A.H.E.A.D

Affordable Housing Enabled by Automation-oriented Design

Jingxiang Liu
4402499
Jingxiang.liu@live.com

Tutors
Architecture: Mo Smit
Building technology tutor: Maarten Meijs
Thematic research tutor: Pieter Stoutjesdijk
Board examiner: Remon Rooij
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INTRODUCTION
1.1 PROBLEM STATEMENT

Housing is fundamental human right

- Habitat for Humanity

Why is not a question
1.1 PROBLEM STATEMENT

- Indonesia has a population of over **255 million** people and is the world's 4th most populous country
- Over **29.13 million** Indonesian are poor
- More than **735,000 housing units** needed each year
- The backlog has gone up to **13.6 million** in 2015

Productivity: Lots of homes needed to be built
1.1 PROBLEM STATEMENT

Densification: Urbanization and migration aggravates the densification in cities
1.1 PROBLEM STATEMENT

Affordability: The market and government unable to cover middle-low income people
1.1 PROBLEM STATEMENT

Quality: The quality of kampung is often minimal.

- Makeshift Building Material
- High horizontal density
- Limited vertical density
- Slow pace of construction
- Low-sanitation
- Limited access to public infrastructure and facilities
- Prone to environmental hazards
- Low technical housing quality
1.2 CONCEPT

Automation in manufacturing greatly improves productivity and efficiency.

Automation: new solution to housing problems
Process flowchart of automated construction
1.3 OBJECTIVES

<table>
<thead>
<tr>
<th>Productivity</th>
<th>Vertical Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affordability</td>
<td>Customization</td>
</tr>
</tbody>
</table>

INTRODUCTION  DESIGN  CONTEXT  RESEARCH  DESIGN
2.1 STRUCTURE OF RESEARCH & DESIGN

- Typology & context
- Housing prototype
- A.H.E.A.D
- Automated construction system
- Optimized building system
- Principles for product in automation
- Robotics
2.2 ROBOTICS

Diagram showing the basic composition of a robot arm and its components:
- **Sensor**
- **Actuator**
- **End effector**
- **Base**
- **Controller**
- **Power source**
- **Computer**

**Basic composition**
# 2.2 Robotics

<table>
<thead>
<tr>
<th>Work Envelope</th>
<th>Name</th>
<th>Order of joints</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 x L2 x L3</td>
<td>Cartesian</td>
<td>P - P - P</td>
<td>Suitable for linear motion, medium rigidity, balancing strategy required for asymmetric form</td>
</tr>
<tr>
<td>L1 x L2 x L3</td>
<td>Gantry - Cartesian</td>
<td>P - P - P</td>
<td>Suitable for linear motion, very high rigidity, less required balancing, but takes much space</td>
</tr>
<tr>
<td>(\pi \times r \times L)</td>
<td>Cylindrical</td>
<td>P - R - P</td>
<td>Common model for tower cranes, balancing required, medium rigidity, suitable for handling in vertical direction</td>
</tr>
<tr>
<td>(\pi \times r \times L)</td>
<td>SCARA - Cylindrical</td>
<td>R - R - P</td>
<td>Selective Compliance Articulated Robot Arm (SCARA), very high flexibility in x-y direction but rigid in z direction, high rigidity, common for assembly of smaller elements</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>R - R - P</td>
<td>High flexibility in 3D, but with low rigidity, suitable for jobs that need sophisticated positioning and relatively light</td>
</tr>
</tbody>
</table>

## Kinematic models
## 2.2 ROBOTICS

<table>
<thead>
<tr>
<th></th>
<th>Electric</th>
<th>Hydraulic</th>
<th>Pneumatic</th>
<th>Direct</th>
<th>Indirect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pro</strong></td>
<td>most common used</td>
<td>high and constant moment at various speeds</td>
<td>high and constant moment at various speeds</td>
<td>high precision of joint operation</td>
<td>lighter mechanical arm</td>
</tr>
<tr>
<td></td>
<td>very high precision</td>
<td>high carring ability</td>
<td>very high velocity</td>
<td>high power through direct transmission</td>
<td>changeable revolute velocity</td>
</tr>
<tr>
<td></td>
<td>simplicity of control</td>
<td>high precision</td>
<td>ease of maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ease of maintenance</td>
<td>can work long at high moment without damage</td>
<td>can work long at high moment without damage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>relatively low cost</td>
<td>low cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Con</strong></td>
<td>the moment changes as speed varies</td>
<td>expensive energy source</td>
<td>low precision</td>
<td>heavy weight of the mechanical arm</td>
<td>less precision</td>
</tr>
<tr>
<td></td>
<td>heavy load would damage the motor</td>
<td>extensive and expensive maintenance</td>
<td>vibration when it stops</td>
<td>constant revolute velocity</td>
<td>less power</td>
</tr>
<tr>
<td></td>
<td>low output to weight ratio</td>
<td>risk of oil leaks</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Actuator
2.2 ROBOTICS

Force-Torque Sensors

Force-torque sensors (FT sensors) are pucks installed between the robot flange and the tool that interacts with the part. They measure the force and torque that the robot applies to the part through the tool. FT sensors are used when the force that the robot applies need to be controlled.

Material Removal Tools

This category includes cutting, drilling and deburring tools installed as robot tools.

Welding Torches

Welding torches are efficient end effectors that can be controlled in a sophisticated way for optimized welding. Some torches also come with wire feeder for an even better control of the process.

Tool Changers

Tool changers are used when many different end effectors need to be used in sequence by one robot. They are used to standardized the interface between the robot flange and the base of the tool. They can be manual or automatic.

Grippers

Grippers are the most common type of end effector. They can use different gripping methods and actuation styles. According to actuation styles, there are electric gripper, pneumatic gripper, hydraulic gripper and vacuum gripper.

End effector
2.2 ROBOTICS

1. A collection of independent robots with specific function and are not arranged in a systematic way.

2. A collection of robotics that forms a systematic factory like stationary construction system.

3. A collection of robotics that forms a systematic movable factory that moves itself while constructing each part of the building.

Existing types of automated construction system
2.2 ROBOTICS

Case studies

SAM (Semi-automated Masonry)

AMURAD (Automatic Up-Rising Construction by Advanced Technique), Kajima Corporation

Push-up System, Kajima Corporation

ABCS (Automated building construction system), Oabayshi

SMART (Shimizu manufacturing system by advanced robotic technology), Shimizu

Big Canopy, Oabayshi

Automated construction by contour crafting (Balaguer, 2003)
2.2 ROBOTICS

- There are a variety of suitable application of robot in building construction and they should be according to their characteristics.

- The gantry type is chosen as kinematic type the main body of robotic construction system.

- A horizontally moving system robotic construction is suitable for the product.
2.3 PRODUCT DESIGN PRINCIPLES FOR AUTOMATION

1. Optimized module hierarchy

2. Minimizing types and amount of modules in assembly

3. Optimized module size, weight, and integration level

4. Using integrated connector for modules

Principles for product structure
2.3 PRODUCT DESIGN PRINCIPLES FOR AUTOMATION

1. Minimizing of number of parts needed to build a component

2. Standardization of parts, or reduction of number of type of parts.

3. Optimization for ease of orientation.

4. “Strong axis principle”

5. Be able to be handled in bulk

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Principles for component design
2.3 PRODUCT DESIGN PRINCIPLES FOR AUTOMATION

1. Reduce the types and number of joints

2. Use simpler joints if the elements are need not to be disassemble

3. Use self-aligning design, such as leads, lips and chamfers.

Principles for joint design

- Minimize number of types
- Self-aligning
- Simple joints

Bad | OK | Good
2.3 PRODUCT DESIGN PRINCIPLES FOR AUTOMATION

- Use the principles as check lists in design

- Chose an evolutionary optimization, starting from existing product, structures, systems

- Learn from precedents project and add them to design

Conclusion
2.4 EXISTING HOUSING TYPOLOGIES

1. t-terrace
2. L-living room, or guest room (ruang tamu)
3. b-bedroom (kamar tidur)
4. d-dining room (ruang makan)
5. k-kitchen (dapur)
6. WC-bathroom (kamar mandi)

Different combinations are possible for various sizes and needs.
2.4 EXISTING HOUSING TYPOLOGIES

Social housing A
2.4 EXISTING HOUSING TYPOLOGIES

Social housing A
2.4 EXISTING HOUSING TYPOLOGIES

Social housing B
2.4 EXISTING HOUSING TYPOLOGIES

Social housing B
2.4 EXISTING HOUSING TYPOLOGIES

Social housing C
2.4 EXISTING HOUSING TYPOLOGIES

Social housing B
2.4 EXISTING HOUSING TYPOLOGIES

- Relatively small housing units, **tight private space**
- **Shared corridor** as public space
- Better **sun light** condition and space for **activities** and **greenery**

Conclusion
CONTEXT
3.1 LOCATION

Location of Cigondewah
3.1 LOCATION

Location of project in Cigondewah
3.2 SITE & PROGRAM

Main roads
3.2 SITE & PROGRAM
3.2 SITE & PROGRAM

Kampungs
3.2 SITE & PROGRAM

Fields and river
3.2 SITE & PROGRAM

Factory accommodation
3.3 PROBLEMS

Uncontrolled densification
3.3 PROBLEMS

Uncontrolled densification
3.3 PROBLEMS

Minimal living quality for migrants
3.3 PROBLEMS

Large ground coverage of provided accommodation
DESIGN
4.1 THE ACS
4.1 THE ACS

Hydraulic telescopic cylinder
capacity 6~8 tons, length 2~6 m, cost < $10,000
4.1 THE ACS

Main girder and electric motor robotized overhead crane, span 18m, capacity <5 ton, cost < $10,000
4.1 THE ACS

Construction elevator
capacity 1~2 ton, cost < $30,000
4.1 THE ACS

Main manipulator with hydraulic clamp on telescopic cylinder, total 3 DOF, P-R-R
capacity 2 ton, cost < $3000 + $10,000 + $5000
4.1 THE ACS

Bolt fastener, light duty robotic arm with special end effector and sensor, total 4 DOF, P-R-P-P

Cost < $15,000
4.1 THE ACS

Total cost of machinery of the ACS:
less than $83,000 (one time investment)

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit price $/m²</th>
<th>Building area m²</th>
<th>total $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcement steel</td>
<td>4</td>
<td>320 * 14 = 4,480</td>
<td>17,920</td>
</tr>
<tr>
<td>Formwork</td>
<td>11</td>
<td></td>
<td>49,280</td>
</tr>
<tr>
<td>Concrete work</td>
<td>6</td>
<td></td>
<td>26,880</td>
</tr>
<tr>
<td>Scaffolding construction</td>
<td>3</td>
<td></td>
<td>13,440</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2</td>
<td></td>
<td>8,960</td>
</tr>
<tr>
<td>Management</td>
<td>2</td>
<td>320 * 14 = 4,480</td>
<td>8,960</td>
</tr>
<tr>
<td>Mechanical equipment</td>
<td>9</td>
<td></td>
<td>40,320</td>
</tr>
<tr>
<td>Material turnover</td>
<td>9</td>
<td></td>
<td>40,320</td>
</tr>
<tr>
<td>Material amortization</td>
<td>10</td>
<td></td>
<td>44,800</td>
</tr>
<tr>
<td><strong>Total $/m²</strong></td>
<td><strong>56</strong></td>
<td></td>
<td><strong>250,880</strong></td>
</tr>
</tbody>
</table>

4.2 THE BUILDING SYSTEM

The building system include only heavy structural elements that require less dexterity.
4.2 THE BUILDING SYSTEM

- a1. Connection plates bolted to column
- a2. Connection plates welded to column
- a3. Nut glued to connection plates
- a4. Bolt fastener operation

Column with welded connection plates, guiding chamfers and glued nuts
weight 240kg / unit
4.2 The Building System

Precut beam with welded guiding chamfers
weight 60kg/m, 240kg ~ 440kg / unit
4.2 THE BUILDING SYSTEM

Precast and precut lightweight concrete slab

weight 153kg/m, 370kg ~ 1,100kg / unit
4.3 THE CONSTRUCTION

b1. positioning
b2. descending and clamping
b3. rotating and ascending
b4. necessary translation and rotation
b5. descending

Operation for column
4.3 THE CONSTRUCTION

b1. positioning  
b2. rotating  
b3. descending and clamping  
b4. necessary translation and rotation  
b5. descending

Operation for beam
4.3 THE CONSTRUCTION

b1. positioning  b2. descending and clamping  b3. necessary translation and rotation  b4. descending

Operation for floor slab
4.3 THE CONSTRUCTION

Step 01. Starting point of one construction cycle
4.3 THE CONSTRUCTION

Step 02. Lifting up of the system, manipulator picks element from elevator
Step 03. Lifting telescopic cylinder for installation of border column
4.3 THE CONSTRUCTION

Step 04. Bolt fastening with the specialty robotic arm
Step 05. Continue lifting cylinders and installation of the border columns
Step 06. Installation of inner columns
4.3 THE CONSTRUCTION

Step 07. Installation of floor slabs
4.3 THE CONSTRUCTION

Step 08. Installation of beams, finish point of construction cycle
4.4 THE ARCHITECTURE

The three aspects of design constraining each other and forms an integral.
4.4 THE ARCHITECTURE

General Information

<table>
<thead>
<tr>
<th>Project Name</th>
<th>A.H.E.A.D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
<td>The factory</td>
</tr>
<tr>
<td>Total storeys</td>
<td>14</td>
</tr>
<tr>
<td>Building Height</td>
<td>39.6m</td>
</tr>
<tr>
<td>Program</td>
<td>Residential, Commercial, Production (site)</td>
</tr>
<tr>
<td>Gross floor area</td>
<td>4,480m²</td>
</tr>
<tr>
<td>Site Area</td>
<td>3,000m²</td>
</tr>
<tr>
<td>Building Footprint</td>
<td>400m²</td>
</tr>
<tr>
<td>Ground Coverage Ratio</td>
<td>13%</td>
</tr>
<tr>
<td>Floor Area Ratio</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Location: undeveloped open field owned by the factory
4.4 THE ARCHITECTURE

New social relationship between the people
4.4 THE ARCHITECTURE

The ACS workflow chart
4.4 THE ARCHITECTURE

More efficient and profitable use of land
4.4 THE ARCHITECTURE

The building and the context isometric
4.4 THE ARCHITECTURE

Value for the factory

- Faster payback
- Better landuse
- Sustainable cycle
- Reputation and responsibility
4.4 THE ARCHITECTURE

Value for the workers
4.4 THE ARCHITECTURE

Value for the villagers

Rent from worker

Better environment

New job opportunities
4.4 THE ARCHITECTURE

Regular grid with controlled spacing
4.4 THE ARCHITECTURE

Basic typology: row house with shared corridor
4.4 THE ARCHITECTURE

Conventional ways to increase scale
4.4 THE ARCHITECTURE

Abandoned due to observed drawbacks
4.4 THE ARCHITECTURE

New typology: shared corridor as perimeter
4.4 THE ARCHITECTURE

Division of interior space with certain degree of freedom
4.4 THE ARCHITECTURE

Double height of corridor for better atmosphere
4.4 THE ARCHITECTURE

Balconies at odd number floors increase space and for better communication.
4.4 THE ARCHITECTURE

Different types of housing units

TYPE 1/2 A

TYPE 1/2 B

TYPE 1/4 A

TYPE 1/4 B

Shared grey space
Rental space
Shared interior space
Private space

37 m²
for family
3~4 persons

1 Living room + Dining space
1 Kitchen
1 WC
2 Bedroom
4.4 THE ARCHITECTURE

Different types of housing units

Shared grey space  Rental space  Shared interior space  Private space

TYPE 1/2 B

TYPE 1/2 A

TYPE 1/4 B

TYPE 1/4 A

32 m² for couple 2 persons
1 Living room + Dining space
1 Kitchen
1 WC
1 Bedroom

Different types of housing units
4.4 THE ARCHITECTURE

Different types of housing units

- TYPE 1/2 B
- TYPE 1/4 A
- TYPE 1/4 B
- TYPE 1/4 A

Shared grey space
Rental space
Shared interior space
Private space

70 m² for big family
6–8 persons
1 Living room + Dining space
1 Kitchen
1 WC
4 Bedroom

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4.4 THE ARCHITECTURE

Different types of housing units

TYPE 1/2 A
TYPE 1/2 B
TYPE 1/4 A
TYPE 1/4 B

Shared grey space
Rental space
Shared interior space
Private space
4.4 THE ARCHITECTURE

- Exterior Shading Panels
- Self-shading Corridor
- Ventilated Inner Corridor & Traditional Transom Windows

Climate considerations
4.4 THE ARCHITECTURE

- Wall finishing: Wooden boards
- Wall finishing: Woven bamboo mat
- Wall finishing: Treated bamboo boards
- Wall finishing: Brick
- Railing panel: Metal mesh
- Shading panel: Plastic textile

Materials used in the building
4.4 THE ARCHITECTURE
THANK YOU!