Future proof buildings
A Sustainable approach for transforming 1960’s high rise residential buildings.

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TU Delft Building Technology
Introduction

Description of gallery flats

Challenges and improvement strategy for the high-rise flats

Case study

Add-on design

Performance analysis

Building design

Conclusions
Introduction
Sustainable development

The goal of sustainable development is to meet the needs of present generations without jeopardising the ability of future generations to meet their needs.

(European commission, 2016)
Impact of the building industry

- Resources: 50%
- Energy: 40%
- Water: 30%
- CO₂: 35%
- Waste: 40%

(Ministerie van Infrastructuur en Milieu, 2016)
More than 100,000 dwellings are currently reaching the age of 50 each year

(Canon volkshuisvesting Nederland)
Popularity of the high rise flats

Post WW2 housing shortages

Architectural views
Research Question

What type of approach can ensure that post world war 2 high-rise residential buildings can keep providing a high-quality living space for their inhabitants while at the same time meeting the current sustainability goals?
Description of gallery access flats
• 6.7% of the current housing stock consists of high rise buildings.

• 60% of these buildings were built during the nineteen sixties and seventies.
• made using concrete prefab construction methods developed after the war.

• The most common type of flat made during this era was the gallery flat.

• 2% of the total building stock in the Netherlands consists of gallery access flats which account for 125,000 flats.

• High rise flats all share common spaces like the entrance hall, rubbish disposal, staircases and the lift.
Typical floorplan gallery flat
Challenges of high rise residential flats
Building physical challenges

- ventilation loss
- not airtight
- aged heating system
- condense
- acoustic insulation
- bad thermal insulation
- thermal leaks
- 18 °C
- 0 °C
Social, spatial and economic challenges

Space shortage

Monotony

Vandalism

Bad accessibility

Closed plinth

(Duijvestein & Dorst, 2004)
Possible improvement strategies

- Nothing
- Maintenance
- Renovation
- Refurbishment
- Demolition
- Replacement

**Choice**

**Refurbishment**

- Able to deal with many of the challenges
- Drastic approach with more possibilities
- Save energy and resources by maintaining the building

*Building layers (Brand, 1994)*
Façade refurbishment strategies

- Improved thermal insulation
- Short transformation period
- More unique appearance for building and dwellings
- A more flexible floorplan and extra space
- Demountable/reusable elements
Add-on options

The hanging addon

The half supported addon

The self-supporting addon

Choice

Self-supporting addon

• Not restricted by weight
• Drastic approach with
• More possibilities
• Freedom in adapting the building
Addon built up

Small element built up

Large element built up

Unitized built up

Choice

Unitized built up

- Short built times
- Not at all labor intensive on site
- High finish due to build up in factory
- Little waste on site
- Demountable / reusable in one piece
Structural built up

- Separately demountable
- Same structure regardless of placement

Choice

Units in frame construction

Stacking of the units
Unit built up

Frame unit

Choice

Shell unit

• Minimal height/thickness due to combination of façade and structure into one shell
• Demountable into large elements
• Structural integrity by itself
Case study
Current situation
Pictures case study flat balcony side
Pictures case study flat gallery side
Building system & sections

MUWI building system
• Building blocks 50x19x21 cm
• Lightweight concrete floors on T shaped beams 60 cm apart
• Reinforced lintel
Single dwelling facades and floorplan layout

<table>
<thead>
<tr>
<th>Rooms</th>
<th>Current dimensions (m²)</th>
<th>Required dimensions (m²)</th>
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<tbody>
<tr>
<td>Living room</td>
<td>18.65</td>
<td>14.81</td>
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<tr>
<td>Dining room</td>
<td>-</td>
<td>9.99</td>
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<tr>
<td>Main bedroom</td>
<td>13.0</td>
<td>10.4</td>
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<tr>
<td>Second bedroom</td>
<td>11.56</td>
<td>6.16</td>
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<tr>
<td>Kitchen</td>
<td>6.75</td>
<td>6.48</td>
</tr>
<tr>
<td>Bathroom</td>
<td>3.18</td>
<td>2.72</td>
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<tr>
<td>Toilet</td>
<td>1.03</td>
<td>0.98</td>
</tr>
<tr>
<td>Outdoor space</td>
<td>4.31</td>
<td>4.93</td>
</tr>
<tr>
<td>Storage room</td>
<td>5.0</td>
<td>5.0</td>
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Add-on design
Single dwelling facades
Single dwelling structural dimensions
Addon placement
Limits add-on dimensions
Potential floorplans with add-on
Addon two variants in depth
Window frame placement
Increased structural performance options

- Slab
- Framework
- Lattice girder
- Laminated glass
- Double slab and columns
- Columns with scaffolding
Placement isolation

1 and 4

- Inside insulation
- Outside insulation (combined)
- Outside insulation (separate)
- Sandwich insulation

Choice

Thermal bridging and prefabrication
Façade with or without panel finish
Addon extra functions
Material choice add-on units

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density kg/m³</th>
<th>Young’s modulus GPa</th>
<th>Embodied energy MJ/kg</th>
<th>CO₂ production kg CO₂ / kg</th>
<th>Thermal conductivity λ in W/mK</th>
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</thead>
<tbody>
<tr>
<td>GRP</td>
<td>1750</td>
<td>72-85</td>
<td>100</td>
<td>8.1</td>
<td>0.32</td>
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<tr>
<td>Glulam</td>
<td>450</td>
<td>12-14</td>
<td>12</td>
<td>0.84</td>
<td>0.13</td>
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<tr>
<td>High performance concrete</td>
<td>2800</td>
<td>25-27</td>
<td>3.58</td>
<td>0.48</td>
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</table>

- Concrete (high performance)
- Laminated timber
- Fiber reinforced polymers (FRP)
# Insulation material

### Rc > 4.5

<table>
<thead>
<tr>
<th>Isolation materials</th>
<th>Thermal conductivity $\lambda$ in W/mK</th>
<th>Thickness of panels in mm</th>
<th>Density kg/m³</th>
<th>Embodied energy MJ/kg</th>
<th>CO₂ production kg CO₂ eq</th>
<th>Shadow costs in € / kg</th>
<th>Life span years</th>
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<tbody>
<tr>
<td>Sheep wool</td>
<td>0.035</td>
<td>158</td>
<td>26</td>
<td>20.9</td>
<td>88.90</td>
<td>7.86</td>
<td>75</td>
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<tr>
<td>Cellulose</td>
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<td>70</td>
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<td>Flax</td>
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<tr>
<td>Cork</td>
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<td>180</td>
<td>120</td>
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<td>32.10</td>
<td>4.66</td>
<td>40</td>
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<tr>
<td>Wood fibres</td>
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<td>55</td>
<td>17</td>
<td>19.30</td>
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<td>40</td>
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<tr>
<td>Glass wool</td>
<td>0.035</td>
<td>158</td>
<td>25</td>
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<td>75</td>
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<tr>
<td>Rock wool</td>
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<td>158</td>
<td>48</td>
<td>16.8</td>
<td>8.01</td>
<td>0.81</td>
<td>75</td>
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<tr>
<td>Aerogel</td>
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<td>59</td>
<td>135</td>
<td>53</td>
<td>-</td>
<td>-</td>
<td>75</td>
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<tr>
<td>XPS</td>
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<td>88.6</td>
<td>15.80</td>
<td>1.79</td>
<td>75</td>
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<tr>
<td>PIR / PUR</td>
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<td>104</td>
<td>33</td>
<td>101.5</td>
<td>21.90</td>
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<td>75</td>
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<td>Resol foam</td>
<td>0.020</td>
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<td>36</td>
<td>88</td>
<td>17.10</td>
<td>1.88</td>
<td>75</td>
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<td>Vacuum panel</td>
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<td>195</td>
<td>81.9</td>
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<td>-</td>
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(Lambda.be)
## Window frames

<table>
<thead>
<tr>
<th>Window frames</th>
<th>Density kg/m³</th>
<th>embodied energy MJ/kg</th>
<th>CO₂ production kg CO₂ eq / m²</th>
<th>Shadow costs in € / kg</th>
<th>Life span years</th>
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<tbody>
<tr>
<td>Wood (spruce)</td>
<td>450</td>
<td>12</td>
<td>12.7</td>
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<tr>
<td>Aluminium</td>
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<td>154</td>
<td>17.5</td>
<td>2.4</td>
<td>75</td>
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<tr>
<td>Steel</td>
<td>7800</td>
<td>20.1</td>
<td>31.8</td>
<td>2.79</td>
<td>100</td>
</tr>
<tr>
<td>PVC</td>
<td>1400</td>
<td>77.2</td>
<td>36.5</td>
<td>5.8</td>
<td>40</td>
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<tr>
<td>GRP</td>
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<td>37.5</td>
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Material choice load bearing structure

<table>
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<tr>
<th>Materials</th>
<th>Density kg/m³</th>
<th>Young’s modulus GPa</th>
<th>Embodied energy MJ/kg</th>
<th>CO2 production kg CO2 / kg</th>
<th>Thermal conductivity λ in W/mK</th>
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</thead>
<tbody>
<tr>
<td>glulam</td>
<td>450</td>
<td>12-14</td>
<td>12</td>
<td>0.84</td>
<td>0.13</td>
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<tr>
<td>concrete (reinforced)</td>
<td>2400</td>
<td>100-140</td>
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<td>0.1</td>
<td>2.0</td>
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<td>steel</td>
<td>7800</td>
<td>200-215</td>
<td>20.1</td>
<td>1.37</td>
<td>50</td>
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</table>

Laminated timber

Concrete

Steel

Choice

Steel structure
Add-on wood
Add-on FRP
Add-on concrete vertical
Add-on concrete horizontal

- Correction wheel
- Beam, RHS-CF 300x200x12.5
- Column, SHS-HF 200x200x16

- aluminium window frame, kawneer RT 82 Hi+
- interior insulation, kooltherm k17 λ=0.020 (90m)
- plasterboard (10mm)
Add-on concrete wheels
Add-on concrete wheels
Concrete Add-on wheel
Concrete Add-on wheel system
Concrete Add-on wheel system
Concrete Add-on wheel system
Assembly addon
Assembly addon to building
Performance
## Thermal performance addons

<table>
<thead>
<tr>
<th>Materials</th>
<th>Lambda $\lambda$ in W/mK</th>
<th>Thickness of panels in m</th>
<th>Rc-value m²K/W</th>
<th>Isolation materials</th>
<th>Lambda $\lambda$ in W/mK</th>
<th>Thickness of insulation in m</th>
<th>Rc-value m²K/W</th>
<th>Total Rc-value m²K/W</th>
<th>U-value W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRP</td>
<td>0.32</td>
<td>0.020</td>
<td>0.06</td>
<td>PIR / PUR</td>
<td>0.023</td>
<td>0.20</td>
<td>8.7</td>
<td>8.76</td>
<td>0.112</td>
</tr>
<tr>
<td>Glulam</td>
<td>0.13</td>
<td>0.14</td>
<td>1.08</td>
<td>Phenolic foam</td>
<td>0.020</td>
<td>0.08</td>
<td>4</td>
<td>5.08</td>
<td>0.190</td>
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<td>HP concrete</td>
<td>2</td>
<td>0.12</td>
<td>0.06</td>
<td>Phenolic foam</td>
<td>0.020</td>
<td>0.09</td>
<td>4.5</td>
<td>4.56</td>
<td>0.211</td>
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<table>
<thead>
<tr>
<th>Add-on material</th>
<th>Window frames</th>
<th>U value W / m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wooden add-on</td>
<td>Wood (M Sora, Nature Optimo XL)</td>
<td>0.89</td>
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<tr>
<td>HP Concrete add-on</td>
<td>Aluminium (Kawneer, RT 82 HI+)</td>
<td>0.79</td>
</tr>
<tr>
<td>GRP add-on</td>
<td>GRP (Krone, Ecliptica)</td>
<td>0.71</td>
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## Material impact embodied energy and CO2

<table>
<thead>
<tr>
<th>Wood add-on</th>
<th>Density kg/m³</th>
<th>Square meter m²</th>
<th>Kilo's kg</th>
<th>Embodied energy MJ/kg</th>
<th>CO2 production kg</th>
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</thead>
<tbody>
<tr>
<td>Glulam 140mm</td>
<td>450</td>
<td>6.0</td>
<td>2700</td>
<td>32400</td>
<td>2268</td>
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<tr>
<td>Phenolic foam (Resol) 80mm</td>
<td>36</td>
<td>1.1</td>
<td>40</td>
<td>3520</td>
<td>684</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>2740</strong></td>
<td><strong>35920</strong></td>
<td><strong>2952</strong></td>
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<table>
<thead>
<tr>
<th>Concrete (HPC) add-on</th>
<th>Density kg/m³</th>
<th>Square meter m²</th>
<th>Kilo's kg</th>
<th>Embodied energy MJ/kg</th>
<th>CO2 production kg</th>
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<tbody>
<tr>
<td>HPC 120mm</td>
<td>2800</td>
<td>2.74</td>
<td>7672</td>
<td>27465</td>
<td>3682</td>
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<tr>
<td>Phenolic foam (Resol) 90mm</td>
<td>36</td>
<td>1.2</td>
<td>43</td>
<td>3802</td>
<td>739</td>
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<td><strong>Total</strong></td>
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<td><strong>7715</strong></td>
<td><strong>31267</strong></td>
<td><strong>4421</strong></td>
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<table>
<thead>
<tr>
<th>GRP add-on</th>
<th>Density kg/m³</th>
<th>Square meter m²</th>
<th>Kilo's kg</th>
<th>Embodied energy MJ/kg</th>
<th>CO2 production kg</th>
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<tr>
<td>GRP 2*10mm</td>
<td>1750</td>
<td>0.5</td>
<td>875</td>
<td>87500</td>
<td>7088</td>
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<td>PUR 200mm</td>
<td>33</td>
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<td>18778</td>
<td>3164</td>
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<td><strong>Total</strong></td>
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<td><strong>1060</strong></td>
<td><strong>106278</strong></td>
<td><strong>10252</strong></td>
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<table>
<thead>
<tr>
<th>Steel structure</th>
<th>Density kg/m³</th>
<th>Square meter m²</th>
<th>Kilo's kg</th>
<th>Embodied energy MJ/kg</th>
<th>CO2 production kg</th>
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</thead>
<tbody>
<tr>
<td>Steel (11 add-ons)</td>
<td>7800</td>
<td>1.935</td>
<td>15093</td>
<td>303370</td>
<td>20677</td>
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<tr>
<td>Steel per add-on</td>
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<td>1372</td>
<td>27579</td>
<td>1880</td>
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Building design
Design process building
Design process building
Conclusions
Does the designed add-on contribute to good living conditions for the residents while at the same time improving the sustainability of the building?
Technical aspects
- capable of dealing with the building physical challenges
- structurally viable

Spatial aspects
- extra space and more floorplan flexibility

Social aspects
- more diversified flats with a personal image

Environmental aspects
- extending the lifespan of an existing flat.
- flexible and reusable due to demountability

Financial aspects
- quick to install
- Possibly expensive compared to other methods