Modular Building in a Circular Economy

An exploratory research
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Part I: A Circular Economy

Part II: A Circular Building Stock

Part III: Modular Building

Conclusion
The Economics of the Coming Spaceship Earth

Boulding (1966, p. 1)
Industrial Revolution England
Growing demand

Limited supply
“Economics is the study of how society manages its scarce resources”

Mankiw (2012, p. 4)
The construction industry consumes more than half of the global resources and generates the greatest waste stream globally.

Iacovidou & Purnell (2016)
Linear economy in the building industry

Means

Circular economy in the building industry
If the life of a complete building cannot be extended, “it may be possible to exploit the residual life of the modules through partial disassembly of the original product into modules, some of which can then be reused in other assemblies.”

Allwood (2014, p. 462)
Graduation research
How can modular building contribute to a circular building stock?
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Part I: A Circular Economy

1. What is a circular economy and what is the goal of a circular economy?
2. Is a circular economy of growth possible?
How can modular building contribute to a circular building stock?

1. What is a circular economy and what is the goal of a circular economy?
2. Is a circular economy of growth possible?
3. What constitutes a circular building stock?
4. How can the current building stock be characterised?
5. What are the different means to make the current building stock more circular?
1. What is a circular economy and what is the goal of a circular economy?
2. Is a circular economy of growth possible?
3. What constitutes a circular building stock?
4. How can the current building stock be characterised?
5. What are the different means to make the current building stock more circular?
6. What is modular building and what is the current practice of modular building in the Netherlands?
Relevance

→ Societal
   Growing demand, limited supply; do more with less

→ Scientific
   Lack of research on CE in built environment meso-scale (building)

→ Practical
Research

→ **Objective**: *explore* how modular building can contribute to a circular building stock;

  Aiming to resolve or improve a situation in practice – *starting point*

  Recommendations for further research

→ **Method**: qualitative research
Methodology

→ **Parts I & II:** Literature study and exploratory interviews

→ **Part III:** Literature study and collective case study
  (data from suppliers’ website; semi-structured interviews; site visits)
Part I: A Circular Economy
Circular economy

Common elements:
→ Maximising the value / productivity of materials;
→ Eliminating waste

By keeping materials within a closed loop

Adams, Osmani, Thorpe, & Thornback (2017, p. 16)
Circular economy

Common elements:

→ Maximising the value of materials;
→ Eliminating waste
By keeping materials within a closed loop

Adams, Osmani, Thorpe, & Thornback (2017, p. 16)
Ultimate source
Scarce resources (low entropy)

The ultimates

Ultimate goal
Human well-being of current and future generations

Daly (1977)
The economic system; the intermediates

Ultimate source
Scarce resources (low entropy)

Intermediate means
Factors of production

Intermediate goals

Ultimate goal
Human well-being of current and future generations

Daly (1977)
The economic system; **the intermediates**

- **Ultimate source**
  - Scarce resources (low entropy)

- **Intermediate means**
  - Factors of production

- **Intermediate goals**
  - Growth in the GDP

- **Ultimate goal**
  - Human well-being of current and future generations

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Daly (1977)
Based on a report in which a circular economy is said to “translate into a GDP increase of as much as 7 percentage points (....) [that] arise from increasing consumption”

Increase production

→ Discovering and mining raw materials;
→ Growing the labour force;
→ Creating superior technology;
→ Increasing specialisation
Increase production

→ Discovering and mining raw materials; limited supply
→ Growing the labour force; increasing demand
→ Creating superior technology;
→ Increasing specialisation
The economic system; **the intermediates**

- **Ultimate source**
  - Scarce resources (low entropy)

- **Intermediate means**
  - Factors of production

- **Intermediate goals**
  - Development of the stock

- **Ultimate goal**
  - Human well-being of current and future generations

Daly (1977)
Steady-state economy

Development of the stock:

→ Increasing service-efficiency of the stock:

\[
\frac{\text{services}}{\text{stock}}
\]

→ Increasing durability of the stock:

\[
\frac{\text{stock}}{\text{throughput}}
\]

Daly (1977)
Steady-state economy

Concepts:

→ **Service** is the satisfaction experienced needs are met

→ **Stock** is the total inventory of economic goods and human bodies

→ **Throughput** is the entropic physical flow of matter-energy through the economic system

Daly (1977)
services
stock
Population size

Stock of goods

Increase

Remain constant

Uncontrollable variable

Controllable variable

Legend

Growth in Gross Domestic Product

Development in the service-efficiency and the durability of the stock
“Practical” circular economy

Concepts:

→ **Utility** is the satisfaction experienced needs are met, indicated in willingness to pay [€/year]

→ **Stock** is the total inventory of economic goods [kg]

→ **Raw material and waste** are the entropic physical flow of matter-energy through the economic system [kg/year]

Based on Daly (1977)
A “practical” circular economy is an economy of both development and growth. The goal is to control the size of the stock of goods* and to increase the utility and the durability of this stock.
Part II:
A Circular Building Stock
Increase the utility of the building stock

Increase the durability of the building stock
Utility

Loss of utility
Loss of utility due to locational factors

No loss of utility
“We are attached to the location of our house. Everything and everyone is within reach: our family, the doctor, the pharmacy, and the supermarket.

“If we could change anything about the house, we would like to have all amenities on the ground floor”
Loss of utility due to locational factors

Elderly couple in China refuse to move for road construction

No loss of utility

Loss of utility due to building-related factors
Postal office in North-East Groningen

No loss of utility

Loss of utility due to locational factors

Loss of utility due to building-related factors
Status quo
No intervention
“Traditional” interventions:
Renovation, transformation, demolition

Design strategy:
Design for Adaptability

Status quo
No intervention
"Traditional" interventions:
Renovation, transformation, demolition

Design strategy:
Design for Adaptability

Status quo
No intervention

“Traditional” interventions:
Transformation, demolition

Design strategy:
Design for Relocation

Loss of utility due to building-related factors

Loss of utility due to locational factors
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<td>Design strategy: Design for Adaptability</td>
<td>&quot;Traditional&quot; interventions: Demolition</td>
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<td>Design strategy: Design for Relocation</td>
<td>Design strategy: Design for Deconstruction and Reuse</td>
<td>Design strategy: Design for Adaptability</td>
<td>Location X</td>
<td>Location Y</td>
<td>Location Z</td>
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Loss of utility due to locational factors:

- Design for Adaptability
- Design for Deconstruction and Reuse
- Design for Relocation
Modular building
Part III: Modular Building
Modular building
Modular building

“Modular construction uses three-dimensional or volumetric units that are prefabricated and are essentially fully finished in factory conditions, and are assembled on site to create complete buildings or major parts of buildings”

Lawson, Ogden, & Goodier (2014, p. 1)
“Modular construction systems are closed systems in which the elements are prefabricated by the manufacturers independent of a particular building. For a modular construction system, a particular number of elements are pre-determined which can be organised into complete entities by combining them in a number of different ways”

Staib, Dörrhöfer, & Rosenthal (2008, p. 43)
Modular building

Single-configuration modular building
→ Volumetric units;
→ Assembled on site into one configuration

Multi-configuration modular building
→ Elements;
→ Can be combined into a number of different configurations
Multi-configuration modular building

Multi-configuration modular building

Status quo
No intervention

Multi-configuration modular building

Single-configuration modular building

Loss of utility due to building-related factors

Loss of utility due to locational factors
Collective case study

→ Three to fifteen cases;
→ The firms provide modular housing solutions;
   Housing is chosen as a focus, because of its large share in the total building stock
→ The firms describe their product as “modular”;
→ The firms mention “circular economy” or “scarcity of resources” on their website;
→ The firms are located in the Netherlands;
   Subject to the regulations laid down in the Building Decree
   Practical limitations: Dutch interviews and visits
Topics

→ Idea behind the firm

→ Modular building
  The firm’s reasons for building modular
  Interpretation of modular building
  What constitutes as a module

→ The characteristics of the product
  Adjustable
  Relocatable
  Deconstructable and reusable
→ Idea behind the firm

Frustration with the way things go in the building industry, the wish to offer a “better” product than traditional housing;
The wish to give the client freedom in the design (sometimes even after construction) for an affordable price
Reasons for building modular

Being able to offer the client freedom to design an affordable dwelling;

Being able to offer the client freedom to relocate or adapt the building after construction;

Being able to enjoy the advantages of prefabrication: parts are made in factory conditions, transported to the site and constructed mostly within a few days.
Topics

→ Interpretation of modular building

Building in a permanently adaptable manner;
An industrial way of building; an advanced form of prefabrication;
Building on a fixed grid; building with modules that have a standardised dimension
Interpretation of modular building

A module is a standardised panel or a volumetric unit, that can be assembled in a number of configurations on site (multi-configuration modular building);

A is a jigsaw puzzle piece, that can be assembled in a single configuration on site (single-configuration modular building).
Characteristics of the product: adaptable?

Most of the products can be customised by the client in the design phase;

Some of the products can be customised by the client in the operations phase;

The degree of customisation is constrained by the chosen building construction, rules and regulations and integrated service installations.
Characteristics of the product: relocatable?

Most of the products can be relocated;

A possible constraint is the financing construction: if the building serves as collateral for the bank, it can not simply be relocated.
Characteristics of the product: deconstructable and reusable?

All products can be deconstructed, some up until the level of the element as a result of the use of dry connections; others up until the level of the component as the elements are glued together;

The financing construction that constrains relocation also constrains deconstruction;

The parts can be reused within the building system of the firm.
Conclusion
Conclusion

How can modular building contribute to a circular building stock?

Multi-configuration modular building allows for adaptation, relocation, deconstruction and reuse
Prevents loss of utility
Conclusion

However

→ Constrained by construction system; modules are designed to be used within the system (intrafirm modularity);
→ Constrained by rules and regulations;
→ Constrained by financing construction (collateral for the bank)
Complexity of the demand-supply problem

→ **Demand**: Natural growth rate in NL will be negative as of 2038 (CBS, 2016)

→ **Supply**: Type of material

  Cause of scarcity: Geologically rare; extraction financially unviable; supply concentrated in politically unstable countries (Hobson, 2016)

Scarcity not a driver in building industry (Rijskwaterstaat, 2015):
Discussion / limitations

Collective case study

→ Inclusion criteria; niche market (small share)
→ Utility / durability
→ Primary or secondary materials
→ Housing; other typologies?
Discussion / limitations

Sustainability linkages
Recommendations

- Raw material
  - Mined material
  - Mono material
  - Composite material
  - Bulk material
- Element
  - Sub-component
  - Component
  - Super-component
  - Building part
- Building

Activities:
- Purifying
- Combining
- Manufacturing into shape
- Adjusting form
- Assembling
- Connecting
Reflection

Circular economy as multi-disciplinary subject; both fantastic and terrible
References


