EXPLOITING MORPHOLOGY OF UNPROCESSED MATERIAL BY REVERSE ENGINEERING IN ARCHITECTURE

P4 presentation
Progress evaluation
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2nd Mentor: Marcel Bilow
Delegate Examiner: Ruud Binnekamp

Sustainable Design Graduation Studio
MSc Building Technology, TU Delft
“EXPLOITING MORPHOLOGY OF UNPROCESSED MATERIAL BY REVERSE ENGINEERING IN ARCHITECTURE”

Thesis progress
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AGENDA

1. Introduction / Abstract
2. Research outline
3. Methodology
4. Relevance
5. Case design
6. Feasibility
7. Workflow study
8. Prototyping
9. Final workflows
10. Reflection
INTRODUCTION

TRADITIONAL CRAFTSMANSHIP

Unprocessed materials & manual labour
DIGITAL CRAFTSMANSHIP

Advances in computational design & digital manufacturing
INTRODUCTION

TRADITIONAL CRAFTSMANSHIP VS DIGITAL CRAFTSMANSHIP

- Same typology
- Same material
- Different processing techniques
MATERIAL CHARACTERISTICS

PROCESSED MATERIAL (PLYWOOD)

3500 MJ/m³

14x

Typical embodied energy (resin production + manufacturing)

UNPROCESSED MATERIAL (GREEN TIMBER)

250 MJ/m³

Typical embodied energy (manufacturing)

TYPICAL EMBODIED ENERGY OF CONSTRUCTION TIMBER PRODUCTS BASED ON DATA FROM PUETTMANN AND WILSON (PUETTMANN & WILSON, 2007)
CASE STUDY - AA

- Design & Make project
- AA London - Hooke park

“It was the prime intention to use and exploit the natural strength of the joints of Y-shaped locally sourced tree logs”

Coco van Egeraat - Structural engineer at Arup (2016)
1. DEFINITION OF ELEMENT TYPOLOGY

2. ANALYSIS OF NEEDED TECHNIQUES TO PROCESS ELEMENTS

3. CLASSIFICATION AND CATALOGUING OF ELEMENTS

4. TRANSLATION FROM ANALOGUE TO VIRTUAL (REVERSE ENGINEERING)

5. COMPARING ANALOGUE WITH VIRTUAL DATA

6. DESIGN INTENTION

7. DETAILING DESIGNING FOR COMMUNICATION ERRORS

8. VIRTUAL TO PHYSICAL
RESEARCH OUTLINE

PROBLEM STATEMENT
Processing of materials into predictable and predefined shaped elements costs time, energy and wastes material. Emerging technology to shortcut this process, like reverse engineering, is available but not adopted in architectural applications yet.

OBJECTIVE
By using reverse engineering, existing morphology of elements/materials can be exploited to shortcut architectural engineering thus lower consumption of material, time and energy or identify possibilities for currently unused materials.

Unprocessed materials versus processed materials
How can reverse engineering exploit morphology of unprocessed materials to shortcut architectural engineering?

- What are architectural applications for reverse engineering?
- What resources are needed to prototype this application?
- What design exercise can demonstrate this application?
- What challenges lead to a functioning prototype?
- Does this application shortcut the process of architectural engineering?
- Does this shortcut save time, energy or material?
# METHODOLOGY

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<th>Phase</th>
<th>Relevance</th>
<th>Feasibility</th>
<th>Challenges</th>
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<td>Type</td>
<td>Literature Study</td>
<td>Technical Pillars</td>
<td>Required Resources</td>
<td>Step by Step Prototype of Challenges</td>
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<td>Output</td>
<td>Application to Prototype</td>
<td>State of Development &amp; Available Resources</td>
<td>Defining Prototyping Challenges based on Desktop Research</td>
<td>Conclusion</td>
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**Academic Debate:**
“What are relevant applications for reverse engineering in architectural engineering?”

**Specific Material & Design Intention:**

**Literature Study:**

**Literature Study & Inquiry:**

**Desktop Study & Design:**

**Prototype Steps & Outline:**

**Answer on Research Question:**

**Technical Pillars:**
“What is the current state of development of relevant technologies?”

**Required Resources:**

**Defining Prototyping Challenges Based on Desktop Research:**

**Conclusion:** Does this application shortcut the process of architectural engineering? (save time, energy or material)

**Prototyping:**
RELEVANCE

(Re)Use of Unprocessed Materials

Information on availability

Technical mismatch elements vs design

Architectural Engineering
(RE)USE OF UNPROCESSED MATERIALS

Information on availability

Technical mismatch elements vs design
“CARE creates a computer model of an object through measurements of the object, as it exists in the real world. In this context, we define CARE as the reversal of CAE or the ability to generate a CAD model from a real-world tangible object.” (Raja & Fernandes, 2007).
RELEVANCE

DEBATE ON CAD & CAM

[LEFT] OWN DIAGRAM - IMAGES FROM TREE TRUSS ARTICLE (MOLLIKA & SELF, 2016)
RELEVANCE

DEBATE ON CAD & CAM

[LEFT] OWN DIAGRAM - IMAGES FROM TREE TRUSS ARTICLE (MOLLICA & SELF, 2016)
RELEVANCE

DEBATE ON CAD & CAM

ARCHITECTURAL PRECEDENTS OF UNPROCESSED MATERIALS

Tectonic structures

Stereotomic structures

[LEFT] OWN DIAGRAM - IMAGES FROM TREE TRUSS ARTICLE (MOLLIÇA & SELF, 2016)
PRECEDEMENTS

TECTONIC STRUCTURES
PRECEDEENTS

STEREOTOMIC STRUCTURES
CASE DESIGN

CASE DESIGN

Element → Fundamental → Typology → Structure

wall
DIAGRAMS BY AUTHOR

TYPOLOGIES

DRY STACK WALLS

STRAIGHT WALLS

DOME

ARCHED WALLS

FREEFORM VAULT

ARCH
CASE STUDIES

**EVOLUTIONARY**
- [Bottom Right] Gaudi Retaining Wall (Huerta, 2016)
- [Top Right] Clauchan Stone Hut
- [Top Middle] Aran Islands Stone Wall
- [Bottom Middle] Balancing Rocks Artwork (Grab, 2013)

**FABRICATED**
- [Top] Fabricated Artwork
- [Bottom] Fabricated Sculpture
CASE DESIGN
## FEASIBILITY

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<tr>
<th>EVOLUTIONARY BY CRAFTSMANSHIP</th>
<th>FABRICATED BY STEREOTOMY</th>
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<td>Sorting rocks on size and purpose</td>
<td>Thrust surface of intention</td>
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<tr>
<td>Interpretation &amp; planning of result</td>
<td>Interface of elements</td>
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<tr>
<td>Heuristic choices and organic process</td>
<td>Complexity of interfaces depends on typology</td>
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ACCOMODATING NEIGHBOURING ROCKS
STEREOTOMIC DEFINITIONS

ACCOMODATING NEIGHBOURING ROCKS

DIAGRAMS BY AUTHOR
STEREOTOMIC DEFINITIONS

FACE DIRECTION
STEREOTOMIC DEFINITIONS

FACE DIRECTION

COMBINED

DIAGRAMS BY AUTHOR
STEREOTOMIC DEFINITIONS

NEIGHBOURS

VERTEX CONFIGURATION

SEARCH OBJECTIVE

DIAGRAMS BY AUTHOR
STEREOTOMIC TYPOLOGIES

TYPOLOGIES
STEREOTOMIC TYPOLOGIES

TYPOLOGIES

POPULATING

DIAGRAMS BY AUTHOR
STEREOTOMIC DESIGN
INVENTORY

SOURCE

BATCH

STRUCTURED

SPREAD
INVENTORY

DATABASE
DIGITIZING

TRANSLATION FROM ANALOG TO VIRTUAL

CATALOG

ANALOG

VIRTUAL
DIGITIZING

3D DIGITIZING

CATALOG

2D DIGITIZER

3D DIGITIZER

2D POLYGON

RATIONALISE

3D POLYGON

VIRTUAL

ANALOG

POINT REFERENCING

2D POLYGON

3D POLYGON

POINT REFERENCING
LAYOUT & ASSEMBLY

Fig. 1. An example of a cutting problem.

N. Chernov et al. / Computational Geometry 43 (2010) 535–553
LAYOUT & ASSEMBLY

2D POLYGON

LINEAR ANGLE MATCHER

2D NESTING SOFTWARE

LINEAR LAYOUT

ROCKSOLVER

2D LAYOUT

2D LAYOUT

3D VERTEX MATCHER

3D MESH

3D POLYGON

3D PACKING SOFTWARE

3D LAYOUT RATIONALISED

MANUAL ASSEMBLY

ROBOTIC ASSEMBLY

ROBOTIC ASSEMBLY
CRAFTSMANSHIP

MANUAL ASSEMBLY

ROBOTIC ASSEMBLY

VIRTUAL

ANALOG

ASSEMBLY
The design is controlled by 3 aspects:

- Material
- Process (Computation & Heuristics)
- Design intention

- Envisioning of the result.
- By the potential of the material
- Possibilities of the process
INVENTORY

REMOTE IDENTIFICATION & LOCATION

BATCH

STRUCTURED

SPREAD

IDENTIFICATION BY LOCATION

CATALOG

VISUAL REFERENCE

2D DIGITIZER

2D POLYGON

3D POLYGON

3D MESH

3D DIGITIZER

RATIONALISE

RATIONALISE

3D SCANNING

IDENTIFICATION BY LOCATION

VISUAL REFERENCE

2D NESTING SOFTWARE

2D LAYOUT

CRAFTSMANSHIP

2D LAYOUT

3D LAYOUT

RATIONALISED

3D LAYOUT

LINEAR LAYOUT

MANUAL ASSEMBLY

ROBOTIC ASSEMBLY

ROBOTIC ASSEMBLY

(DOUBLE) CURVED STRUCTURES

DESIGN INTENTION

PLANAR STRUCTURES

ROCKSOLVER

3D PACKING SOFTWARE

3D VERTEX MATCHER

LINEAR ANGLE MATCHER

ROCKSOLVER

3D PACKING SOFTWARE

3D VERTEX MATCHER

876

54321

8

ANALOG VIRTUAL ANALOG

[TOP] SELECTION OF PROTOTYPING ROCKS - BY AUTHOR

[BOTTOM] REFERENCE TAG ROCK NR7 - BY AUTHOR
2D DIGITIZING

HEURISTIC CHOISE ON MAIN FACE
3D SCANNING

- Photogrammetry
- Structured Light
- Laser Triangulation
- Laser Point Clouds

Precision:
- >2mm
- 2mm
- 0.5mm
- 0.05mm
NESTING SOFTWARE

2D DIGITIZER

2D POLYGON

3D DIGITIZER

RA3N LOCATION ID IDENTIFICATION CATALOG

2D LAYOUT

2D NESTING SOFTWARE

876 54321 8

ANALOG VIRTUAL ANALOG
NESTING SOFTWARE

DESIGN INTENTION

BEST RESULT (RHINONEST)
ROCKSOLVER
ROCKSOLVER

DESIGN INTENTION

[Top Left] Intention Virtual & Physical
[Bottom Left] Rocksolver Solution Screenshot (Lambert, 2017b)
ROCKSOLVER

DESIGN INTENTION

RESULT

[Top Left] Intention Virtual & Physical
[Bottom Left] Rocksolver Solution Screenshot (Lambert, 2017b)
[Top Right] Built Result & Comparison to Layout - By Author
ANGLE MATCHER
HUMAN-MACHINE INTERACTION

DESIGN INTENTION

RESULT

[TOP LEFT] EXAMPLE OF DRY STON WALL (REFERENCE MISSING)
[REST] BY AUTHOR
VERTEX MATCHER

DESIGN INTENTION

RESULT

[TOP LEFT] GAUDÍ RETAINING WALL (HUERTA, 2006)
[REST] BY AUTHOR
ENVISIONED WORKFLOWS

- Traditional craftsmanship
  (Skilled people, limited applications & small scale)
- Rocksolver workflow
  (Untrained people, limited applications & small scale)
- Human machine collaboration
  (Untrained people, extended applications & scaled up)
- Fully automated
  (No manual labour, extended applications & scaled up)

INCREASINGLY INFEASIBLE
TRADITIONAL CRAFTSMANSHIP

STEPS

• Material source in batch
• Sorting & grouping manually
• Intrinsic design intention
• Guiding foundation
• Assembly based on heuristic choices and mental design process
• Structure (unique)
ROCKSOLVER

STEPS

• Material source in batch
• Labelling for location by identification
• 2D Digitizing
• Database
• Rocksolver layout generation (with heuristic input)
• Interpretation of layout
• Structure (with deviations to layout caused by interpretation)
HUMAN-MACHINE INTERACION

STEPS

• Material source in batch
• Scanning by wearable photogrammetry device
• Identification by location through reporting GPS data per element
• Database
• Design intention & stereotomic relations
• Suggestion of best element by convex matcher
• Assembly by instructions of machine
• Update of physical state of structure (interpretation)
• Iterative interaction till finished
• Structure (with deviations to intention & accurate final model)
AUTOMATED

STEPS

• Material source quarry
• Scanned & tagged in automatically
• Remote identification & location
• Layout generated by convex matcher & physics engine
  (acting as human interpretation)
• Assembly by robot arm
• Structure (no deviations to layout)
SOME UNEXPECTED PROBLEMS DOWN THE ROAD...

DIAGRAM BY AUTHOR
DIFFERENT WAYS ROUND IT

DIAGRAM BY AUTHOR
END PRODUCTS

MAP OF WORKFLOWS
- State of technology
- Proof of concepts
- Possibilities

ENVISIONED WORKFLOWS
- Strategies
- Impact
- Answer on main research question

CASE DESIGN (+ MOCK UP)
- Applications
- Possibilities
- Relevance
QUESTIONS?