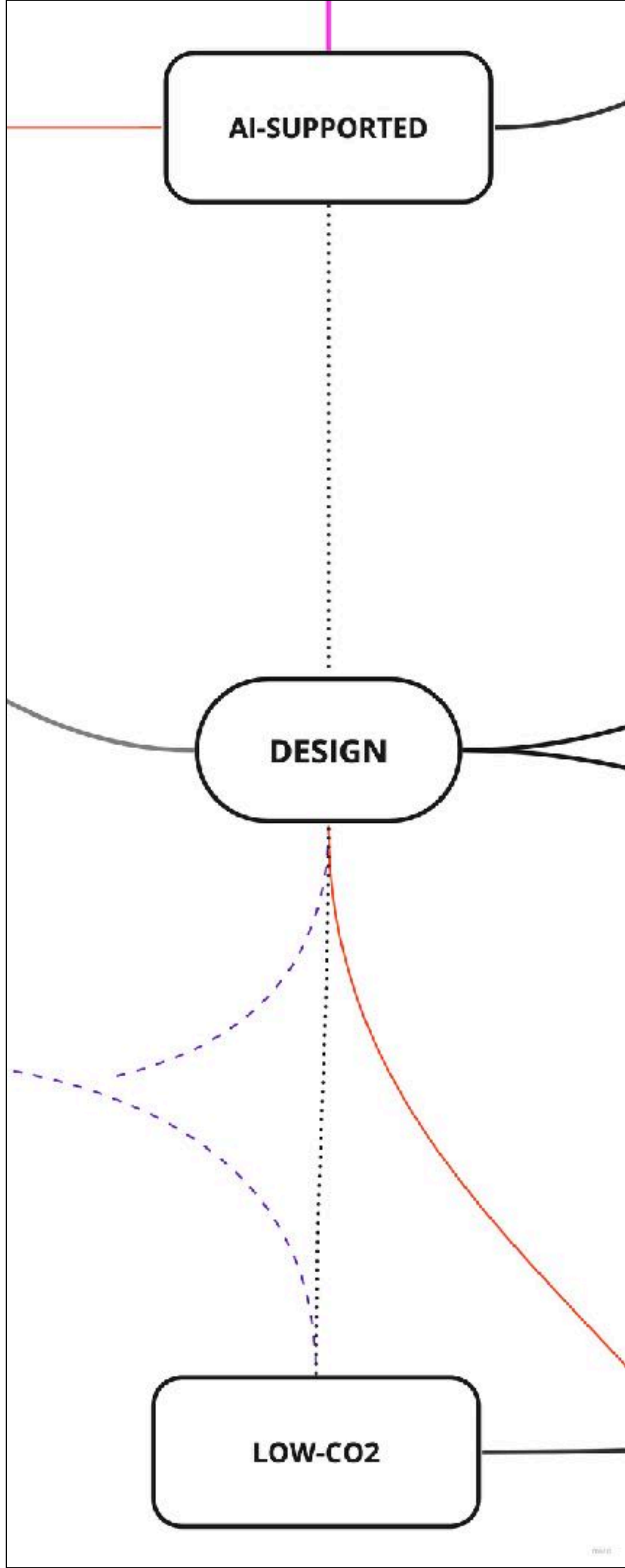
Ai-supported low CO2 circular design

A material driven approach

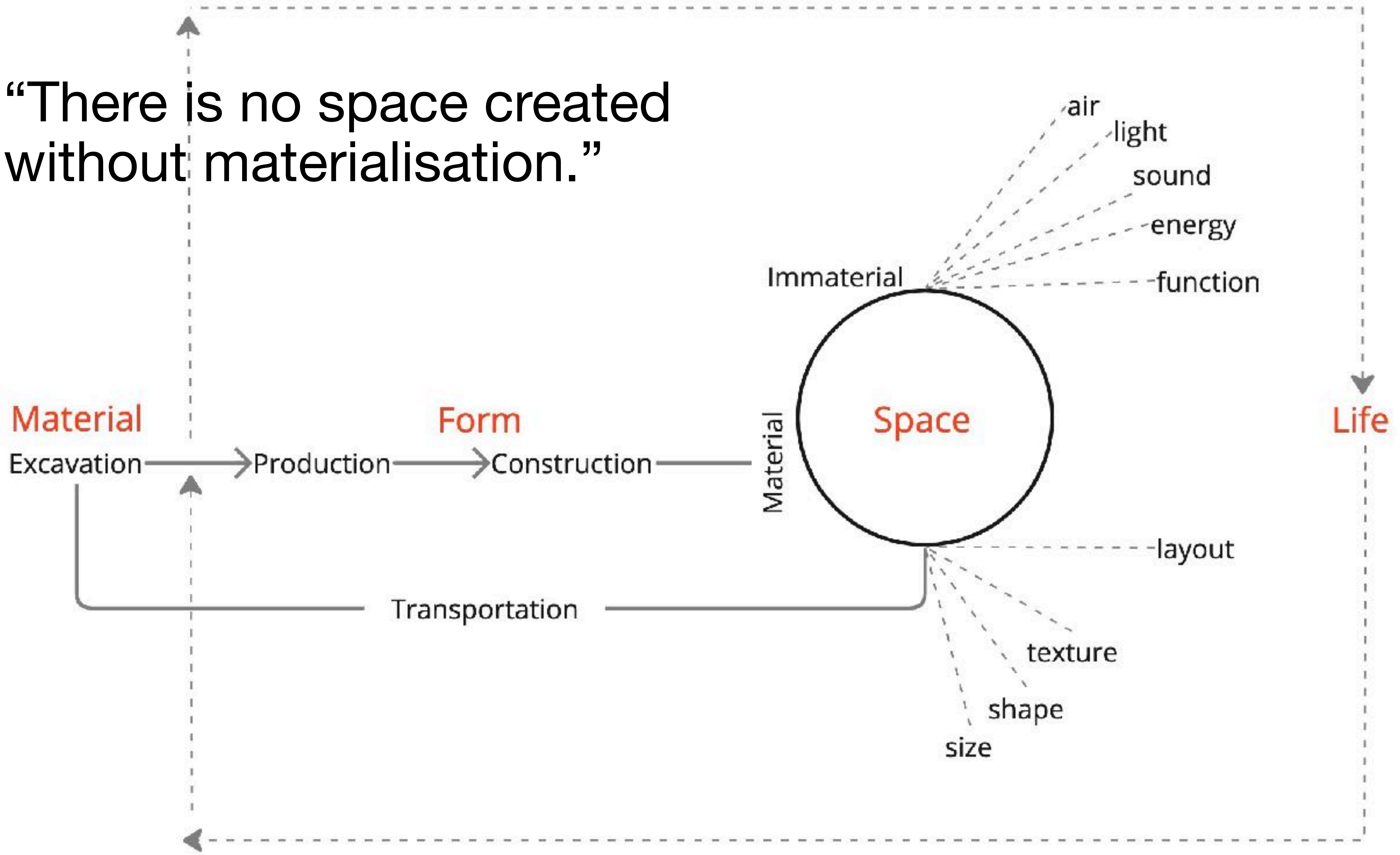
Peng lee, 09.2023

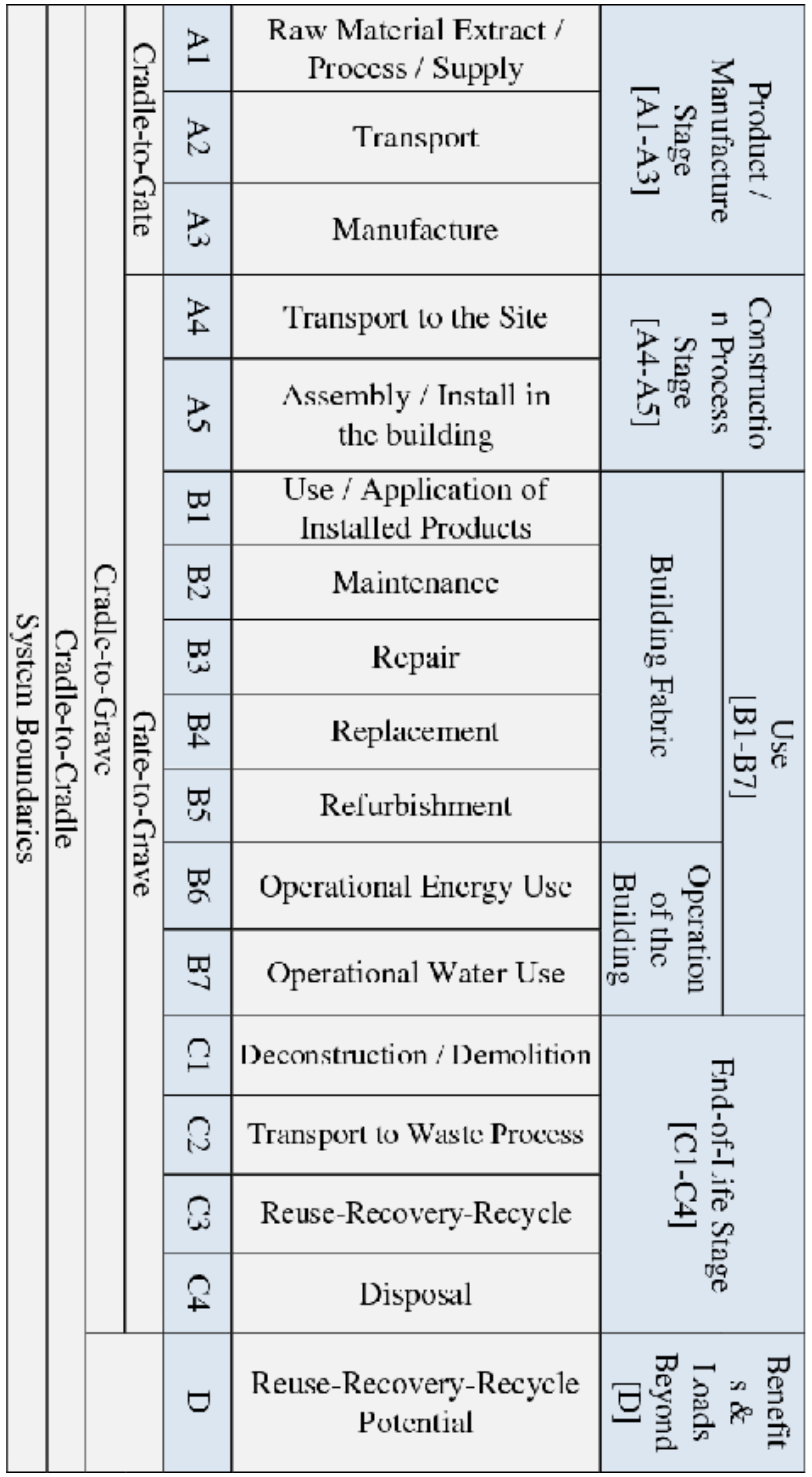


Design

From building life cycle to material scenarios

“There is no space created without materialisation.”





System Boundaries	Cradle-to-Cradle	Cradle-to-Grave	Cradle-to-Gate	A1	Raw Material Extract / Process / Supply	Product / Manufacture Stage [A1-A3]	
				A2	Transport		
				A3	Manufacture		
			Gate-to-Grave	A4	Transport to the Site	Construction Process Stage [A4-A5]	
				A5	Assembly / Install in the building		
				B1	Use / Application of Installed Products	Use [B1-B7]	Building Fabric
				B2	Maintenance		
				B3	Repair		
				B4	Replacement		
				B5	Refurbishment		
				B6	Operational Energy Use		Operation of the Building
				B7	Operational Water Use		
				C1	Deconstruction / Demolition	End-of-Life Stage [C1-C4]	
				C2	Transport to Waste Process		
				C3	Reuse-Recovery-Recycle		
				C4	Disposal		
				D	Reuse-Recovery-Recycle Potential	Benefits & Loads Beyond [D]	

LCA stages. Re-drew based on Silvestre et al. (2016)

Impact

Low CO2 approach

CONDITION AFTER INTERVENTION

- CONDITION BEFORE INTERVENTION

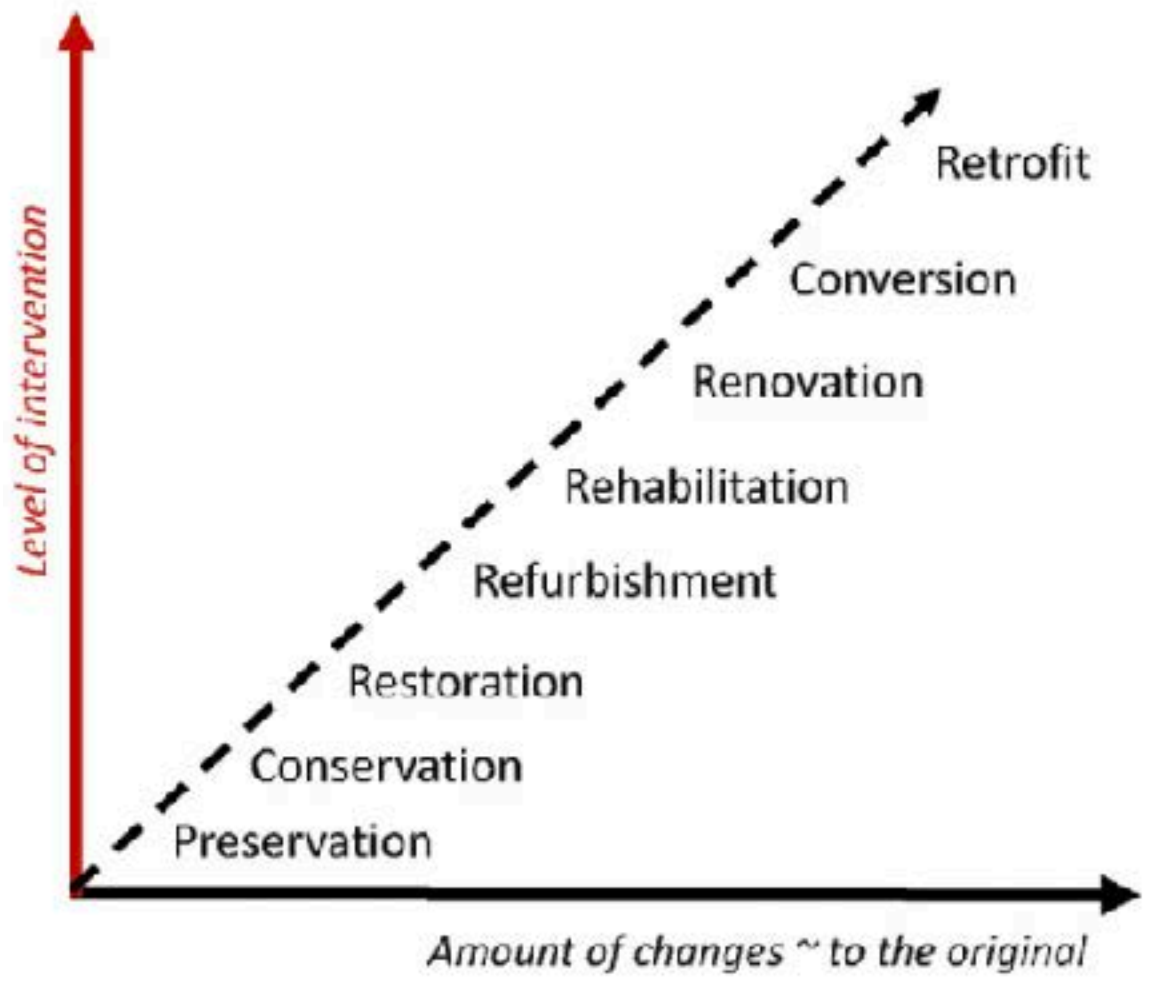
= IMPACT

Energy and emission

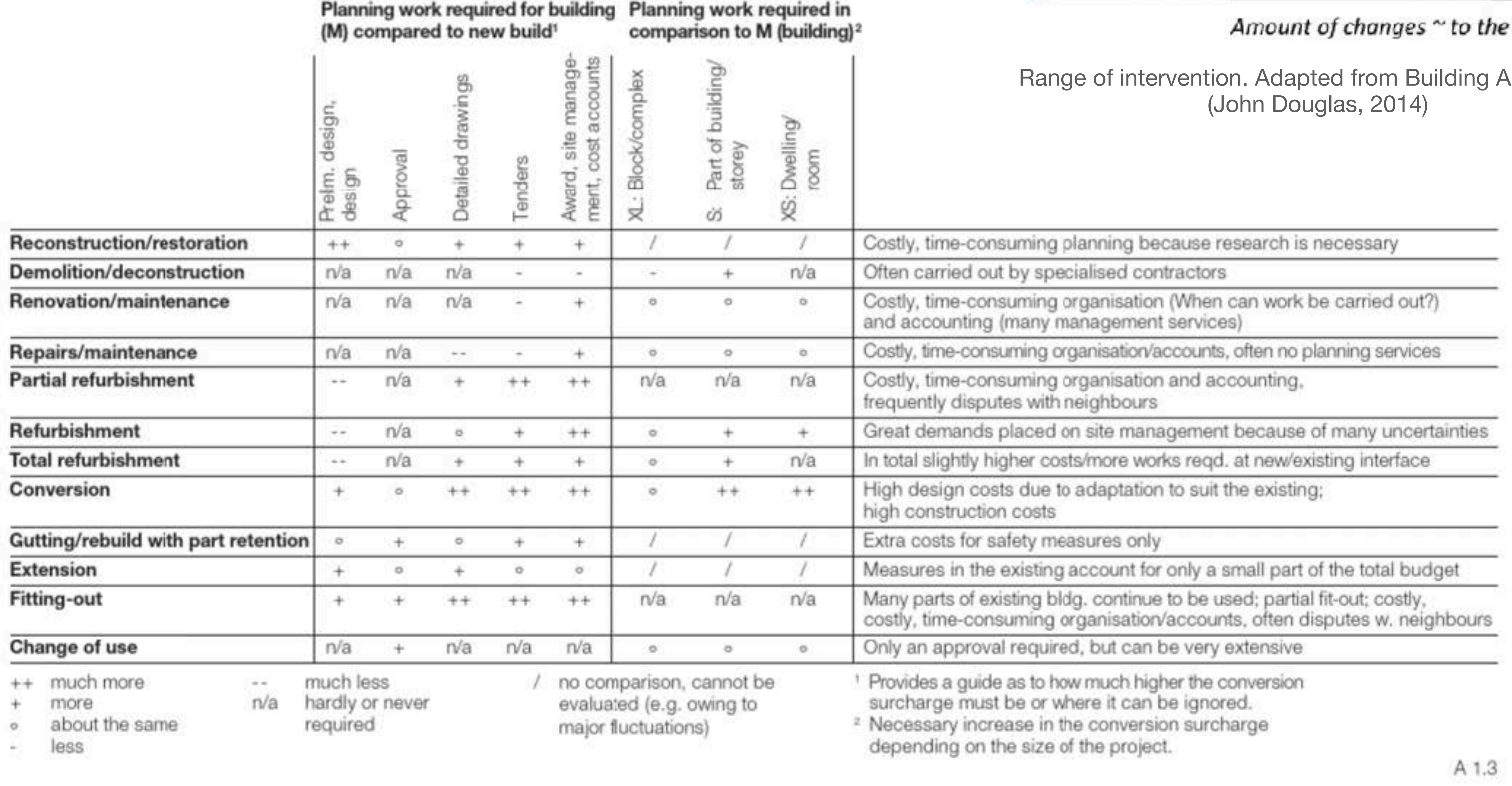
Cost

Time

Comfort



Range of intervention. Adapted from Building Adaptation. (John Douglas, 2014)



	Planning work required for building (M) compared to new build[1]					Planning work required in comparison to M (building)[2]			
	Prelm. design, design	Approval	Detailed drawings	Tenders	Award, site management, cost accounts	XL: Block/complex	S: Part of building/ storey	XS: Dwelling/ room	
Reconstruction/restoration	++	∘	+	+	+	/	/	/	Costly, time-consuming planning because research is necessary
Demolition/deconstruction	n/a	n/a	n/a	-	-	-	+	n/a	Often carried out by specialised contractors
Renovation/maintenance	n/a	n/a	n/a	-	+	∘	∘	∘	Costly, time-consuming organisation (When can work be carried out?) and accounting (many management services)
Repairs/maintenance	n/a	n/a	--	-	+	∘	∘	∘	Costly, time-consuming organisation/accounts, often no planning services
Partial refurbishment	--	n/a	+	++	++	n/a	n/a	n/a	Costly, time-consuming organisation and accounting, frequently disputes with neighbours
Refurbishment	--	n/a	∘	+	++	∘	+	+	Great demands placed on site management because of many uncertainties
Total refurbishment	--	n/a	+	+	+	∘	+	n/a	In total slightly higher costs/more works reqd. at new/existing interface
Conversion	+	∘	++	++	++	∘	++	++	High design costs due to adaptation to suit the existing; high construction costs
Gutting/rebuild with part retention	∘	+	∘	+	+	/	/	/	Extra costs for safety measures only
Extension	+	∘	+	∘	∘	/	/	/	Measures in the existing account for only a small part of the total budget
Fitting-out	+	+	++	++	++	n/a	n/a	n/a	Many parts of existing bldg. continue to be used; partial fit-out; costly, costly, time-consuming organisation/accounts, often disputes w. neighbours
Change of use	n/a	+	n/a	n/a	n/a	∘	∘	∘	Only an approval required, but can be very extensive

++	much more	--	much less	/	no comparison, cannot be evaluated (e.g. owing to major fluctuations)
+	more	n/a	hardly or never required		
∘	about the same				
-	less				

[1] Provides a guide as to how much higher the conversion surcharge must be or where it can be ignored.

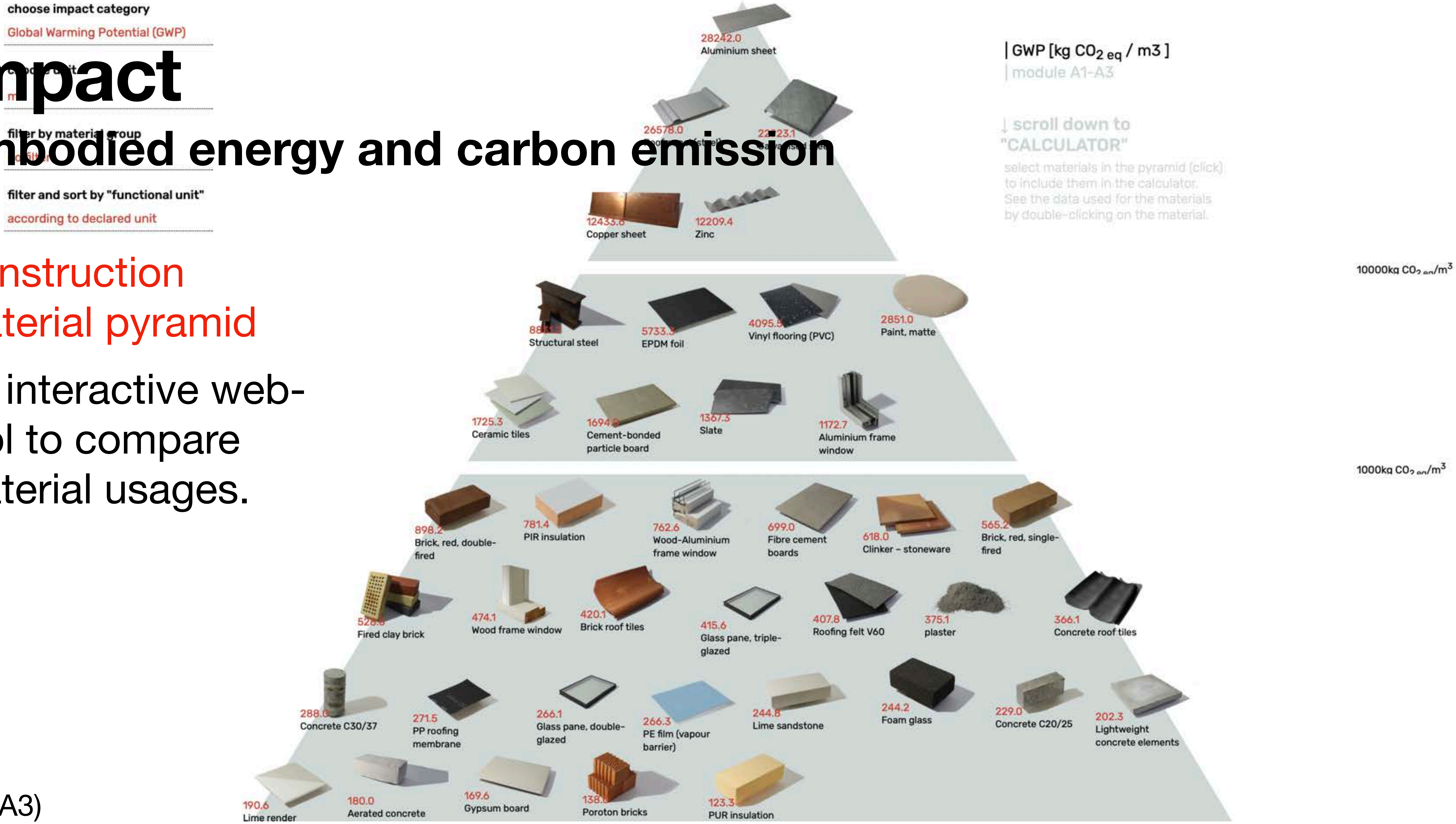
[2] Necessary increase in the conversion surcharge depending on the size of the project.

A 1.3

Levels of Intervention. Refurbish Manual. (Georg Giebeler, 2009)

Impact

Embodied energy and carbon emission



choose impact category
Global Warming Potential (GWP)

filter by material group

filter and sort by "functional unit"
according to declared unit

| GWP [kg CO_2 eq / m3]
| module A1-A3

↓ scroll down to "CALCULATOR"

select materials in the pyramid (click) to include them in the calculator. See the data used for the materials by double-clicking on the material.

Construction
Material pyramid

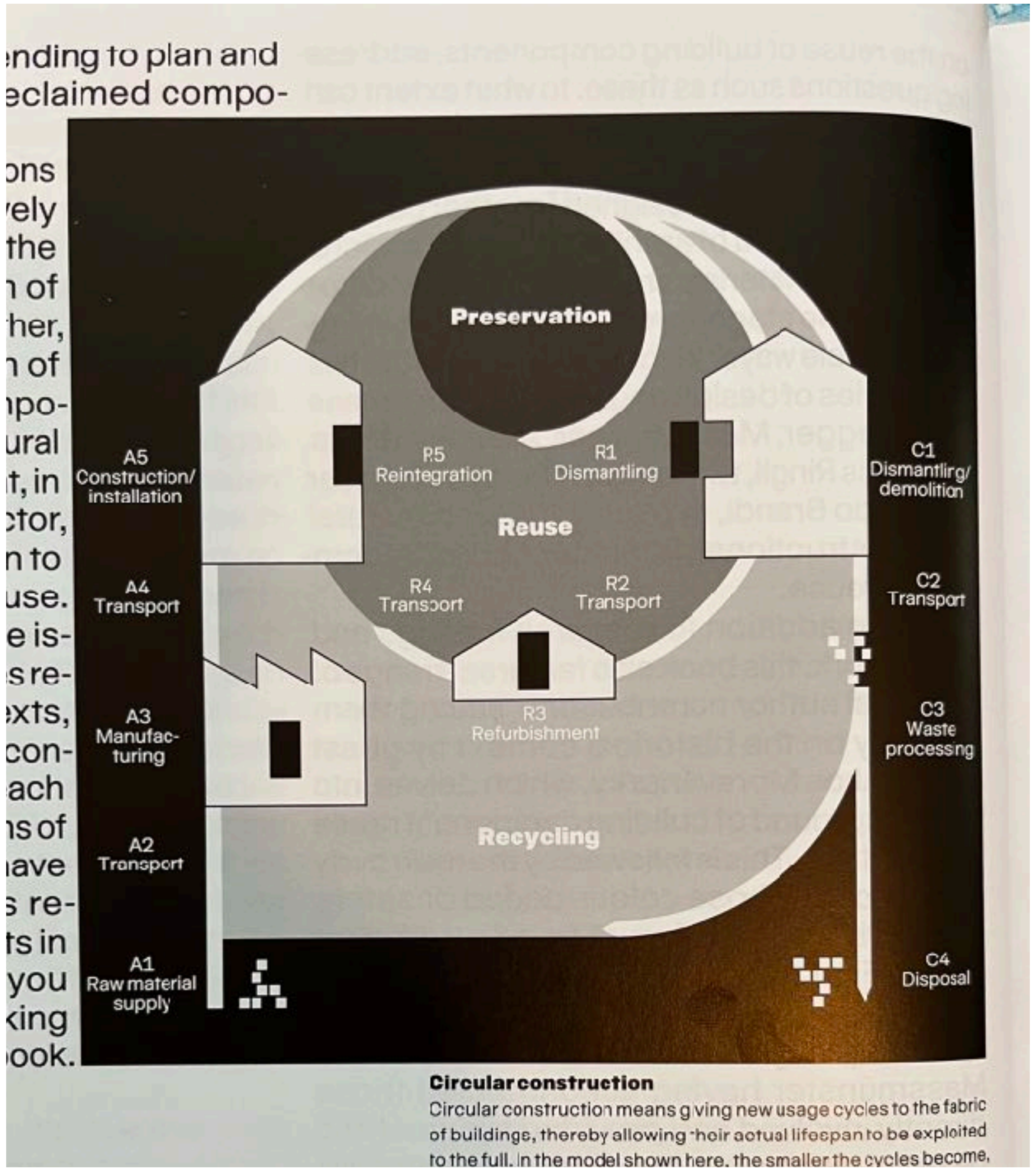
An interactive web-tool to compare material usages.

(A1-A3)

https://www.materialepyramiden.dk. CINARK (Julie Zepernick Jensen, 2019)

Circular Design

Material repair, reuse, and recycle



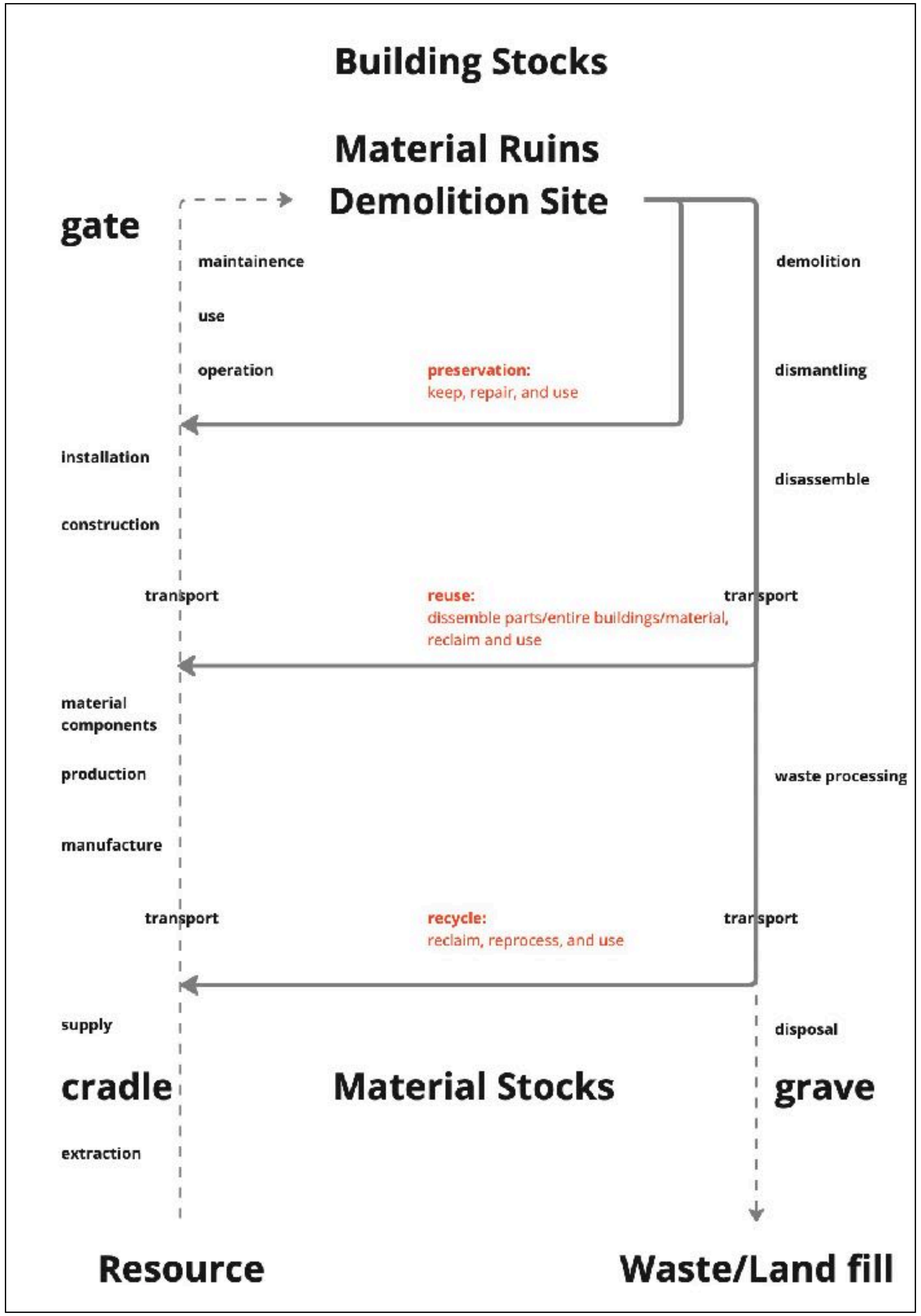
Circular construction
Circular construction means giving new usage cycles to the fabric of buildings, thereby allowing their actual lifespan to be exploited to the full. In the model shown here, the smaller the cycles become,

Reuse in Construction. 2022

Preservation/
the in situ retention of the fabric of buildings or parts of buildings in order to extend their usage.

Reuse/
the reutilisation of building components irrespective of any divergence in quality standards between their original and new usage contents. (Cutting or resizing)

Recycle/
The extensive conversion of building material into new materials or products via processes in which their original form is broken down. (Such as shredding or melting.)



Building Stocks

Material Ruins

Demolition Site

gate

maintainence

use

operation

preservation:
keep, repair, and use

demolition

dismantling

installation

construction

disassemble

transport

reuse:
dissemble parts/entire buildings/material, reclaim and use

transport

material components

production

manufacture

waste processing

transport

recycle:
reclaim, reprocess, and use

transport

supply

disposal

cradle

Material Stocks

grave

extraction

Resource

Waste/Land fill

AI-Supported Circular Design

An informal/formal material literacy

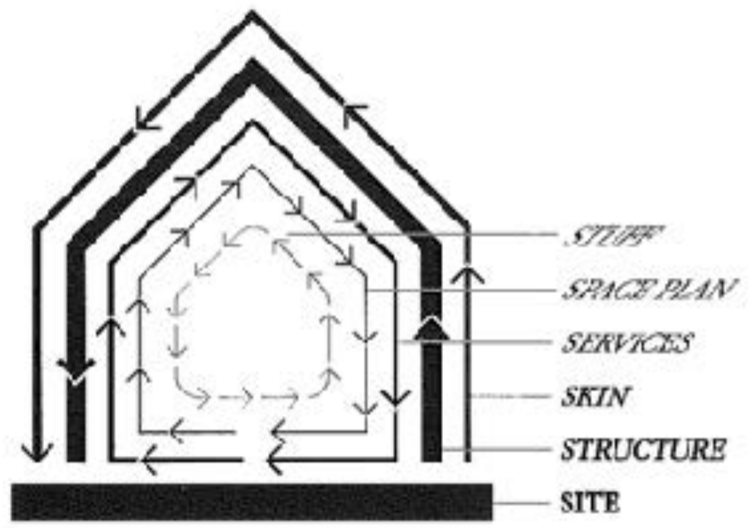
Research Question:

- What are the available existing materials?
- How do we make the materials available?
- How do we question the process?
- How does Artificial Intelligence support us in the design process?

Material (Data) Intelligence

- Material What? Ruins Inspection and Material information - material bank
- Material How? Material Type - Building Layer - Scale

Concrete
Bricks
Metal
Timber
…



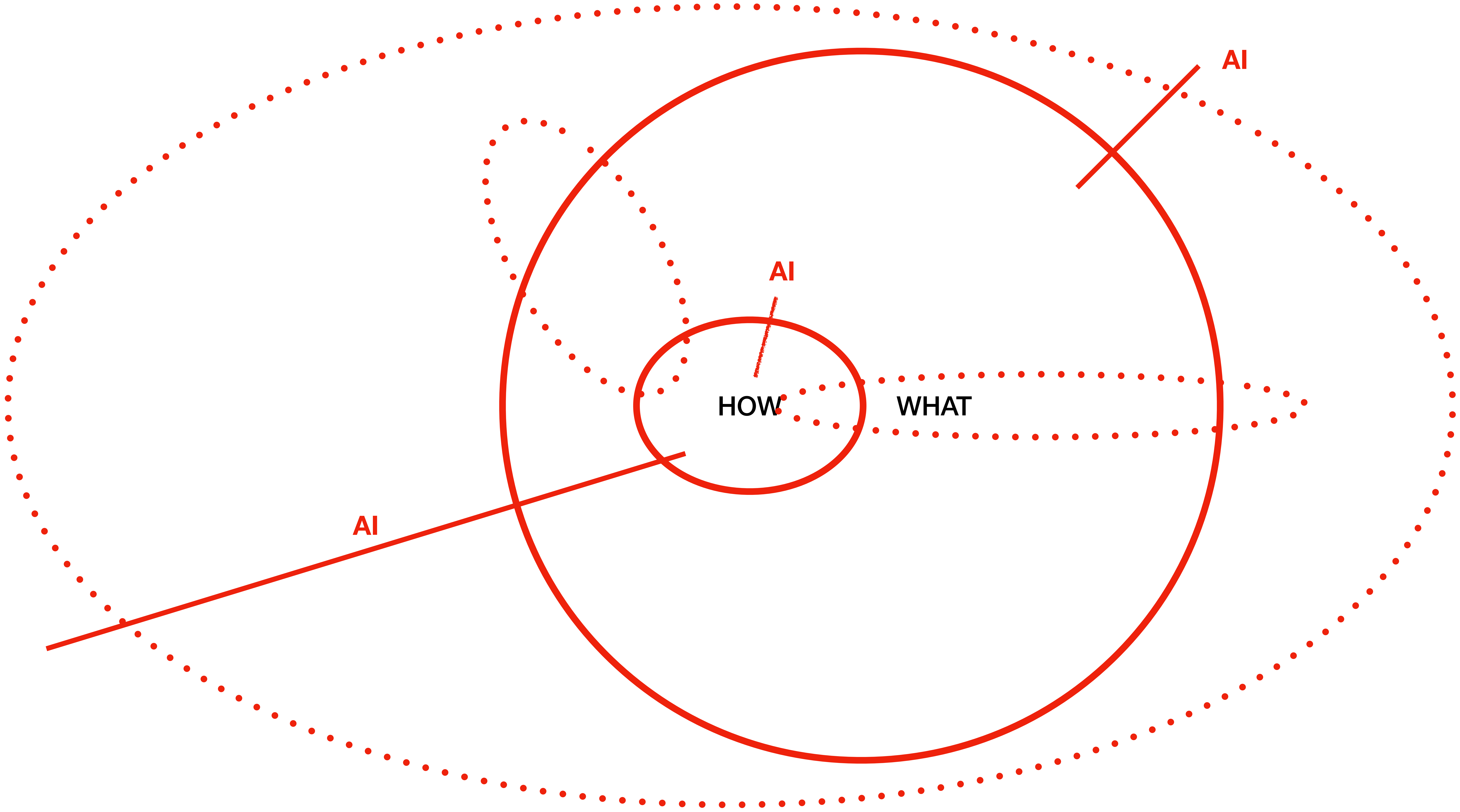
Brand, 1994

Repair
Reuse
Recycle

Evaluation Tool

- Material Right?

ENGINEER - MANAGEMENT - ARCHITECT


AI
AI
HOW
WHAT
AI

AI-Supported Circular Design

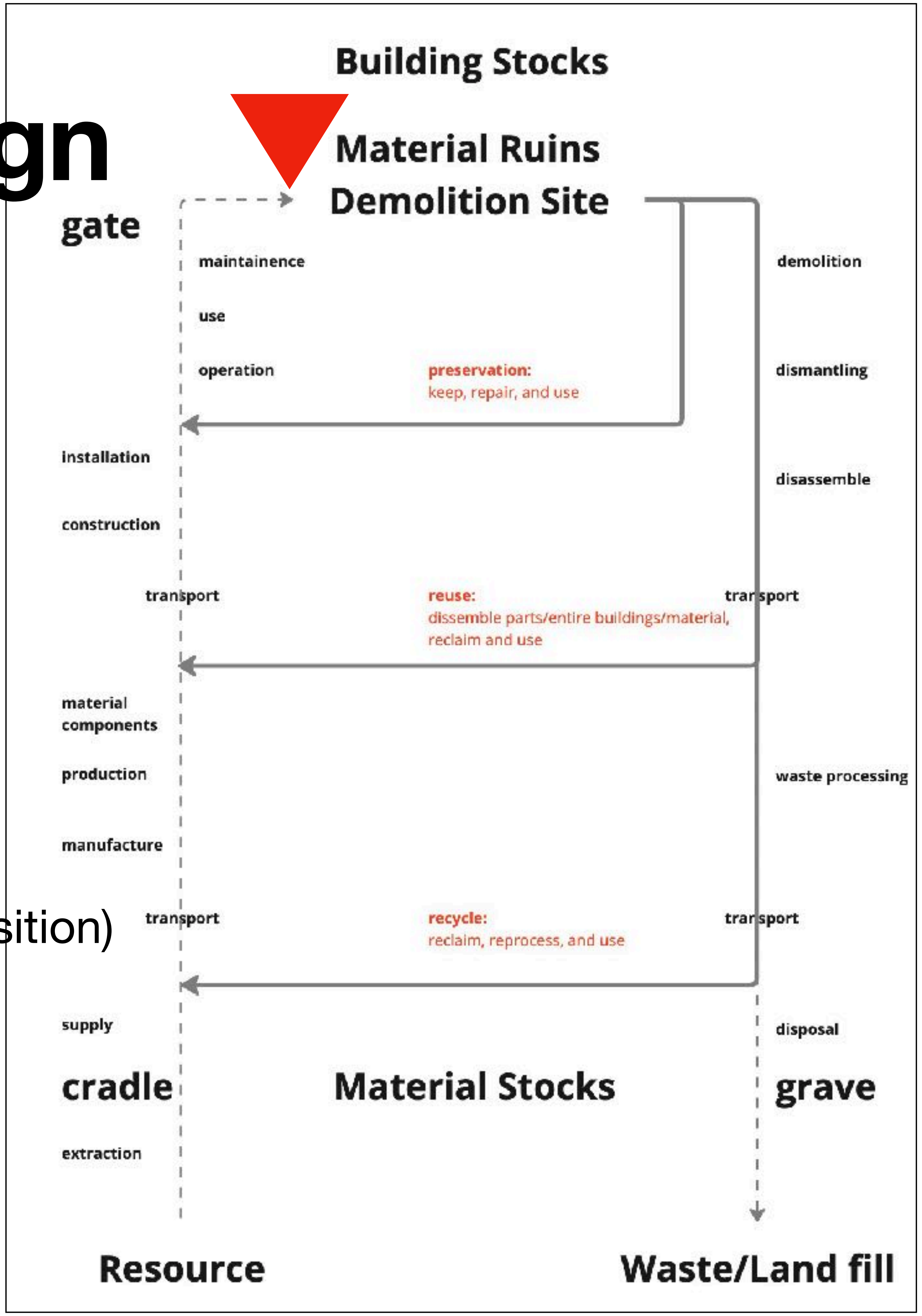
Material what, where?

Material Ruins Information

What are the available existing materials?

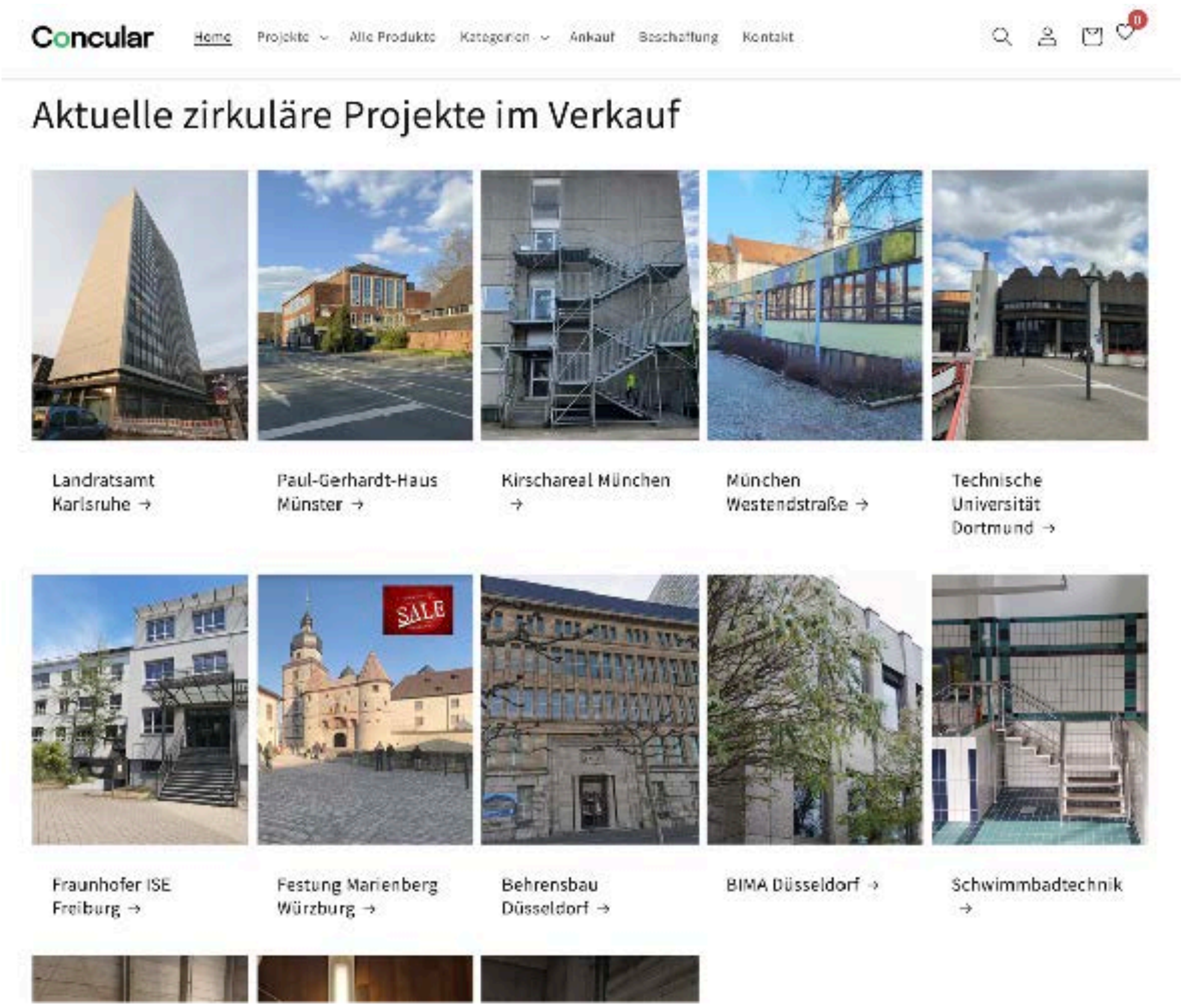
- Where are the material ruins/demolition sites?(transportation)
- What were/are the sites?(building typology)(function)
- Why are they (demolished) now?(value)(toxic)
- When would they be cleared out?

- What are the existing material components?(function)(composition)
- What quality did they have?(value)(durability)(texture)
- What are the construction?
- What are the amount, size, shape?



Case studies

Material what, where?

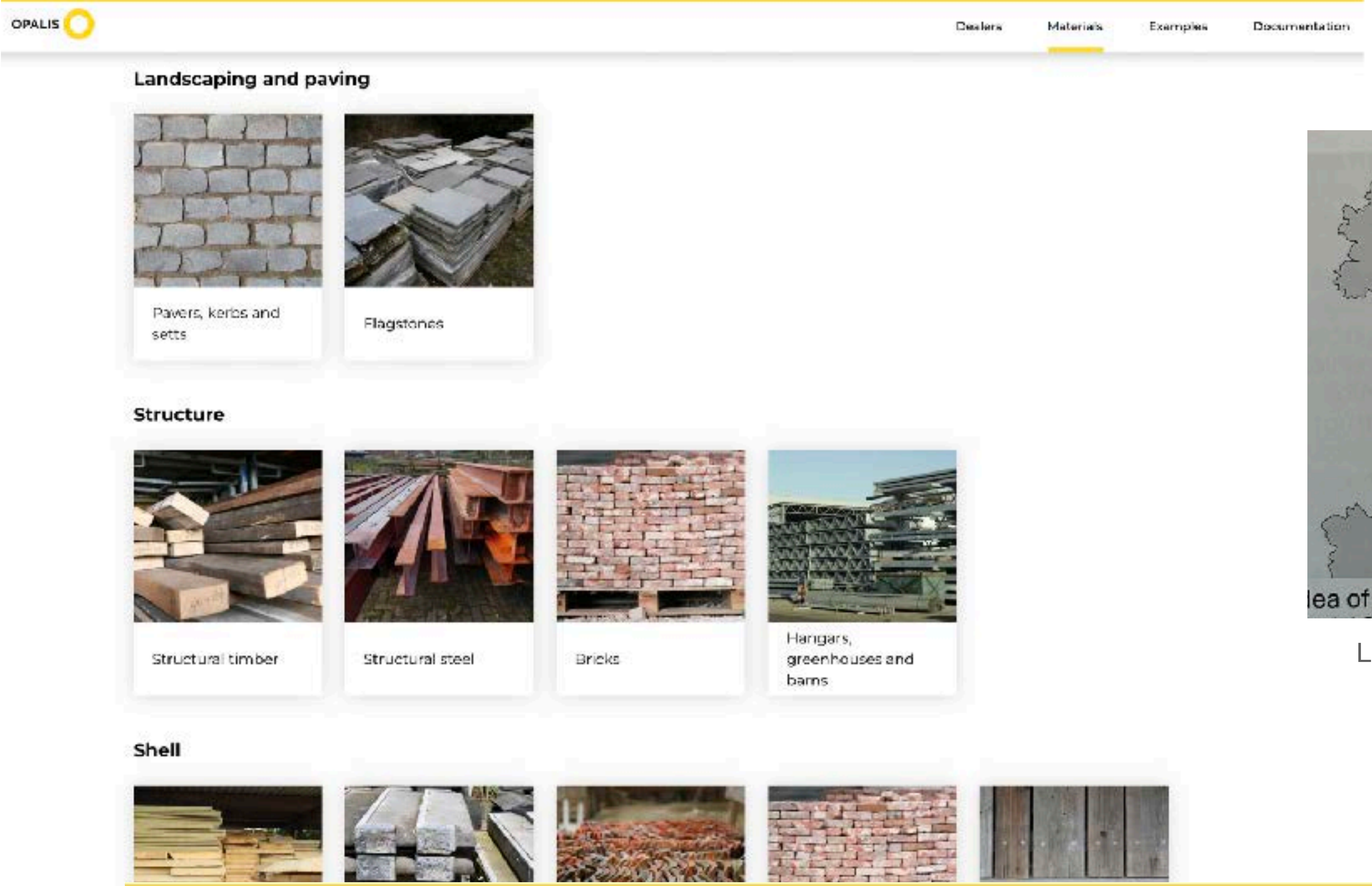


Concular Home Projekte Alle Produkte Kategorien Ankauf Beschaffung Kontakt

Aktuelle zirkuläre Projekte im Verkauf

- Landratsamt Karlsruhe →
- Paul-Gerhardt-Haus Münster →
- Kirschareal München →
- München Westendstraße →
- Technische Universität Dortmund →
- Fraunhofer ISE Freiburg →
- Festung Marienberg Würzburg →
- Behrensbau Düsseldorf →
- BIMA Düsseldorf →
- Schwimmbadtechnik →

Demolishing sites. Concular.



OPALIS Dealers Materials Examples Documentation

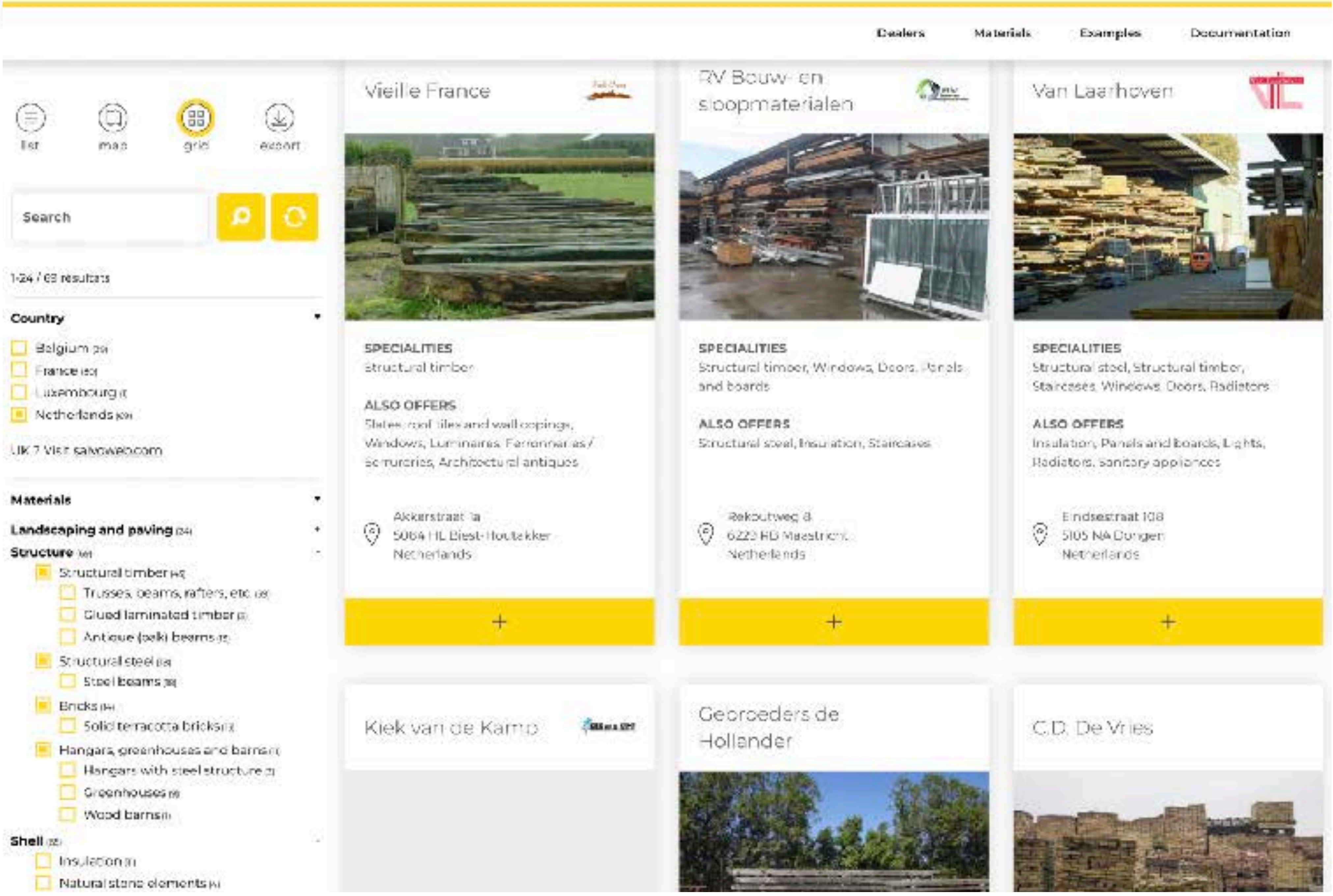
Landscaping and paving

- Pavers, kerbs and setts
- Flagstones

Structure

- Structural timber
- Structural steel
- Bricks
- Hangars, greenhouses and barns

Shell



Dealers Materials Examples Documentation

Search

1-24 / 69 results

Country

- ☐ Belgium (28)
- ☐ France (63)
- ☐ Luxembourg (1)
- ☑ Netherlands (69)

UK ? Visit salvoweb.com

Materials

Landscaping and paving (24)

Structure (61)

- ☑ Structural timber (45)
  - ☐ Trusses, beams, rafters, etc (38)
  - ☐ Glued laminated timber (5)
  - ☐ Antique (oak) beams (5)
- ☑ Structural steel (18)
  - ☐ Steel beams (18)
- ☑ Bricks (14)
  - ☐ Solid terracotta bricks (3)
- ☑ Hangars, greenhouses and barns (7)
  - ☐ Hangars with steel structure (3)
  - ☐ Greenhouses (9)
  - ☐ Wood barns (1)

Shell (25)

- ☐ Insulation (1)
- ☐ Natural stone elements (4)

Vieille France

SPECIALITIES
Structural timber

ALSO OFFERS
Slates, roof tiles and wall copings, Windows, Luminaires, Ferronneries / Serrureries, Architectural antiques

Akkerstraat 1a
5064 HL Biest-Houtakker
Netherlands

RV Bouw- en sloopmaterialen

SPECIALITIES
Structural timber, Windows, Doors, Panels and boards

ALSO OFFERS
Structural steel, Insulation, Staircases

Rekoutweg 8
6222 RD Maastricht
Netherlands

Van Laarhoven

SPECIALITIES
Structural steel, Structural timber, Staircases, Windows, Doors, Radiators

ALSO OFFERS
Insulation, Panels and boards, Lights, Radiators, Sanitary appliances

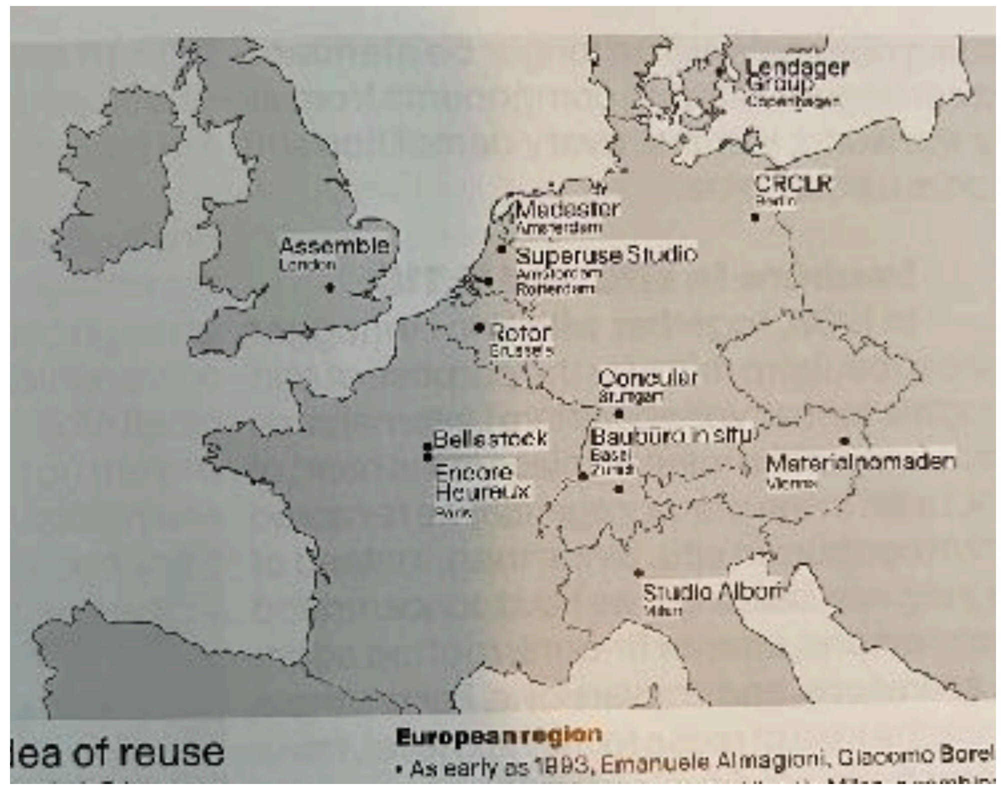
Eindsestraat 108
5105 NA Dongen
Netherlands

Kiek van de Kamp

Gebroeders de Hollander

C.D. De Vries

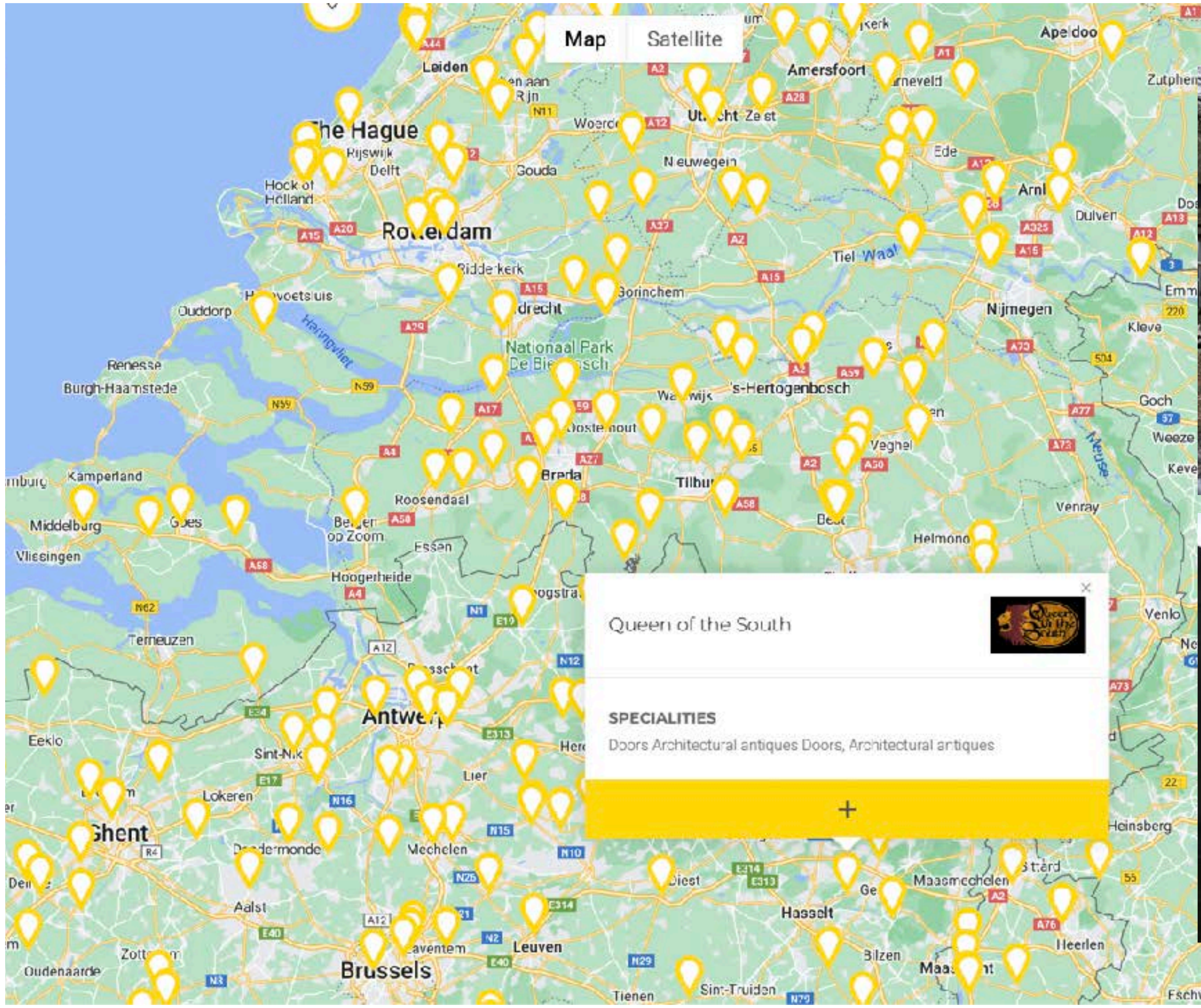
Available material components and material stocks. OPALIS by ROTORDC.



Leading companies with reuse approaches.
Reuse in Construction. 2022.

Case studies

(AI-Supported) Material bank, network, literacy



Queen of the South

SPECIALITIES

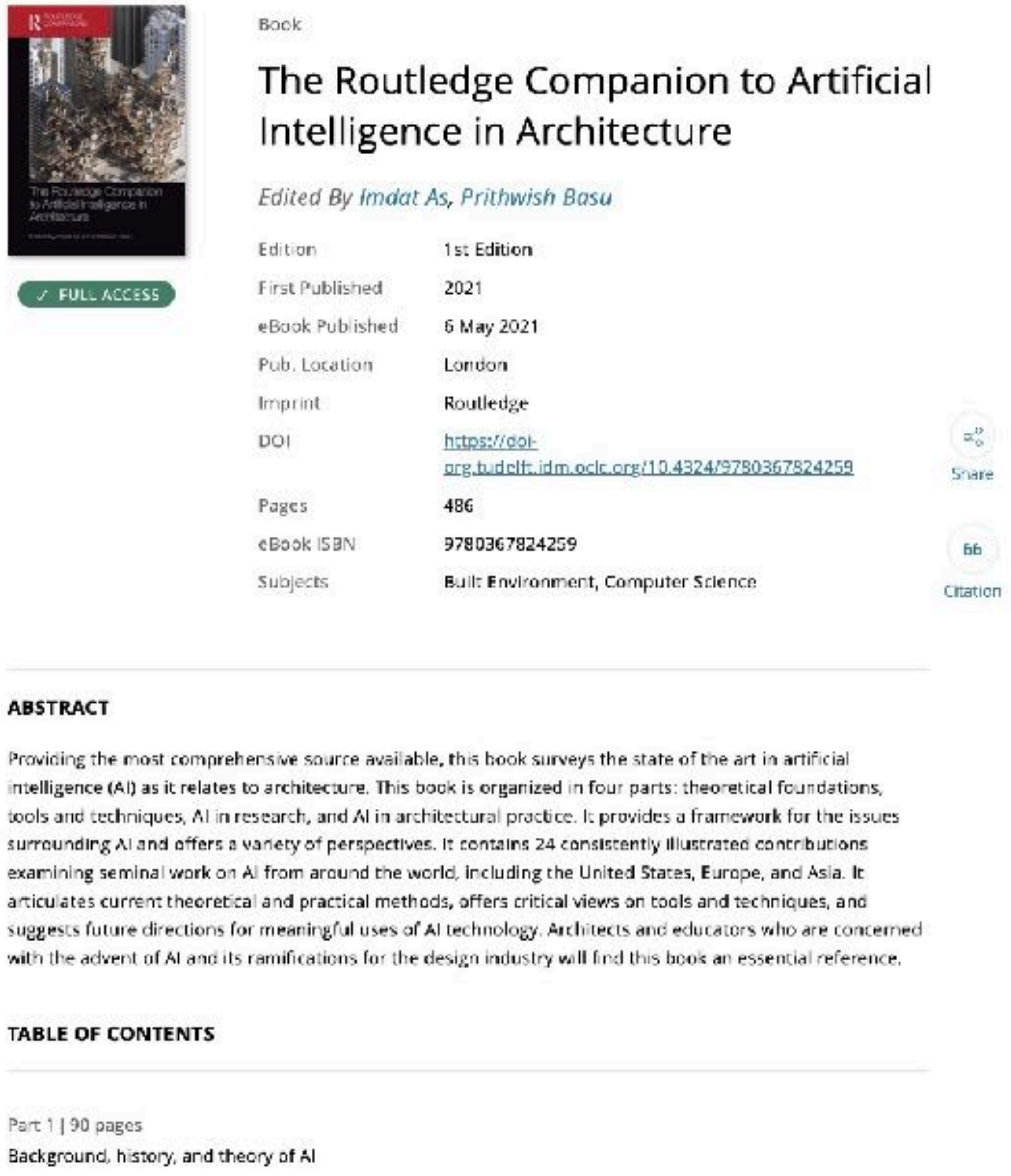
Doors Architectural antiques Doors, Architectural antiques

Queen of the south

C,D, De Vries

Case studies

AI-supported material harvesting



Book

The Routledge Companion to Artificial Intelligence in Architecture

Edited By *Imdat As*, *Prithwish Basu*

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eBook Published	6 May 2021
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Pages	486
eBook ISBN	9780367824259
Subjects	Built Environment, Computer Science

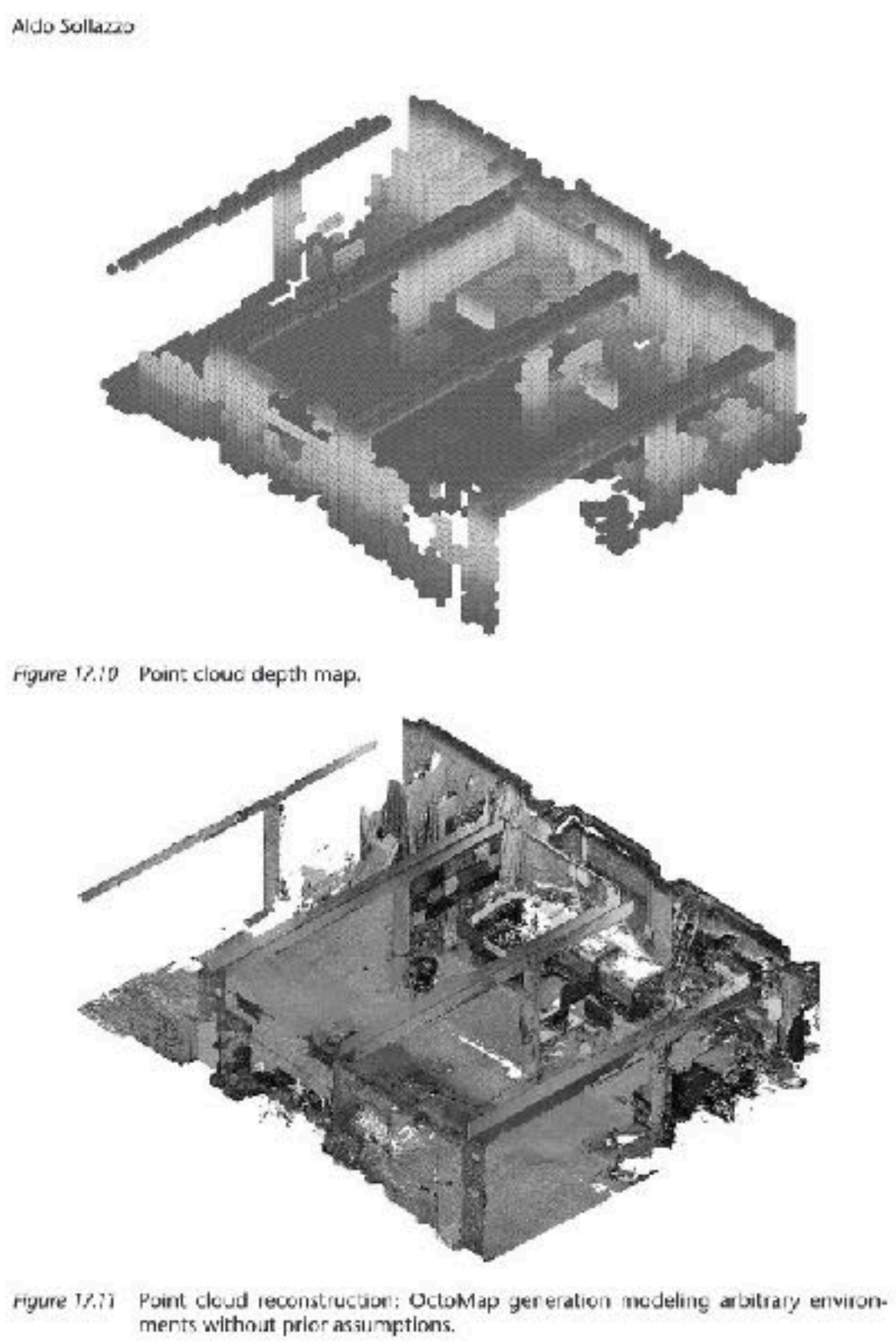
ABSTRACT

Providing the most comprehensive source available, this book surveys the state of the art in artificial intelligence (AI) as it relates to architecture. This book is organized in four parts: theoretical foundations, tools and techniques, AI in research, and AI in architectural practice. It provides a framework for the issues surrounding AI and offers a variety of perspectives. It contains 24 consistently illustrated contributions examining seminal work on AI from around the world, including the United States, Europe, and Asia. It articulates current theoretical and practical methods, offers critical views on tools and techniques, and suggests future directions for meaningful uses of AI technology. Architects and educators who are concerned with the advent of AI and its ramifications for the design industry will find this book an essential reference.

TABLE OF CONTENTS

Part 1 | 90 pages

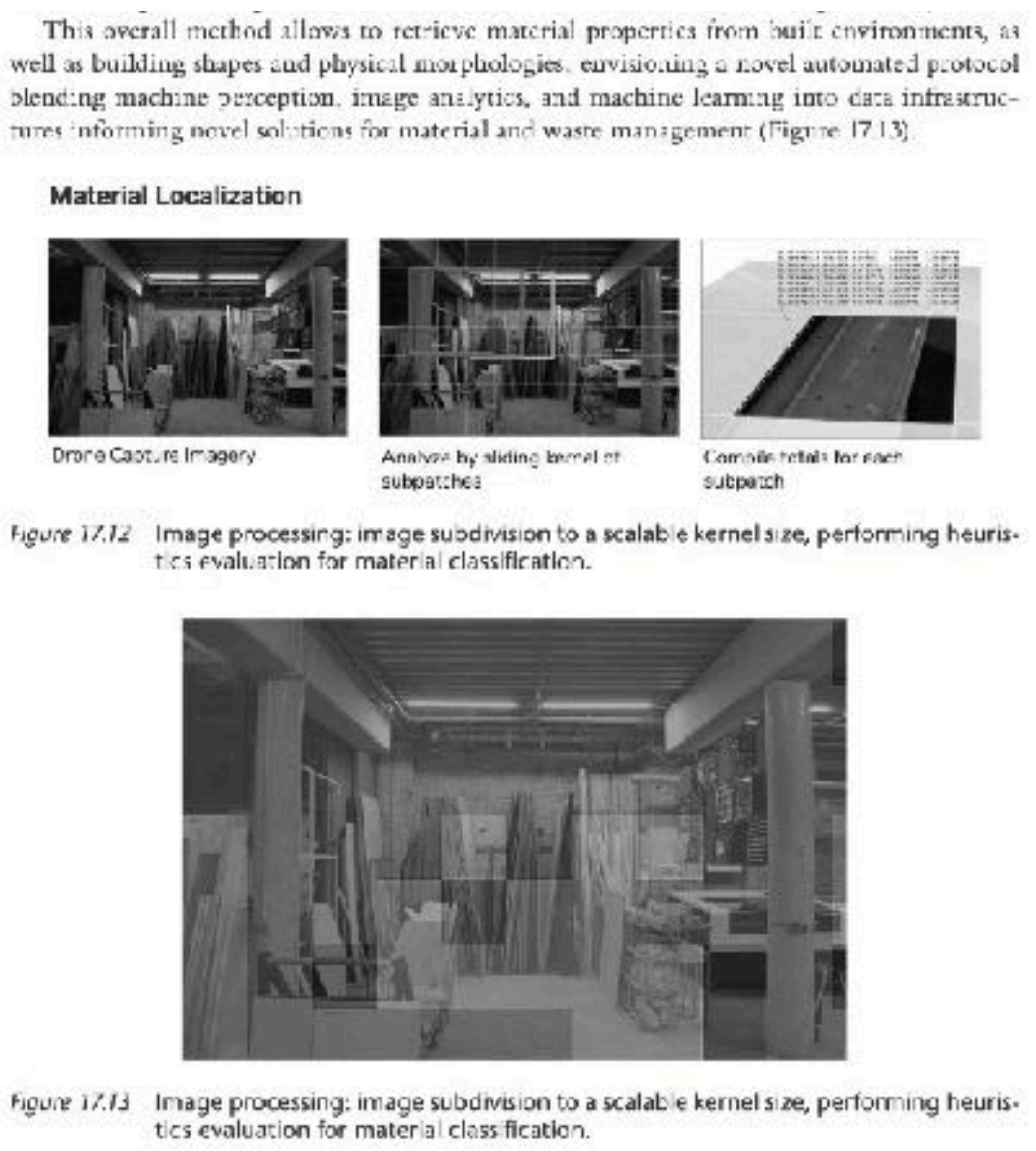
Background, history, and theory of AI



Aldo Sollazzo

Figure 17.10 Point cloud depth map.

Figure 17.11 Point cloud reconstruction: OctoMap generation modeling arbitrary environments without prior assumptions.



This overall method allows to retrieve material properties from built environments, as well as building shapes and physical morphologies, envisioning a novel automated protocol blending machine perception, image analytics, and machine learning into data infrastructures informing novel solutions for material and waste management (Figure 17.13).

Figure 17.12 Image processing: image subdivision to a scalable kernel size, performing heuristics evaluation for material classification.

Figure 17.13 Image processing: image subdivision to a scalable kernel size, performing heuristics evaluation for material classification.

Digitizing material collation from demolition sites

1 Building Inspection
2 Material Classification and Localisation
3 Geometry Reconstruction


Educational Programmes

PROGRAM

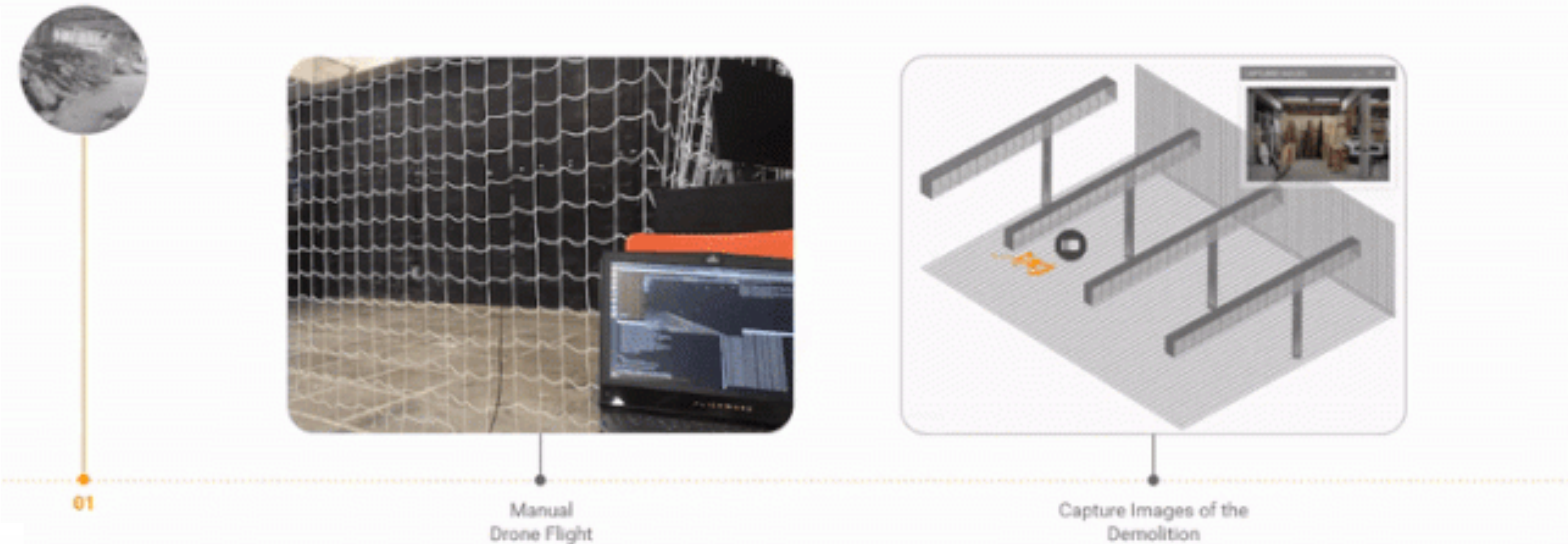
MATERIAL (DATA) INTELLIGENCE | TOWARDS A CIRCULAR BUILDING ENVIRONMENT

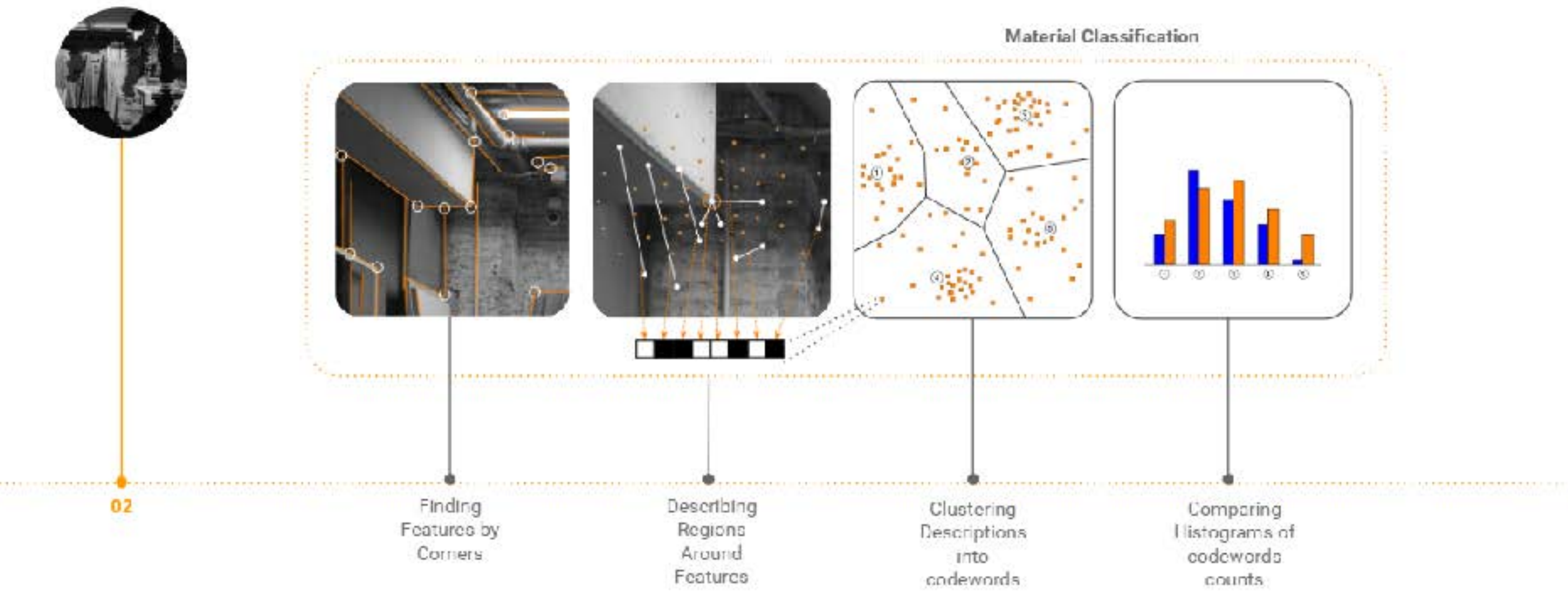
roberto.enrique.vargas

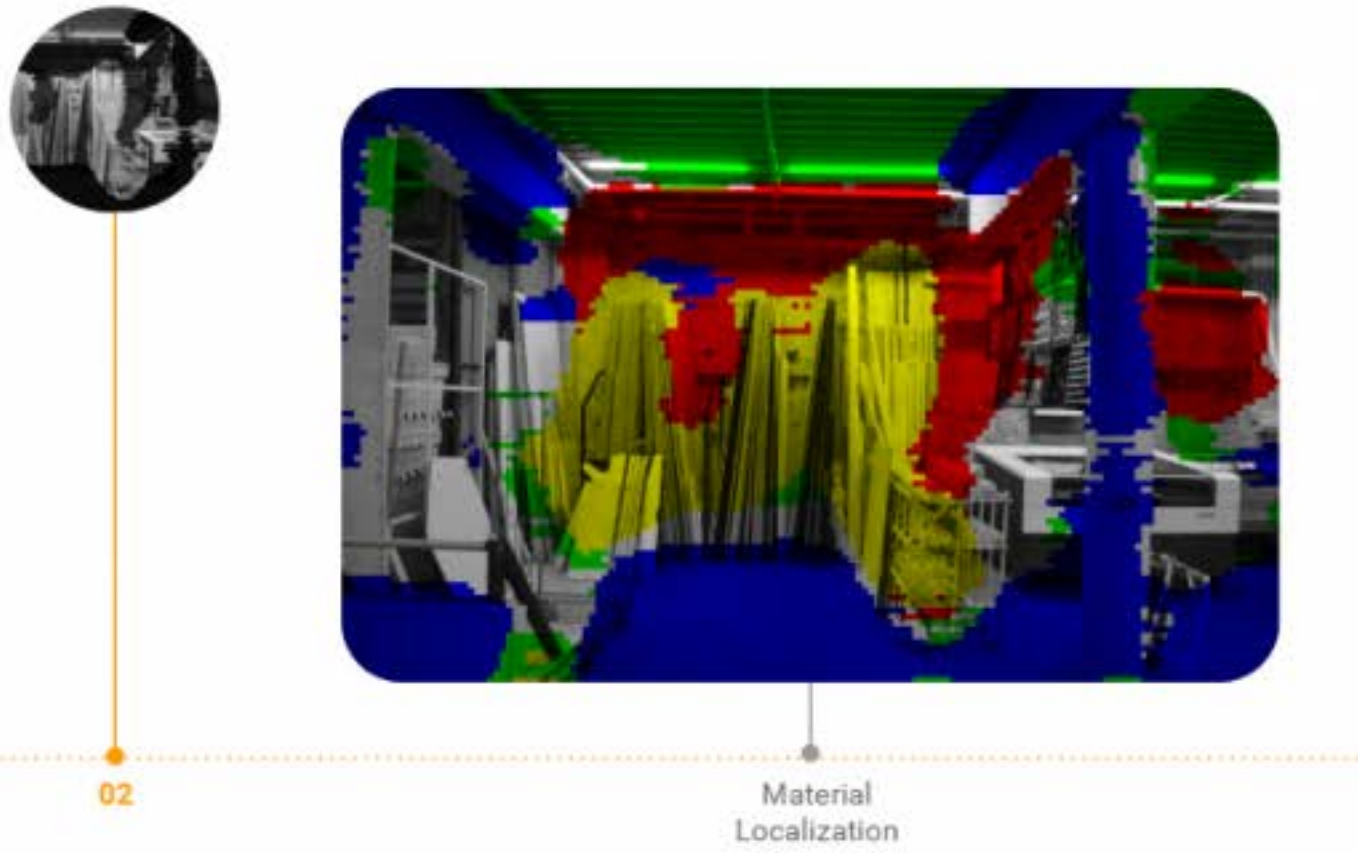
PROGRAM
MRAC 01

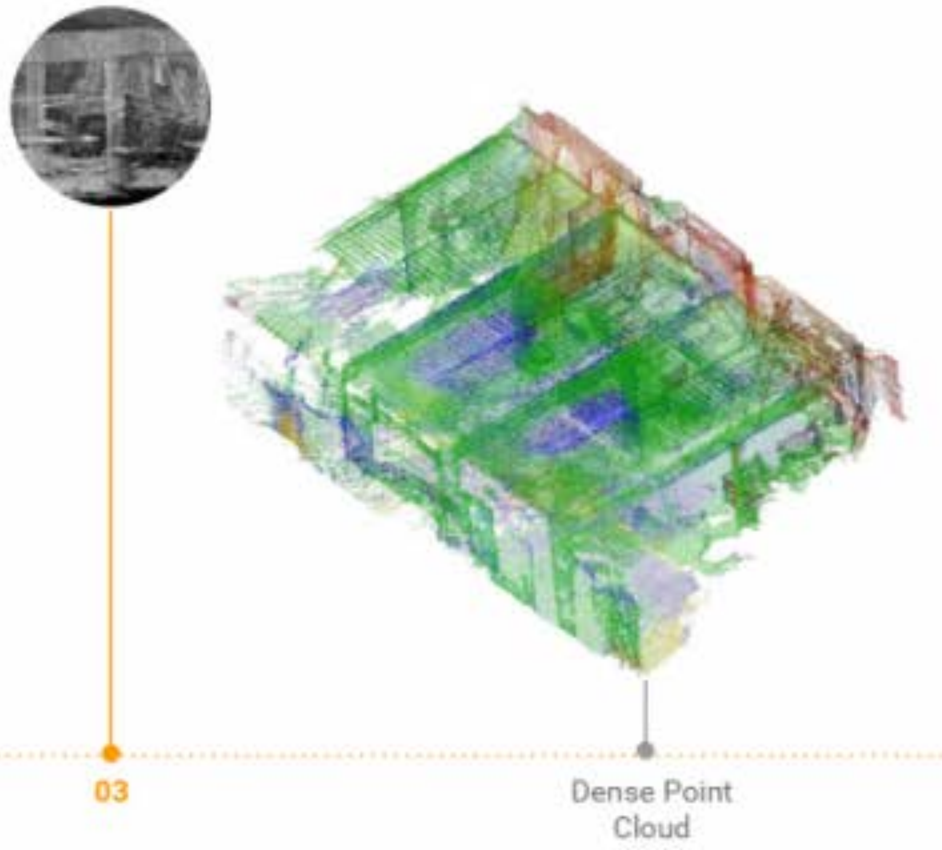
COURSE
R.3 STUDIO III

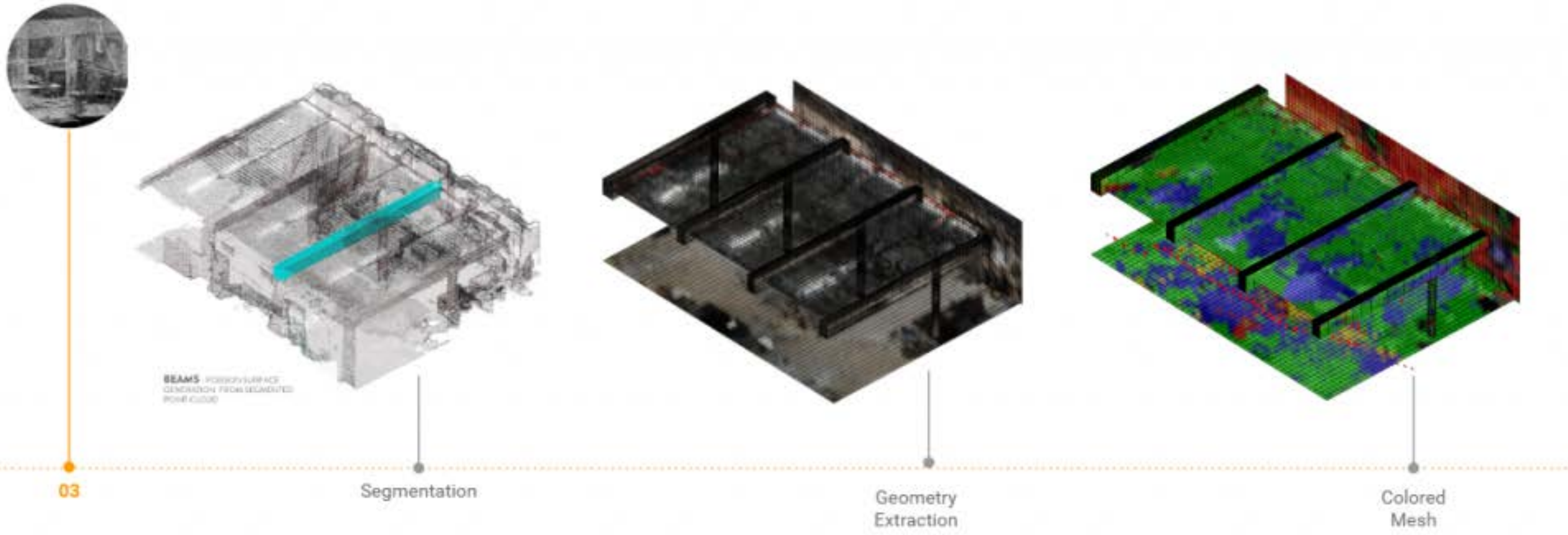
Institute for advanced architecture of Catalonia, Barcelona, 2020











Case studies

AI-supported material harvesting

Resources, Conservation and Recycling
Volume 183, August 2022, 106362

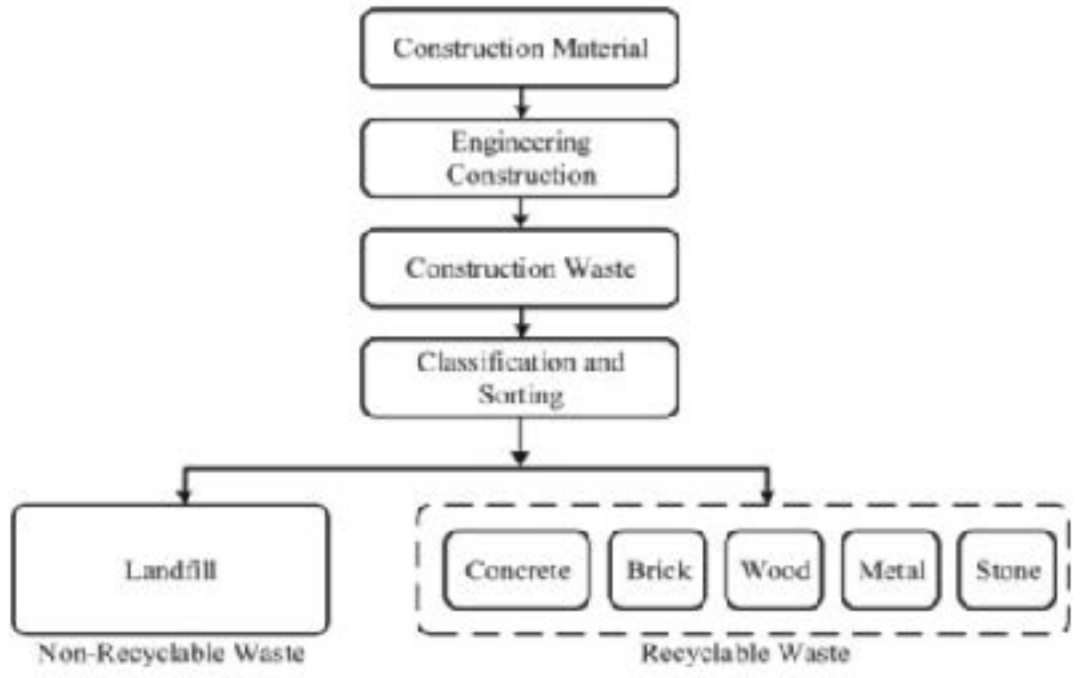
Full length article

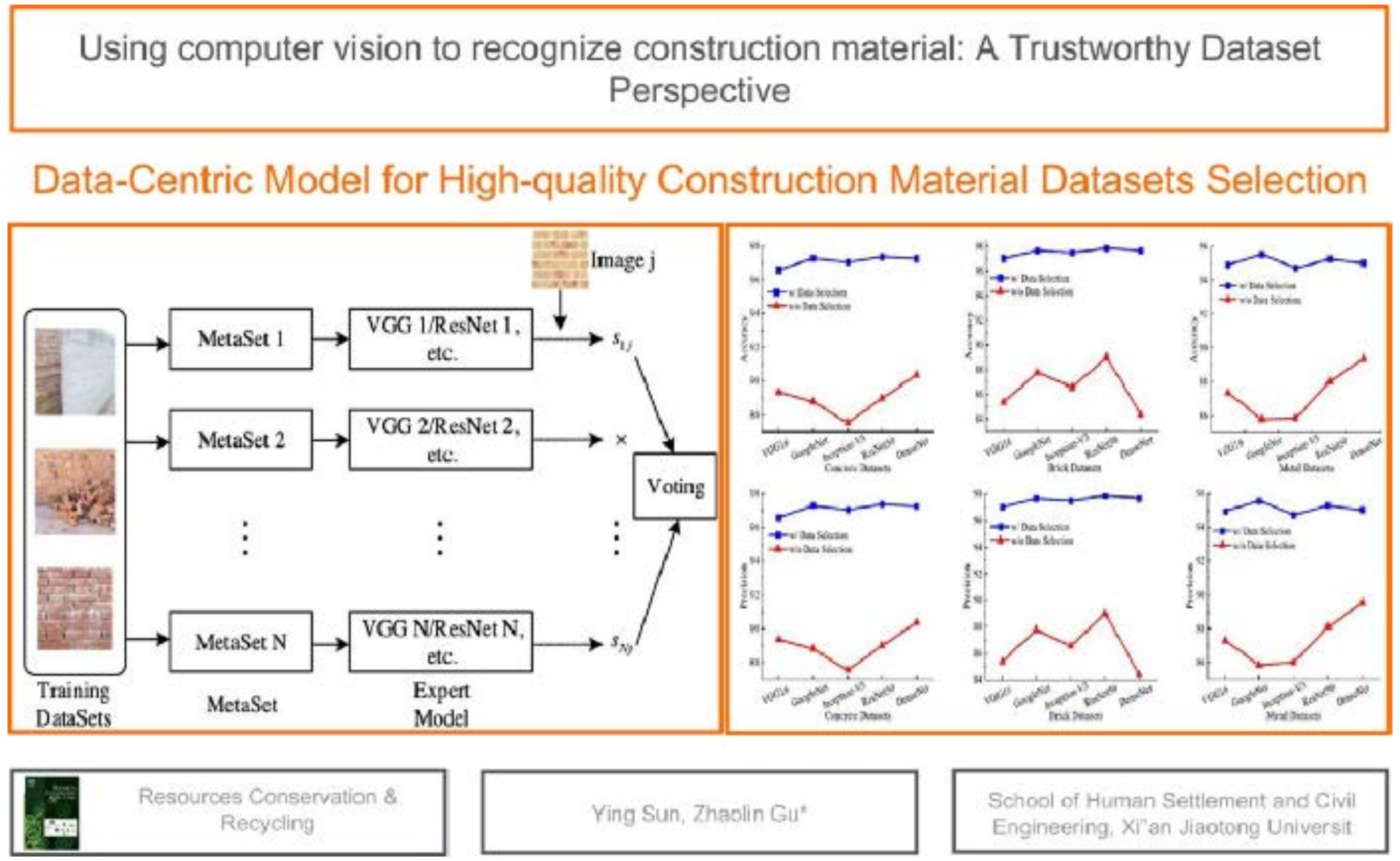
Using computer vision to recognize construction material: A Trustworthy Dataset Perspective

Ying Sun [a] [b], Zhaolin Gu [a]

[a] School of Human Settlement and Civil Engineering, Xi"an Jiaotong University, Xi"an 710049, China
[b] College of Media and Arts, Chongqing University of Posts and Telecommunications, Chongqing 400065, China

Received 9 December 2021, Revised 1 April 2022, Accepted 11 April 2022, Available online 20 April 2022, Version of Record 20 April 2022.





Using computer vision to recognize construction material: A Trustworthy Dataset Perspective

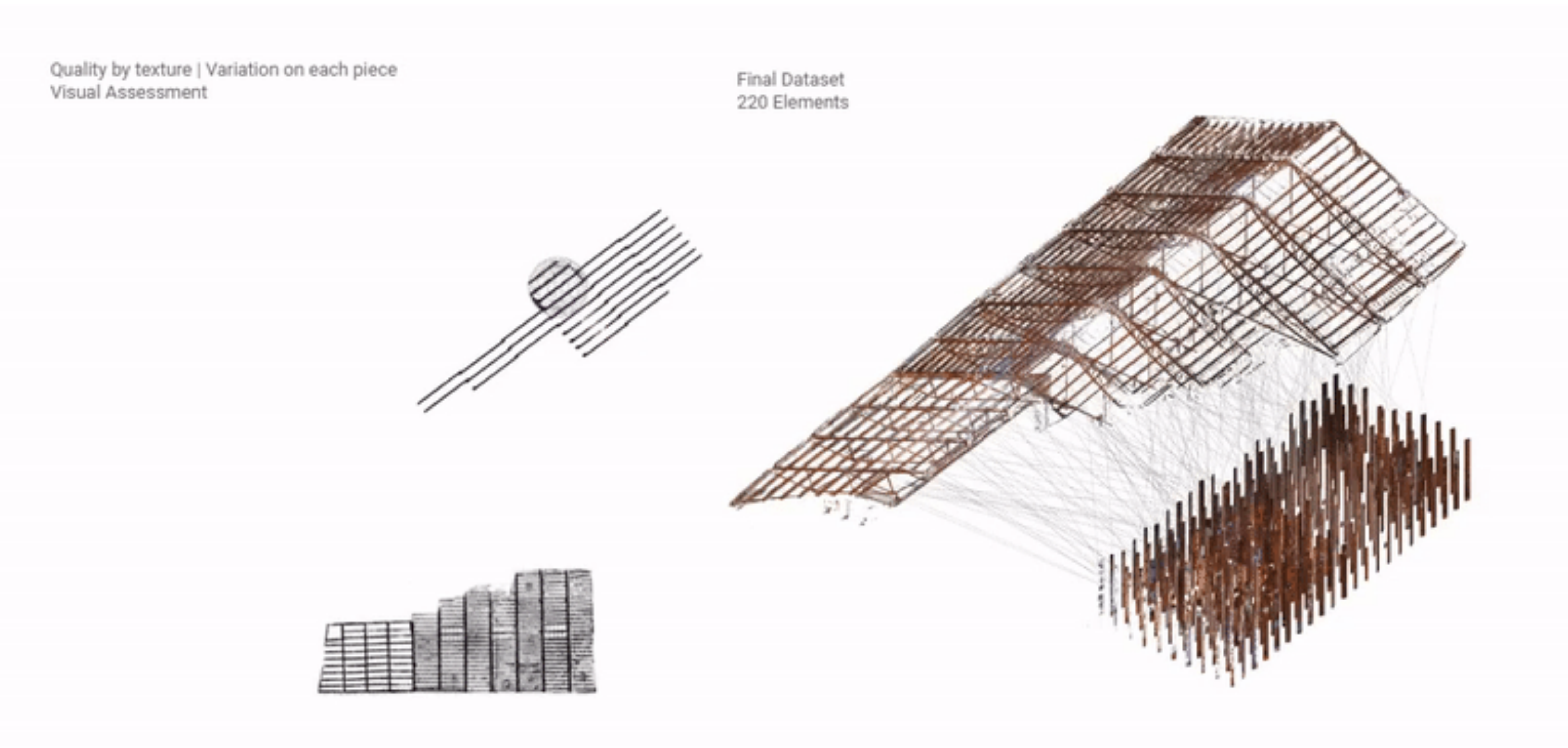
Data-Centric Model for High-quality Construction Material Datasets Selection

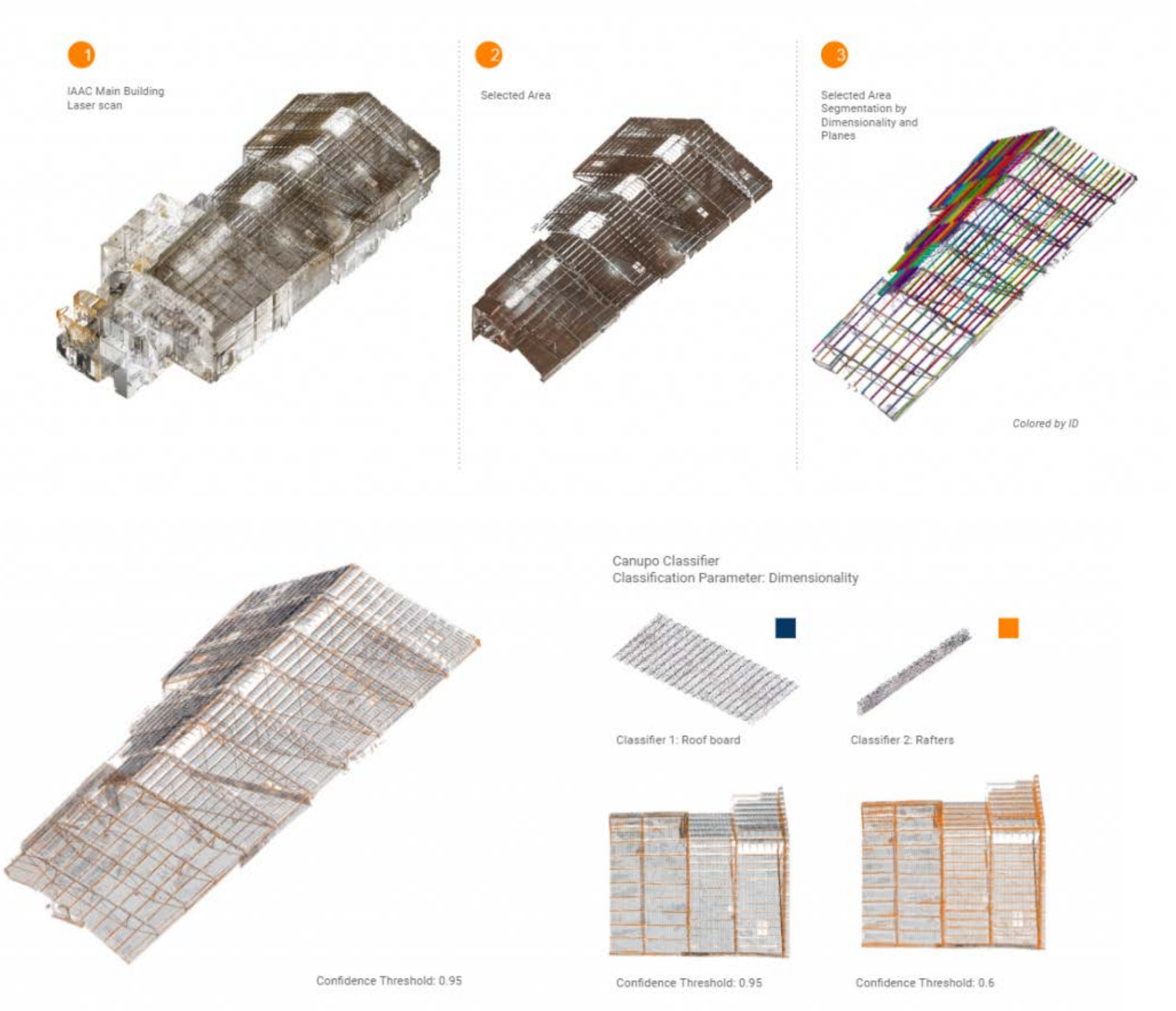
Resources Conservation & Recycling

Ying Sun, Zhaolin Gu*

School of Human Settlement and Civil Engineering, Xi"an Jiaotong Universit

Case studies





AI-Supported Circular Design

Material How

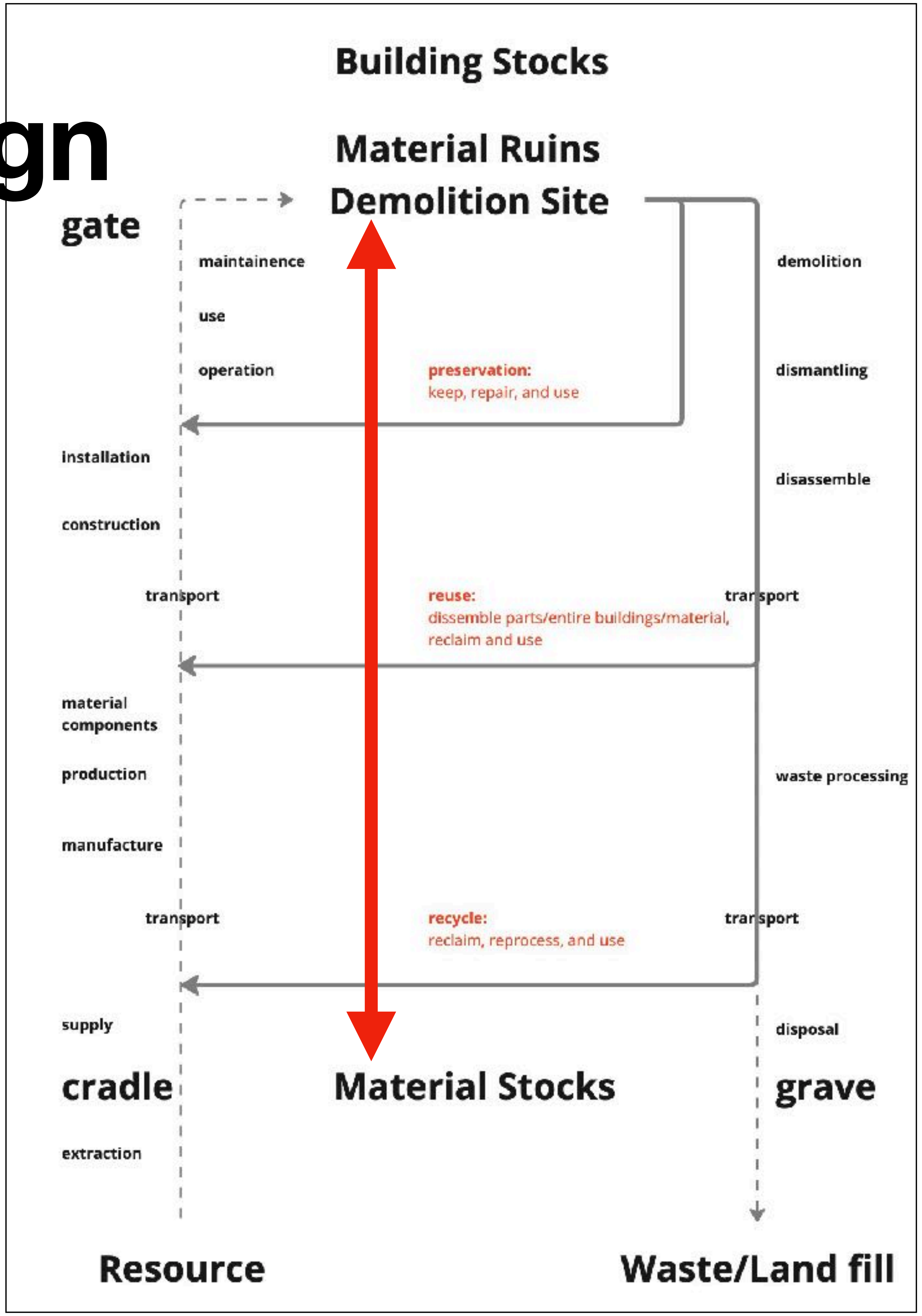
How do we make materials available?

1 How can the they be kept, repaired, transformed (adapted reuse) and reutilised to safeguard embodied energy?

2 How can the building parts be disassembled and converted into components fit for reuse elsewhere, with minimal change of material quality from their previous use?

3 How can the recovered materials be processed into new engineered products, with extensive change of material characters from their previous form?

* How to remove, relocate, and store reclaimed materials?



Building Stocks

Material Ruins

Demolition Site

gate

maintainence

use

operation

preservation:
keep, repair, and use

demolition

dismantling

installation

disassemble

construction

transport

reuse:
dissemble parts/entire buildings/material, reclaim and use

transport

material components

production

waste processing

manufacture

transport

recycle:
reclaim, reprocess, and use

transport

supply

disposal

cradle

Material Stocks

grave

extraction

Resource

Waste/Land fill

An extensive report

Case study of K118: A building made from construction waste

"Wetter AG took care of the steel construction for the vertical extension. It has been associated with the project for over two years."

Component map

"They found a high-bay warehouse with hundreds of steel sections in the Zellweger textile machine factory." ... "Yes, that sounds good. When do we have to get them out by?" "The demolition excavators will be here in three days."

Component catalogue: A selection of components involved in the study

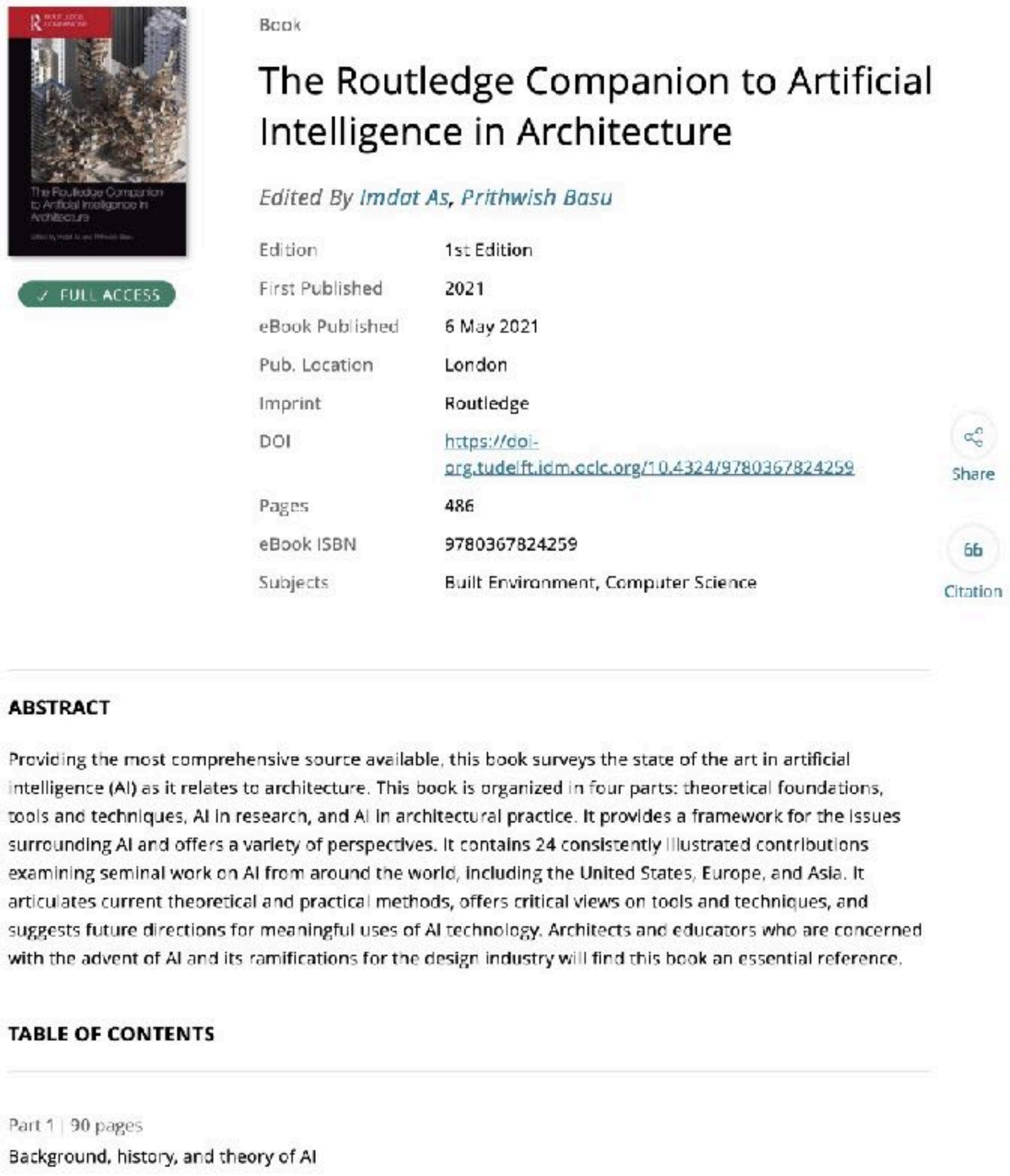
"In the case of the small, glazed, industrial windows from Sulzer Werk 1, which is located across from Hall 118, different questions arose."

Design and construction: Process

Case Studies

Brick Reuse, Lendager,

Case Studies



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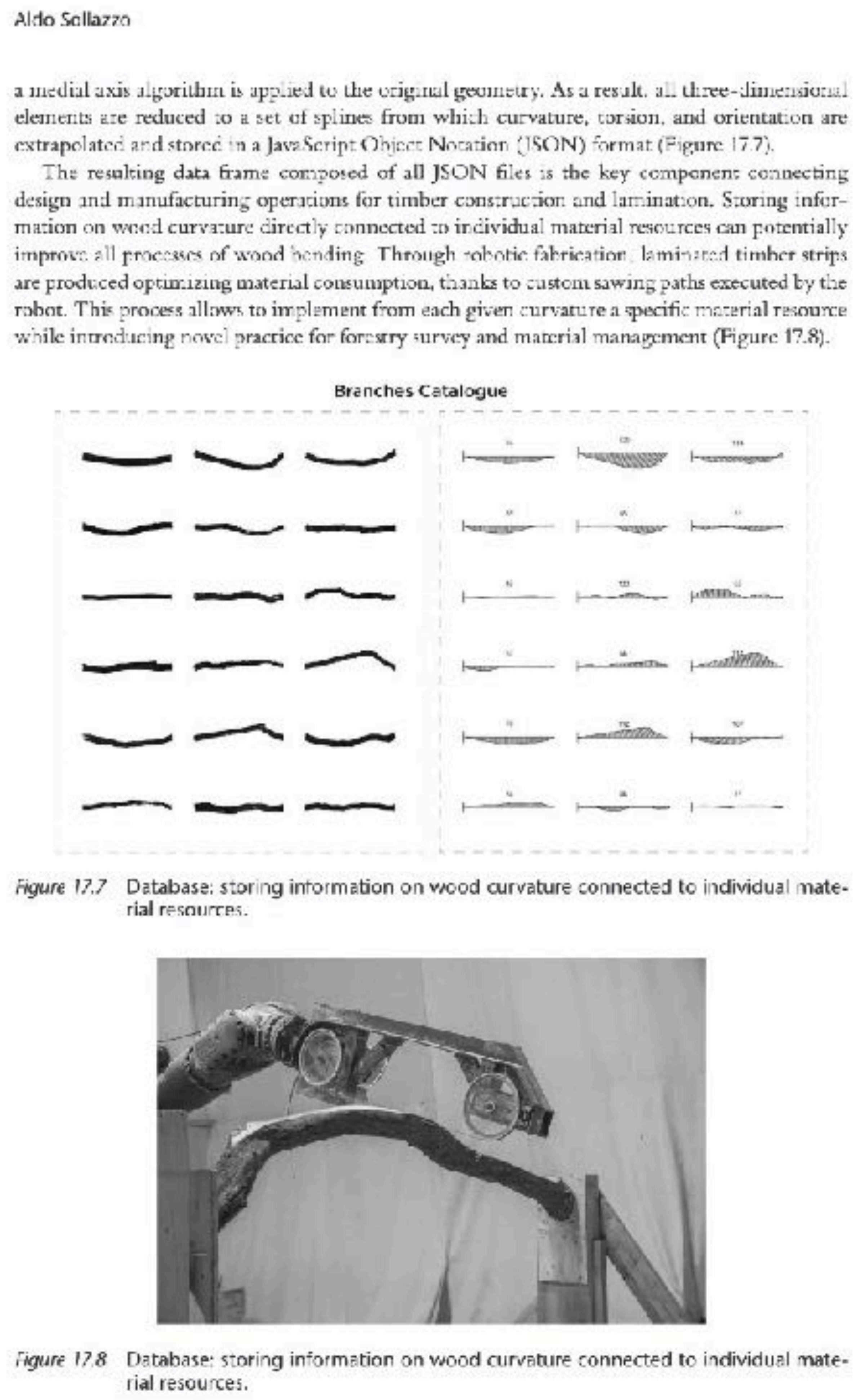


Aldo Sollazzo

a medial axis algorithm is applied to the original geometry. As a result, all three-dimensional elements are reduced to a set of splines from which curvature, torsion, and orientation are extrapolated and stored in a JavaScript Object Notation (JSON) format (Figure 17.7).

The resulting data frame composed of all JSON files is the key component connecting design and manufacturing operations for timber construction and lamination. Storing information on wood curvature directly connected to individual material resources can potentially improve all processes of wood bending. Through robotic fabrication, laminated timber strips are produced optimizing material consumption, thanks to custom sawing paths executed by the robot. This process allows to implement from each given curvature a specific material resource while introducing novel practice for forestry survey and material management (Figure 17.8).

Figure 17.7 Database: storing information on wood curvature connected to individual material resources.

Figure 17.8 Database: storing information on wood curvature connected to individual material resources.

Automating forestry survey for timber construction

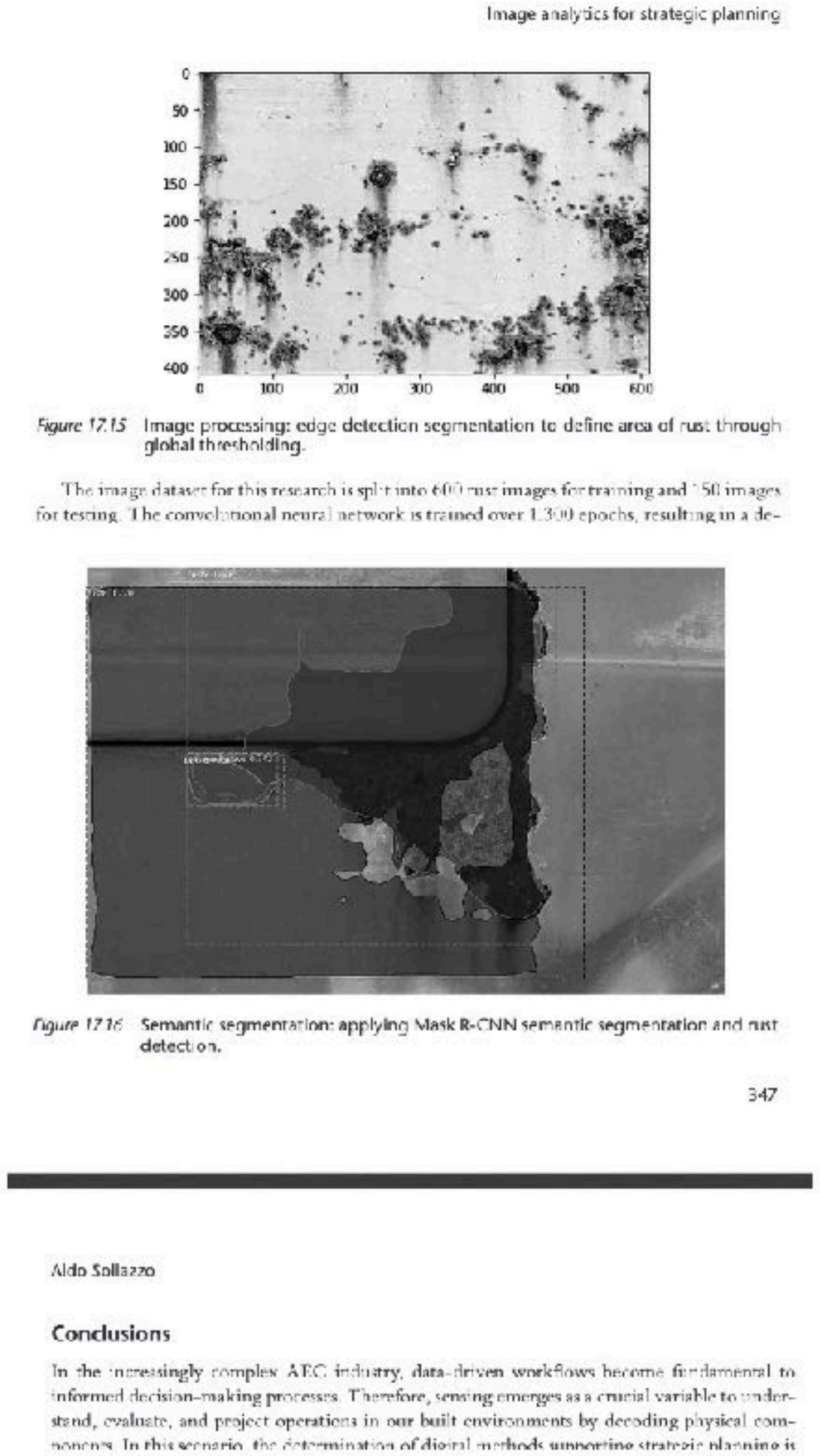


Image analytics for strategic planning

Figure 17.15 Image processing: edge detection segmentation to define area of rust through global thresholding.

The image dataset for this research is split into 600 rust images for training and 150 images for testing. The convolutional neural network is trained over 1,300 epochs, resulting in a de-

Figure 17.16 Semantic segmentation: applying Mask R-CNN semantic segmentation and rust detection.

347

Aldo Sollazzo

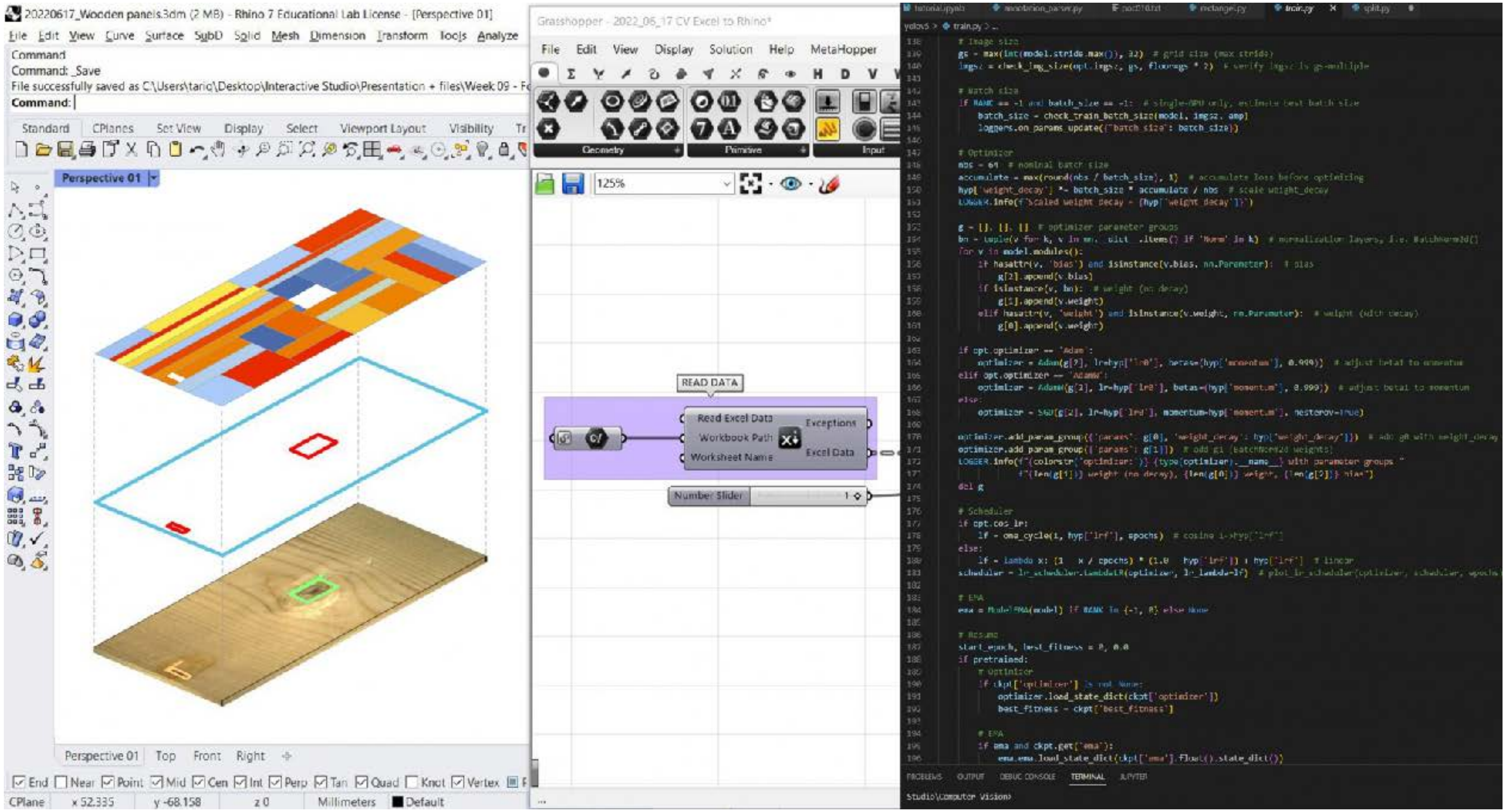
Conclusions

In the increasingly complex AEC industry, data-driven workflows become fundamental to informed decision-making processes. Therefore, sensing emerges as a crucial variable to understand, evaluate, and project operations in our built environments by decoding physical components. In this scenario, the determination of digital methods supporting strategic planning is

Autonomous inspection system for building maintenance

Case Studies

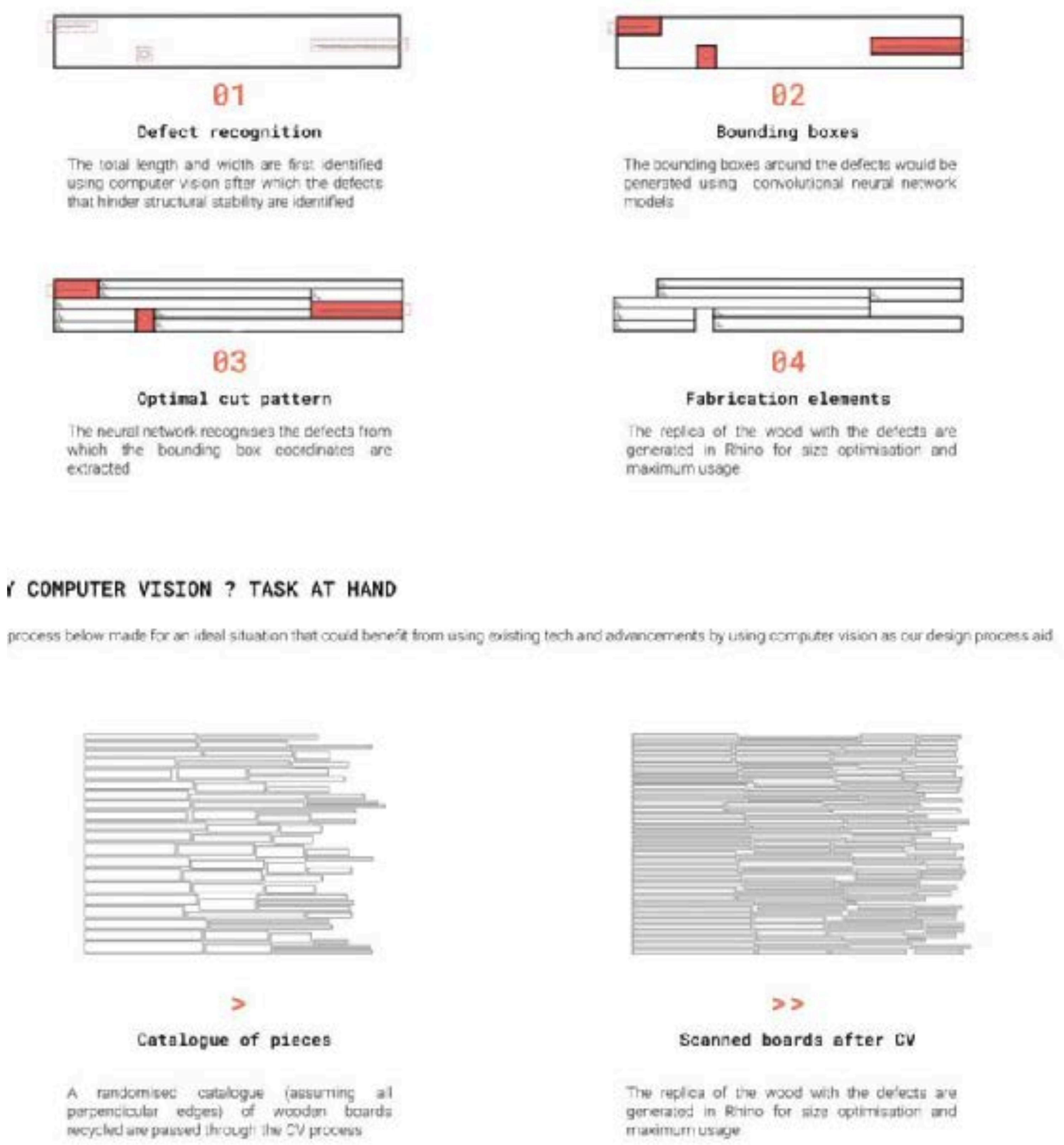
Timber defect recognition and resizing



```
Command
Command: _Save
File successfully saved as C:\Users\tariq\Desktop\Interactive Studio\Presentation + files\Week 09 - F
Command:
```

```
    # Image size
    gs = max(int(model.stride.max()), 32)  # grid size (max stride)
    imgsz = check_img_size(opt.imgsz, gs, floor=gs * 2)  # verify imgsz is gs-multiple

    # Batch size
    if RANK == -1 and batch_size == -1:  # single-GPU only, estimate best batch size
        batch_size = check_train_batch_size(model, imgsz, amp)
        loggers.on_params_update({"batch_size": batch_size})

    # Optimizer
    nbs = 64  # nominal batch size
    accumulate = max(round(nbs / batch_size), 1)  # accumulate loss before optimizing
    hyp['weight_decay'] *= batch_size * accumulate / nbs  # scale weight_decay
    LOGGER.info(f"Scaled weight_decay = {hyp['weight_decay']}")

    g = [], [], []  # optimizer parameter groups
    bn = tuple(v for k, v in nn.__dict__.items() if 'Norm' in k)  # normalization layers, i.e. BatchNorm2d()
    for v in model.modules():
        if hasattr(v, 'bias') and isinstance(v.bias, nn.Parameter):  # bias
            g[2].append(v.bias)
        if isinstance(v, bn):  # weight (no decay)
            g[1].append(v.weight)
        elif hasattr(v, 'weight') and isinstance(v.weight, nn.Parameter):  # weight (with decay)
            g[0].append(v.weight)

    if opt.optimizer == 'Adam':
        optimizer = Adam(g[2], lr=hyp['lr0'], betas=(hyp['momentum'], 0.999))  # adjust beta1 to momentum
    elif opt.optimizer == 'AdamW':
        optimizer = AdamW(g[2], lr=hyp['lr0'], betas=(hyp['momentum'], 0.999))  # adjust beta1 to momentum
    else:
        optimizer = SGD(g[2], lr=hyp['lr0'], momentum=hyp['momentum'], nesterov=True)

    optimizer.add_param_group({'params': g[0], 'weight_decay': hyp['weight_decay']})  # add g0 with weight_decay
    optimizer.add_param_group({'params': g[1]})  # add g1 (BatchNorm2d weights)
    LOGGER.info(f"{colorstr('optimizer:')} {type(optimizer).__name__} with parameter groups "
                f"{len(g[1])} weight (no decay), {len(g[0])} weight, {len(g[2])} bias")
    del g

    # Scheduler
    if opt.cos_lr:
        lf = one_cycle(1, hyp['lrf'], epochs)  # cosine 1->hyp['lrf']
    else:
        lf = lambda x: (1 - x / epochs) * (1.0 - hyp['lrf']) + hyp['lrf']  # linear
    scheduler = lr_scheduler.LambdaLR(optimizer, lr_lambda=lf)  # plot_lr_scheduler(optimizer, scheduler, epochs

    # EMA
    ema = ModelEMA(model) if RANK in {-1, 0} else None

    # Resume
    start_epoch, best_fitness = 0, 0.0
    if pretrained:
        # Optimizer
        if ckpt['optimizer'] is not None:
            optimizer.load_state_dict(ckpt['optimizer'])
            best_fitness = ckpt['best_fitness']

        # EMA
        if ema and ckpt.get('ema'):
            ema.ema.load_state_dict(ckpt['ema'].float().state_dict())
```

```
Studio\Computer Vision>
```



01

Defect recognition

The total length and width are first identified using computer vision after which the defects that hinder structural stability are identified

02

Bounding boxes

The bounding boxes around the defects would be generated using convolutional neural network models

03

Optimal cut pattern

The neural network recognises the defects from which the bounding box coordinates are extracted

04

Fabrication elements

The replica of the wood with the defects are generated in Rhino for size optimisation and maximum usage

COMPUTER VISION ? TASK AT HAND

process below made for an ideal situation that could benefit from using existing tech and advancements by using computer vision as our design process aid

\>

Catalogue of pieces

A randomised catalogue (assuming all perpendicular edges) of wooden boards recycled are passed through the CV process

\>>

Scanned boards after CV

The replica of the wood with the defects are generated in Rhino for size optimisation and maximum usage

Msc2 TUD Design Studio: Interactive architecure. (Max Sterry, Mimi Cepic , Tarique Ali, Tobine Rasmussen.2022)

AI-Supported Circular Design

Material Right?

How do we evaluate the process and decisions?

Is reuse or recycle necessarily better, lower-impacted, or more time consuming, inflexible, or costly?

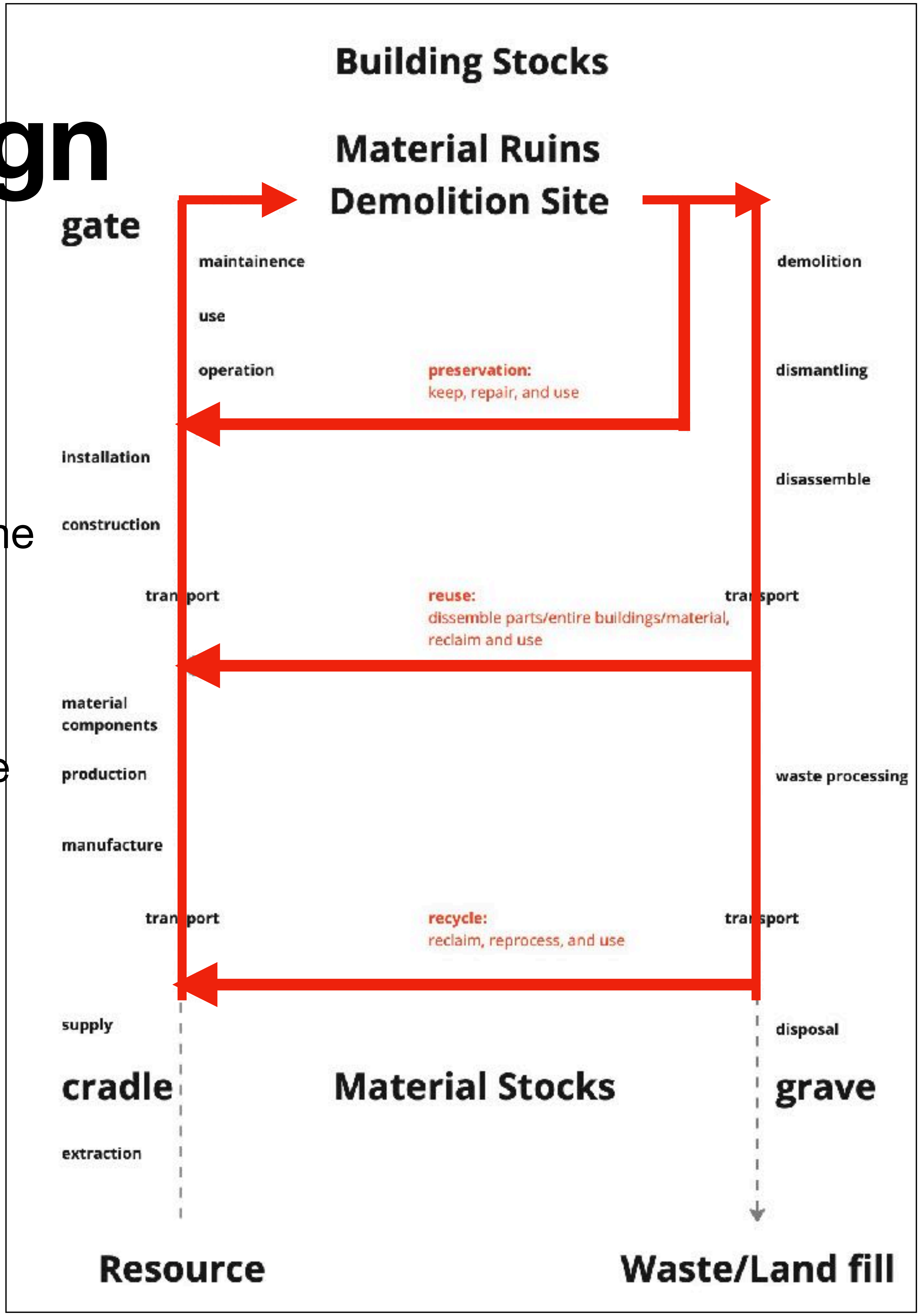
How do we calculate, quantify, visualise the engineering results?

How do we model the material and project construction under the scope of time?

How do we deal with architectural cases and materials that vary from case to case?

How do AI support this, in comparison with what computer can and cannot do?

What are the means, tools? Who needs the information?



AI-Supported Circular Design

Material Right?

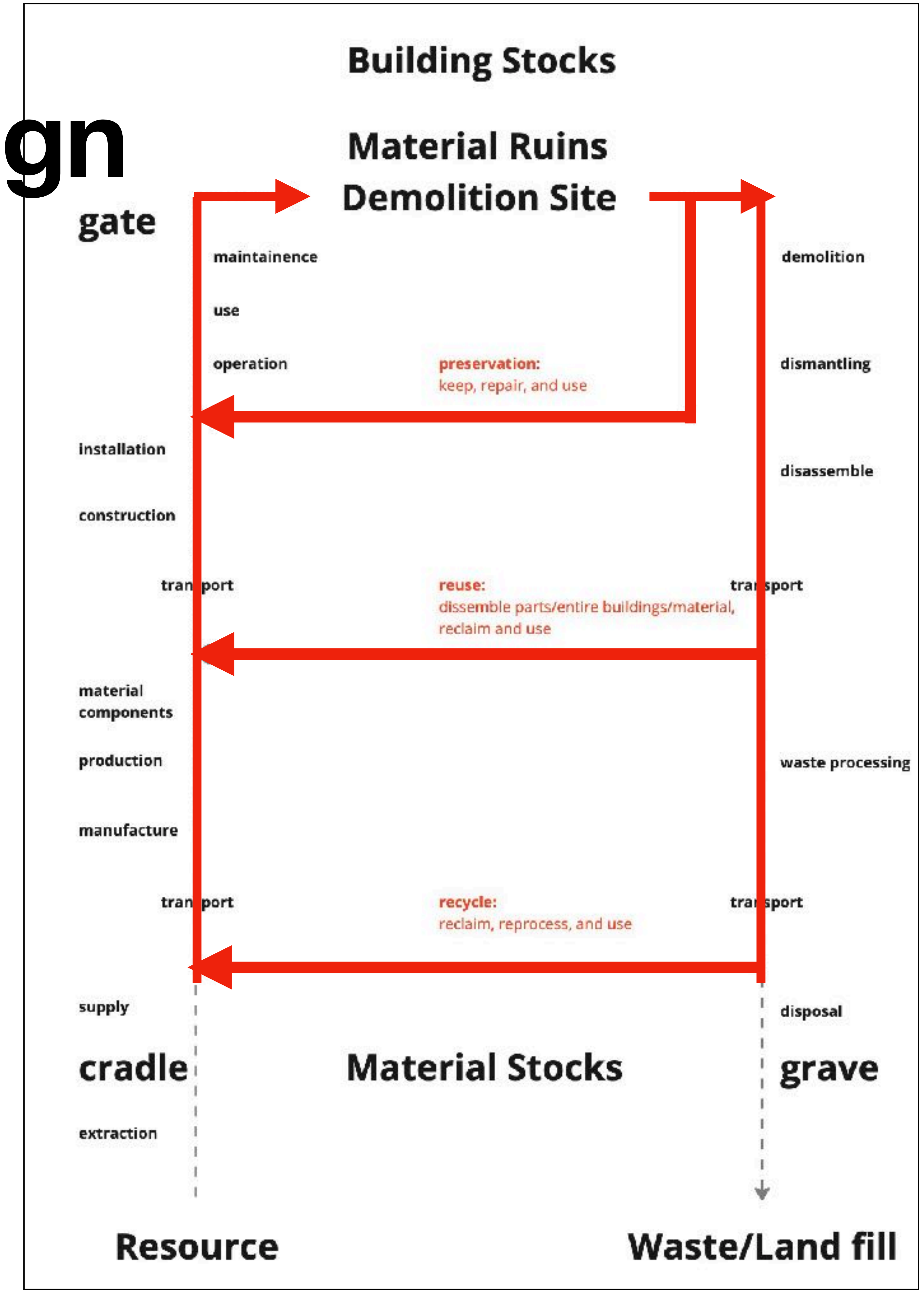
How do we evaluate the design process?

Engineer: CO2 emission, energy consumption, durability…

Management: cost, construction time, material supply/demand, transportation…

Design: architectural language, comfort, material quality, construction type, details…

(Clients, stakeholders, users)



Design for future reuse

BIM-based whole-life performance estimator

Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator

Lukman A. Akanbi[a], Lukumon O. Oyedele[a,*], Olugbenga O. Akinade[a], Anuoluwapo O. Ajayi[a], Manuel Davila Delgado[a], Muhammad Bilal[a], Sururah A. Bello[b]

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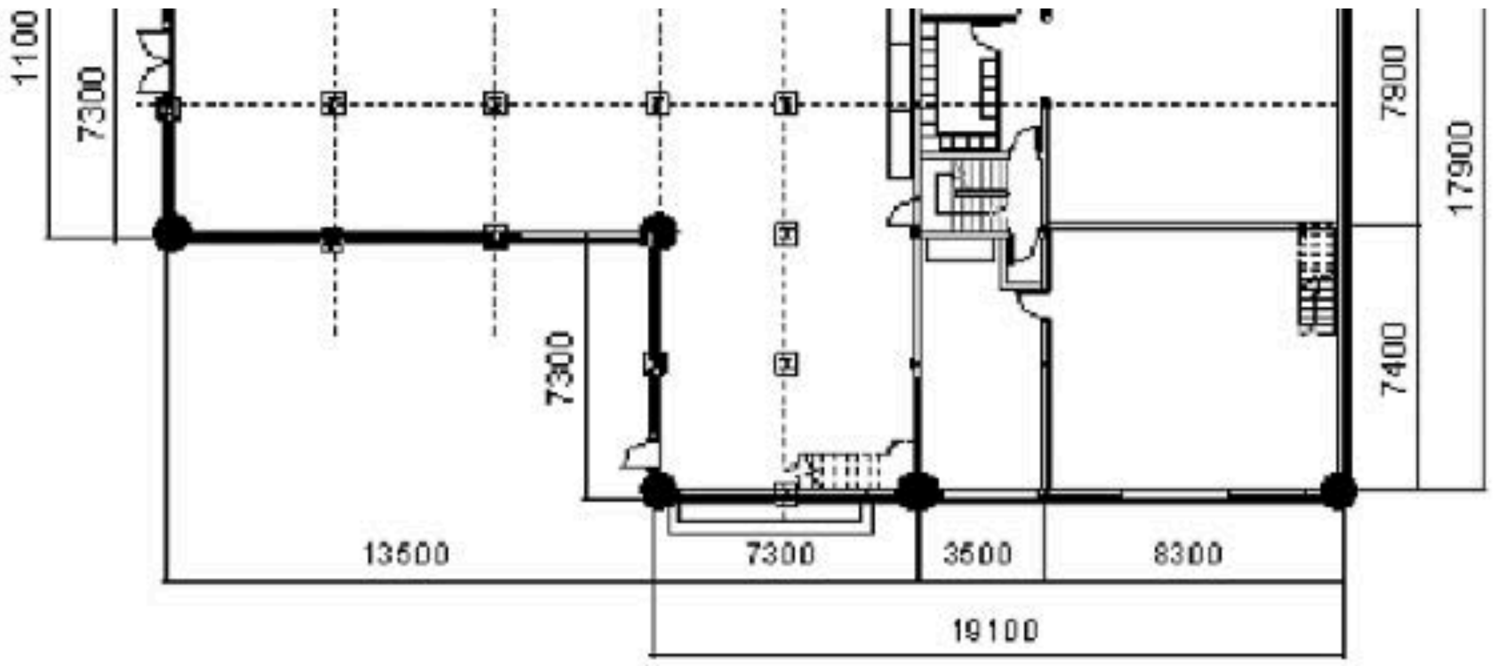
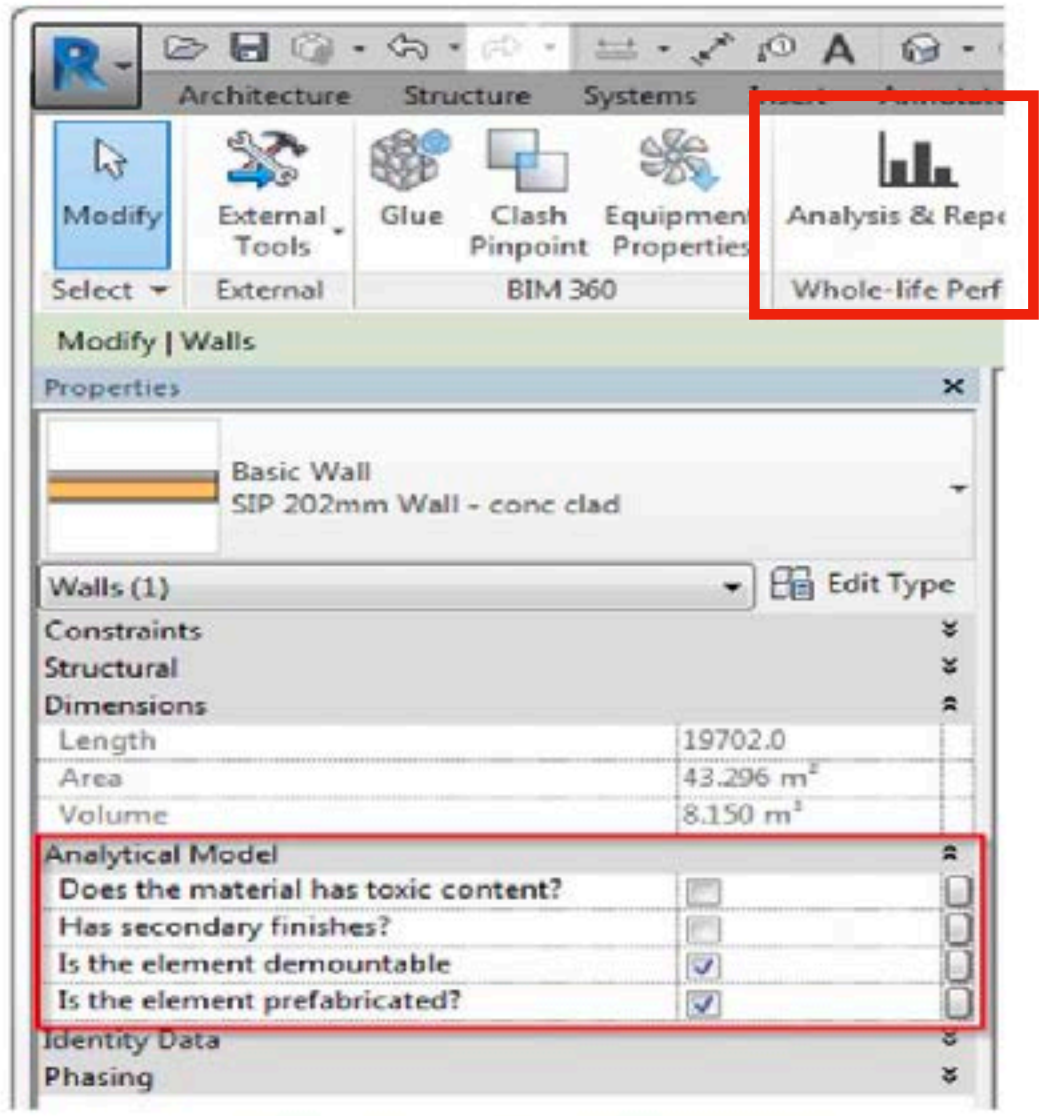
ARTICLE INFO

Keywords:
Building information modelling (BIM)
Whole-life performance profile
Building materials
End-of-life
Circular economy

ABSTRACT

The aim of this study is to develop a BIM-based Whole-life Performance Estimator (BWPE) for a salvage performance of structural components of buildings right from the design stage. A review literature was carried out to identify factors that influence salvage performance of structural co buildings during their useful life. Thereafter, a mathematical modelling approach was adopted to d using the identified factors and principle/concept of Weibull reliability distribution for manufactu The model was implemented in Building Information Modelling (BIM) environment and it was test study design. Accordingly, the whole-life salvage performance profiles of the case study building we The results show that building design with steel structure, demountable connections, and pref semblies produce recoverable materials that are mostly reusable. The study reveals that BWPE is means for determining how much of recoverable materials from buildings are reusable and recyclab of its useful life. BWPE will therefore provide a decision support mechanism for the architects and analyse the implication of designs decision on the salvage performance of buildings over time. It useful to the demolition engineers and consultants to generate pre-demolition audit when the bui end of its life.



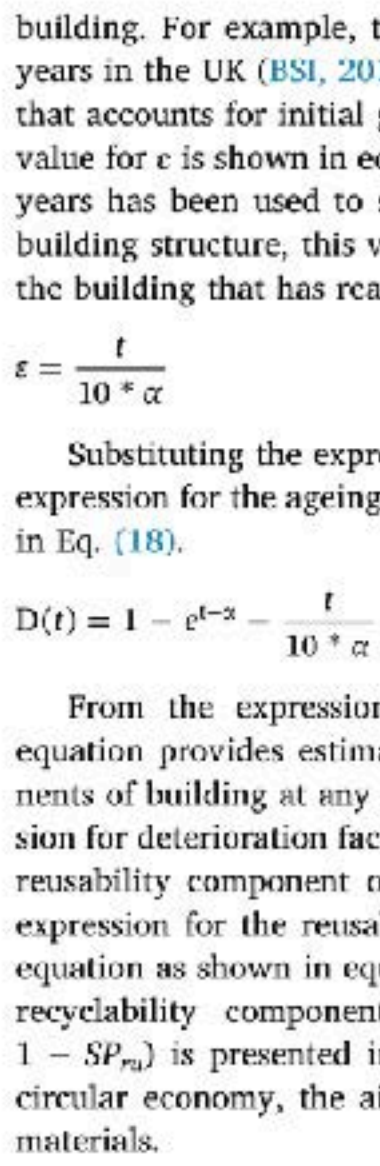


Basic Wall
SIP 202mm Wall - conc clad

Dimensions	
Length	19702.0
Area	43.296 m²
Volume	8.150 m³

Analytical Model	
Does the material has toxic content?	☐
Has secondary finishes?	☐
Is the element demountable	☑
Is the element prefabricated?	☑

Fig. 7. Custom Parameter Creation Interface in Revit.



building. For example, t
years in the UK (BSI, 20
that accounts for initial
value for ε is shown in e
years has been used to
building structure, this v
the building that has rea

$$\varepsilon = \frac{t}{10 * \alpha}$$

Substituting the expr
expression for the ageing
in Eq. (18).

$$D(t) = 1 - e^{t-\alpha} - \frac{t}{10 * \alpha}$$

From the expression
equation provides estim
nents of building at any
sion for deterioration fac
reusability component
expression for the reusa
equation as shown in eq
recyclability componen
$1 - SP_{ru}$) is presented i
circular economy, the a
materials.

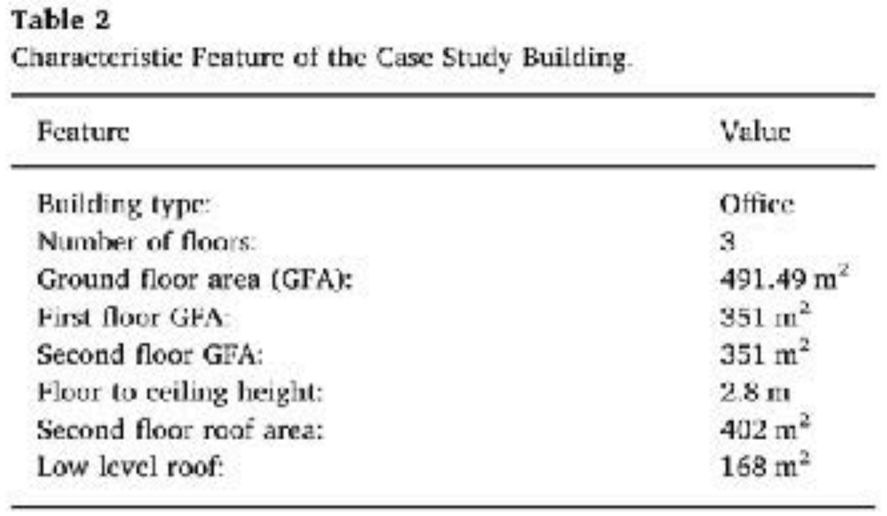


Table 2
Characteristic Feature of the Case Study Building.

Feature	Value
Building type:	Office
Number of floors:	3
Ground floor area (GFA):	491.49 m²
First floor GFA:	351 m²
Second floor GFA:	351 m²
Floor to ceiling height:	2.8 m
Second floor roof area:	402 m²
Low level roof:	168 m²

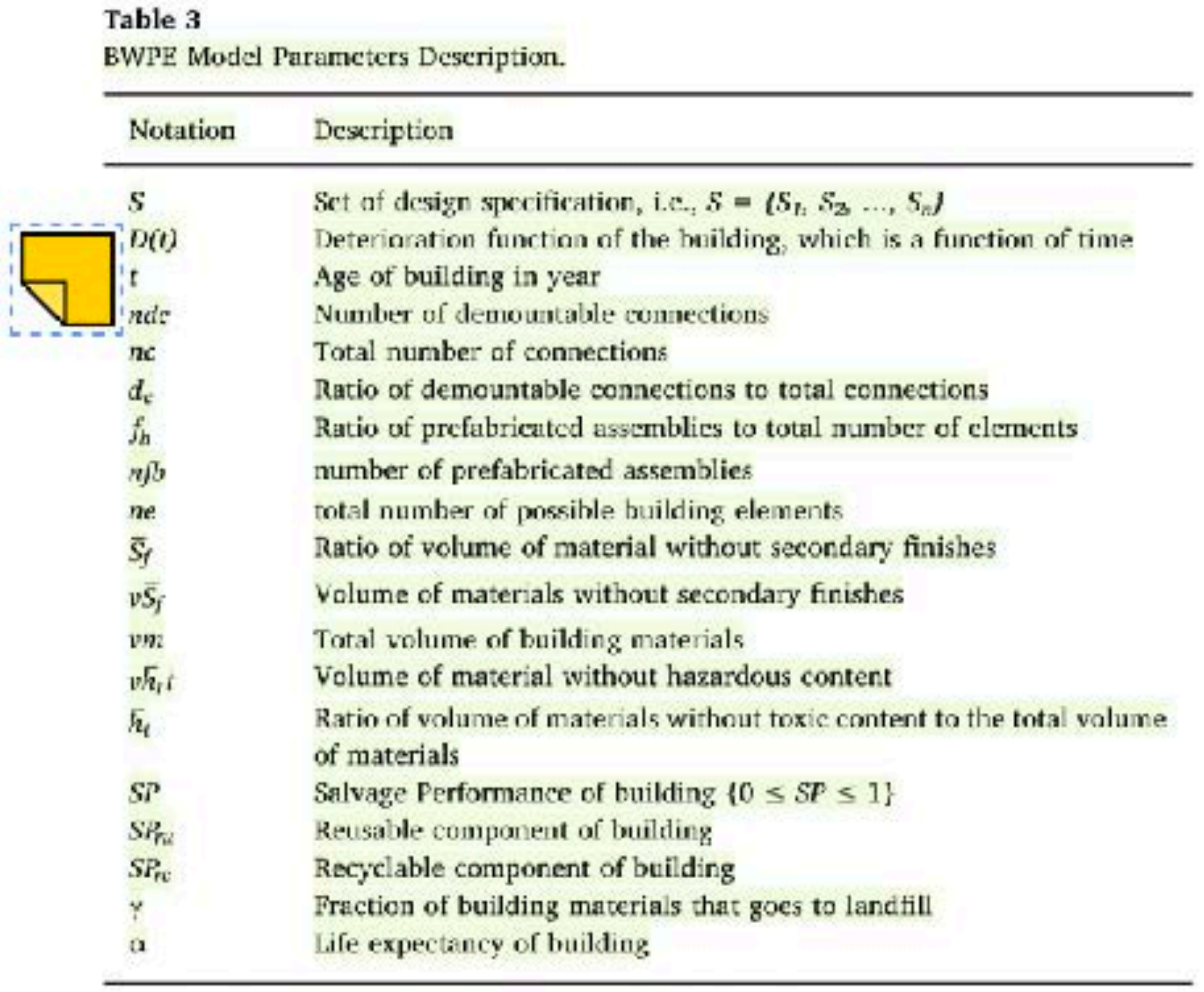
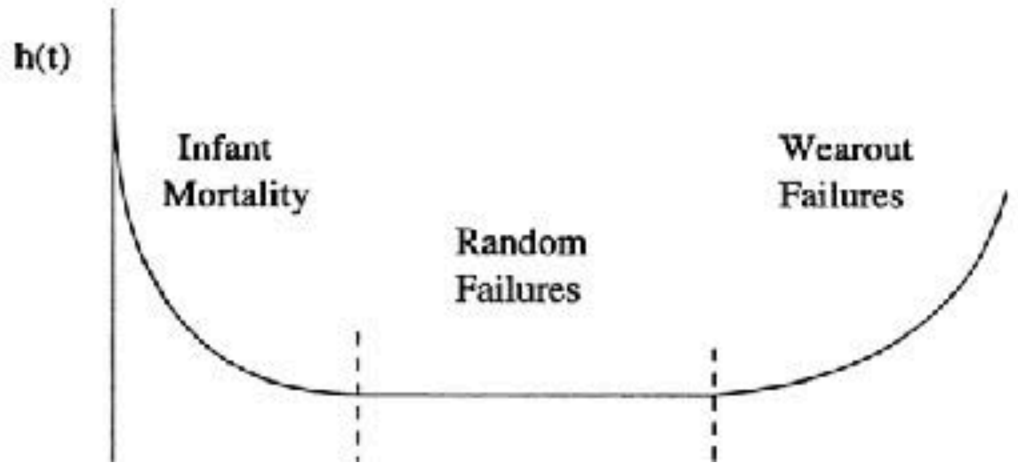


Table 3
BWPE Model Parameters Description.

Notation	Description
S	Set of design specification, i.e., $S = \{S_1, S_2, ..., S_n\}$
$D(t)$	Deterioration function of the building, which is a function of time
t	Age of building in year
ndc	Number of demountable connections
nc	Total number of connections
d_c	Ratio of demountable connections to total connections
f_b	Ratio of prefabricated assemblies to total number of elements
nfb	number of prefabricated assemblies
ne	total number of possible building elements
$\bar{S_f}$	Ratio of volume of material without secondary finishes
$v\bar{S_f}$	Volume of materials without secondary finishes
vm	Total volume of building materials
$v\bar{h_t}$	Volume of material without hazardous content
$\bar{h_t}$	Ratio of volume of materials without toxic content to the total volume of materials
SP	Salvage Performance of building $\{0 \leq SP \leq 1\}$
SP_{ru}	Reusable component of building
SP_{rc}	Recyclable component of building
γ	Fraction of building materials that goes to landfill
α	Life expectancy of building



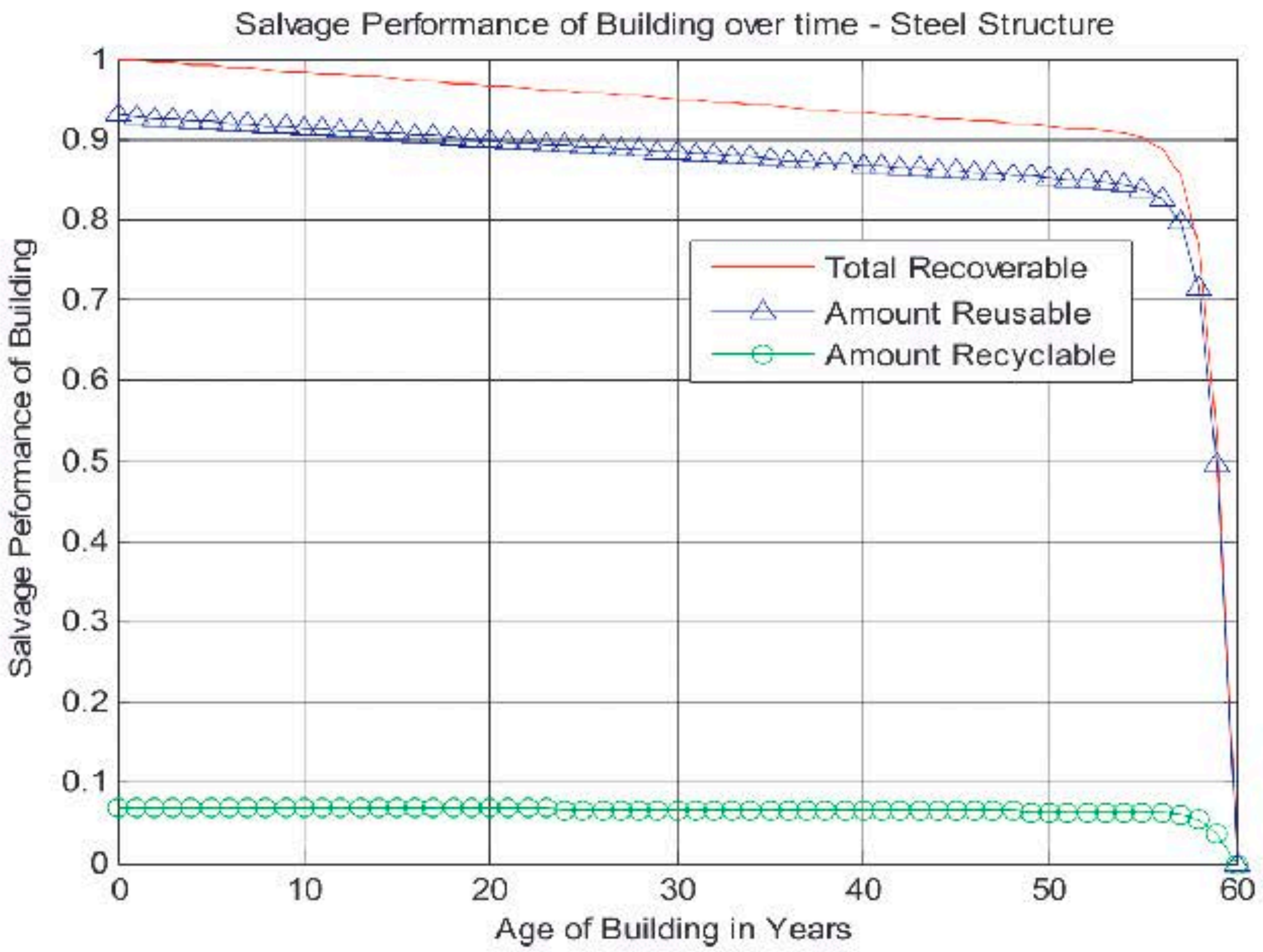
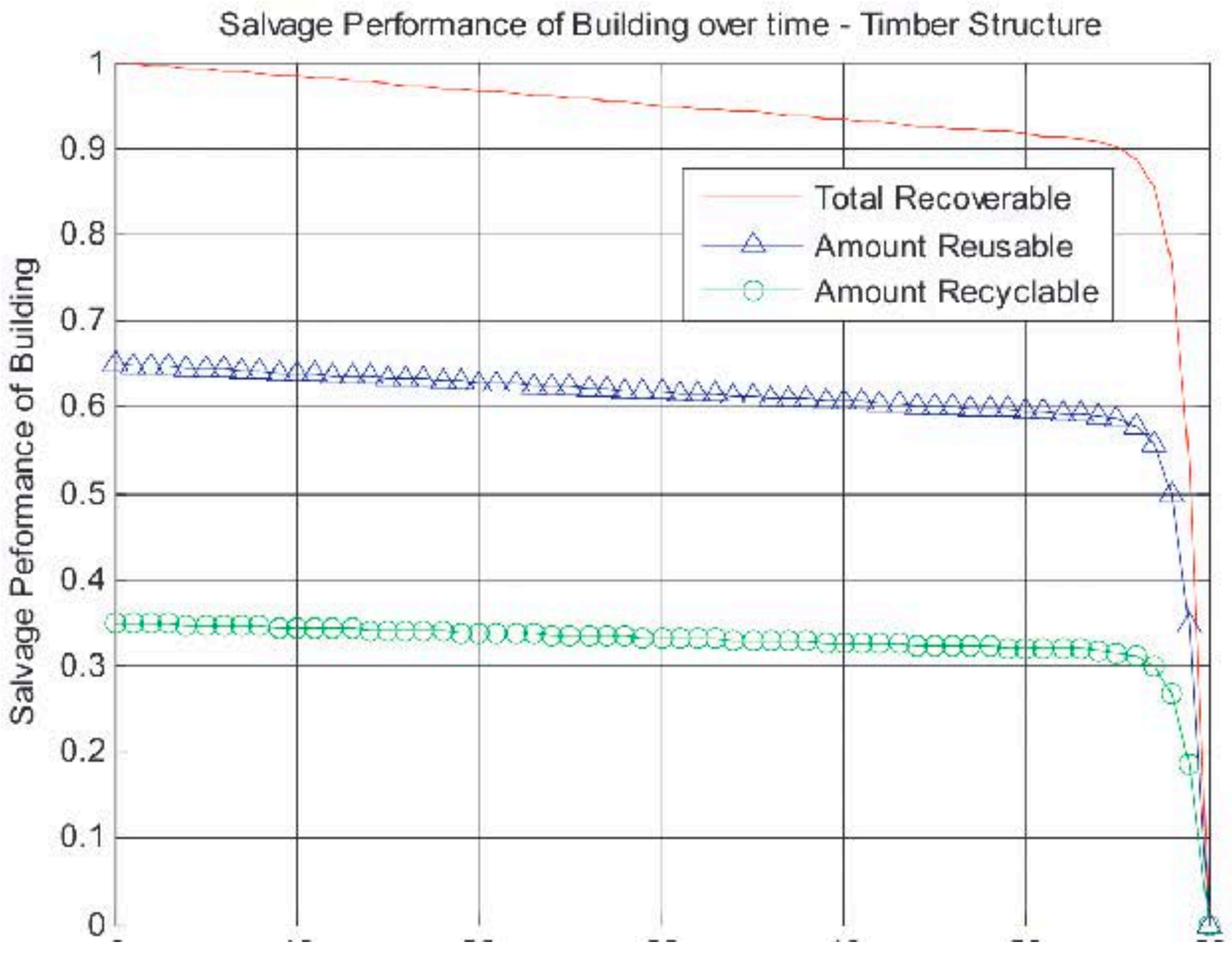


Fig. 9. Salvage Performance of Case Study Building – Steel Structure.



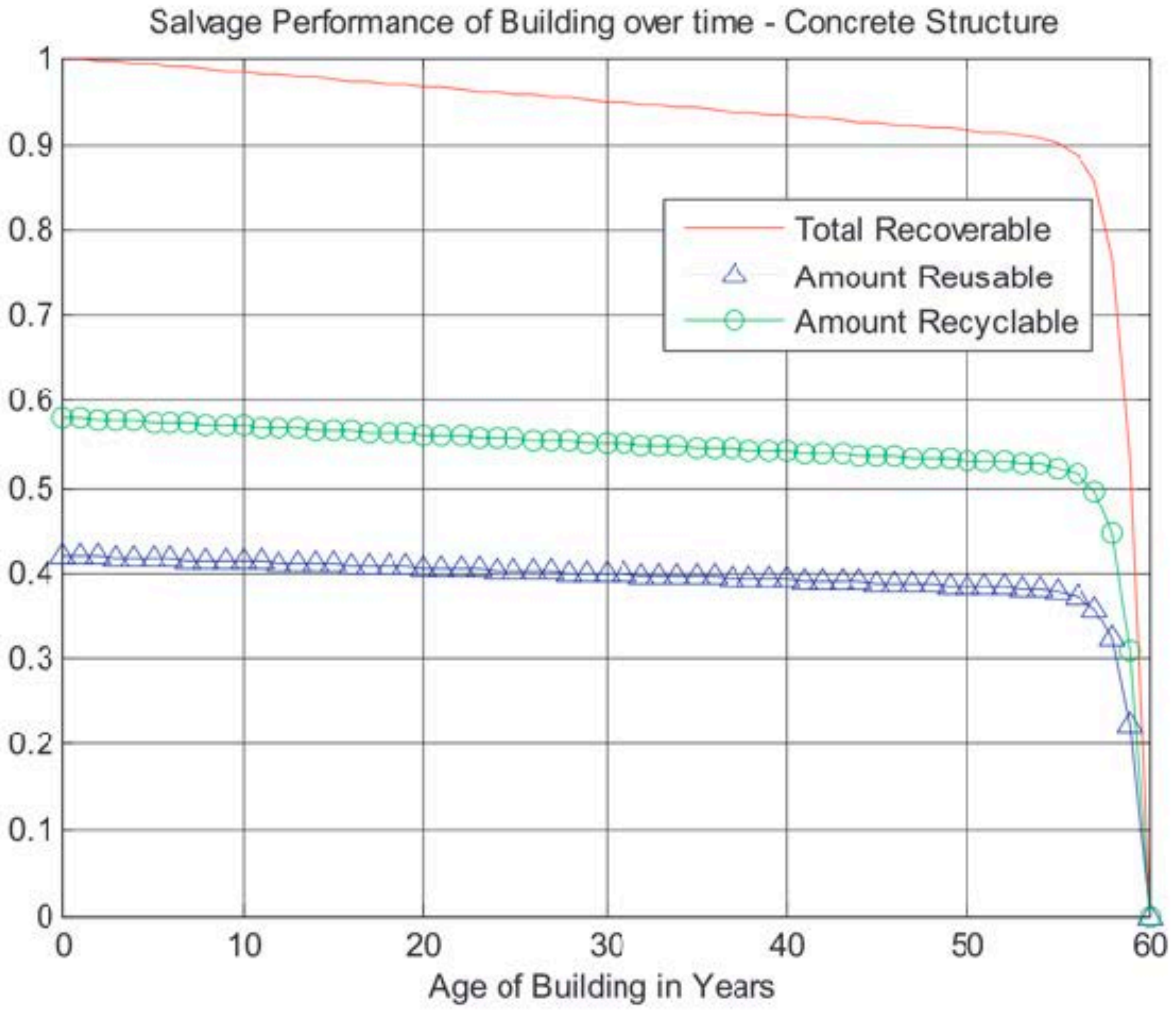


Fig. 11. Salvage Performance of Case Study Building – Concrete Structure.

Reuse management

Disassembly sequence

Wordcount: Manuscript & Abstract(8,808) + Figure captions (126) + Text in figures (804) = **9,738 words**

"A novel selective disassembly sequence planning method for adaptive reuse of buildings"

Sanchez, Benjamin[1,2,4] and Haas, Carl[1,3]

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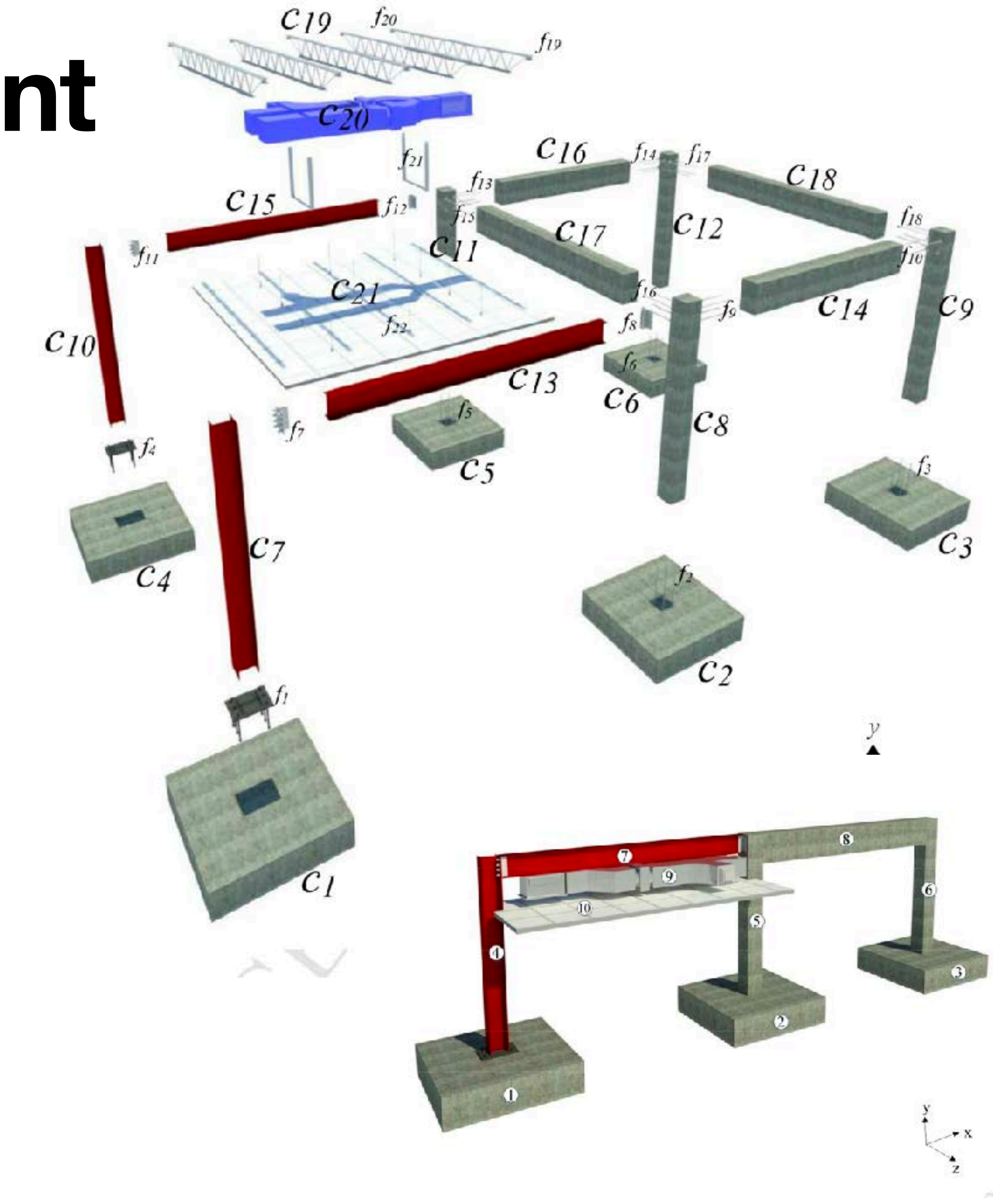
[3]chaas@uwaterloo.ca
[4]corresponding author

Abstract:
Adaptive reuse of buildings can be an attractive alternative to new construction in terms of sustainability and a circular economy. Achieving net benefits with adaptive reuse partly relies on efficiently planning building disassembly. The aim of this paper is to describe a new efficient single-target selective disassembly sequence planning method developed for adaptive reuse of buildings. Finding a global optimum disassembly planning solution for buildings can be time consuming and physically impractical due to the high number of possible solutions. The method developed seeks to minimize environmental impact and removal costs using rule-based recursive analyses for planning recovery of target components from multi-instance building subsystems based upon physical, environmental and economic constraints. Rule-based recursive methods have been demonstrated to be an efficient alternative to find near-optimal



Assembly components:
1. Concrete isolated foundation 1830x1830x457mm
2. Concrete isolated foundation 1830x1830x457mm
3. Concrete isolated foundation 1830x1830x457mm
4. Steel column W10X49
5. Concrete column 120x120mm
6. Concrete column 120x120mm
7. Steel beam W12X26
8. Concrete column 120x200mm
9. Ventilation ducting system
10. Compound ceiling 2'x4' ACT System

Attachment elements specifications:
The interface between the steel column (4) and the concrete isolated foundation (1) is compounded by a thick base plate, bolts set in pockets, and anchor plates.
The interface between the steel beam (7) and the concrete column (5) is compounded by a connection plate on an epoxy bed, expending anchors, HSFG bolts, and shims.
The interface between the steel beam (7) and the steel column (4) is compounded by double angles shop-welded to the web of the beam and double angles field-bolted to the web of the column.
The ventilation ducting system (9) is attached to the steel beam (7) through metal duct straps every 900 mm.
The piece of compound ceiling ACT system (10) is attached to the steel beam (7) through hanger wire for drop suspended ceiling grids.

Insulation material data analysis

Web-based decision tool for refurbishment

ROTUNDORO. A web-based decision support tool for building refurbishment.

Julia Katharina Kaltenegger, Master Thesis, October 2021,
email: jul.kaltenegger@gmail.com

Institute: Eindhoven University of Technology
Faculty: Department of the Built Environment
Master: Architecture, Building and Planning
Master Program: Urban Systems and Real Estate (URSE) &
Construction Management and Engineering (CME)
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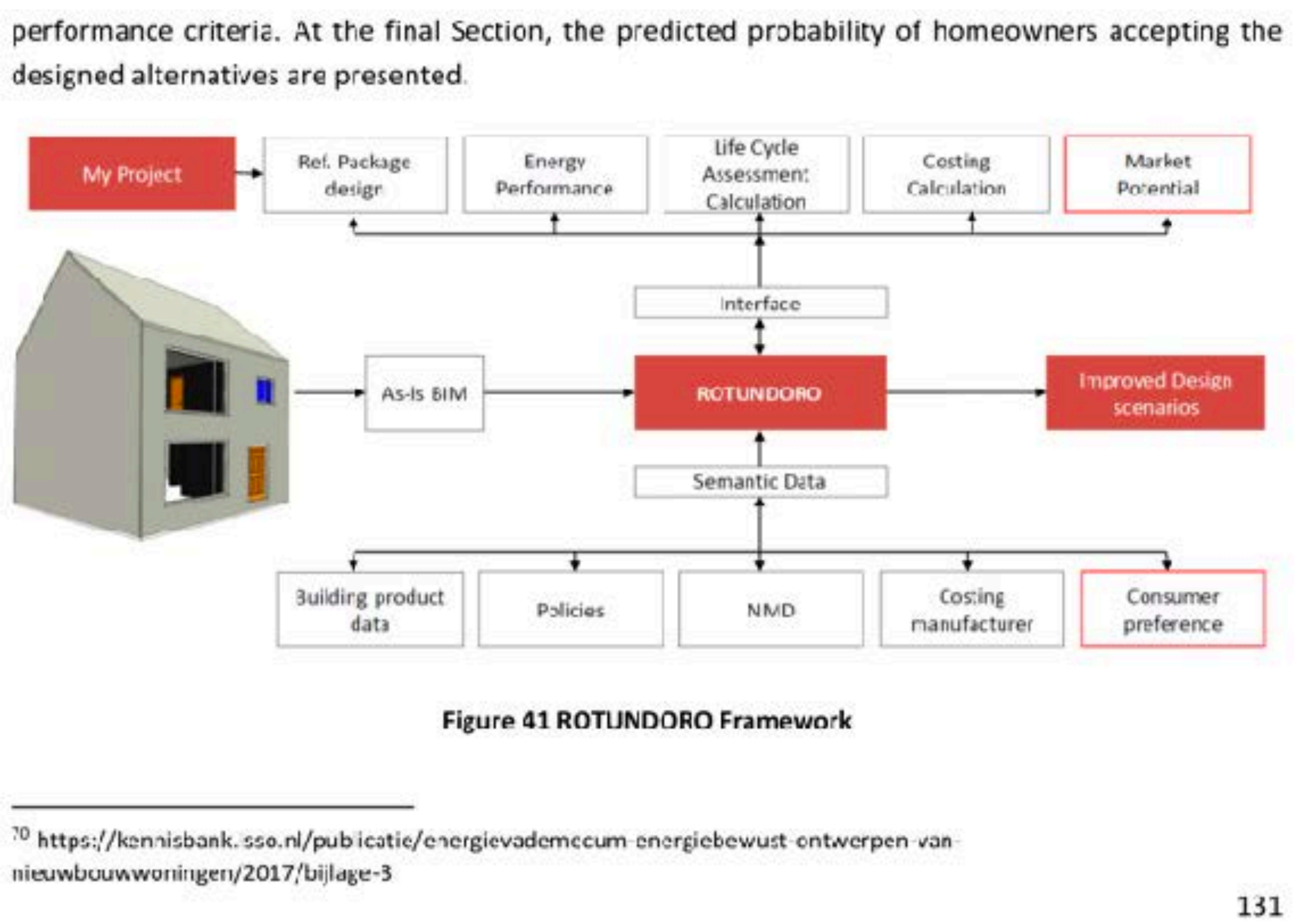
Chairman (CME): Prof.dr.ir.B. de Vries, Graduation Supervision (CME): Dr.ir. Pieter Pauwels (p.pauwels@tue.nl)

Abstract

When refurbishing residential buildings, insulation materials play a crucial role in improving housing quality and energy efficiency. Materials however differ in a wide set of criteria. It reaches beyond the thermal properties and addresses environmental, economic, health and safety characteristics. In collective decision-making, it remains difficult to find trade-offs between these criteria. This thesis introduces a web-based tool ROTUNDORO [Latin: circular] that offers an algorithm to assess refurbishing insulation materials, considering engineering evaluation methods and consumer preferences. The tool employs and expands on Building Information Modelling (BIM) practice on the one side and behavioural economic research on the other side. First, the Linked Building Data (LBD) method is used to link material performance to building components and to evaluate them with Life Cycle Assessment (LCA) and cost analysis. Applied to a Dutch terrace house (Rijwoning) as a use case, the tool shows that bio-based materials perform best in environmental concerns, low embodied



performance criteria. At the final Section, the predicted probability of homeowners accepting the designed alternatives are presented.

Figure 41 ROTUNDORO Framework

---

[70] https://kennisbank.sso.nl/publicatie/energievademecum-energiebewust-ontwerpen-van-nieuwbouwwoningen/2017/bijlage-3

4.3 Comparative Material Analysis

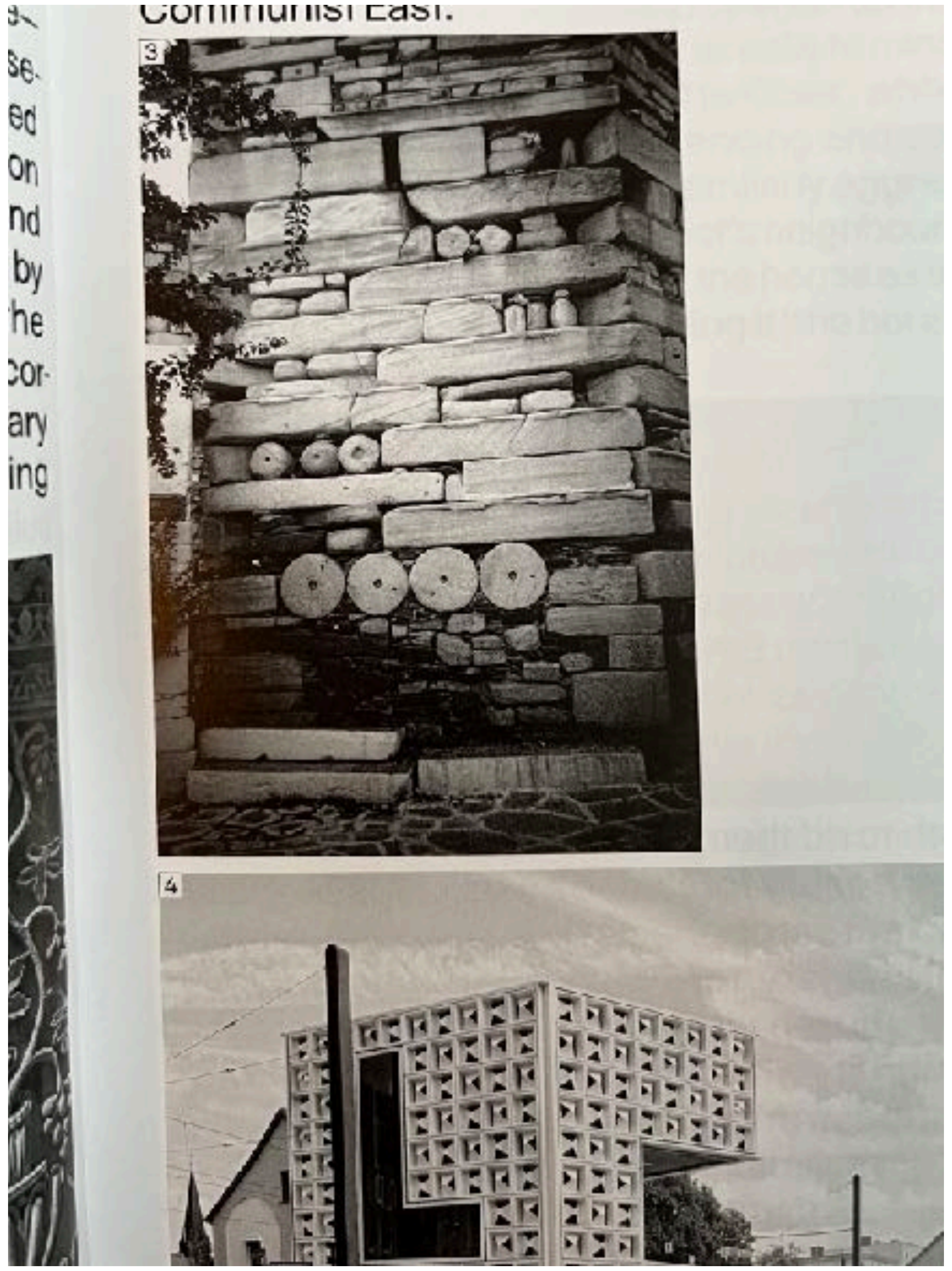
ous Section, decision parameters to evaluate materials are studied. Various insulation a rials re analysed to create a comparative study. The material classification was divided according to the sourcing materials. These are non-renewables such as fossil fuel-based materials, mineral-based and bio-based materials, see **Table 18**. Find the comparative analysis per Rc-Value in the **Appendix B.**

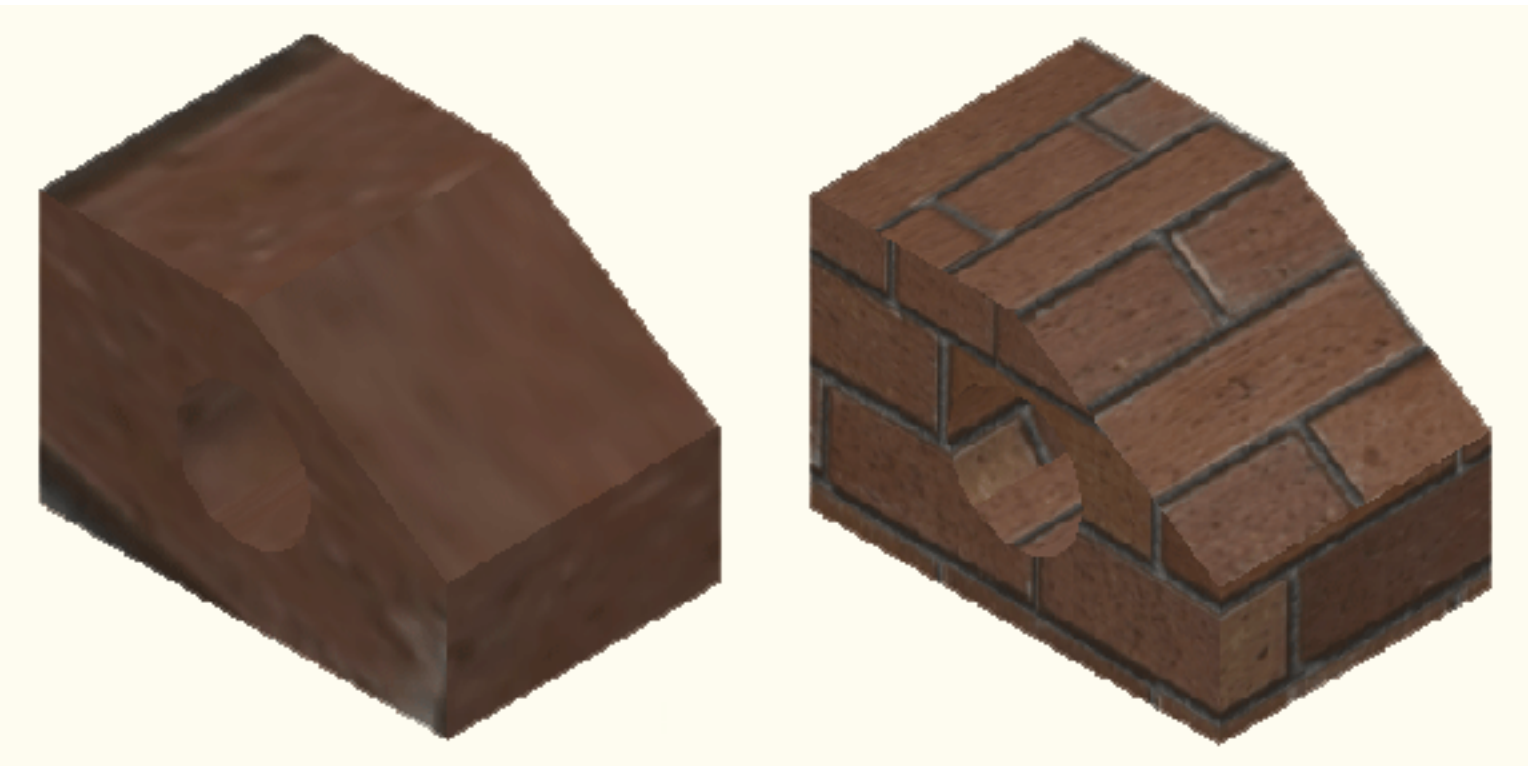
Name	Lambda (λ)	Density (ρ)	Weight	EE	EC	Costing	Lifetime	Fire rating	Toxic Hazards	dB drop	VDRF
	W/mK	*kg/m³*	*kg/m²*	*MJ/m²*	*(kgCO2eq/m²)*	*€/m2*	*years*	*A-F*	*g/m³*	*dB*	*µ-value*
Mineral-based											
Glass Woo	0.034	18.4	1.06 - 4.07	51.50 - 196.91	1.60 - 6.12	6.80 - 20.00	75	A2	129.5	8.52	0.29 - 1.11
Rock Woo	0.035	45	2.68 – 10.24	48.90 - 186.97	2.90 - 11.09	7.40 - 26.00	75	A1	172.1	7.85	0.36 - 1.37
Fossil-based											
PUR	0.026	33	1.44 - 5.49	179.30 - 680.70	11.60 - 43.90	7.86 - 23.00	75	E	11.4	11.54	22.10 - 84.50
EPS	0.0325	23	1.24 - 4.75	117.50 - 449.26	8.70 - 33.26	5.85 - 21.00	75	E	27.6	2.16	15.19 - 58.09
XPS	0.027	35	1.61 - 6.14	178.20 - 681.35	24.80 - 94.82	8.11 - 39.92	75	E	≤ 27.6	4.81	26.39 - 100.91
Bio-based											
Flax wool	0.041	31	2.16 - 8.26	86.30 - 329.97	2.60 - 9.94	24.08 - 67.25	40	C	≥ 129.5	10.17	0.52 - 2.00
Wood Fibre	0.038	45	21.96 - 83.98	23.50 - 89.40	0.62 – 2.35	6.91 - 30.17	100	C-D	≥ 129.5	21.00	0.97 - 3.71
Cellulose	0.04	70	4.76 - 18.20	8.80 - 33.30	0.29 - 1.11	55.50 - 90.00	30	C	≥ 129.5	10.90	0.85 - 3.25
Sheep Woo	0.0412	25	1.75 - 6.70	21.54 82.35	-2.10 - -8.03	13.48 - 51.55	100	E	≥ 129.5	6.52	0.70 - 2.68
Hemp Lime	0.067	340	38.73 - 148.07	152.63 - 583.57	-8.59 - -32.84	23.92 - 91.46	100	B	≥ 129.5	16.48	1.59 - 6.10

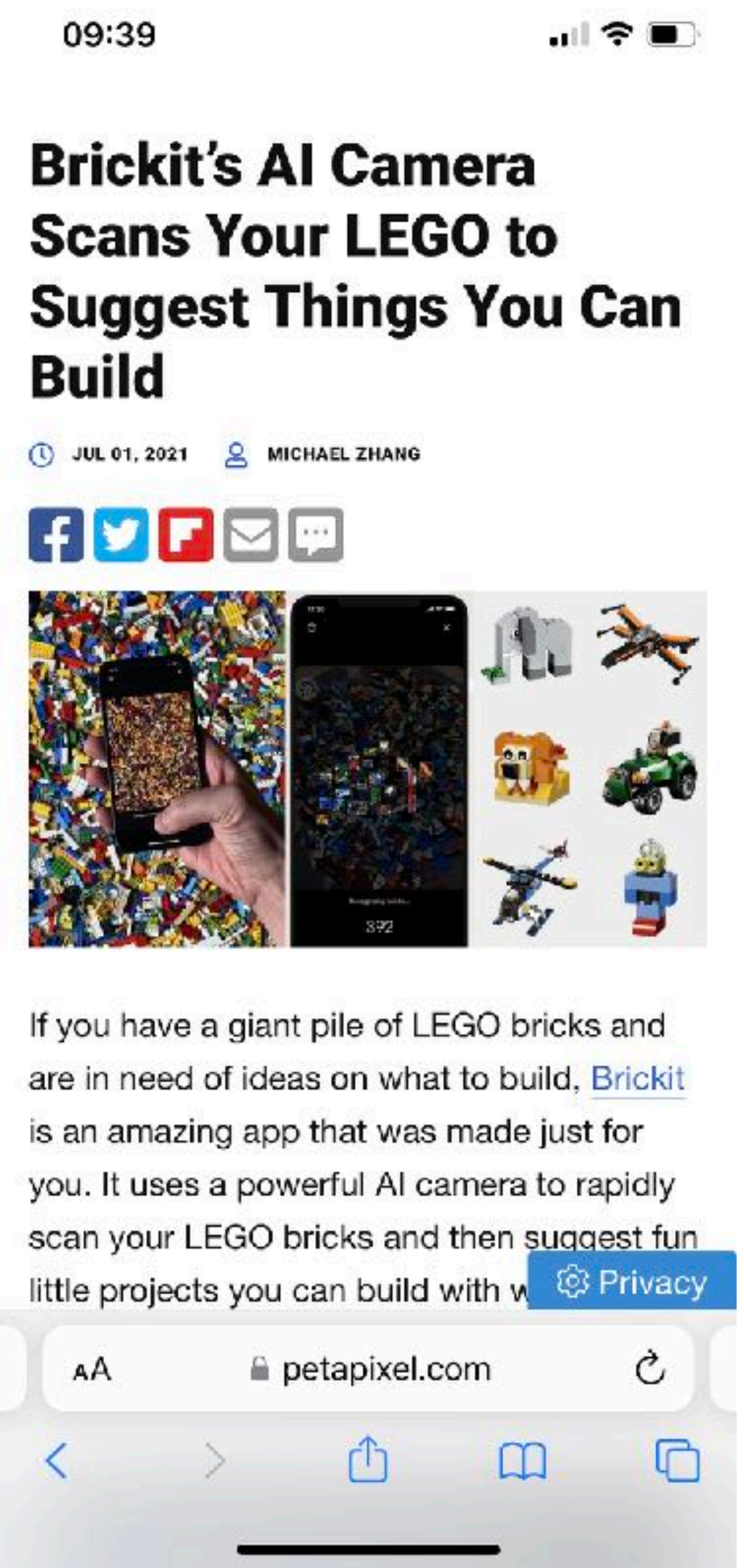
Table 18 Material Comparative Analysis Rc 1.7 - 6.5

Visualisation

3D/2D design tools







09:39

Brickit's AI Camera Scans Your LEGO to Suggest Things You Can Build

JUL 01, 2021 MICHAEL ZHANG

If you have a giant pile of LEGO bricks and are in need of ideas on what to build, Brickit is an amazing app that was made just for you. It uses a powerful AI camera to rapidly scan your LEGO bricks and then suggest fun little projects you can build with w

Conclusion

Direction

- Architectural projects vary from case to case, so as materials.
- AI comes in where human does poorly and machine cannot do.
- Material what. Material bank - network - literacy: gleaning/mining/harvesting from building stocks, demolition site. Supply and demand. Count, size, type
- Material how. The realisation of repair, reuse, recycle from one site, to one project. The combination of the three in one project. (Concrete, timber, brick, earth, glass….) (specific moments/compartments)
- Material right. The results examination, visualisation, calculation, and comparison. Material mapping from data base. 3d material information modelling. (Extract image)

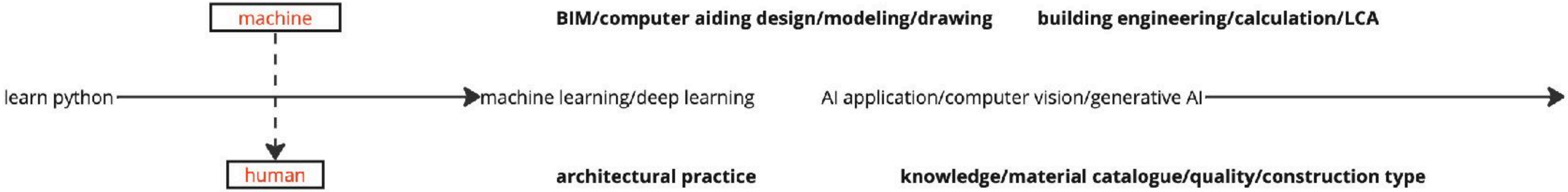
I need to

- Learning programming……
- Pick one/two material?
- Find on architectural project to study
- One demolition project to study
- Company network to browse through
- Material database to work on

Notes

- A system to select carefully on the criteria: Scale, material, method:reuse/ type: such as finish structure…. threads/
- Make a plan
- Find team/ other phd….search managing…know how…
- Terminology cite, literature… be specific
- Research plan

"while architecture field is relatively low tech...."
What can machine do for human in architecture field?
What can't machine do for human in architecture field?
Narrow down to working with existing/renovation/demolition...?



machine

BIM/computer aiding design/modeling/drawing

building engineering/calculation/LCA

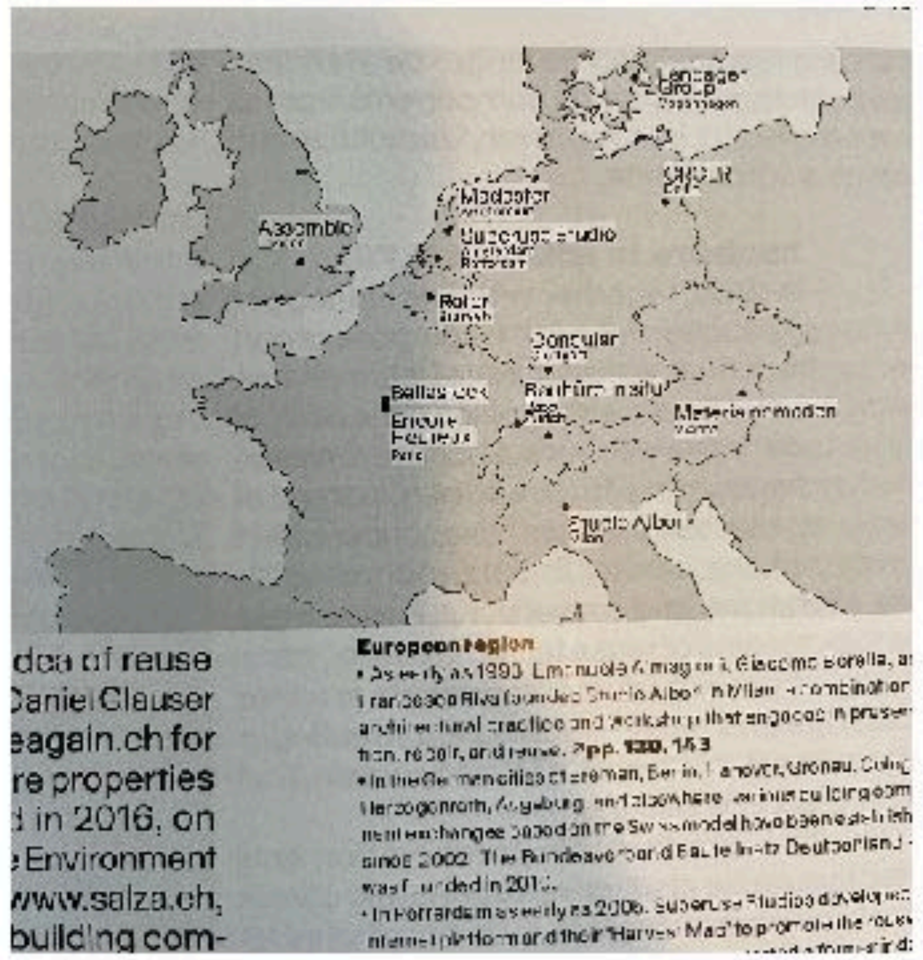
learn python → machine learning/deep learning

AI application/computer vision/generative AI →

human

architectural practice

knowledge/material catalogue/quality/construction type



dea of reuse
Daniel Clauser
eagain.ch for
re properties
d in 2016, on
e Environment
www.salza.ch,
building com-

European region

- As early as 1993, Emanuele Almagioni, Giacomo Borella, a[illegible] Francesca Riva founded Studio Albori in Milan, a combination architectural practice and workshop that engages in preser[illegible] tion, repair, and reuse. ↗ pp. 130, 153
- In the German cities of Bremen, Berlin, Hanover, Gronau, Colog[illegible] Herzogenrath, Augsburg, and elsewhere, various building com[illegible] ment exchanges based on the Swiss model have been establish[illegible] since 2002. The Bundesverband Bauteilnetz Deutschland [illegible] was founded in 2010.
- In Rotterdam as early as 2006, Superuse Studios develop[illegible] internet platform and their "Harvest Map" to promote the reuse [illegible]

learn from companies/firm:
super-reuse
Madaster
Rotor(material bank)
BC (excavated earth to building materials)
...

What are the available materials?
how do you make materials available? make information available?
how do we asses those materials?

bridge the gap, what's missing in field?

- Architectural project varies case by case….
- Material usage also varies case by case….
- If you want to reuse based on existing materials, it’s a very specific approach.

What and Where are the demolition sites?
Why were/are there?
Can they become
Top (material network)
Domolition site to material stocks (how)

Material bank
What materials were/are there?
Down (material literacy)
Material and material availability

Conclusion

- Other materials: Concrete, Glass, Brick, Steel, Timber……
- Vary from buildings to buildings…how do we approach to this very customised process with AI.

- Direction 1 AI and material recognition in a site. Classification. Information. Modelling
- 2 Material mappings. Material modelling based on existing, realtime, available material properties
- Material mappings — combination of materials by AI? Ai supported render/ar/modelling…?
- 3 Material bank/network, calculate count, style, combination of sources from different dealers/storage
- 4 Material literacy. Focused on AI application different materials and their reuse/recycle possibility and application
- AI application on Building/Material modelling…BIM
- Focus on material-driven design starting excavation>>design>>change material to reuse>>CO2 analysis…
- Existing case studies(architectural project) reuse.
- Focus on AI-supported disassemble….

AI-supported Circular Design

- What were the demolition sites?(function)
- Where were they?(transportation)(network)
- Why were they there?(evaluation of left-overs)(hazardous)(value)
- What’s the relations and preferences(same typologies, function)(reasons to reuse)?
- How to reclaim the materials, disassemble, transport?
- How to evaluate/calculation materials from different sources?
- How to store?or real time?(dissemble only while reserved)

- What are the materials there?(classify)
- What quality/construction/value are in those material.(carbon footprint)
- What are the construction?
- What are the counts, sizes, shape…?
- How can they be detached?
- What happened after removed?
- Where does AI come in? Material bank, construction, design, make available? Making material

Transportation

Construction

BUILDING LIFE CYCLE

DESIGN

speed of construction

durability

strength

energy efficiency

emission

aesthetics

thermal comfort

Materials

Material reading/handling
Local resource and meanings
Building depots of materials
Buildings are internventions / episodes

"There is no space created without materialisation."

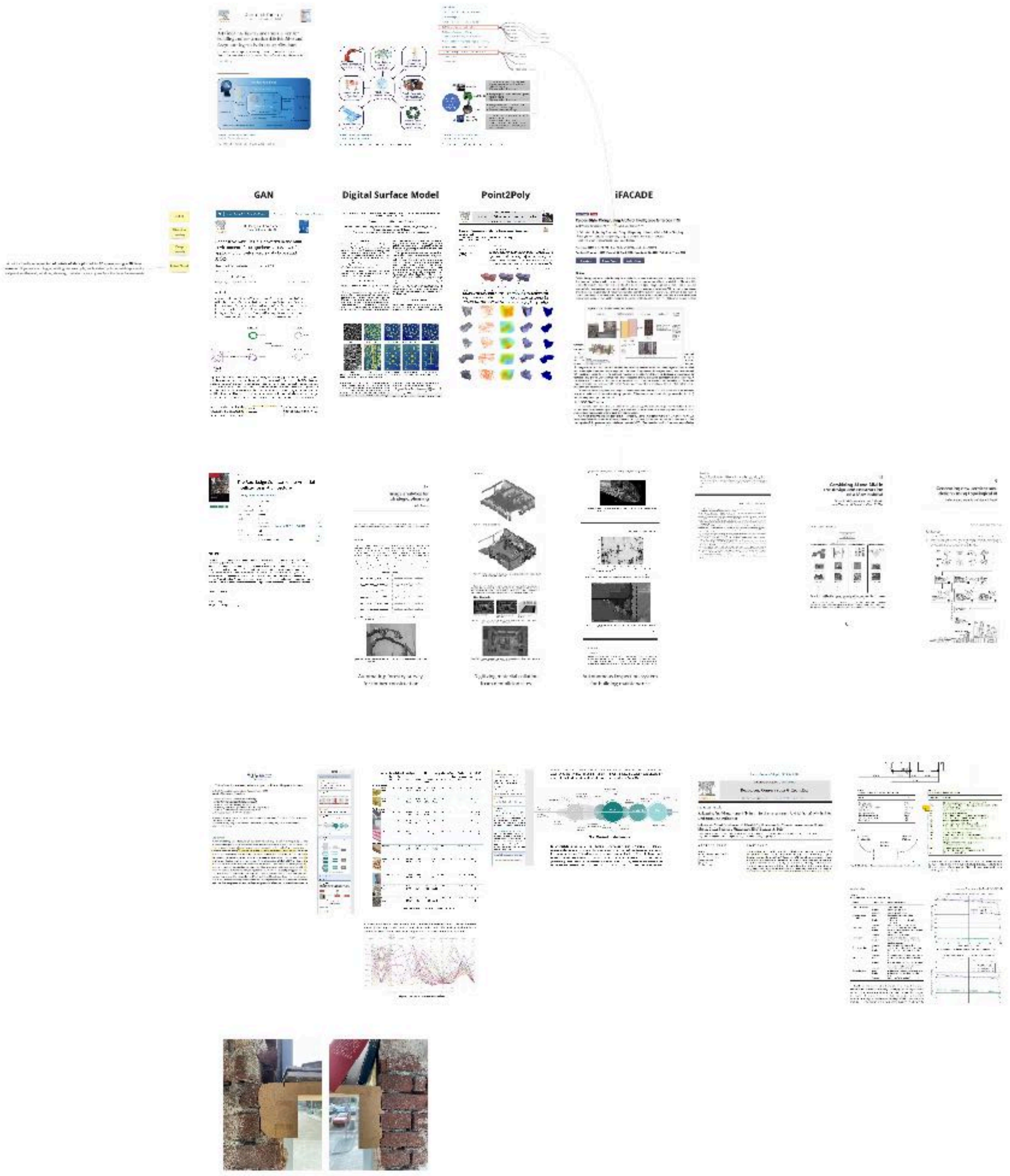
LOW-CO2

IDEA → DESIGN → CUSTOMIZED MATERIALS → OBJECT

IDEA → AVAILABLE MATERIALS → DESIGN → OBJECT

INFORMAL / FORMAL
MATERIAL LITERACY / NETWORK?

Paper reviews



Automation in Construction
Volume 141, September 2022, 104440

Review

Artificial intelligence and smart vision for building and construction 4.0: Machine and deep learning methods and applications

Shanaka Kristombu Baduge [a], Sadeep Thilakarathna [a], Jude Shalitha Perera [a], Mehrdad Arashpour [b], Pejman Sharafi [c], Bertrand Teodosio [d], Ankit Shringi [b], Priyan Mendis [a]

Show more

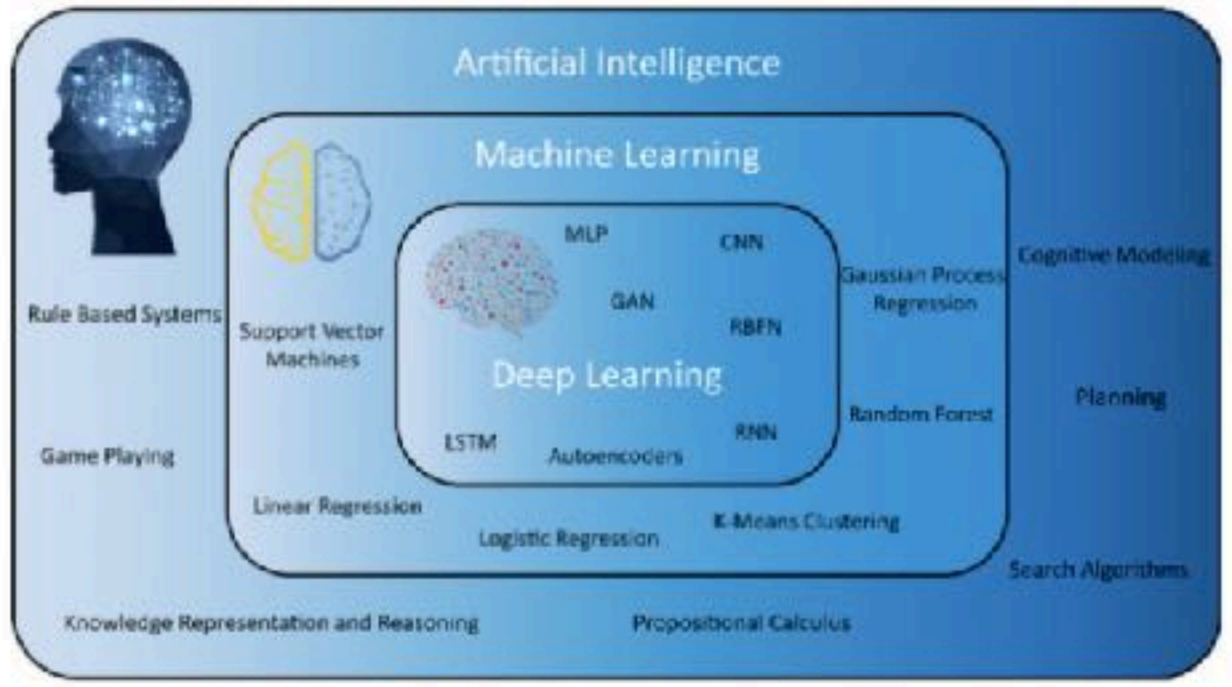
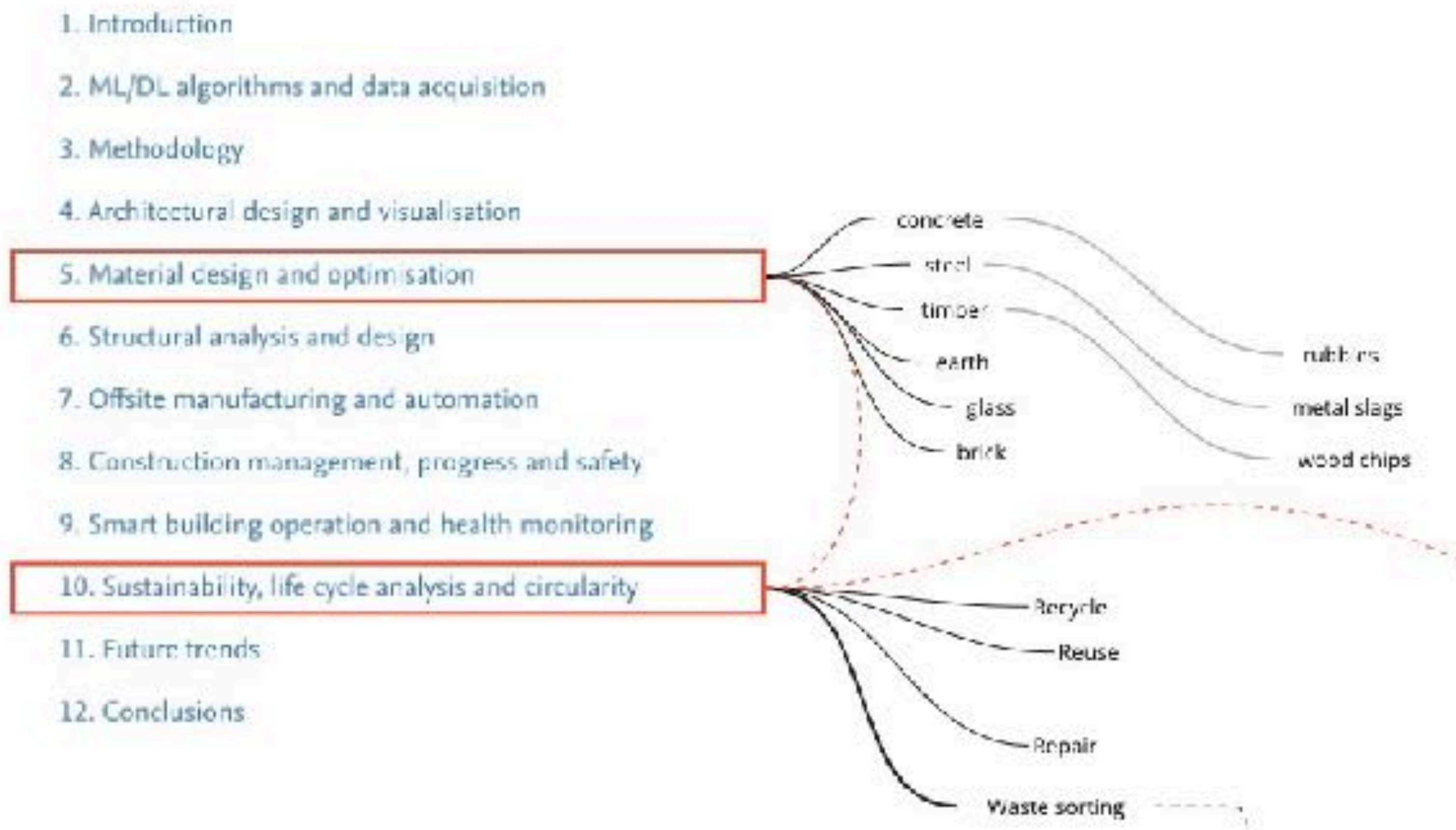
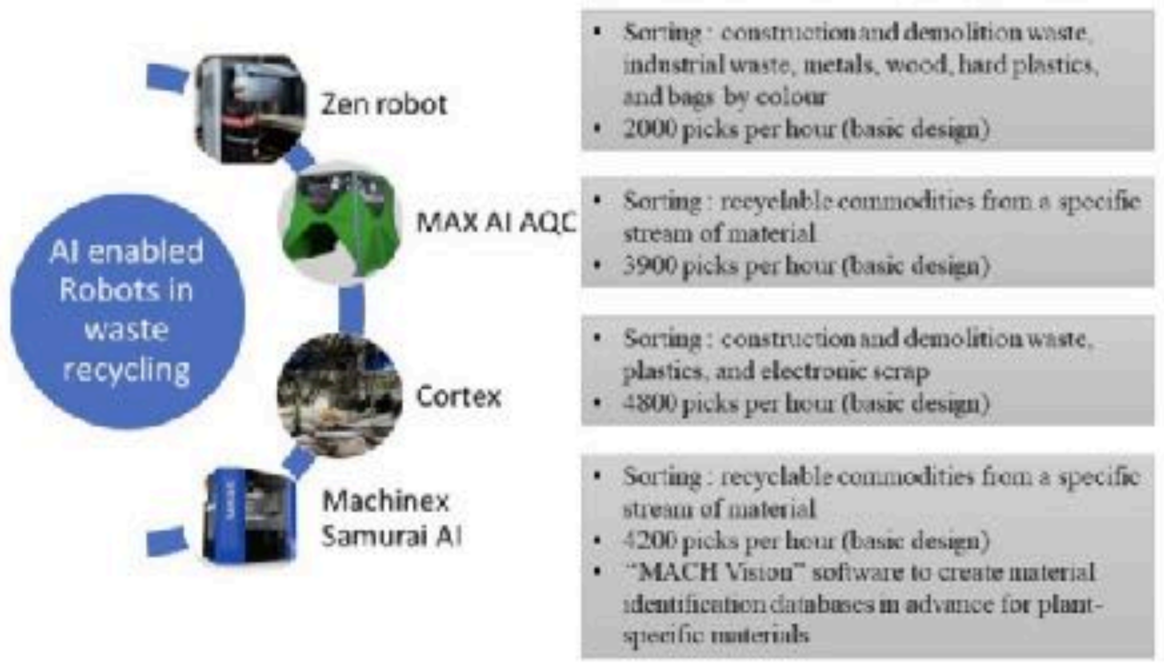


Fig. 1. Domains of AI, ML, DL and widely used algorithms.

Fig. 2. Application AREAS of AI in building and construction industry 4.0.



1. Introduction
2. ML/DL algorithms and data acquisition
3. Methodology
4. Architectural design and visualisation
5. Material design and optimisation
6. Structural analysis and design
7. Offsite manufacturing and automation
8. Construction management, progress and safety
9. Smart building operation and health monitoring
10. Sustainability, life cycle analysis and circularity
11. Future trends
12. Conclusions



- Sorting : construction and demolition waste, industrial waste, metals, wood, hard plastics, and bags by colour
- 2000 picks per hour (basic design)

- Sorting : recyclable commodities from a specific stream of material
- 3900 picks per hour (basic design)

- Sorting : construction and demolition waste, plastics, and electronic scrap
- 4800 picks per hour (basic design)

- Sorting : recyclable commodities from a specific stream of material
- 4200 picks per hour (basic design)
- "MACH Vision" software to create material identification databases in advance for plant-specific materials

Fig. 20. Commercial solutions for automated waste sorting.

GAN

Building and Environment
Volume 223, September 2022, 109477

Generative Adversarial Networks in the built environment: A comprehensive review of the application of GANs across data types and scales

Abraham Noah Wu, Rudi Stouffs, Filip Biljecki

https://doi.org/10.1016/j.buildenv.2022.109477

Abstract

Generative Adversarial Networks (GANs) are a type of deep neural network that have achieved many state-of-the-art results for generative tasks. GANs can be useful in the built environment, from processing large-scale urban mobility data and remote sensing images at the regional level, to performance analysis and design generation at the building level. We analyzed 100 articles to provide a comprehensive state-of-the-art review on how GANs are currently applied to solve challenging tasks in the built

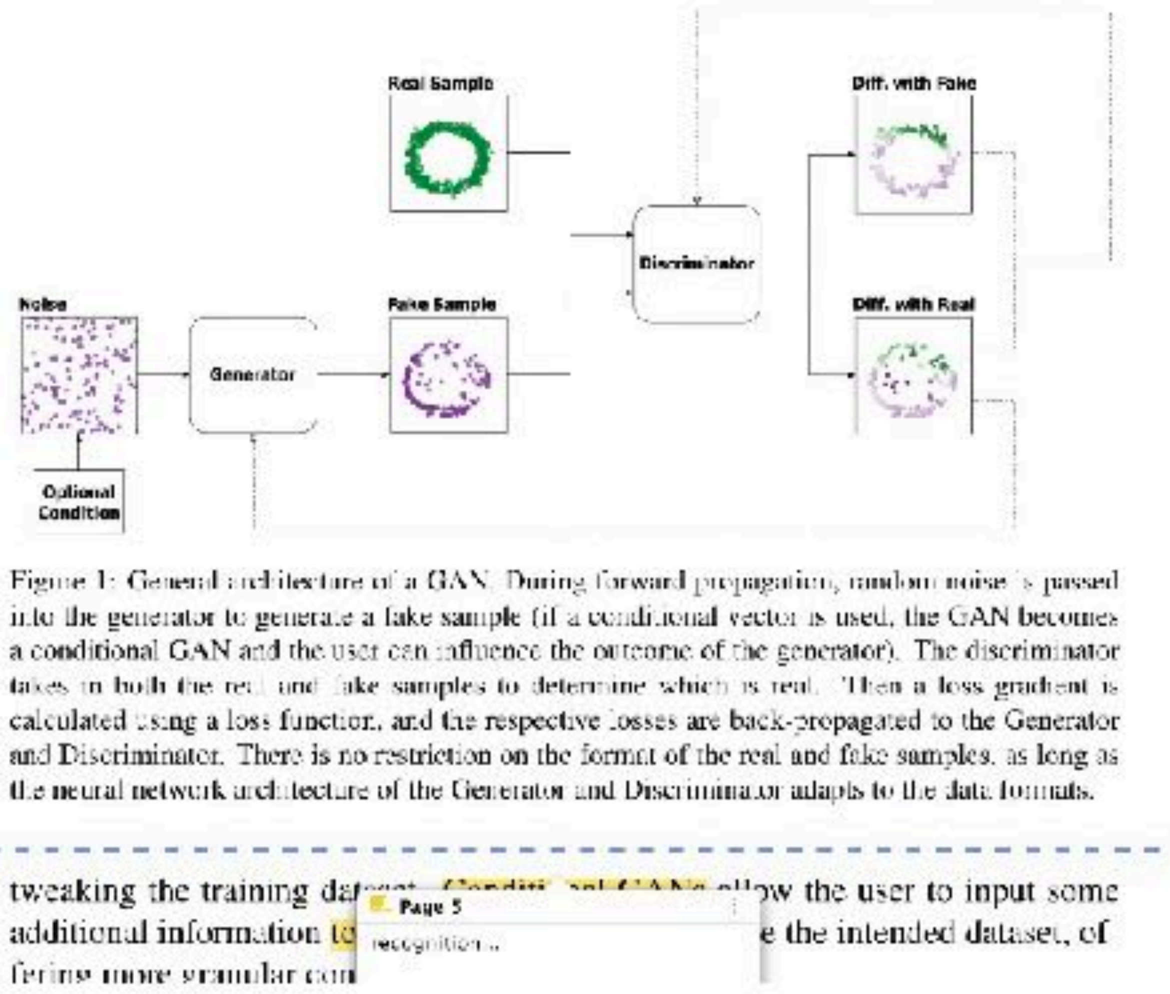
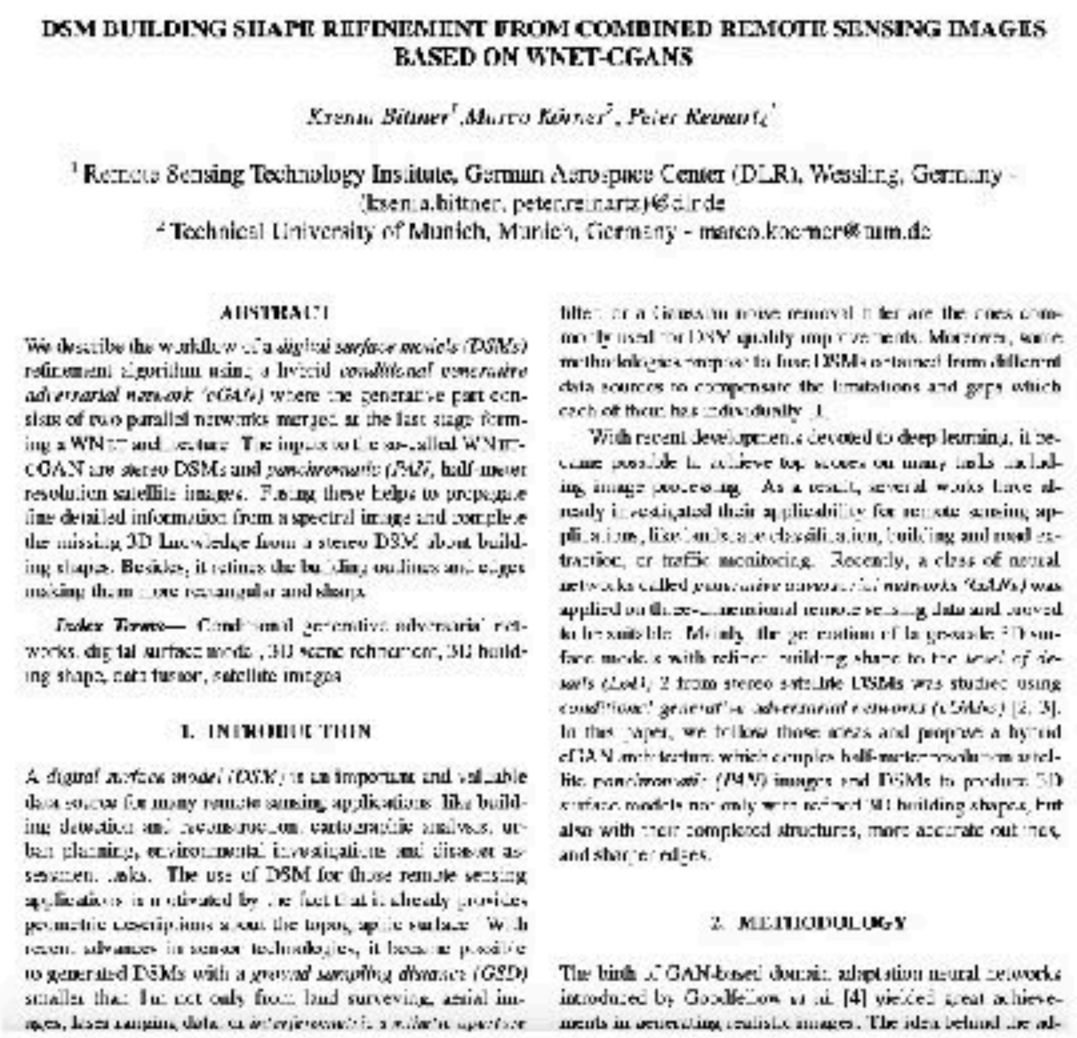


Figure 1: General architecture of a GAN. During forward propagation, random noise is passed into the generator to generate a fake sample (if a conditional vector is used, the GAN becomes a conditional GAN and the user can influence the outcome of the generator). The discriminator takes in both the real and fake samples to determine which is real. Then a loss gradient is calculated using a loss function, and the respective losses are back-propagated to the Generator and Discriminator. There is no restriction on the format of the real and fake samples, as long as the neural network architecture of the Generator and Discriminator adapts to the data formats.

tweaking the training dat... allow the user to input some additional information t... e the intended dataset, of fering more granular con

Digital Surface Model



DSM BUILDING SHAPE REFINEMENT FROM COMBINED REMOTE SENSING IMAGES BASED ON WNET-CGANS

Ksenia Bittner[1], Marco Körner[2], Peter Reinartz[1]

[1] Remote Sensing Technology Institute, German Aerospace Center (DLR), Wessling, Germany - (ksenia.bittner, peter.reinartz)@dlr.de
[2] Technical University of Munich, Munich, Germany - marco.koerner@tum.de

ABSTRACT

1. INTRODUCTION

2. METHODOLOGY

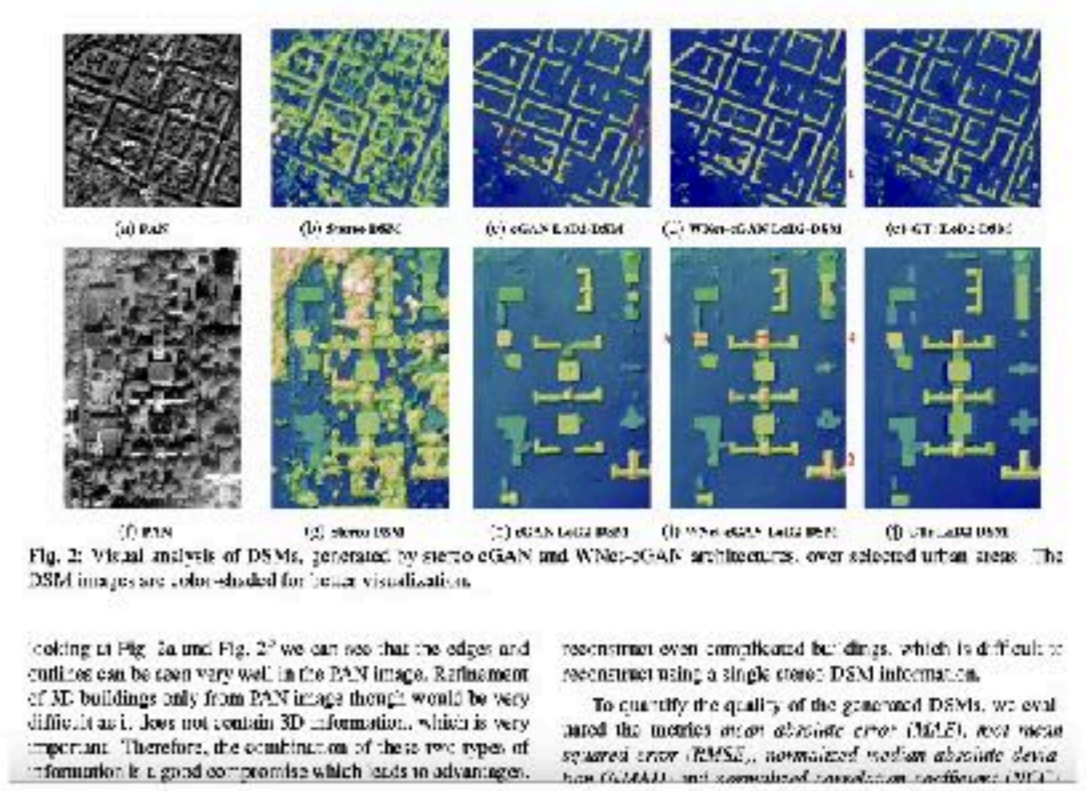
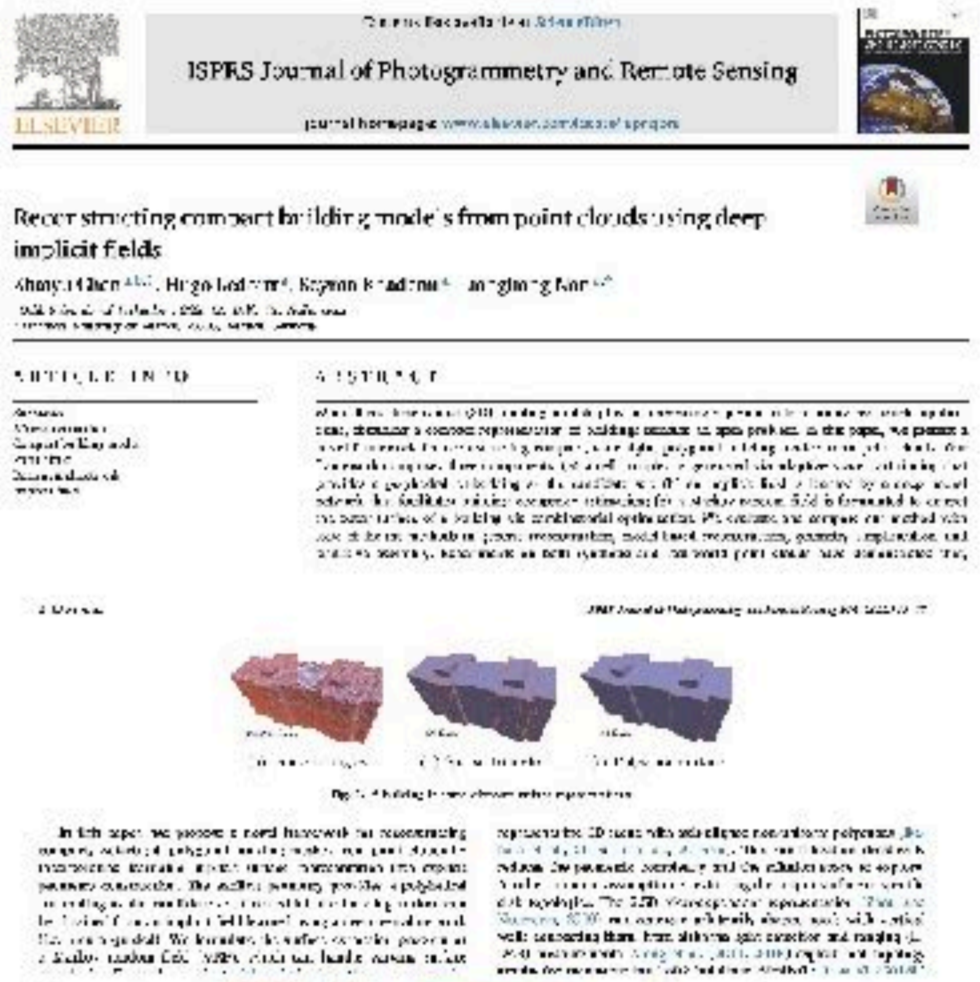


Fig. 2: Visual analysis of DSMs, generated by stereo cGAN and WNet-cGAN architectures, over selected urban areas. The DSM images are color-shaded for better visualization.

Point2Poly

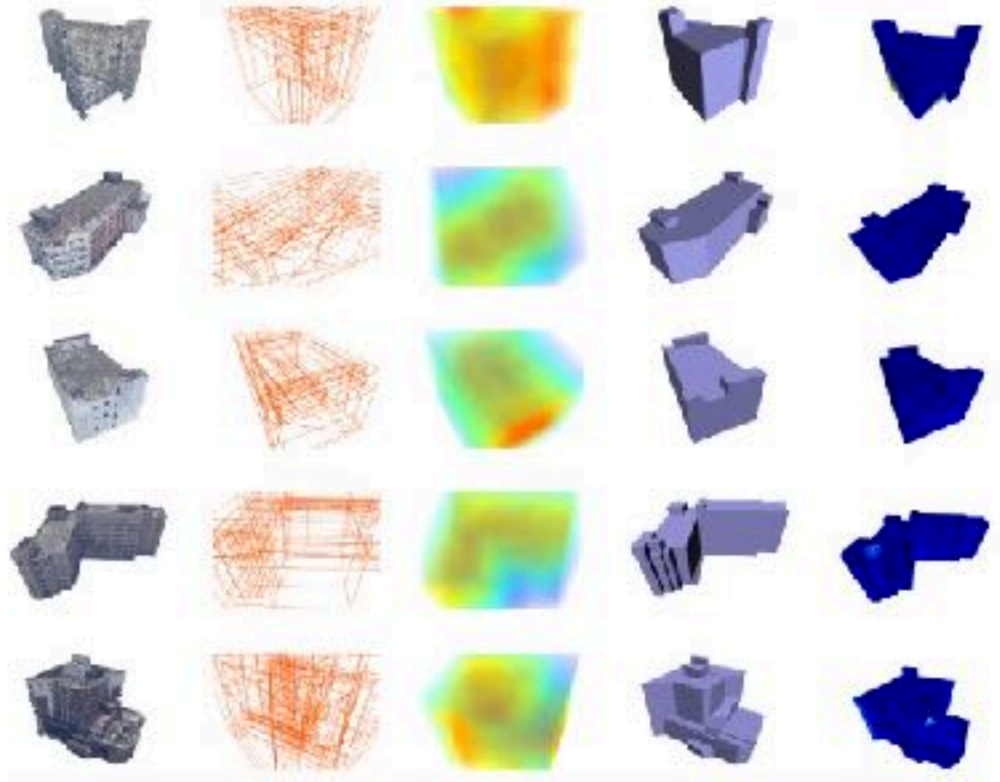


ISPRS Journal of Photogrammetry and Remote Sensing

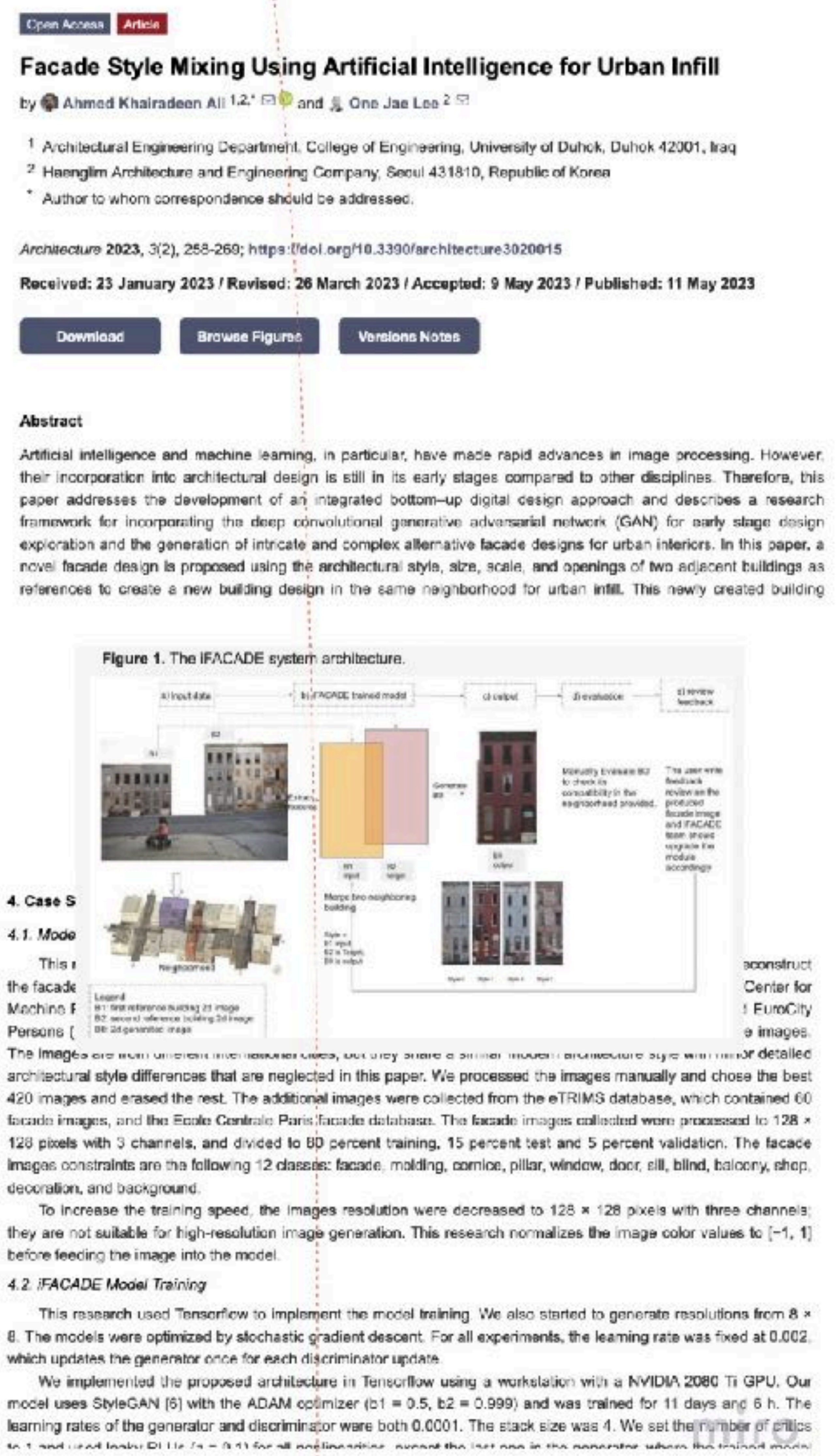
Reconstructing compact building models from point clouds using deep implicit fields

ARTICLE INFO

ABSTRACT



iFACADE



Facade Style Mixing Using Artificial Intelligence for Urban Infill

by Ahmed Khairadeen Ali 1,2,* and One Jae Lee 2

1 Architectural Engineering Department, College of Engineering, University of Duhok, Duhok 42001, Iraq
2 Haenglim Architecture and Engineering Company, Seoul 431810, Republic of Korea
* Author to whom correspondence should be addressed.

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Received: 23 January 2023 / Revised: 26 March 2023 / Accepted: 9 May 2023 / Published: 11 May 2023

Abstract

Artificial intelligence and machine learning, in particular, have made rapid advances in image processing. However, their incorporation into architectural design is still in its early stages compared to other disciplines. Therefore, this paper addresses the development of an integrated bottom–up digital design approach and describes a research framework for incorporating the deep convolutional generative adversarial network (GAN) for early stage design exploration and the generation of intricate and complex alternative facade designs for urban interiors. In this paper, a novel facade design is proposed using the architectural style, size, scale, and openings of two adjacent buildings as references to create a new building design in the same neighborhood for urban infill. This newly created building

Figure 1. The IFACADE system architecture.

Legend
B1: first reference building 2d image
B2: second reference building 2d image
B3: 2d generated image

4. Case S

4.1. Mode

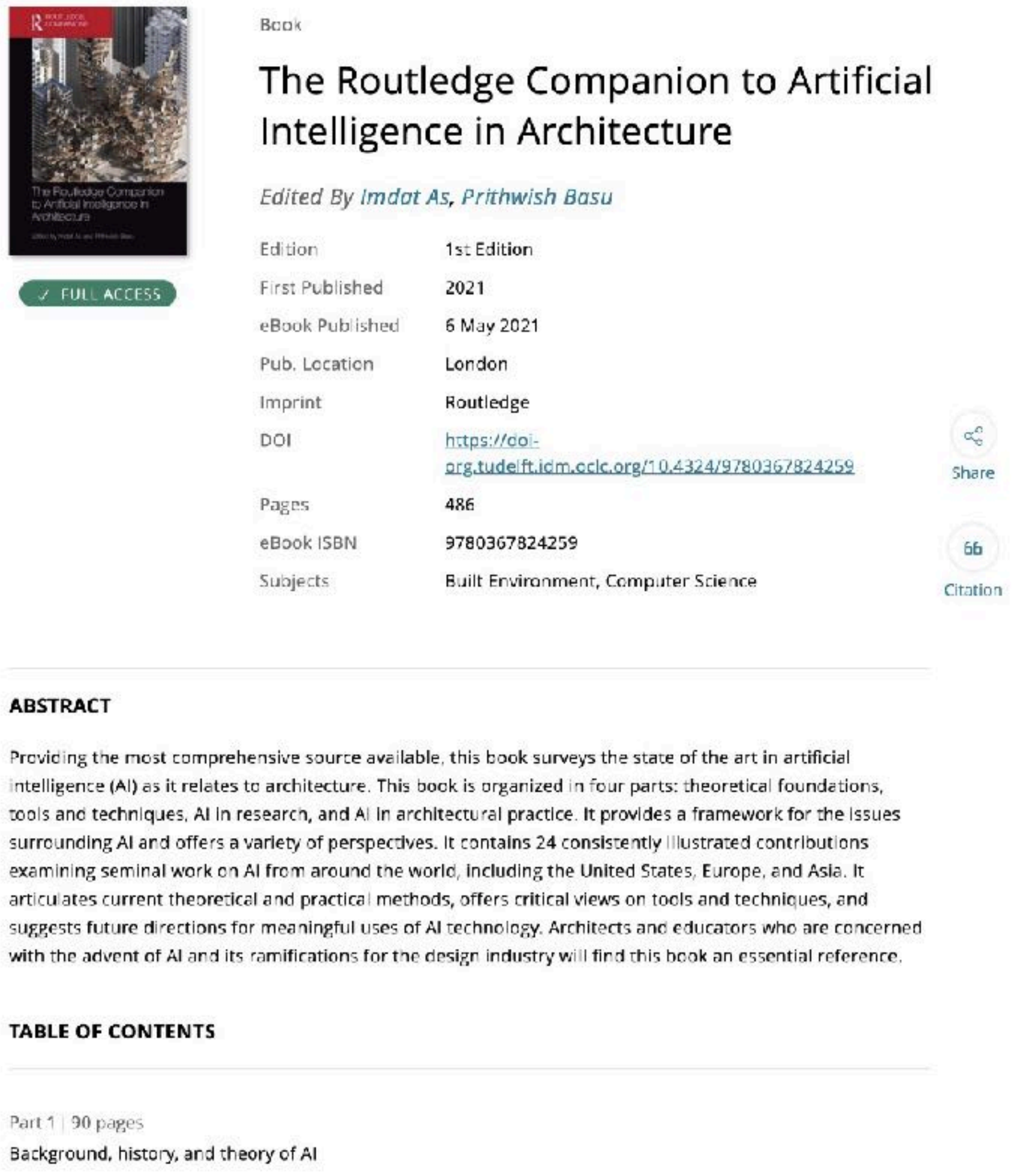
This r... econstruct the facade... Center for Machine P... EuroCity Persons (... e images. The images are from different international cities, but they share a similar modern architecture style with minor detailed architectural style differences that are neglected in this paper. We processed the images manually and chose the best 420 images and erased the rest. The additional images were collected from the eTRIMS database, which contained 60 facade images, and the Ecole Centrale Paris facade database. The facade images collected were processed to 128 × 128 pixels with 3 channels, and divided to 80 percent training, 15 percent test and 5 percent validation. The facade images constraints are the following 12 classes: facade, molding, cornice, pillar, window, door, sill, blind, balcony, shop, decoration, and background.

To increase the training speed, the images resolution were decreased to 128 × 128 pixels with three channels; they are not suitable for high-resolution image generation. This research normalizes the image color values to [−1, 1] before feeding the image into the model.

4.2. IFACADE Model Training

This research used Tensorflow to implement the model training. We also started to generate resolutions from 8 × 8. The models were optimized by stochastic gradient descent. For all experiments, the learning rate was fixed at 0.002, which updates the generator once for each discriminator update.

We implemented the proposed architecture in Tensorflow using a workstation with a NVIDIA 2080 Ti GPU. Our model uses StyleGAN [6] with the ADAM optimizer (b1 = 0.5, b2 = 0.999) and was trained for 11 days and 6 h. The learning rates of the generator and discriminator were both 0.0001. The stack size was 4. We set the number of critics



Book

The Routledge Companion to Artificial Intelligence in Architecture

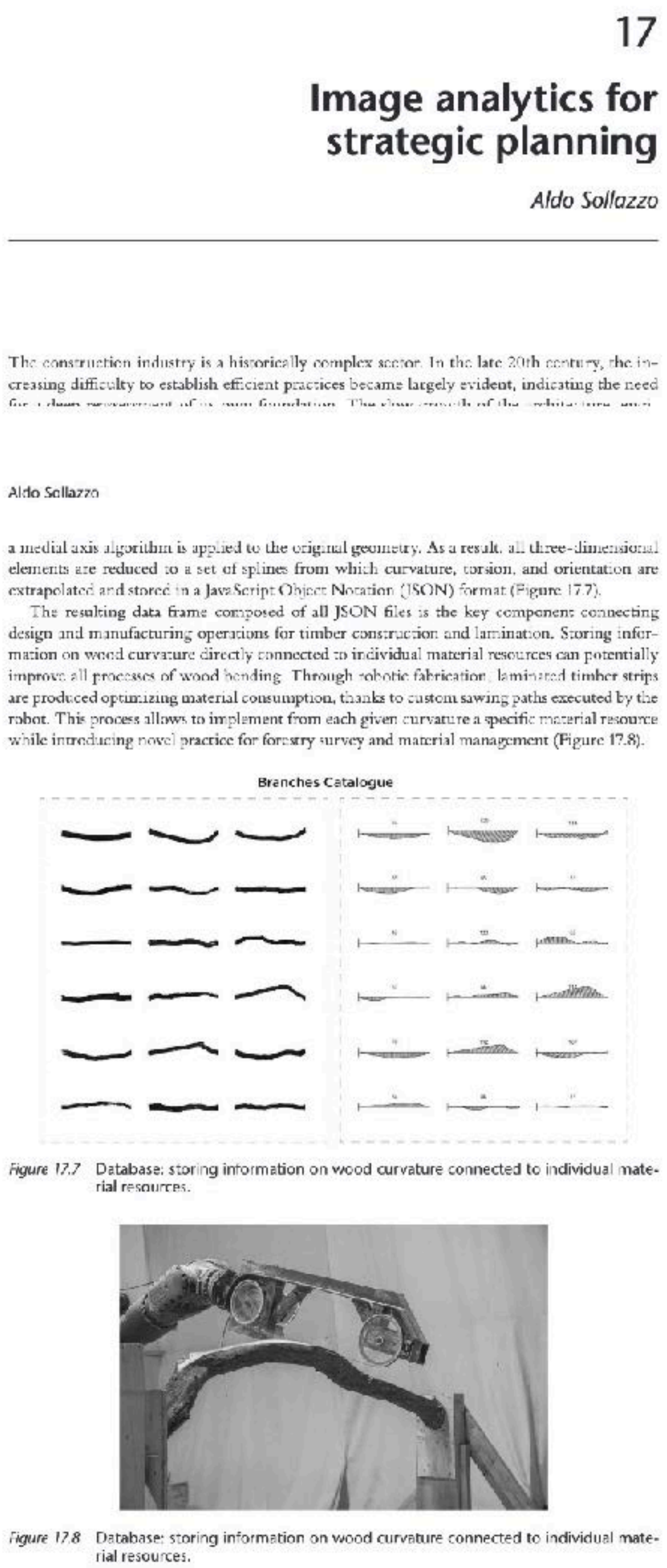
Edited By Imdat As, Prithwish Basu

Edition	1st Edition
First Published	2021
eBook Published	6 May 2021
Pub. Location	London
Imprint	Routledge
DOI	https://doi-org.tudelft.idm.oclc.org/10.4324/9780367824259
Pages	486
eBook ISBN	9780367824259
Subjects	Built Environment, Computer Science

ABSTRACT

Providing the most comprehensive source available, this book surveys the state of the art in artificial intelligence (AI) as it relates to architecture. This book is organized in four parts: theoretical foundations, tools and techniques, AI in research, and AI in architectural practice. It provides a framework for the issues surrounding AI and offers a variety of perspectives. It contains 24 consistently illustrated contributions examining seminal work on AI from around the world, including the United States, Europe, and Asia. It articulates current theoretical and practical methods, offers critical views on tools and techniques, and suggests future directions for meaningful uses of AI technology. Architects and educators who are concerned with the advent of AI and its ramifications for the design industry will find this book an essential reference.

TABLE OF CONTENTS



17

Image analytics for strategic planning

Aldo Sollazzo

The construction industry is a historically complex sector. In the late 20th century, the increasing difficulty to establish efficient practices became largely evident, indicating the need

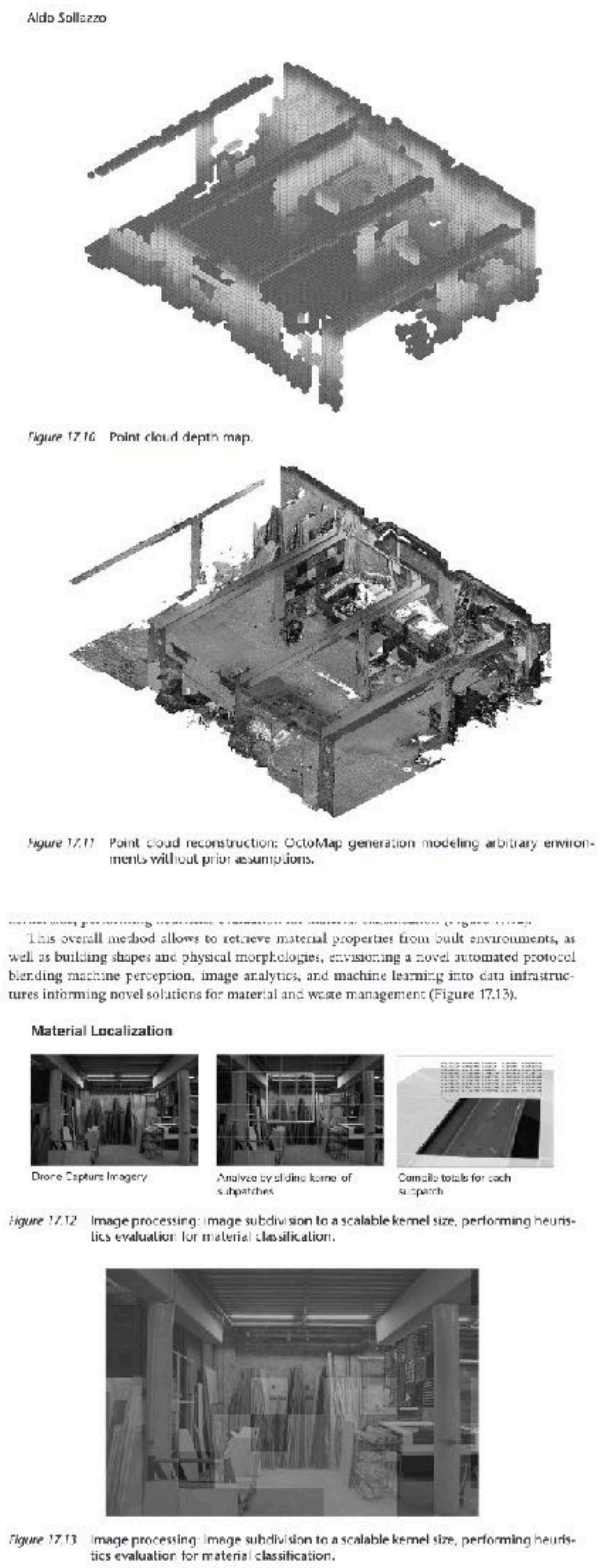
Aldo Sollazzo

a medial axis algorithm is applied to the original geometry. As a result, all three-dimensional elements are reduced to a set of splines from which curvature, torsion, and orientation are extrapolated and stored in a JavaScript Object Notation (JSON) format (Figure 17.7).

The resulting data frame composed of all JSON files is the key component connecting design and manufacturing operations for timber construction and lamination. Storing information on wood curvature directly connected to individual material resources can potentially improve all processes of wood bending. Through robotic fabrication, laminated timber strips are produced optimizing material consumption, thanks to custom sawing paths executed by the robot. This process allows to implement from each given curvature a specific material resource while introducing novel practice for forestry survey and material management (Figure 17.8).

Figure 17.7 Database: storing information on wood curvature connected to individual material resources.

Figure 17.8 Database: storing information on wood curvature connected to individual material resources.



Aldo Sollazzo

Figure 17.10 Point cloud depth map.

Figure 17.11 Point cloud reconstruction: OctoMap generation modeling arbitrary environments without prior assumptions.

This overall method allows to retrieve material properties from built environments, as well as building shapes and physical morphologies, envisioning a novel automated protocol blending machine perception, image analytics, and machine learning into data infrastructures informing novel solutions for material and waste management (Figure 17.13).

Figure 17.12 Image processing: image subdivision to a scalable kernel size, performing heuristics evaluation for material classification.

Figure 17.13 Image processing: image subdivision to a scalable kernel size, performing heuristics evaluation for material classification.

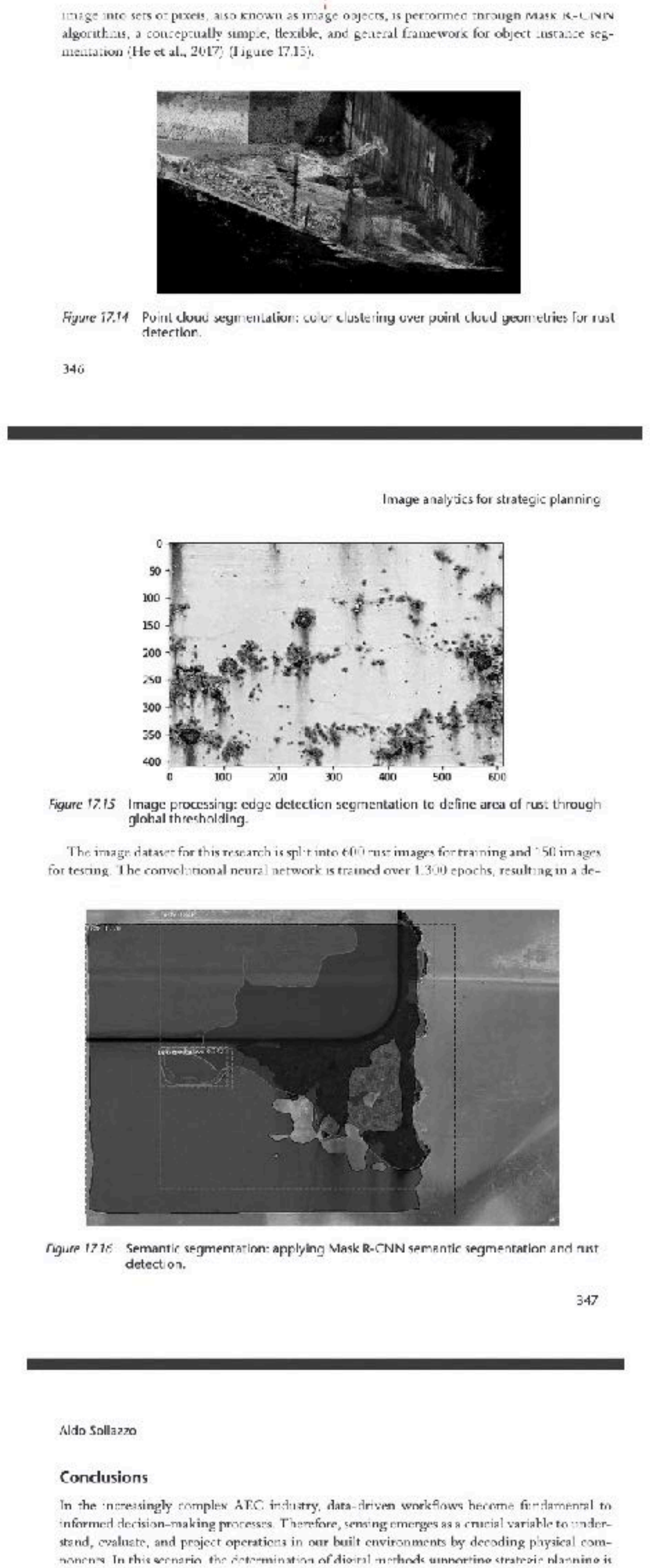


image into sets of pixels, also known as image objects, is performed through Mask R-CNN algorithms, a conceptually simple, flexible, and general framework for object instance segmentation (He et al., 2017) (Figure 17.15).

Figure 17.14 Point cloud segmentation: color clustering over point cloud geometries for rust detection.

346

Image analytics for strategic planning

Figure 17.15 Image processing: edge detection segmentation to define area of rust through global thresholding.

The image dataset for this research is split into 600 rust images for training and 150 images for testing. The convolutional neural network is trained over 1,300 epochs, resulting in a de-

Figure 17.16 Semantic segmentation: applying Mask R-CNN semantic segmentation and rust detection.

347

Aldo Sollazzo

Conclusions

In the increasingly complex AEC industry, data-driven workflows become fundamental to informed decision-making processes. Therefore, sensing emerges as a crucial variable to understand, evaluate, and project operations in our built environments by decoding physical components. In this scenario, the determination of digital methods supporting strategic planning is

Automating forestry survey for timber construction

Digitizing material collation from demolition sites

Autonomous inspection system for building maintenance

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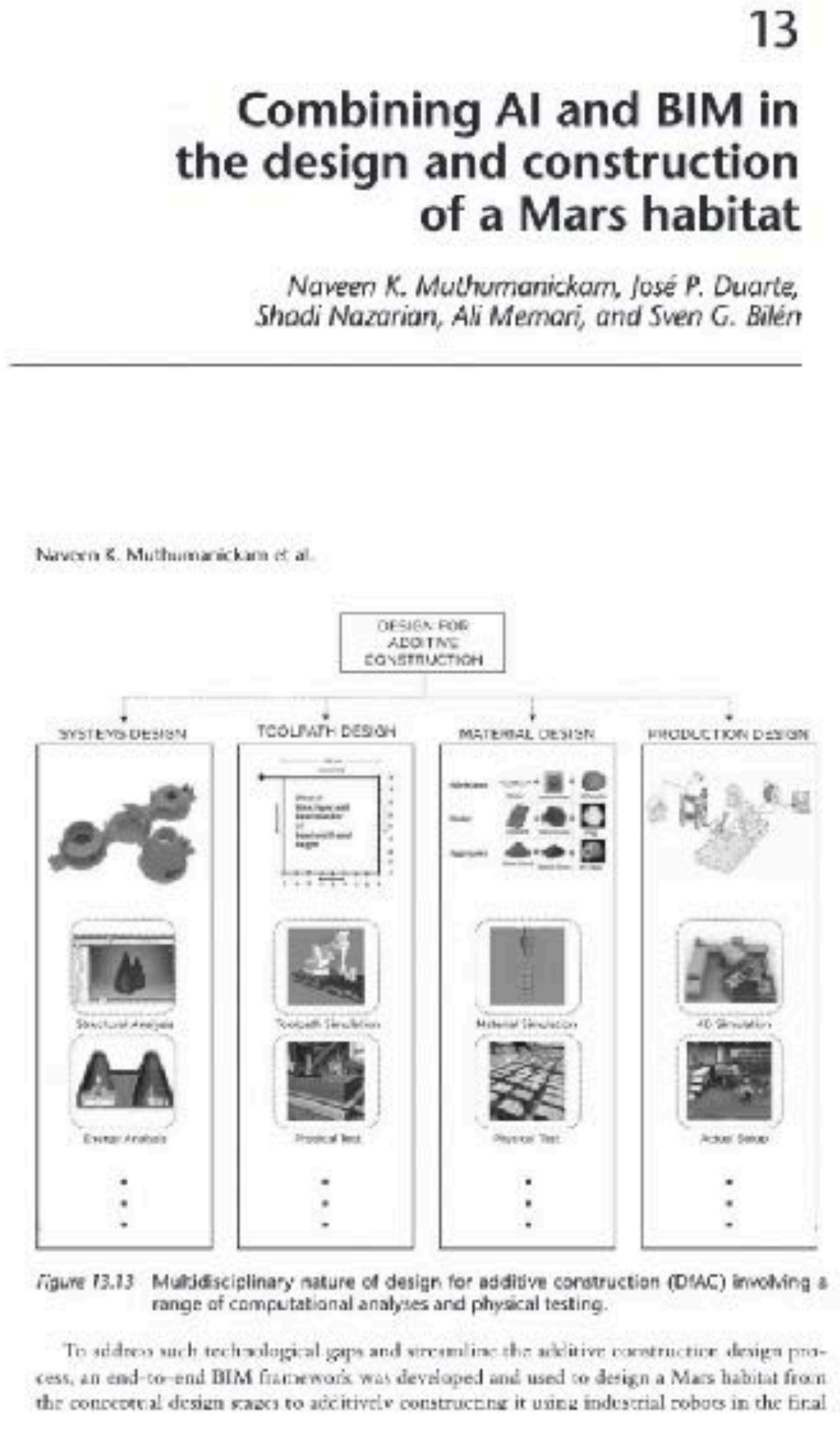


13

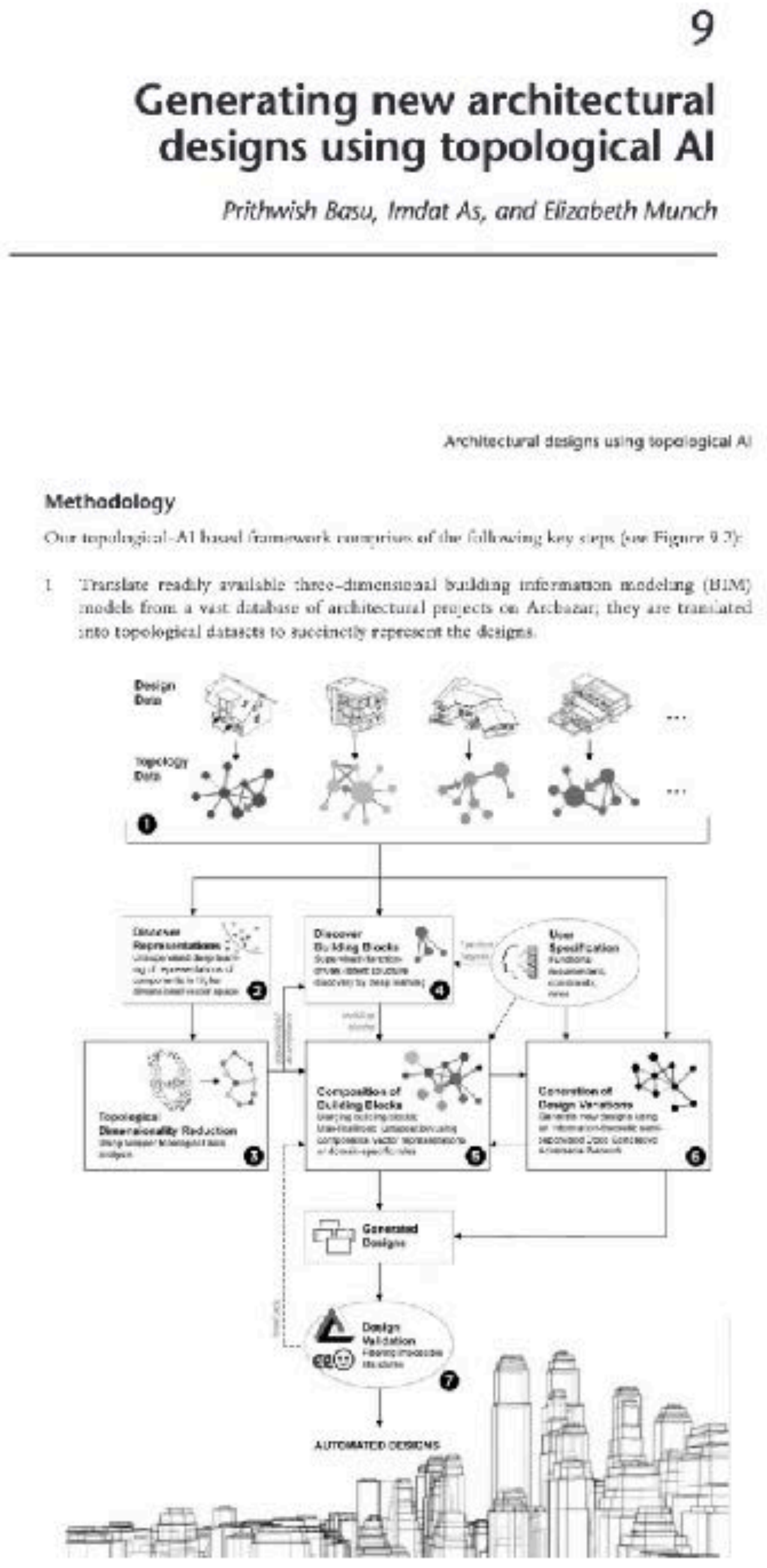
Combining AI and BIM in the design and construction of a Mars habitat

Naveen K. Muthumanickam, José P. Duarte,
Shadi Nazarian, Ali Memari, and Sven G. Bilén

Figure 13.13 Multidisciplinary nature of design for additive construction (DfAC) involving a range of computational analyses and physical testing.

To address such technological gaps and streamline the additive construction design process, an end-to-end BIM framework was developed and used to design a Mars habitat from the conceptual design stages to additively constructing it using industrial robots in the final

C



9

Generating new architectural designs using topological AI

Prithwish Basu, Imdat As, and Elizabeth Munch

Methodology

Our topological-AI based framework comprises of the following key steps (see Figure 9.2):

1 Translate readily available three-dimensional building information modeling (BIM) models from a vast database of architectural projects on Arcbazar; they are translated into topological datasets to succinctly represent the designs.

ROTUNDORO. A web-based decision support tool for building refurbishment.

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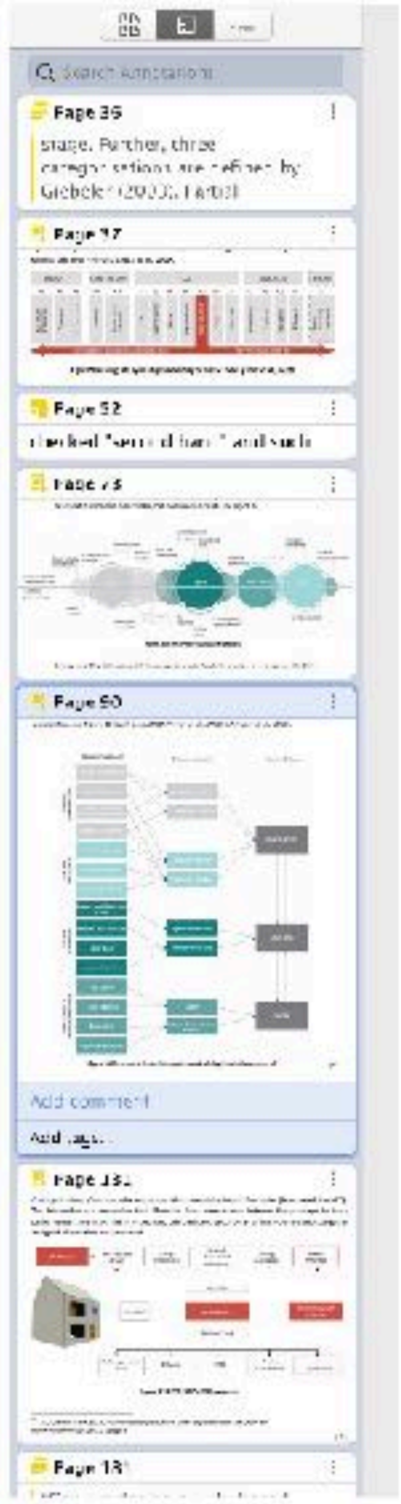
Abstract

When refurbishing residential buildings, insulation materials play a crucial role in improving housing quality and energy efficiency. Materials however differ in a wide set of criteria. It reaches beyond the thermal properties and addresses environmental, economic, health and safety characteristics. In ~~collective decision-making, it remains difficult to find trade-offs between these criteria.~~ This thesis introduces a web-based tool ROTUNDORO [Latin: circular] that offers an algorithm to assess refurbishing insulation materials, considering engineering evaluation methods and consumer preferences. The tool employs and expands on Building Information Modelling (BIM) practice on the one side and behavioural economic research on the other side. First, the Linked Building Data (LBD) method is used to link material performance to building components and to evaluate them with Life Cycle Assessment (LCA) and cost analysis. Applied to a Dutch terrace house (Rijwoning) as a use case, the tool shows that bio-based materials perform best in environmental concerns, low embodied carbon, high noise and humidity reduction. Fossil- and mineral-based materials are yet market-leading, due to low price and easier application techniques in existing constructions (cavity injection). Following the hard data comparison, the tool simulates the probability of acceptance by the homeowners of



Page 36

stage. Further, three categorisations are defined by Giebeler (2008, Table)

Page 37

Page 52

checked "second hand" and such

Page 73

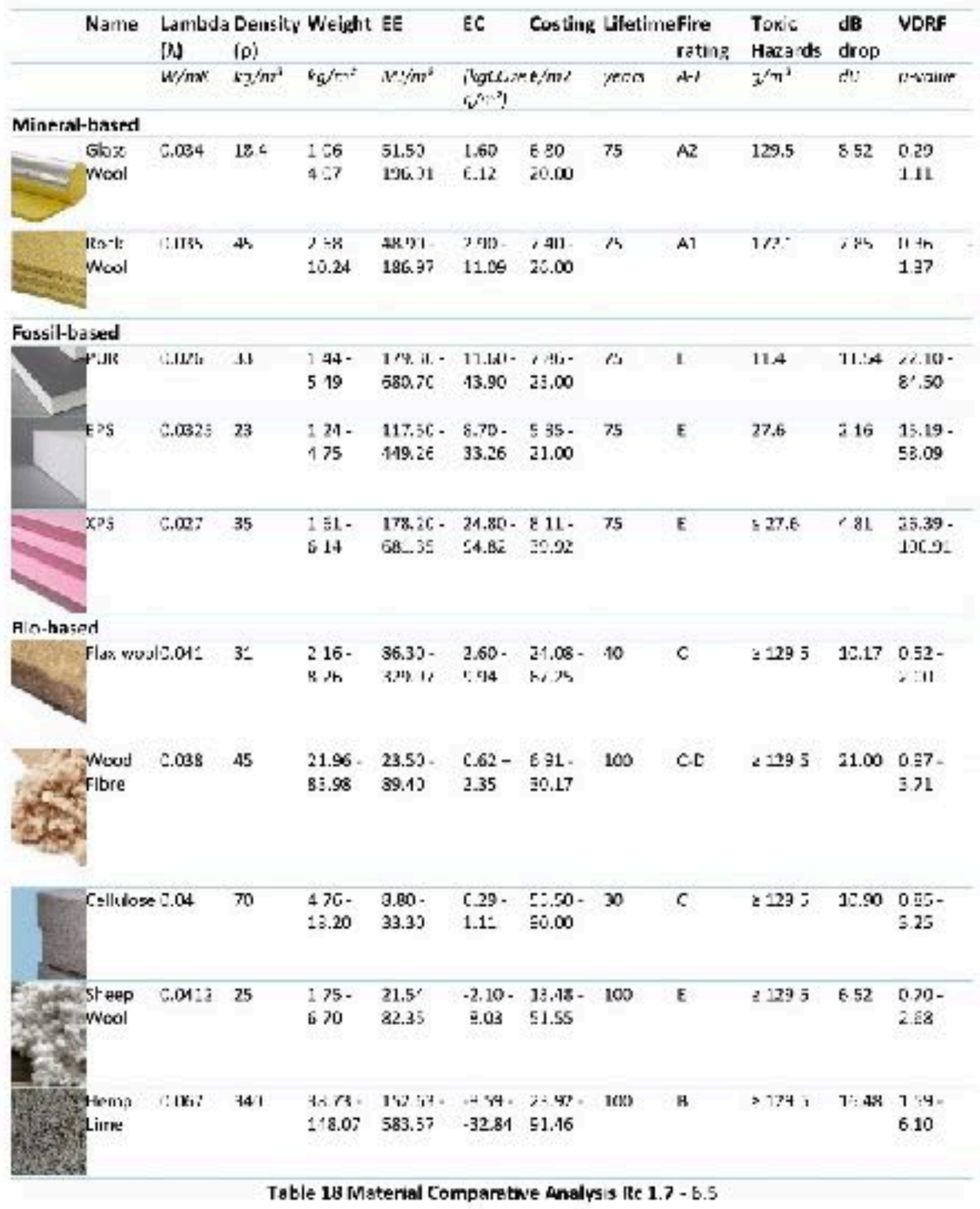
Page 90

Add comment

Add tags...

Page 131

Page 13



Name	Lambda (λ)	Density (ρ)	Weight	EE	EC	Costing	Lifetime	Fire rating	Toxic Hazards	dB drop	VDRF
	W/mK	*kg/m³*	*kg/m²*	*MJ/m²*	*(kgCO₂eq/m²)*	*€/m2*	*years*	*A-F*	*g/m³*	*dB*	*U-value*
Mineral-based											
Glass Wool	0.034	18.4	1.06 - 4.07	51.50 - 196.91	1.60 - 6.12	6.80 - 20.00	75	A2	129.5	8.52	0.29 - 1.11
Rock Wool	0.035	45	2.58 - 10.24	48.91 - 186.97	2.90 - 11.09	7.40 - 20.00	75	A1	172.[illegible]	7.85	0.46 - 1.37
Fossil-based											
PUR	0.026	33	1.44 - 5.19	179.[illegible] - 680.70	11.10 - 43.90	7.76 - 23.00	75	E	11.4	11.54	22.10 - 87.50
EPS	0.0325	23	1.24 - 4.75	117.50 - 449.26	8.70 - 33.26	5.35 - 21.00	75	E	27.6	3.16	15.19 - 58.09
XPS	0.027	35	1.61 - 6.14	178.20 - 681.35	24.80 - 54.82	8.11 - 30.92	75	E	≥ 27.6	4.81	26.39 - 100.91
Bio-based											
Flax wool	0.041	32	2.16 - 8.26	86.30 - 329.17	2.60 - 9.94	21.08 - 67.25	40	C	≥ 129.5	10.17	0.52 - 2.01
Wood Fibre	0.038	45	21.96 - 83.98	23.50 - 89.40	0.62 – 2.35	6.91 - 30.17	100	C-D	≥ 129.5	21.00	0.97 - 3.71
Cellulose	0.04	70	4.70 - 13.20	8.80 - 33.30	0.29 - 1.11	50.50 - 60.00	30	C	≥ 129.5	10.90	0.85 - 3.25
Sheep Wool	0.0413	25	1.75 - 6.70	21.54 - 82.35	-2.10 - 8.03	13.48 - 51.55	100	E	≥ 129.5	6.52	0.70 - 2.68
Hemp Lime	0.067	340	38.73 - 148.07	152.59 - 583.57	-8.59 - -32.84	23.92 - 91.46	100	B	≥ 129.5	15.48	1.59 - 6.10

Table 18 Material Comparative Analysis Rc 1.7 - 6.5

Page 1

It remains difficult to find trade-offs between these criteria.

Stating difficulties, problem, a different angle - perspective

Page 26

Current data exchanges between these tools lack a consistent translation scheme to make them

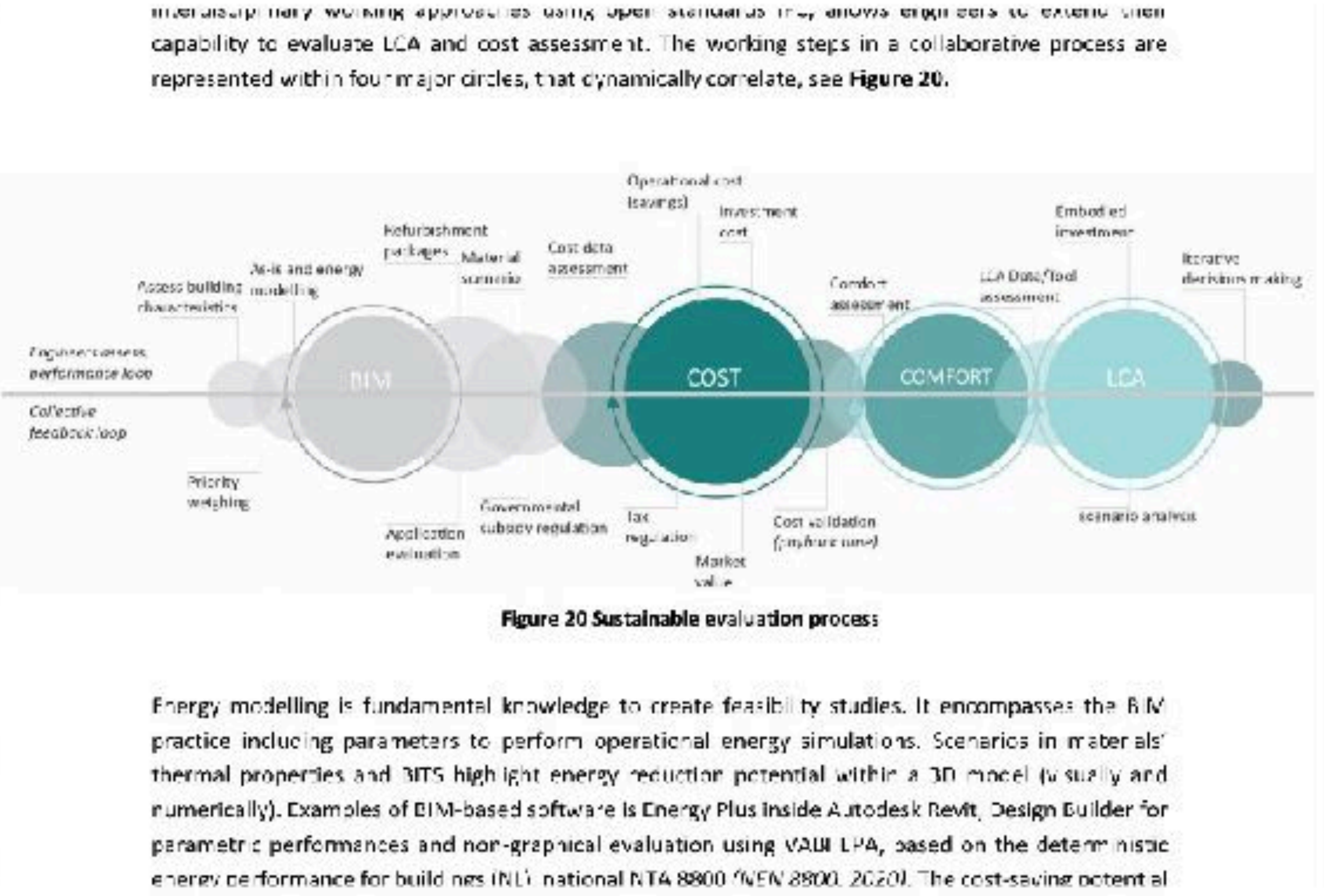
Page 26

with a one decision-support tool is scarce in practice

Page 33

2.1 Dutch refurbishment strategy

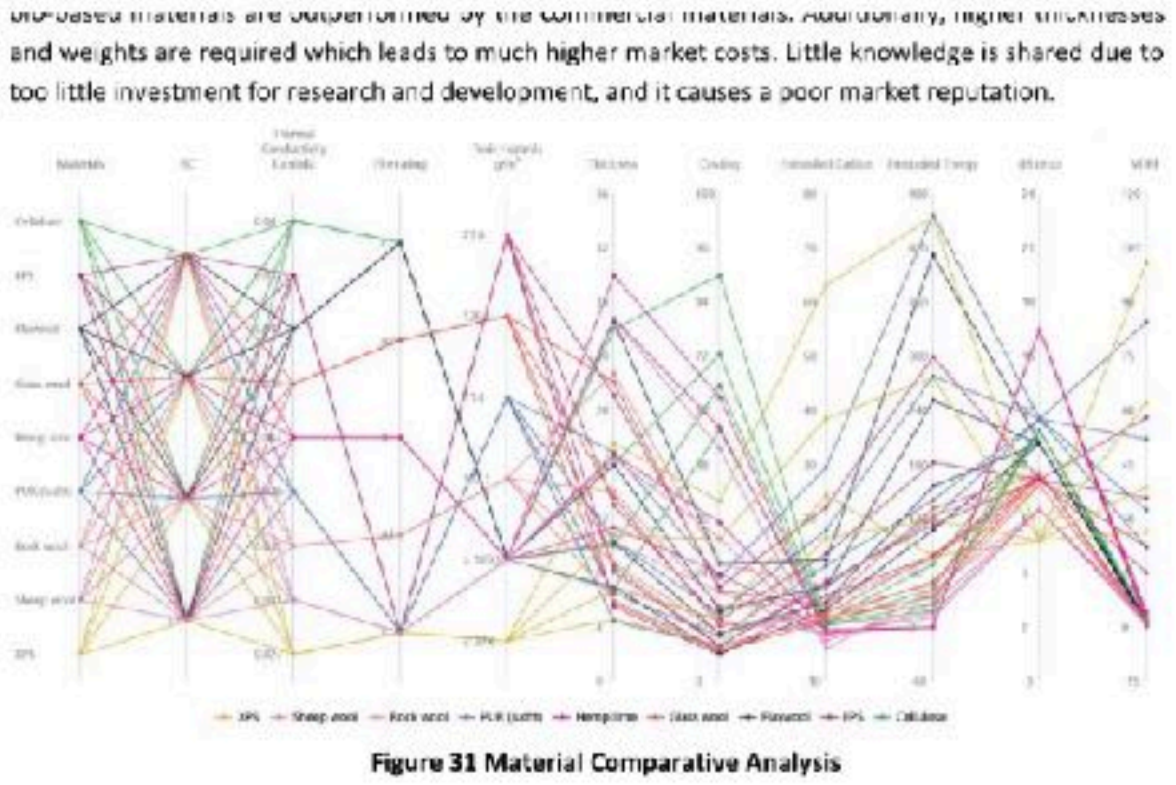
Page 36



capability to evaluate LCA and cost assessment. The working steps in a collaborative process are represented within four major circles, that dynamically correlate, see **Figure 20**.

Figure 20 Sustainable evaluation process

Energy modelling is fundamental knowledge to create feasibility studies. It encompasses the BIM practice including parameters to perform operational energy simulations. Scenarios in materials' thermal properties and BITS highlight energy reduction potential within a 3D model (visually and numerically). Examples of BIM-based software is Energy Plus inside Autodesk Revit, Design Builder for parametric performances and non-graphical evaluation using VABI EPA, based on the deterministic energy performance for buildings (NL) national NTA 8800 (NEN 8800, 2020). The cost-saving potential



and weights are required which leads to much higher market costs. Little knowledge is shared due to too little investment for research and development, and it causes a poor market reputation.

Figure 31 Material Comparative Analysis

Resources, Conservation & Recycling 129 (2018) 175–186

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Full Length Article

Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator

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ABSTRACT

The aim of this study is to develop a BIM based Whole-life Performance Estimator (BWPE
salvage performance of structural components of buildings right from the design stage. A
literature was carried out to identify factors that influence salvage performance of struct
buildings during their useful life. Thereafter, a mathematical modelling approach was adopt
using the identified factors and principle/concept of Weibull reliability distribution for mar
The model was implemented in Building Information Modelling (BIM) environment and it w
study design. Accordingly, the whole-life salvage performance profiles of the case study build

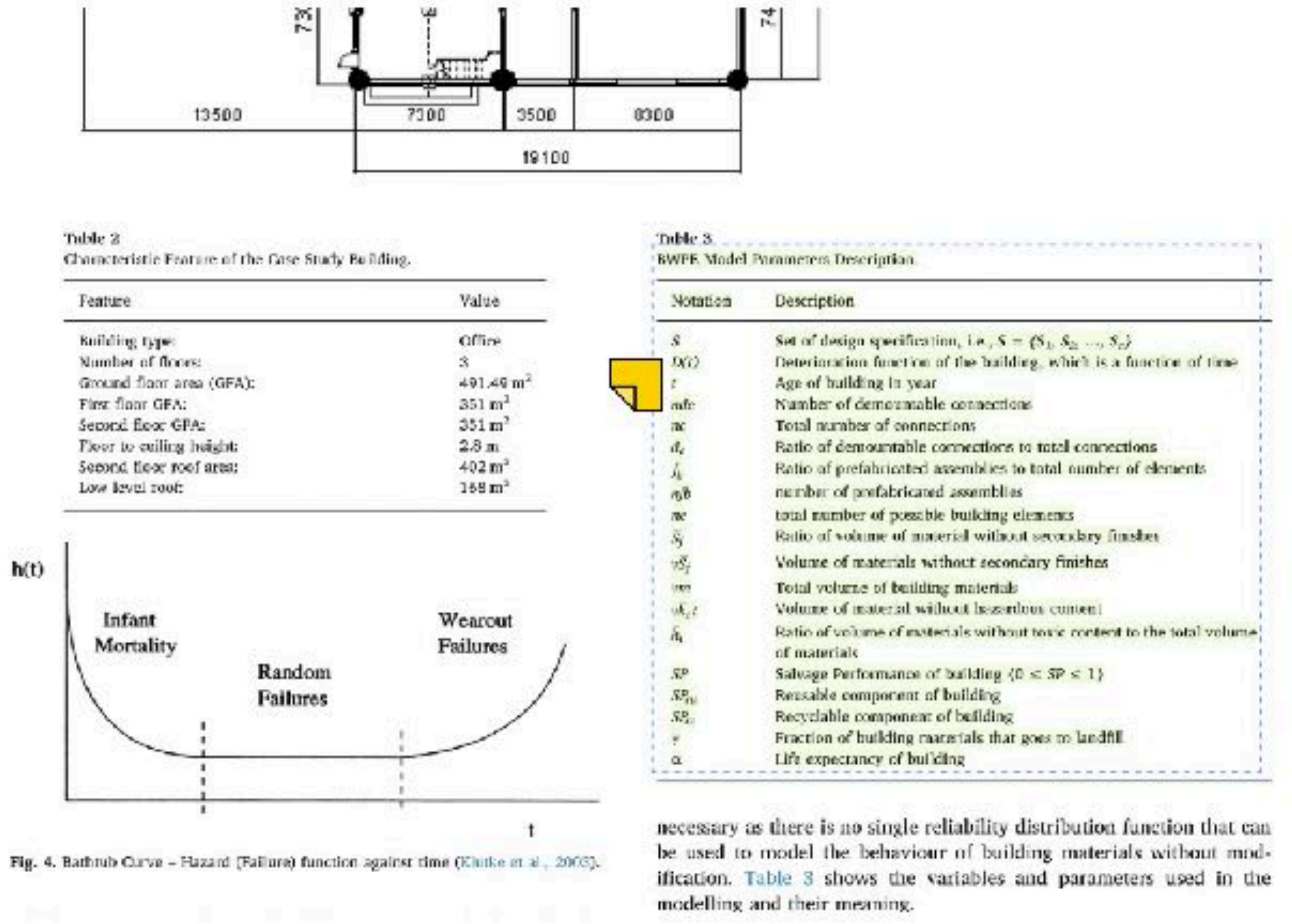


Table 2
Characteristic Feature of the Case Study Building.

Feature	Value
Building type:	Office
Number of floors:	3
Ground floor area (GFA):	491.49 m^2
First floor GFA:	351 m^2
Second floor GFA:	351 m^2
Floor to ceiling height:	2.8 m
Second floor roof area:	402 m^2
Low level roof:	168 m^2

Fig. 4. Bathtub Curve – Hazard (Failure) function against time (Klutke et al., 2003).

Table 3
BWPE Model Parameters Description.

Notation	Description
S	Set of design specification, i.e., $S = \{S_1, S_2, ..., S_n\}$
$D(t)$	Deterioration function of the building, which is a function of time
t	Age of building in year
ndc	Number of demountable connections
nc	Total number of connections
d_c	Ratio of demountable connections to total connections
f_k	Ratio of prefabricated assemblies to total number of elements
n_{pb}	number of prefabricated assemblies
ne	total number of possible building elements
$\bar{S}_j$	Ratio of volume of material without secondary finishes
$v\bar{S}_j$	Volume of materials without secondary finishes
vm	Total volume of building materials
$vk_c t$	Volume of material without hazardous content
$\bar{h}_k$	Ratio of volume of materials without toxic content to the total volume of materials
SP	Salvage Performance of building $(0 \le SP \le 1)$
SP_{ru}	Reusable component of building
SP_{rc}	Recyclable component of building
γ	Fraction of building materials that goes to landfill
α	Life expectancy of building

necessary as there is no single reliability distribution function that can be used to model the behaviour of building materials without modification. Table 3 shows the variables and parameters used in the modelling and their meaning.

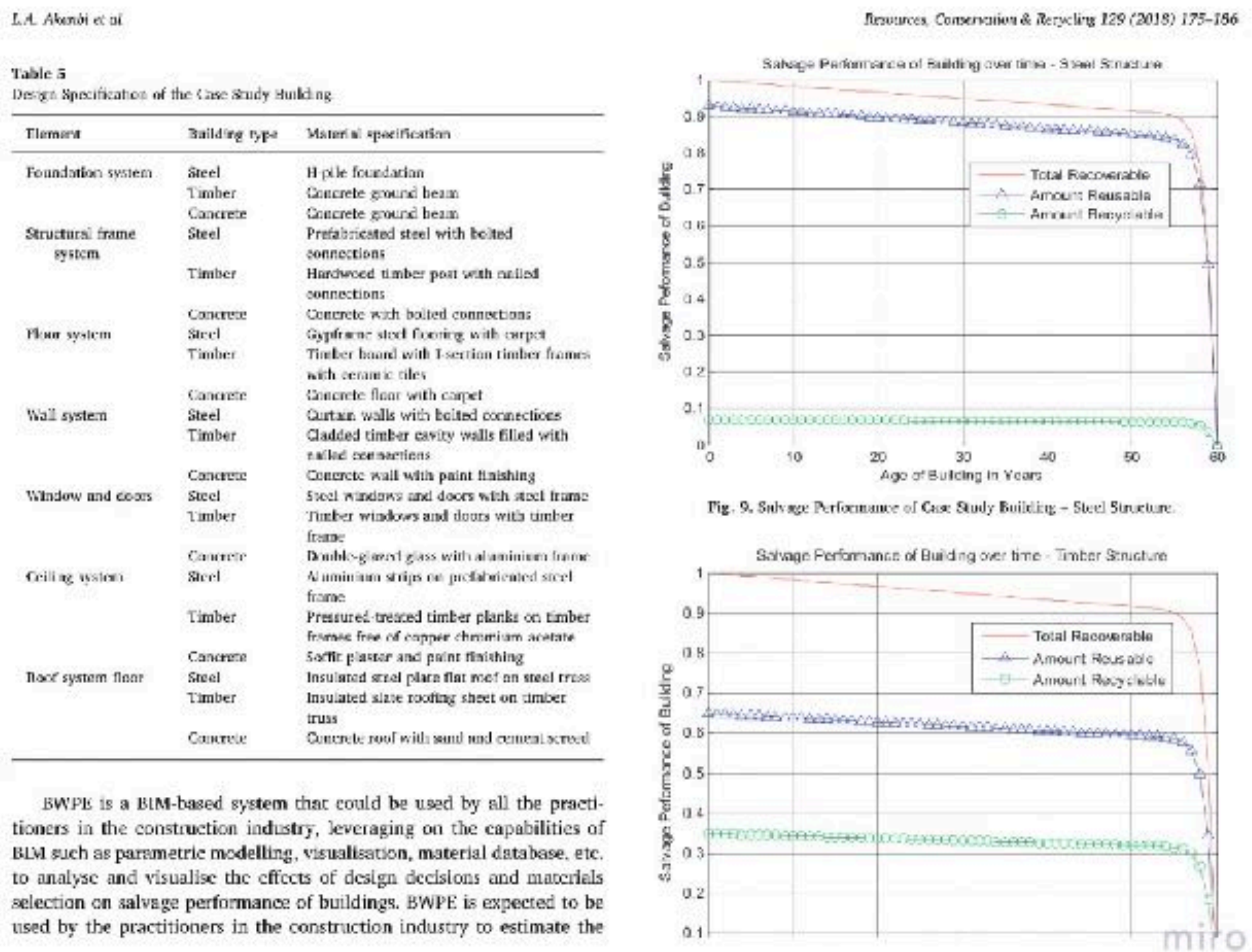


Table 5
Design Specification of the Case Study Building

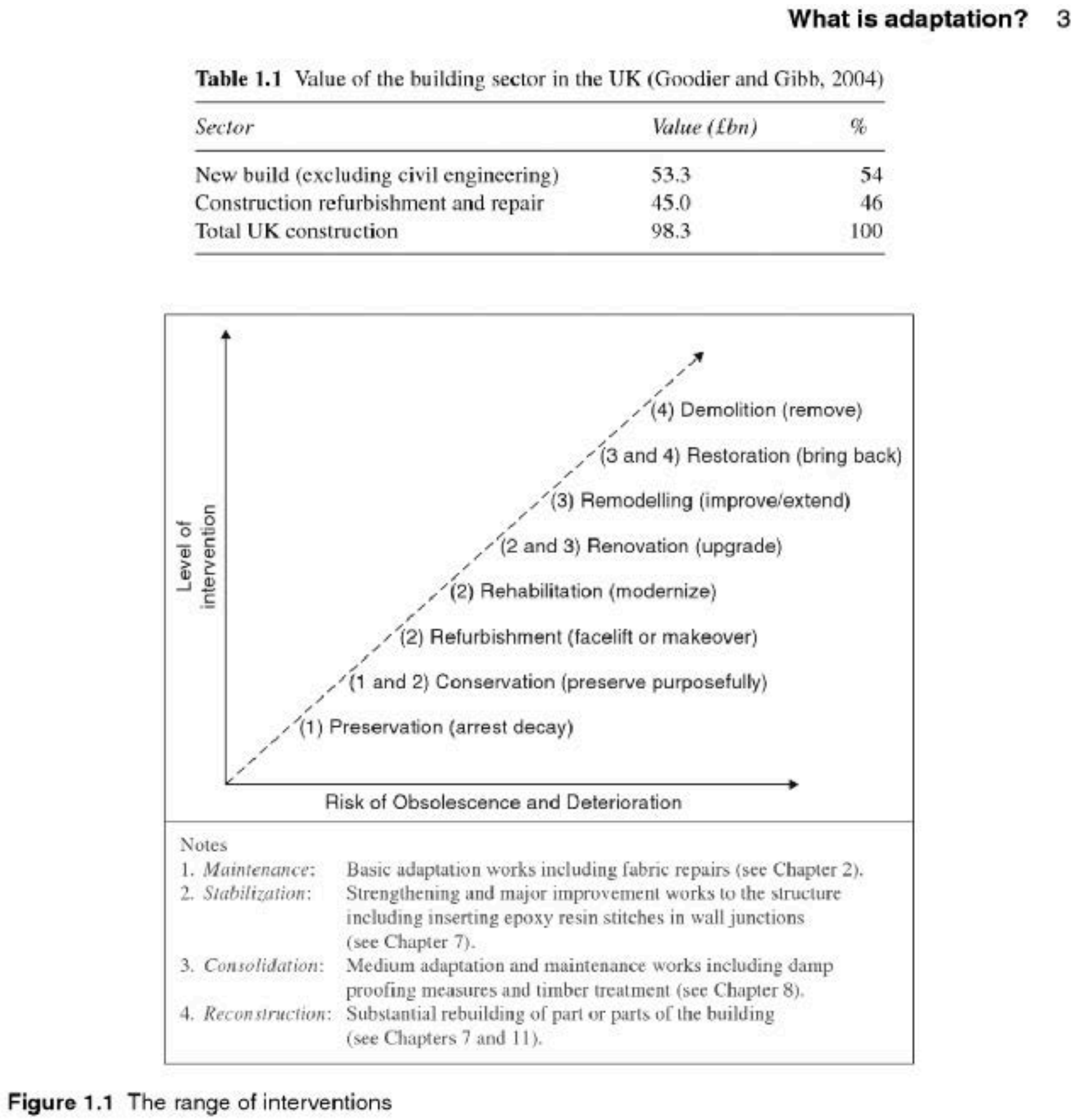
Element	Building type	Material specification
Foundation system	Steel	H-pile foundation
	Timber	Concrete ground beam
	Concrete	Concrete ground beam
Structural frame system	Steel	Prefabricated steel with bolted connections
	Timber	Hardwood timber post with nailed connections
	Concrete	Concrete with bolted connections
Floor system	Steel	Gypframe steel flooring with carpet
	Timber	Timber board with I-section timber frames with ceramic tiles
	Concrete	Concrete floor with carpet
Wall system	Steel	Curtain walls with bolted connections
	Timber	Cladded timber cavity walls filled with nailed connections
	Concrete	Concrete wall with paint finishing
Window and doors	Steel	Steel windows and doors with steel frame
	Timber	Timber windows and doors with timber frame
	Concrete	Double-glazed glass with aluminium frame
Ceiling system	Steel	Aluminium strips on prefabricated steel frame
	Timber	Pressured-treated timber planks on timber frames free of copper chromium acetate
	Concrete	Soffit plaster and paint finishing
Roof system floor	Steel	Insulated steel plate flat roof on steel truss
	Timber	Insulated slate roofing sheet on timber truss
	Concrete	Concrete roof with sand and cement screed

BWPE is a BIM-based system that could be used by all the practitioners in the construction industry, leveraging on the capabilities of BIM such as parametric modelling, visualisation, material database, etc. to analyse and visualise the effects of design decisions and materials selection on salvage performance of buildings. BWPE is expected to be used by the practitioners in the construction industry to estimate the

Fig. 9. Salvage Performance of Case Study Building – Steel Structure.

Definition

- Building adaptation, John Douglas



What is adaptation? 3

Table 1.1 Value of the building sector in the UK (Goodier and Gibb, 2004)

Sector	*Value (£bn)*	%
New build (excluding civil engineering)	53.3	54
Construction refurbishment and repair	45.0	46
Total UK construction	98.3	100

Notes

1. *Maintenance*:	Basic adaptation works including fabric repairs (see Chapter 2).
2. *Stabilization*:	Strengthening and major improvement works to the structure including inserting epoxy resin stitches in wall junctions (see Chapter 7).
3. *Consolidation*:	Medium adaptation and maintenance works including damp proofing measures and timber treatment (see Chapter 8).
4. *Reconstruction*:	Substantial rebuilding of part or parts of the building (see Chapters 7 and 11).

Figure 1.1 The range of interventions

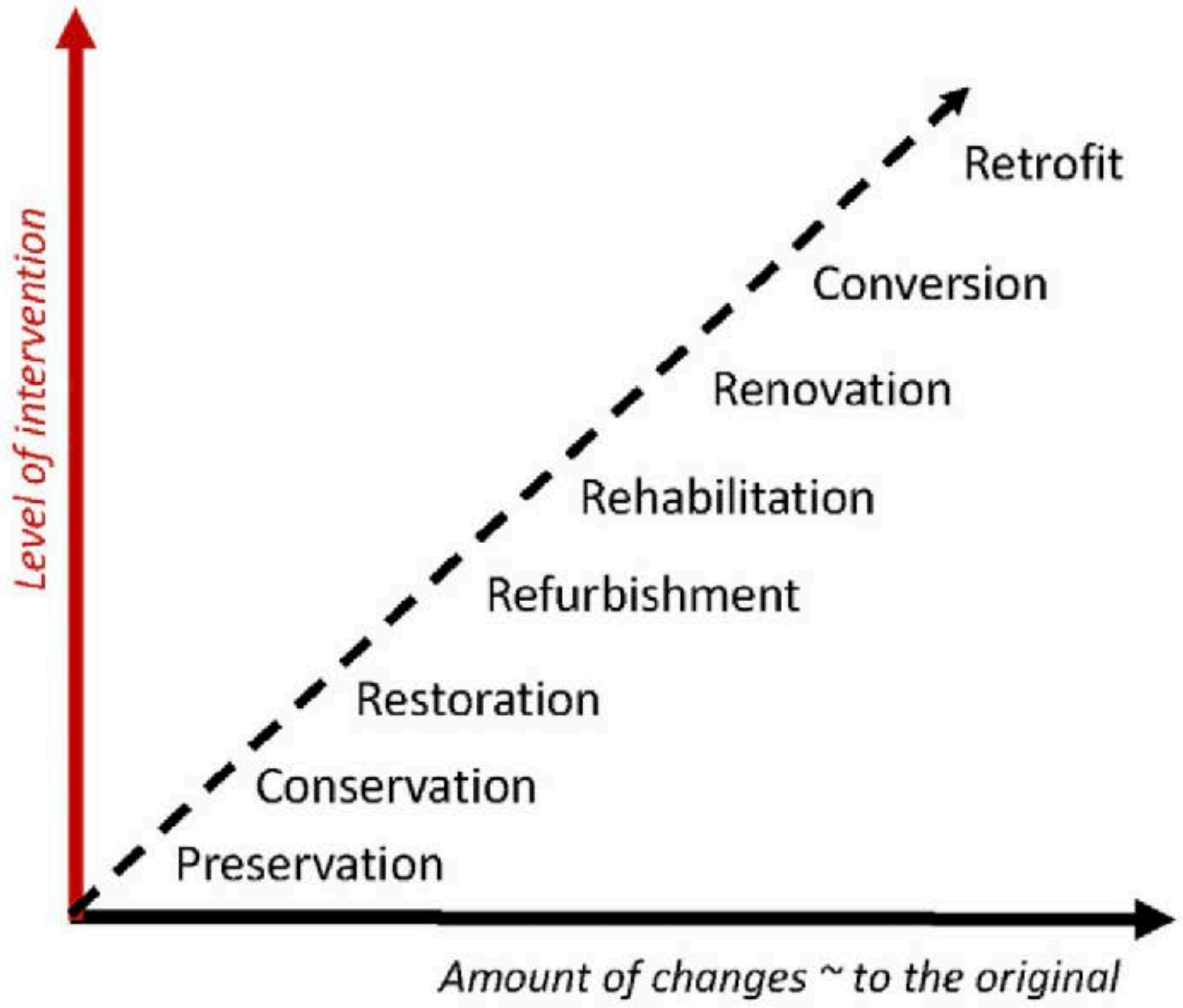
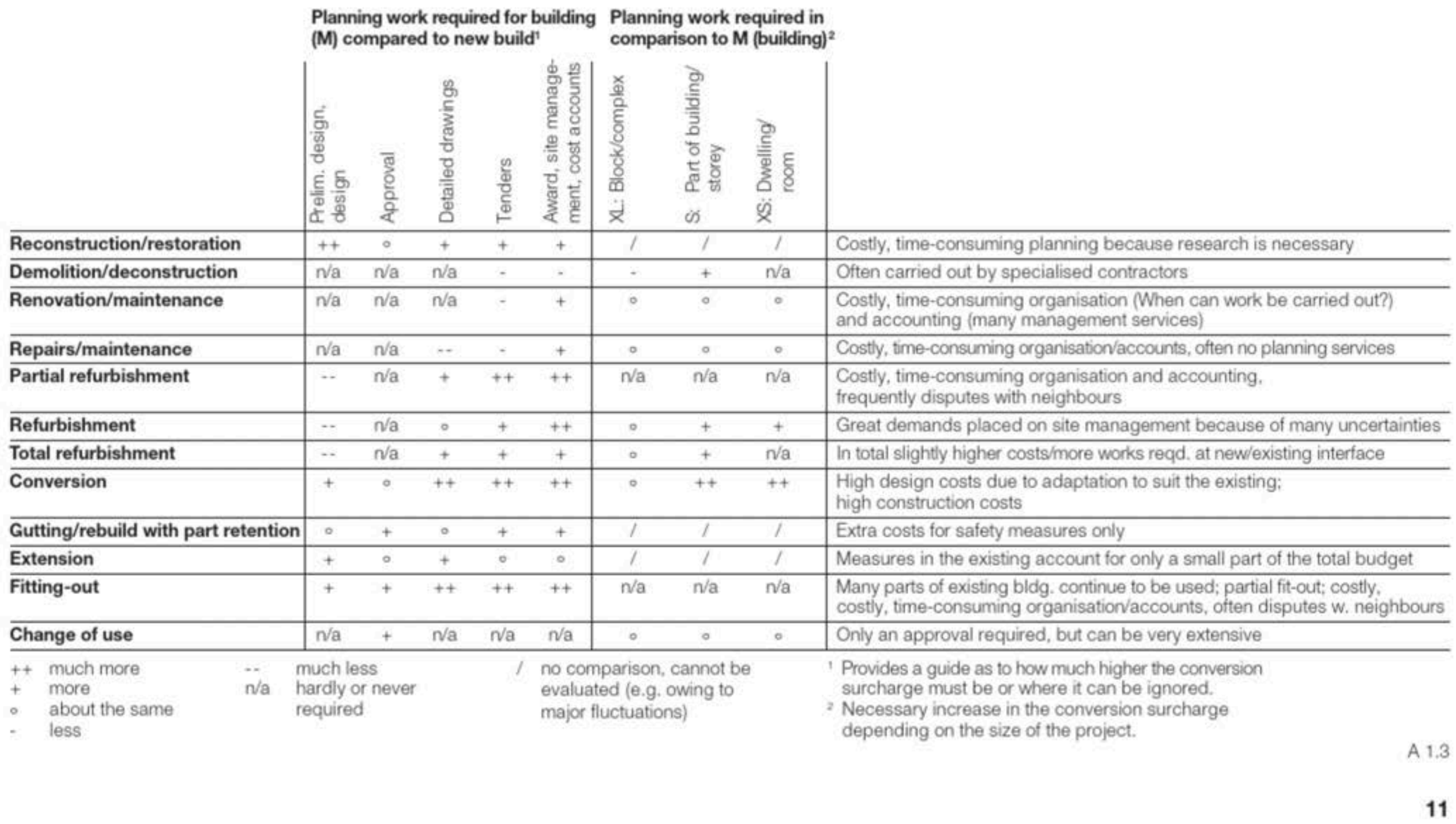


Fig. 1 **Overview of building interventions in the spectrum of adaptive reuse.**
Drawing: Els De Vos

Definition

Refurbish manual, Georg Giebeler



	Planning work required for building (M) compared to new build[1]					Planning work required in comparison to M (building)[2]			
	Prelim. design, design	Approval	Detailed drawings	Tenders	Award, site management, cost accounts	XL: Block/complex	S: Part of building/ storey	XS: Dwelling/ room	
Reconstruction/restoration	++	∘	+	+	+	/	/	/	Costly, time-consuming planning because research is necessary
Demolition/deconstruction	n/a	n/a	n/a	-	-	-	+	n/a	Often carried out by specialised contractors
Renovation/maintenance	n/a	n/a	n/a	-	+	∘	∘	∘	Costly, time-consuming organisation (When can work be carried out?) and accounting (many management services)
Repairs/maintenance	n/a	n/a	--	-	+	∘	∘	∘	Costly, time-consuming organisation/accounts, often no planning services
Partial refurbishment	--	n/a	+	++	++	n/a	n/a	n/a	Costly, time-consuming organisation and accounting, frequently disputes with neighbours
Refurbishment	--	n/a	∘	+	++	∘	+	+	Great demands placed on site management because of many uncertainties
Total refurbishment	--	n/a	+	+	+	∘	+	n/a	In total slightly higher costs/more works reqd. at new/existing interface
Conversion	+	∘	++	++	++	∘	++	++	High design costs due to adaptation to suit the existing; high construction costs
Gutting/rebuild with part retention	∘	+	∘	+	+	/	/	/	Extra costs for safety measures only
Extension	+	∘	+	∘	∘	/	/	/	Measures in the existing account for only a small part of the total budget
Fitting-out	+	+	++	++	++	n/a	n/a	n/a	Many parts of existing bldg. continue to be used; partial fit-out; costly, costly, time-consuming organisation/accounts, often disputes w. neighbours
Change of use	n/a	+	n/a	n/a	n/a	∘	∘	∘	Only an approval required, but can be very extensive

++	much more	--	much less	/	no comparison, cannot be evaluated (e.g. owing to major fluctuations)
+	more	n/a	hardly or never required		
∘	about the same				
-	less				

[1] Provides a guide as to how much higher the conversion surcharge must be or where it can be ignored.

[2] Necessary increase in the conversion surcharge depending on the size of the project.

A 1.3

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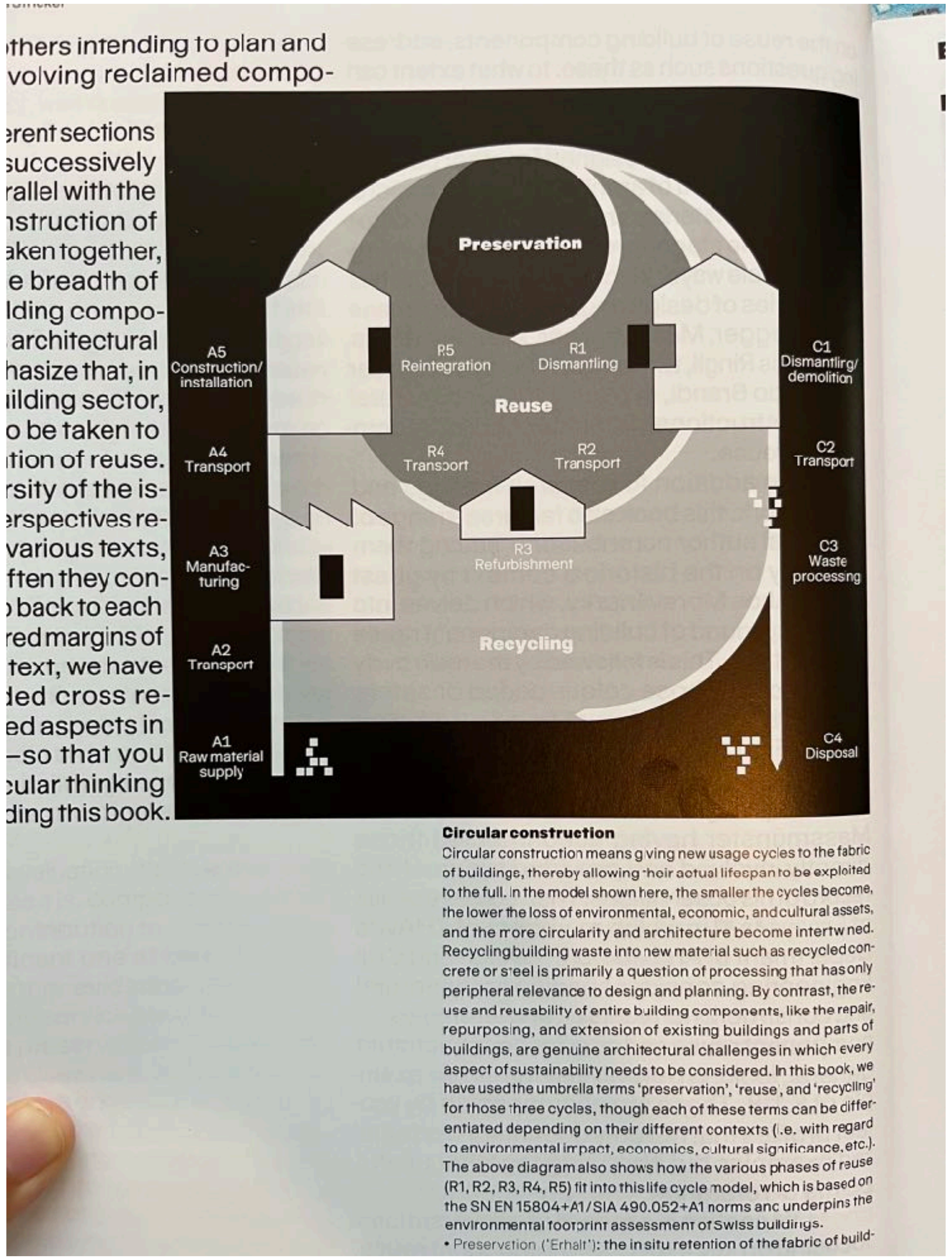
Figure 8 Level of interventions *(Giebeler et al., 2009)*



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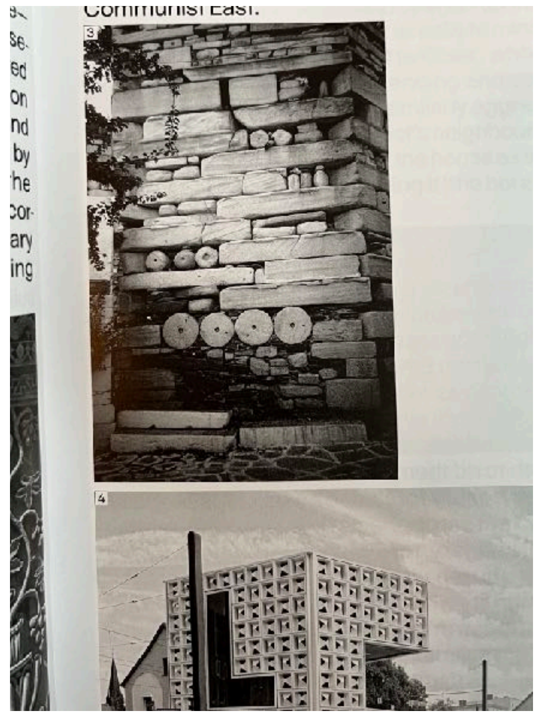
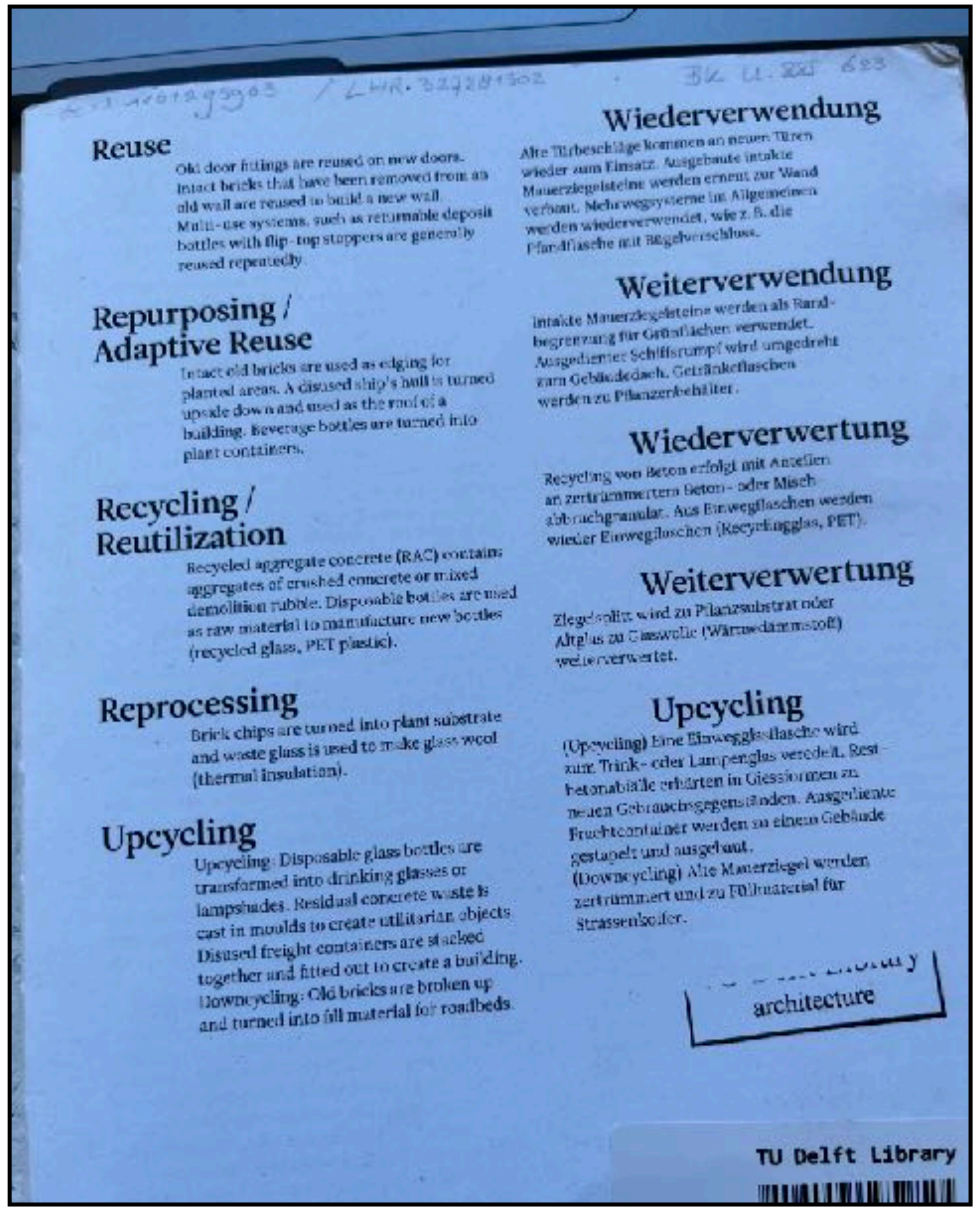
Circular construction

Circular construction means giving new usage cycles to the fabric of buildings, thereby allowing their actual lifespan to be exploited to the full. In the model shown here, the smaller the cycles become, the lower the loss of environmental, economic, and cultural assets, and the more circularity and architecture become intertwined. Recycling building waste into new material such as recycled concrete or steel is primarily a question of processing that has only peripheral relevance to design and planning. By contrast, the reuse and reusability of entire building components, like the repair, repurposing, and extension of existing buildings and parts of buildings, are genuine architectural challenges in which every aspect of sustainability needs to be considered. In this book, we have used the umbrella terms 'preservation', 'reuse', and 'recycling' for those three cycles, though each of these terms can be differentiated depending on their different contexts (i.e. with regard to environmental impact, economics, cultural significance, etc.). The above diagram also shows how the various phases of reuse (R1, R2, R3, R4, R5) fit into this life cycle model, which is based on the SN EN 15804+A1/SIA 490.052+A1 norms and underpins the environmental footprint assessment of Swiss buildings.

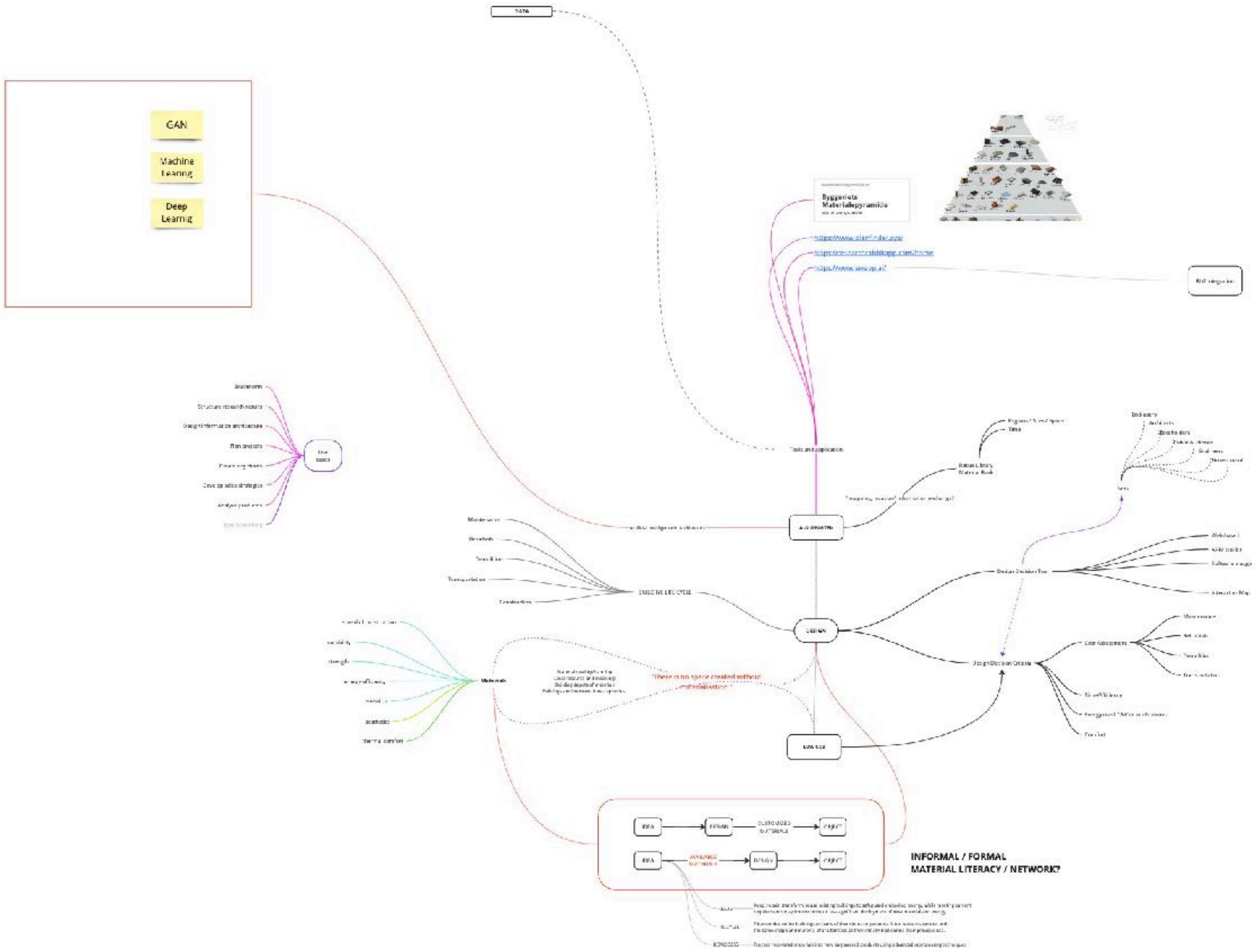
- Preservation ('Erhalt'): the in situ retention of the fabric of build-



Communist East.



Reuse Old door fittings are reused on new doors. Intact bricks that have been removed from an old wall are reused to build a new wall. Multi-use systems, such as returnable deposit bottles with flip-top stoppers are generally reused repeatedly.	**Wiederverwendung** Alte Türbeschläge kommen an neuen Türen wieder zum Einsatz. Ausgebaute intakte Mauerziegelsteine werden erneut zur Wand verbaut. Mehrwegsysteme im Allgemeinen werden wiederverwendet, wie z. B. die Pfandflasche mit Bügelverschluss.
Repurposing / Adaptive Reuse Intact old bricks are used as edging for planted areas. A disused ship's hull is turned upside down and used as the roof of a building. Beverage bottles are turned into plant containers.	**Weiterverwendung** Intakte Mauerziegelsteine werden als Randbegrenzung für Grünflächen verwendet. Ausgedienter Schiffsrumpf wird umgedreht zum Gebäudedach. Getränkeflaschen werden zu Pflanzenbehälter.
Recycling / Reutilization Recycled aggregate concrete (RAC) contains aggregates of crushed concrete or mixed demolition rubble. Disposable bottles are used as raw material to manufacture new bottles (recycled glass, PET plastic).	**Wiederverwertung** Recycling von Beton erfolgt mit Anteilen an zertrümmertem Beton- oder Mischabbruchgranulat. Aus Einwegflaschen werden wieder Einwegflaschen (Recyclingglas, PET).
Reprocessing Brick chips are turned into plant substrate and waste glass is used to make glass wool (thermal insulation).	**Weiterverwertung** Ziegelsplitt wird zu Pflanzsubstrat oder Altglas zu Glaswolle (Wärmedämmstoff) weiterverwertet.
Upcycling Upcycling: Disposable glass bottles are transformed into drinking glasses or lampshades. Residual concrete waste is cast in moulds to create utilitarian objects. Disused freight containers are stacked together and fitted out to create a building. Downcycling: Old bricks are broken up and turned into fill material for roadbeds.	**Upcycling** (Upcycling) Eine Einwegglasflasche wird zum Trink- oder Lampenglas veredelt. Restbetonabfälle erhärten in Giessformen zu neuen Gebrauchsgegenständen. Ausgediente Fruchtcontainer werden zu einem Gebäude gestapelt und ausgebaut. (Downcycling) Alte Mauerziegel werden zertrümmert und zu Füllmaterial für Strassenkoffer.



INFORMAL / FORMAL
MATERIAL LITERACY / NETWORK?

Definition

Reuse, recycle, reprocess

Reuse
Old door fittings are reused on new doors.
Intact bricks that have been removed from an old wall are reused to build a new wall.
Multi-use systems, such as returnable deposit bottles with flip-top stoppers are generally reused repeatedly.

Repurposing/Adaptive Reuse
Intact old bricks are used as edging for planted areas.
A disused ship's hull is turned upside down and used as the roof of a building.
Beverage bottles are turned into plant containers.

Recycling/Reutilisation
Recycled aggregate concrete (RAC) contains aggregates of crushed concrete or mixed demolition rubble.
Disposable bottles are used as raw materials to manufacture new bottles (recycled glass, PET plastics).

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Bricks chips are turned into plant substrate
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