0	(0;298) (0;298) 82.057069	2.36.59613 3.26.613186 (0:317)	1.71.506512 2.69.068668 3.74.69886	0.59.038809 1.41.18675 2.49.776095	[0;373] 0.49.735012 1.50.740135		2.49.041232 3.54.491298 (0.411)				3. 10.535584 {0;486} 0. 19.248818	2.26.692406 3.30.195542 (0:505)
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Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles



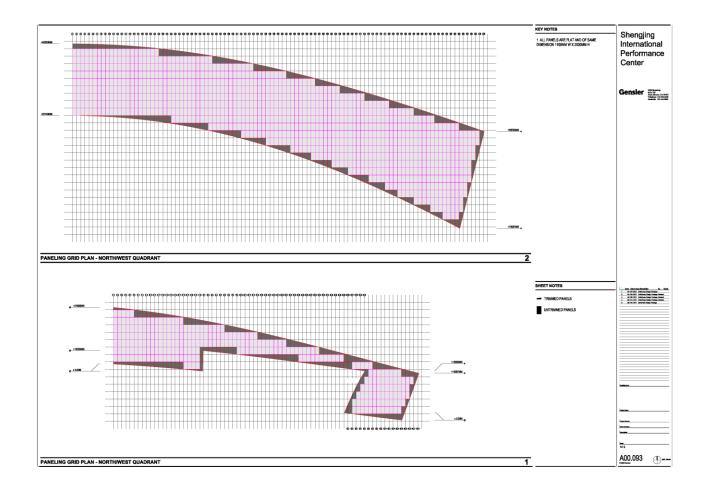
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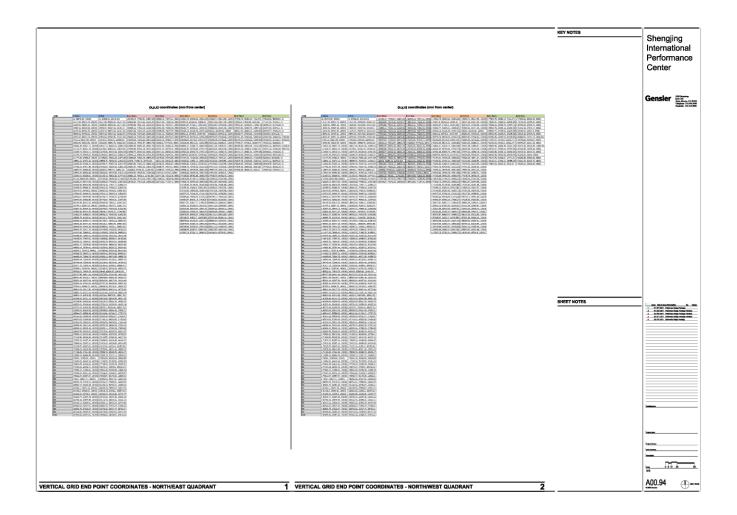
FINAL DOCUMENTATION



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FINAL DOCUMENTATION



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RECAPITULATION

STEP #1:

Identify the curvature conditions through testing the "Mean Curvature", the "Gaussian Curvature" and the Angle between Normals conditions.

STEP #2:

Discuss the tolerances with your fabrication based on the material and technique used.

STEP #3:

Rebuild the surface main grid subdivisions in quads of the size of your panels

STEP #3:

Quantify the amount of cold bending in the paneling material

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CONCLUSIONS

#1:

To design and implement a cost-effective paneling solution it's important to consider the geometrical properties of your design at an early stage.

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AIA

CONCLUSIONS

#1:

To design and implement a cost-effective paneling solution it's important to consider the geometrical properties of your design at an early stage.

#2:

Through the use of parametric and generative design tools we can understand the numbers beyond the geometry and make the necessary changes.

TAP Faster Forward 2011

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CONCLUSIONS

#1:

To design and implement a cost-effective paneling solution it's important to consider the geometrical properties of your design at an early stage.

#2:

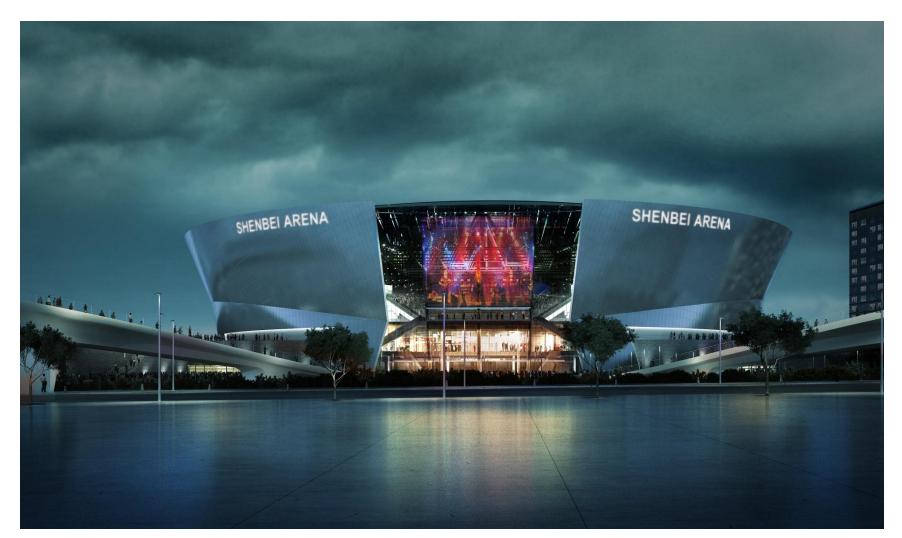
Through the use of parametric and generative design tools we can understand the numbers beyond the geometry and make the necessary changes.

#3:

More cool stuff to come from Gensler, so stay tuned!!!

Cost-effective strategy to panelize a double curved surface Lorenzo Marasso – Gensler Los Angeles





PROJECT CREDITS

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THANK YOU!

Lorenzo Marasso

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Good design makes a difference "