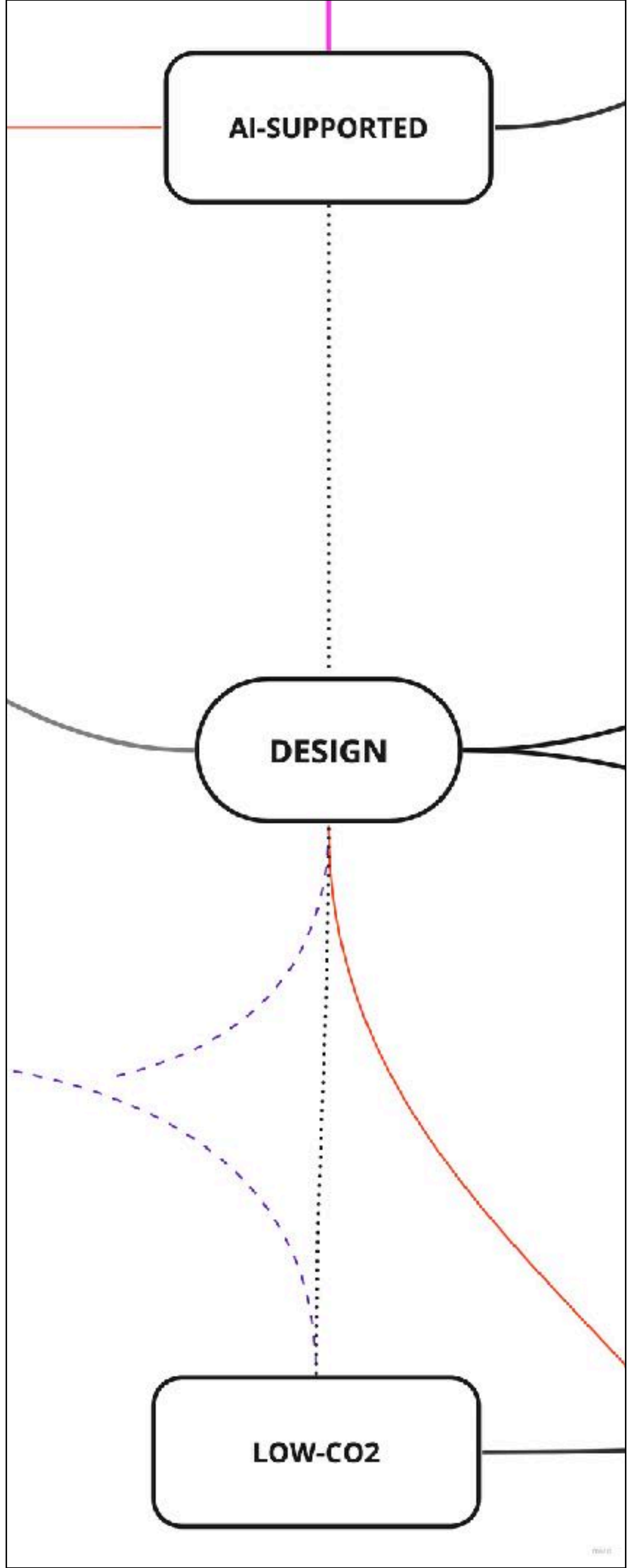
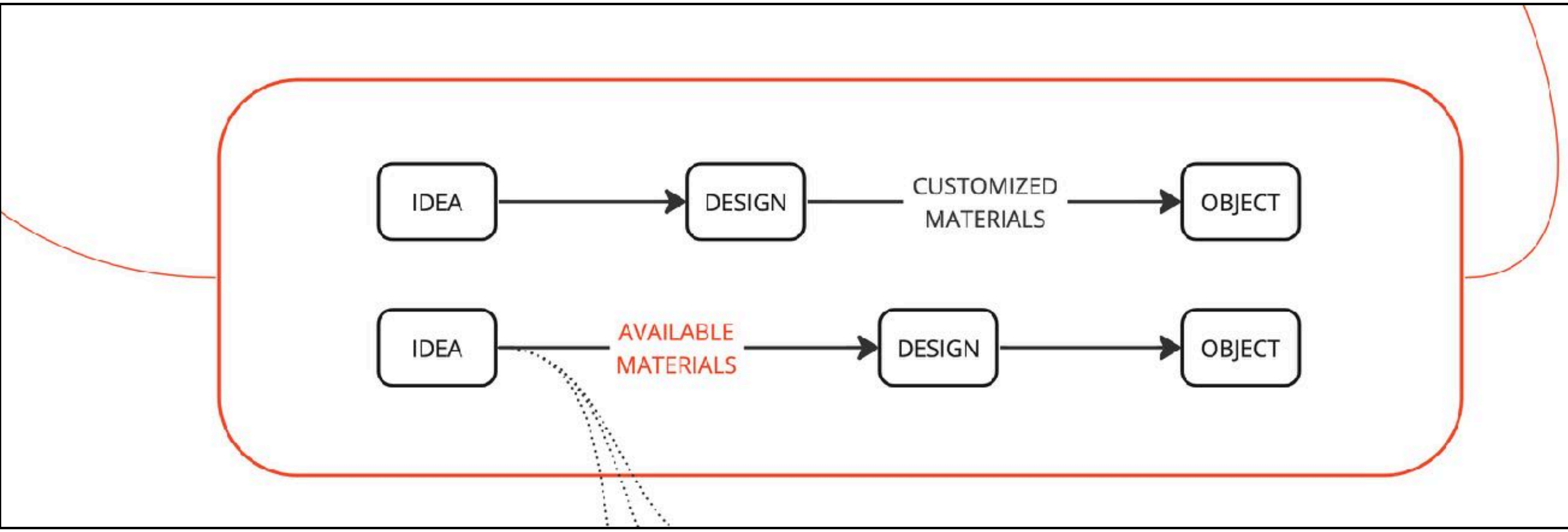
Ai-supported low CO2 circular design

Peng lee, 09.2023


AI-SUPPORTED
DESIGN
LOW-CO2


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
miro



INFORMAL / FORMAL
MATERIAL LITERACY / NETWORK?

miro

"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...?

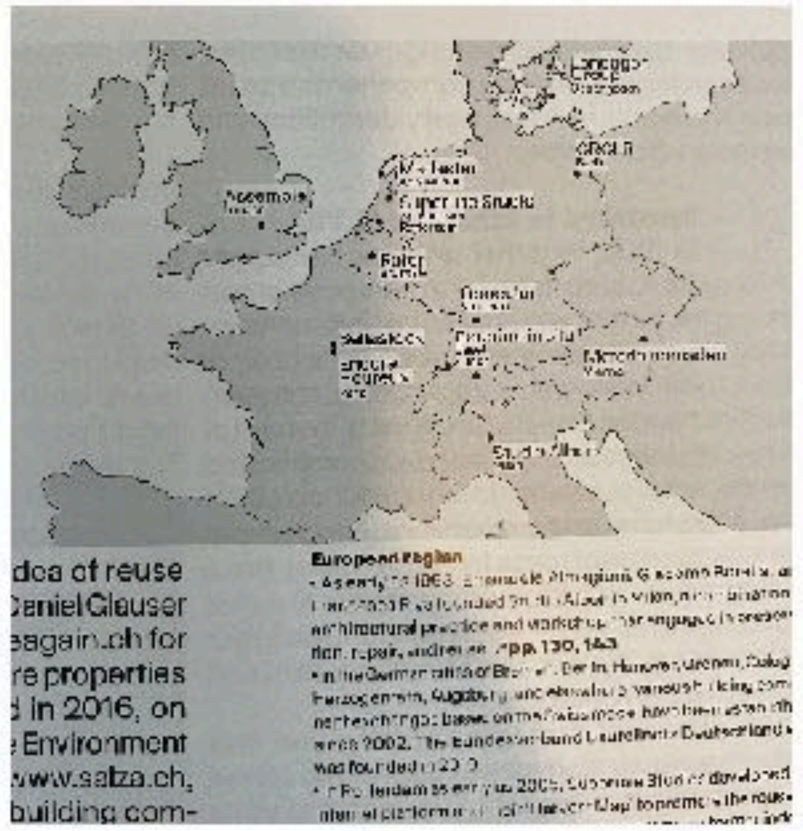
machine

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**

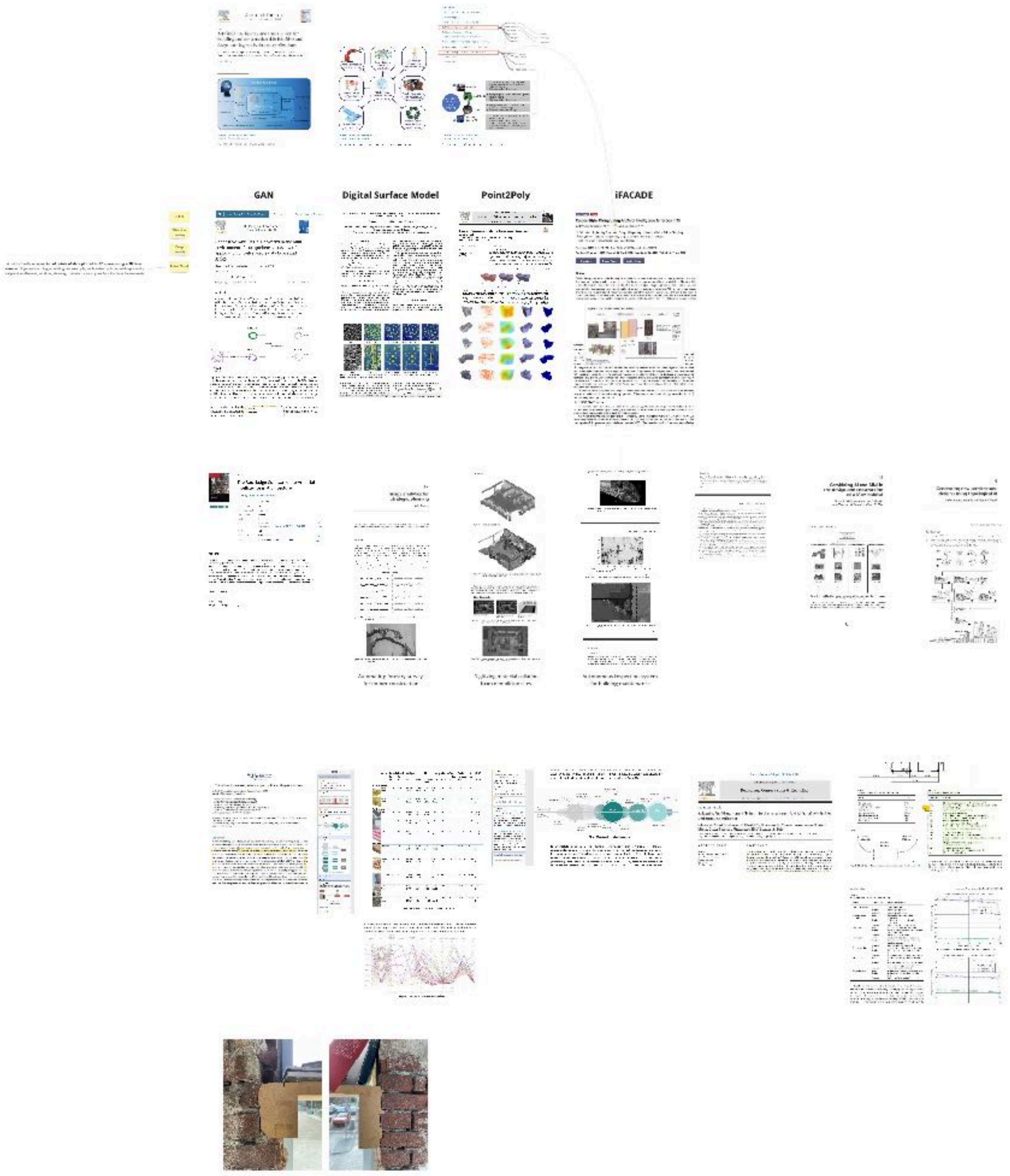


learn from companies/firm:
super-reuse
Madaster
Rotor(material bank)
BC (excavated earth to building materials)
...

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?

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

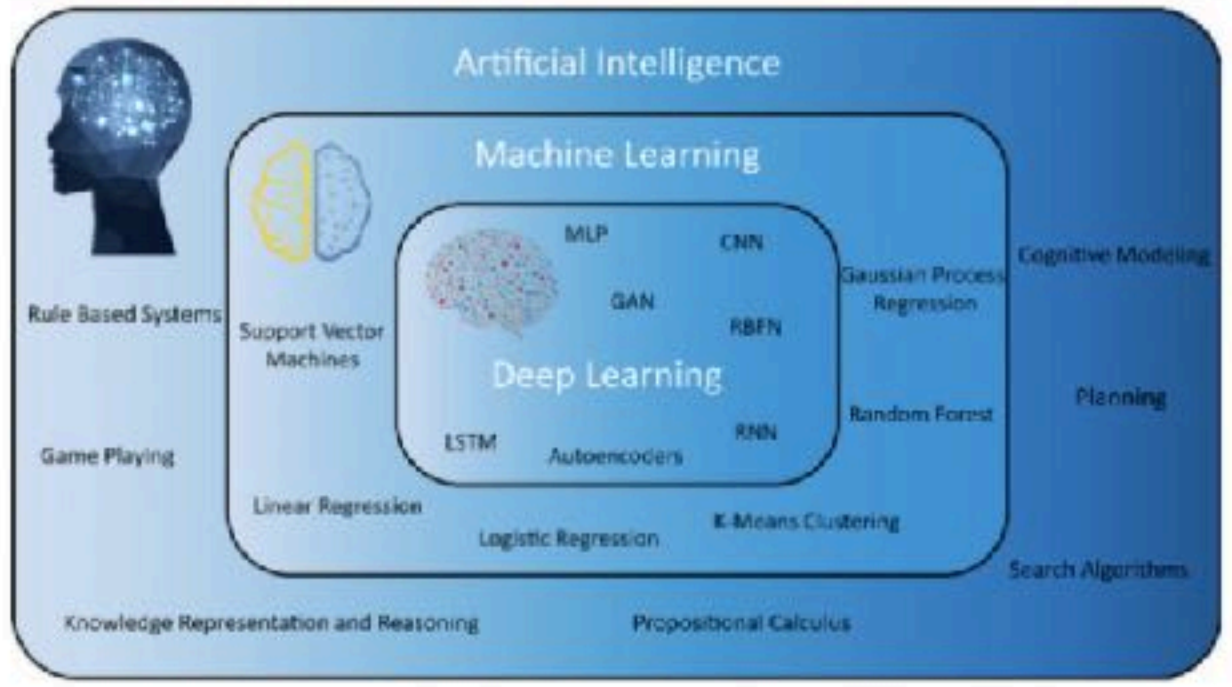


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Fig. 1. Domains of AI, ML, DL and widely used algorithms.

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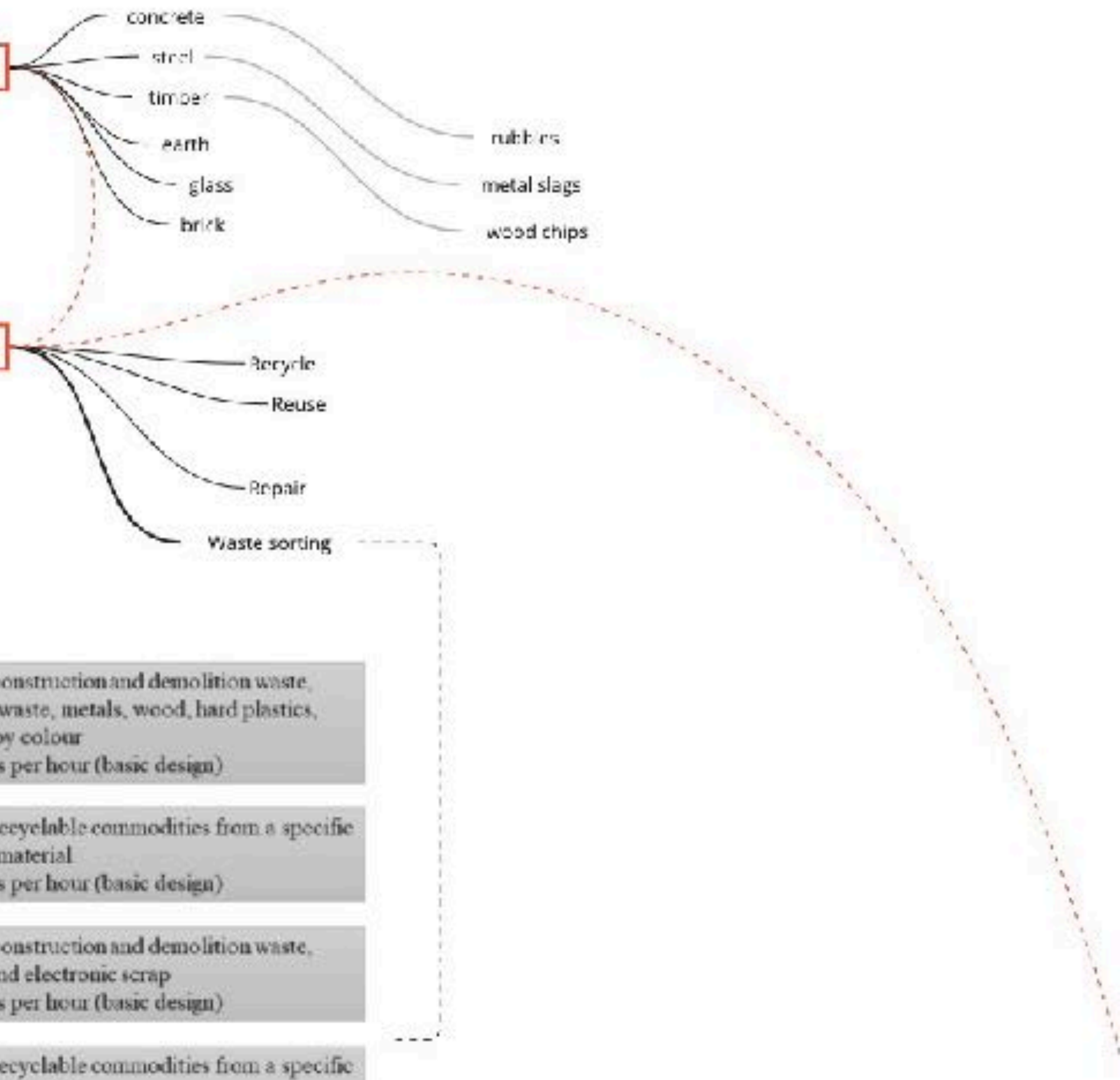
Fig. 2. Application AREAS of AI in building and construction industry 4.0.



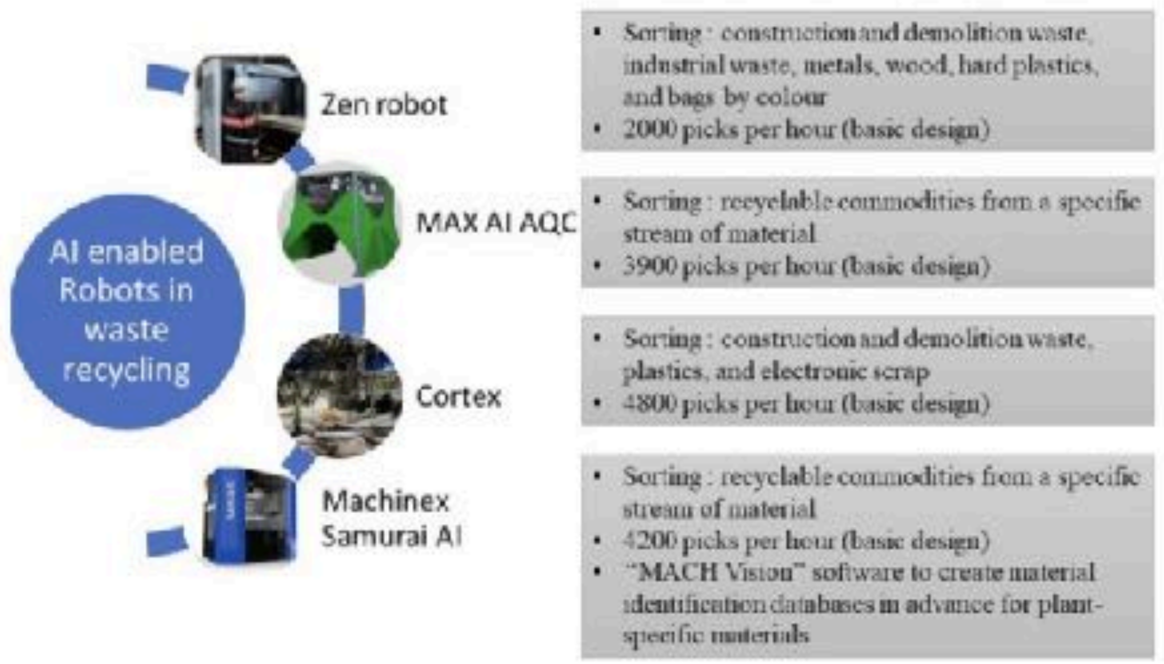


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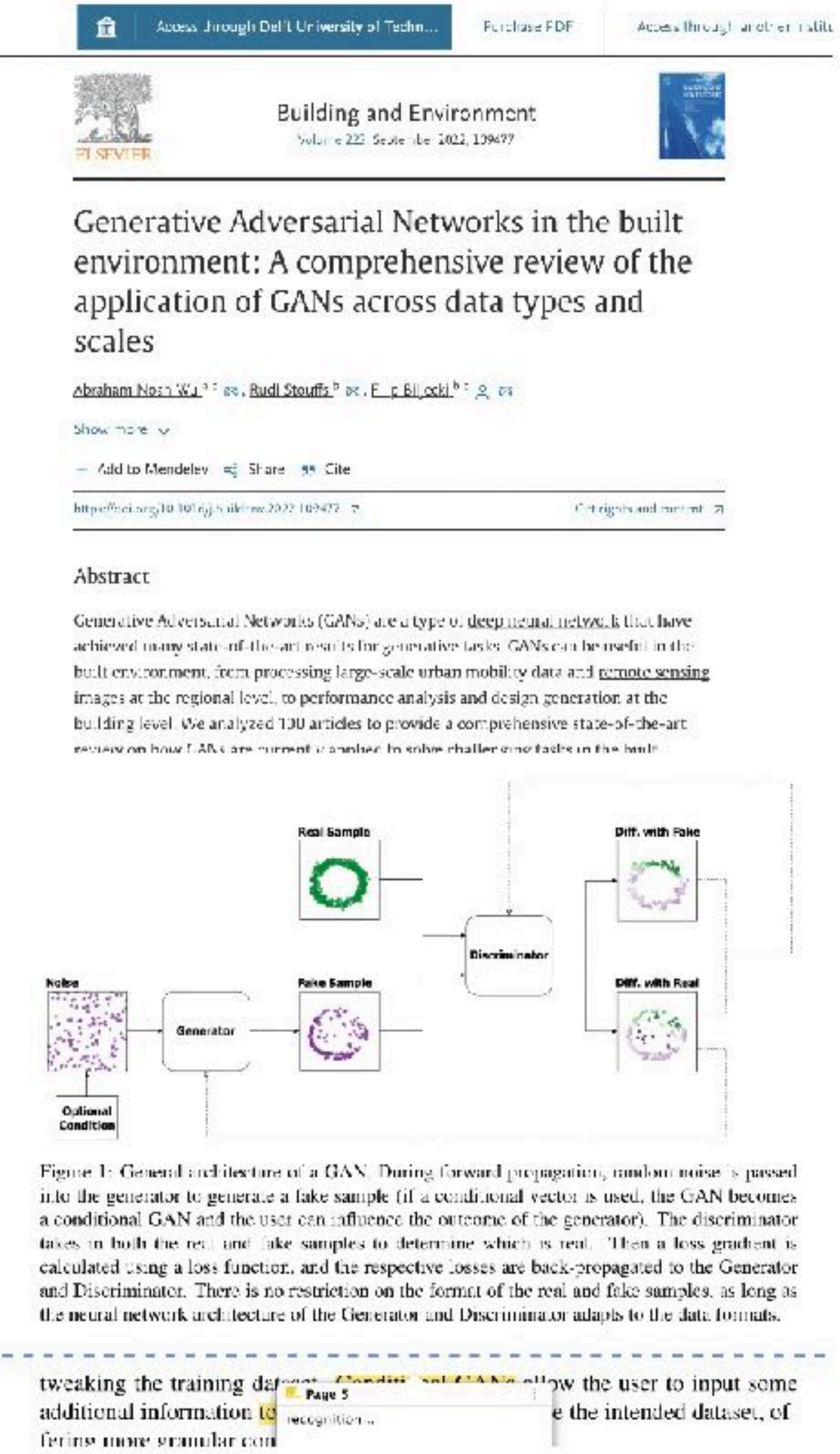
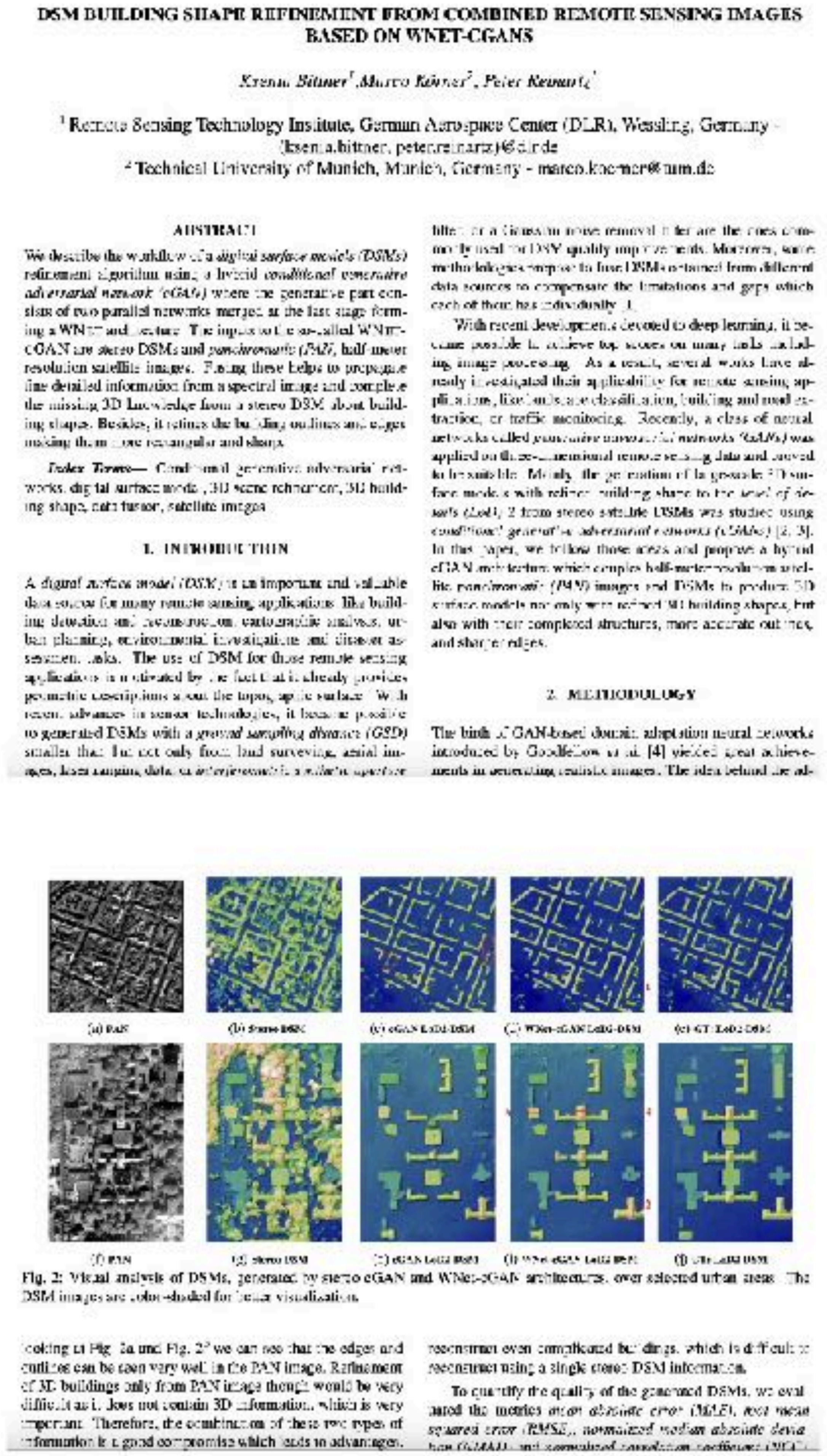
Fig. 20. Commercial solutions for automated waste sorting.

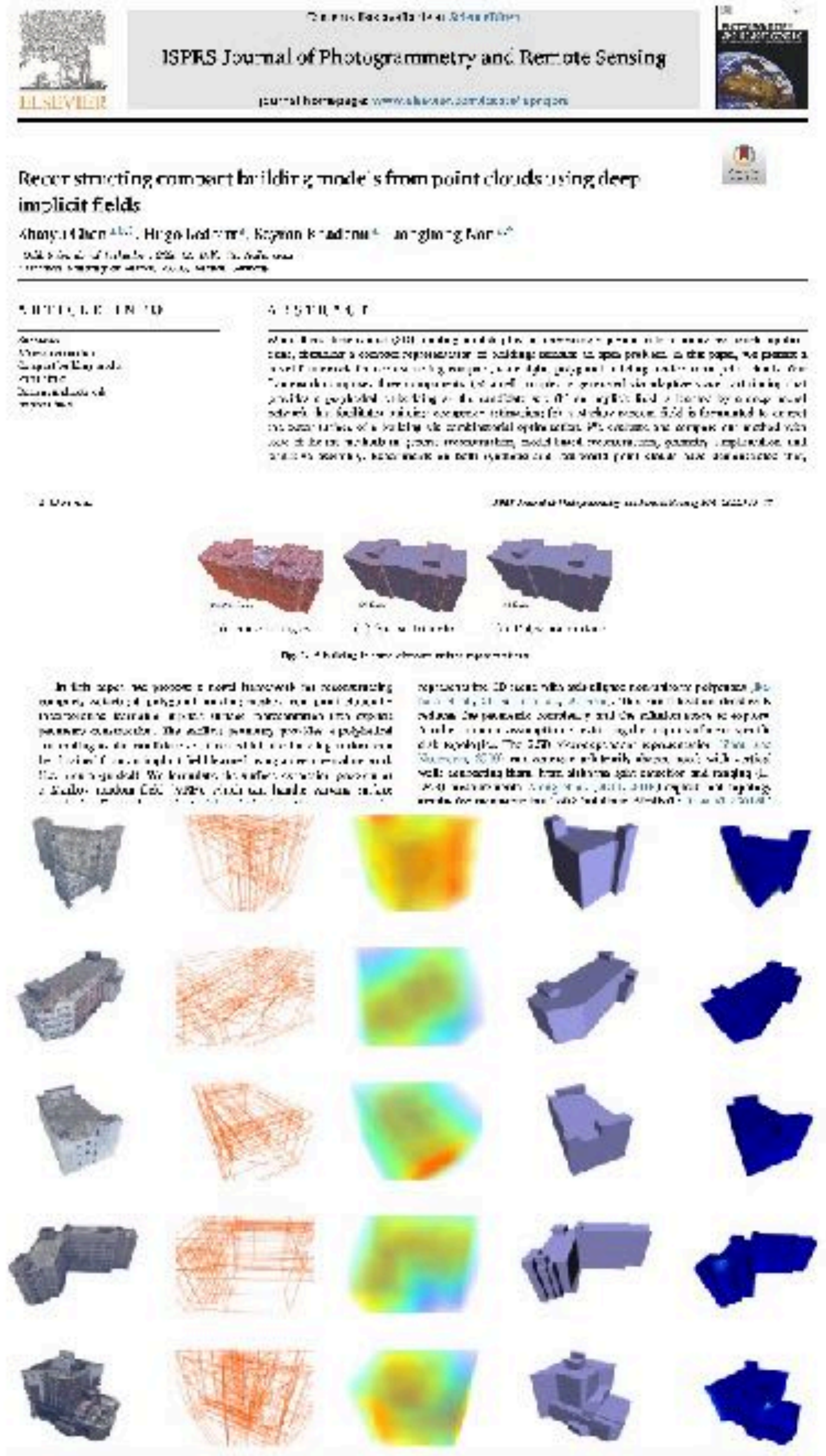
GAN



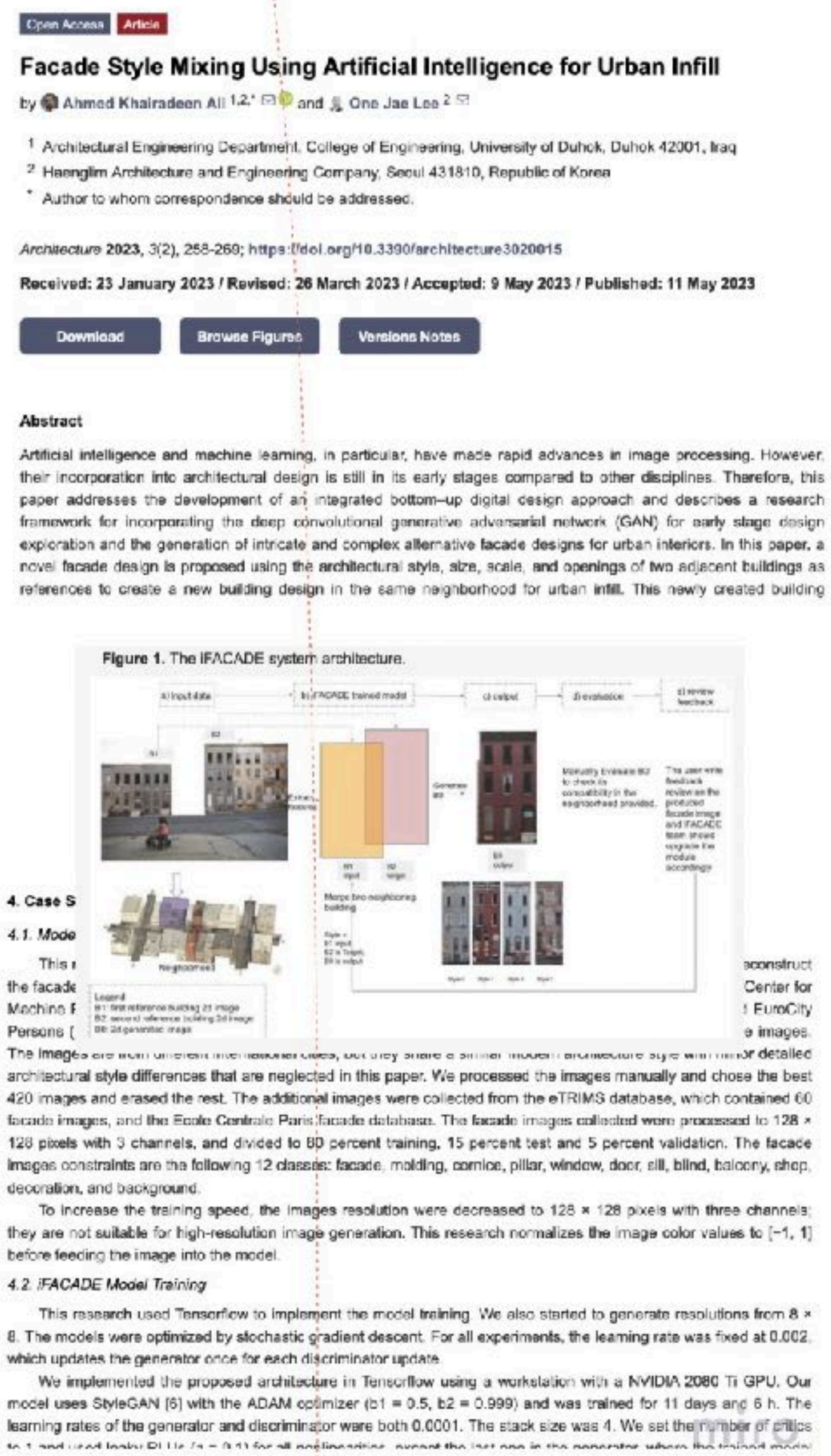
Digital Surface Model



Point2Poly



iFACADE



FULL ACCESS

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

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 sewing 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).

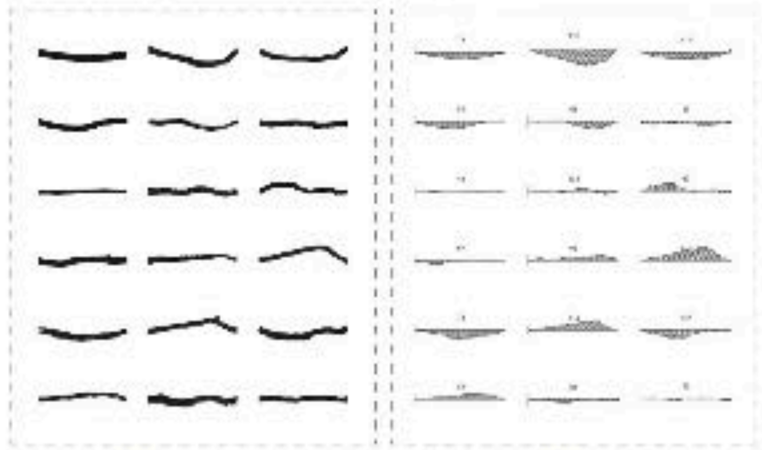


Figure 17.7 Database: storing information on wood curvature connected to individual material resources.

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

Automating forestry survey for timber construction

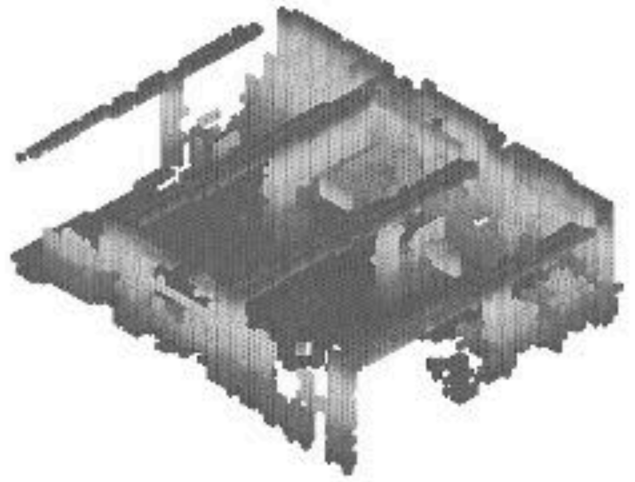


Figure 17.10 Point cloud depth map

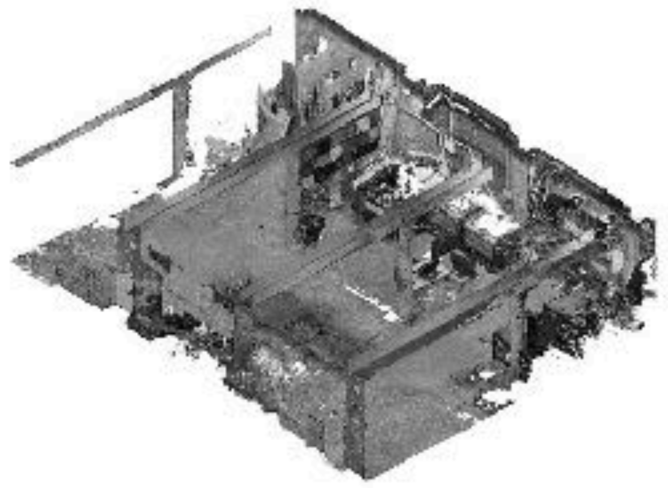


Figure 17.11 Point cloud reconstruction: OctoMap generation modeling arbitrary environments without prior assumptions.

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

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.

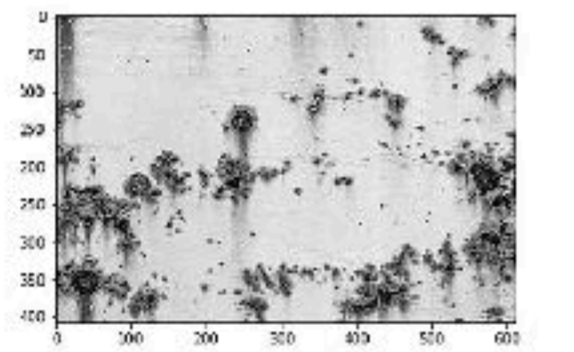


Figure 17.15 Image processing: edge detection segmentation to define area of rust through global thresholding.

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 1,500 epochs, resulting in a de

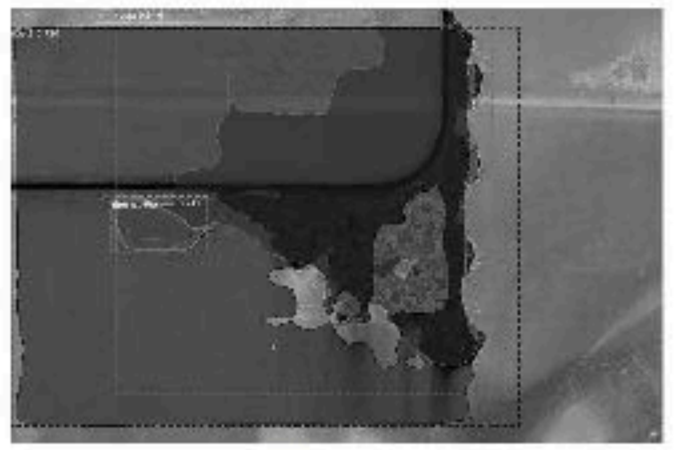


Figure 17.16 Semantic segmentation: applying Mask R-CNN semantic segmentation and rust detection.

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.

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

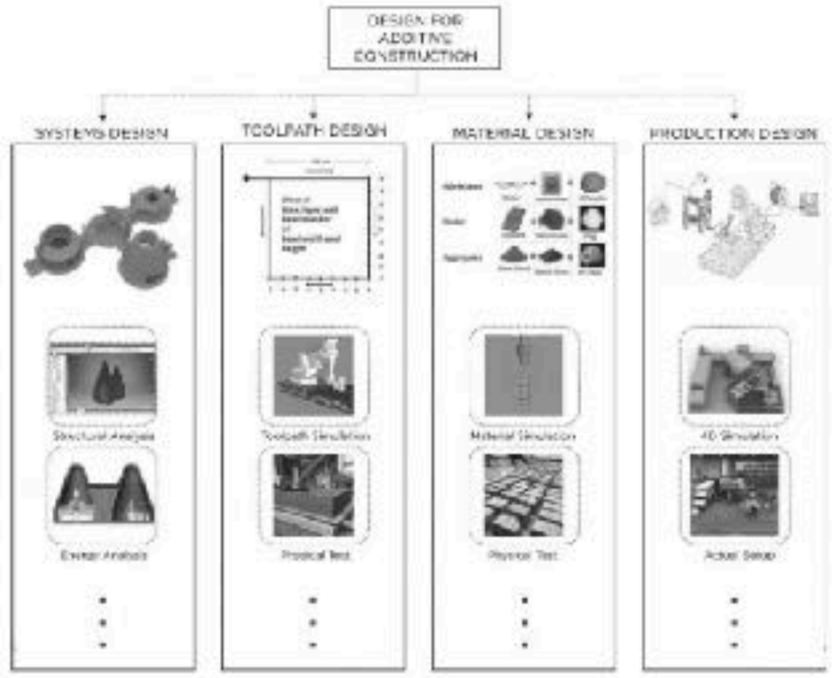


Figure 13.13 Multidisciplinary nature of design for additive construction (DfAC) involving a range of computational analyses and physical testing.

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

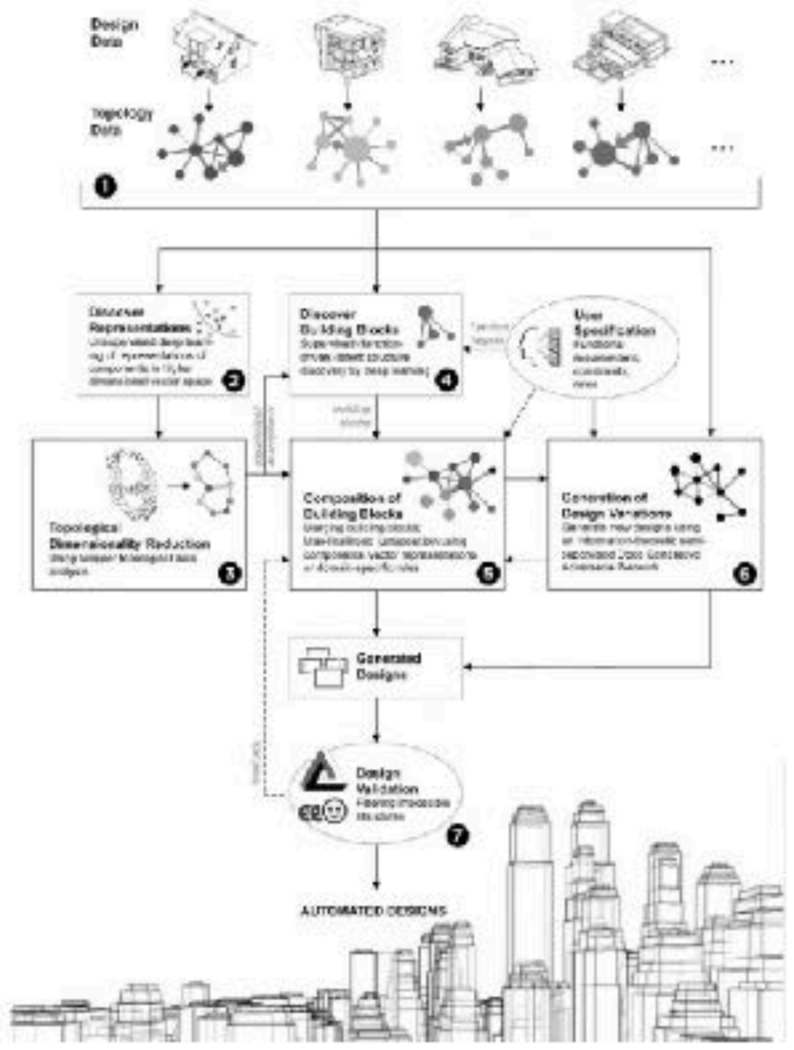
Generating new architectural designs using topological AI

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.

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)
Adresse: Den Dolech 2, 5312 AZ Eindhoven

Chairman (USRE): Prof.dr. Theo A. Arentze, Graduation Supervision (USRE): Dr. Ioulia V. Ossokina (I.V.Ossokina@tue.nl)
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 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

	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	(kgCO₂e/m²)	€/m²	years	A-F	g/m³	dB	u-value
Mineral-based												
	Glass Wool	0.034	18.4	1.06 4.07	51.50 196.01	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	7.46 - 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	5.85 - 21.00	75	E	27.6	3.16	15.19 - 58.09
	XPS	0.027	35	1.51 - 6.14	178.20 - 68[illegible].35	24.80 - 54.82	8.11 - 29.92	75	E	≤ 27.6	4.81	25.39 - 100.91
Bio-based												
	Flax wool	0.041	31	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	8.91 - 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	0.0412	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	152.53 - 583.57	-8.59 - -32.84	23.97 - 91.46	100	B	≥ 129.5	15.48	1.59 - 6.10

Table 18 Material Comparative Analysis Itc 1.7 - 6.5

interdisciplinary working approaches using open standards IFC, allows engineers to extend their 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

bio-based materials are outperformed by the commercial materials. Additionally, higher thicknesses 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.

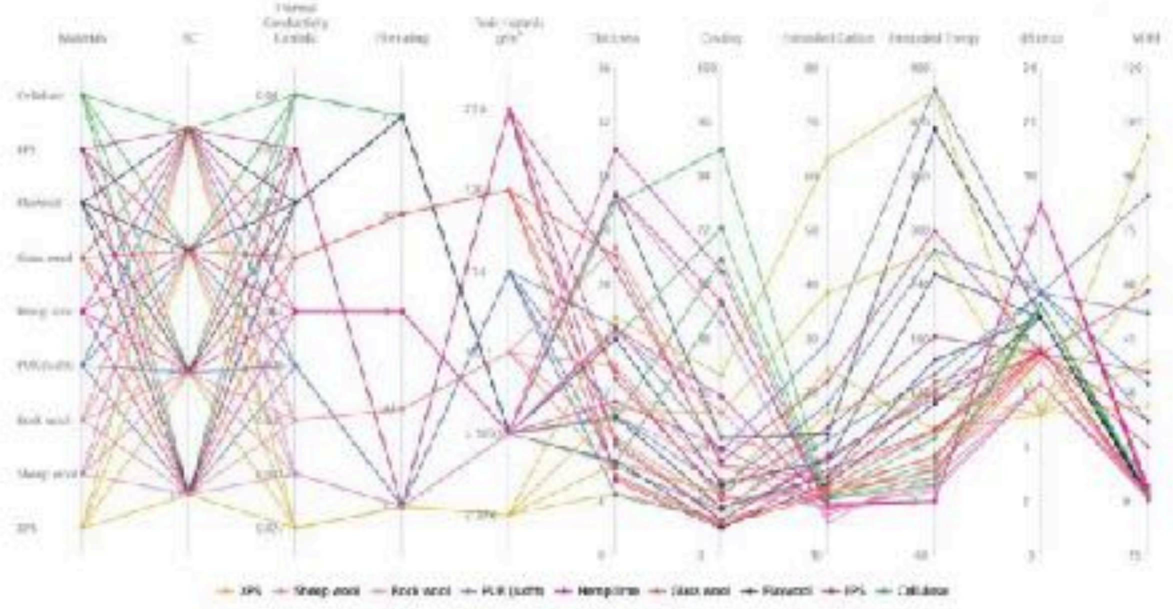


Figure 31 Material Comparative Analysis

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

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full Length Article

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]

[a] Bristol Enterprise, Research and Innovation Centre (BERIC), Bristol Business School, University of the West of the England, Bristol, United Kingdom
[b] Department of Computer Science and Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

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
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 v
study design. Accordingly, the whole-life salvage performance profiles of the case study build

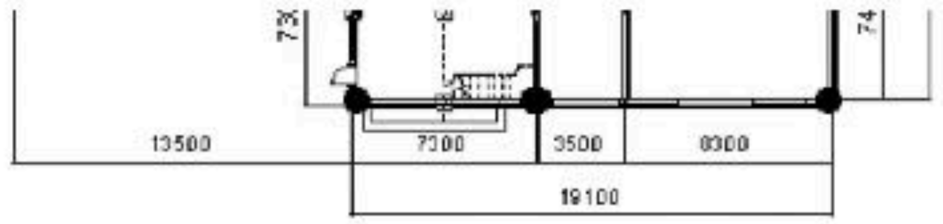


Table 2
Characteristic Feature of the Case Study Building.

Feature	Value
Building type:	Office
Number of floors:	3
Ground floor area (GFA):	491.46 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

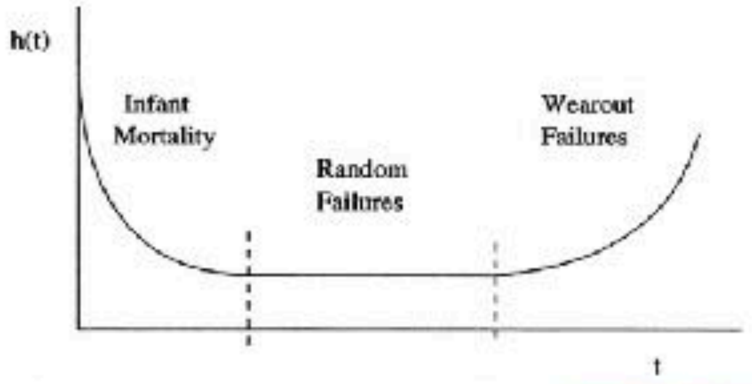


Fig. 4. Bathtub Curve – Hazard (Failure) function against time (Klutke et al., 2003).

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
S_f	Ratio of volume of material without secondary finishes
vS_f	Volume of materials without secondary finishes
vm	Total volume of building materials
$vh_c t$	Volume of material without hazardous content
h_t	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

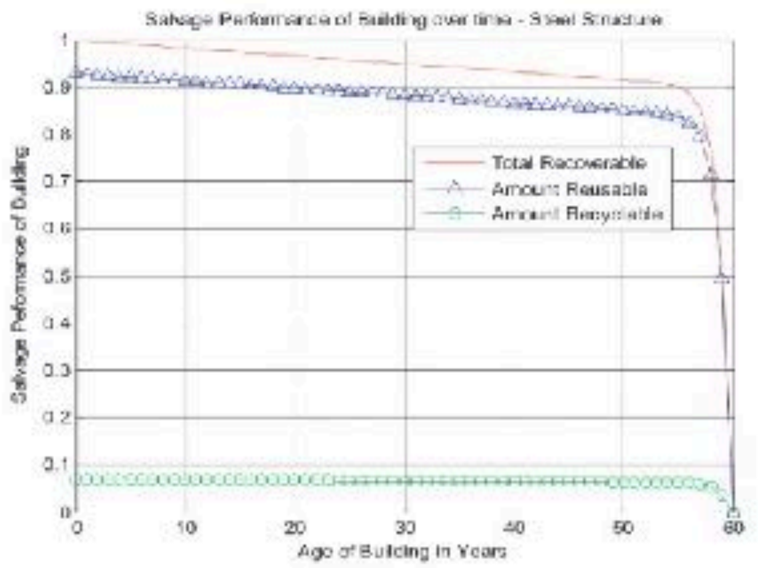
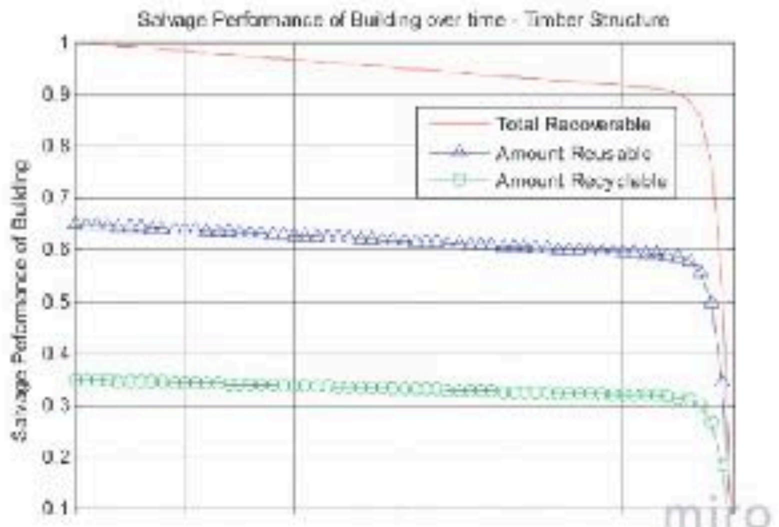


Fig. 9. Salvage Performance of Case Study Building – Steel Structure.

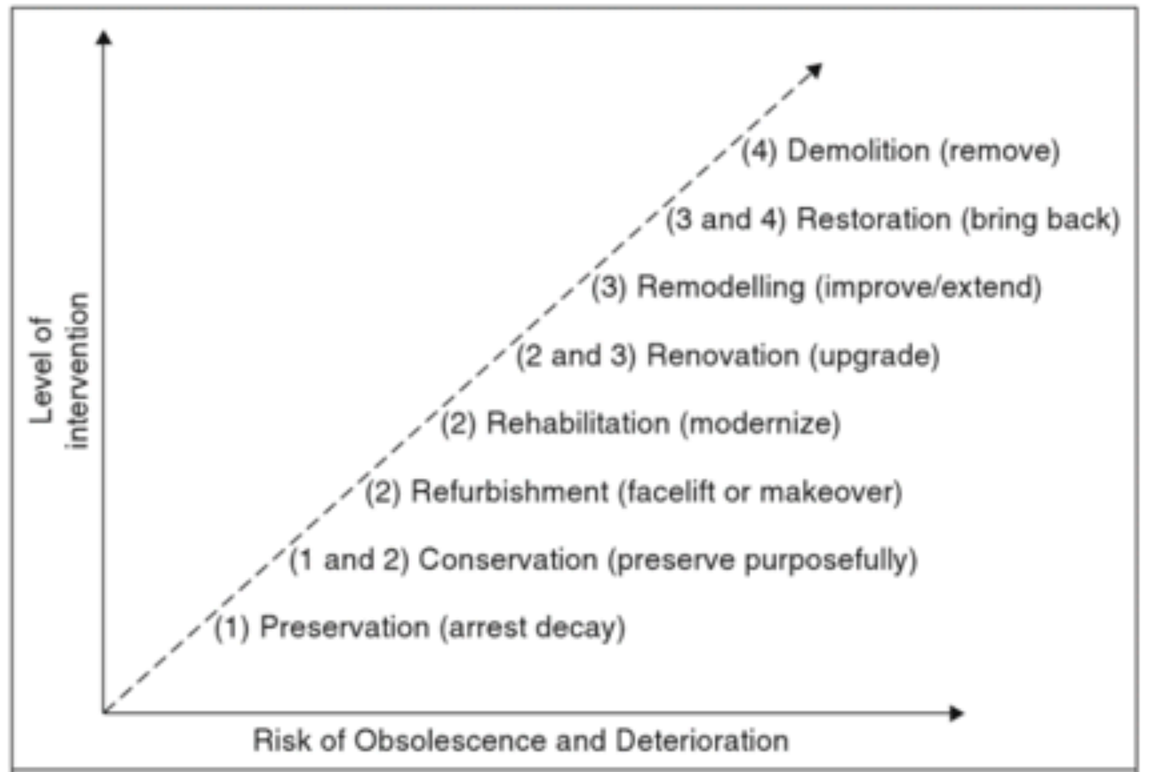


Definition

- Building adaptation, John Douglas

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

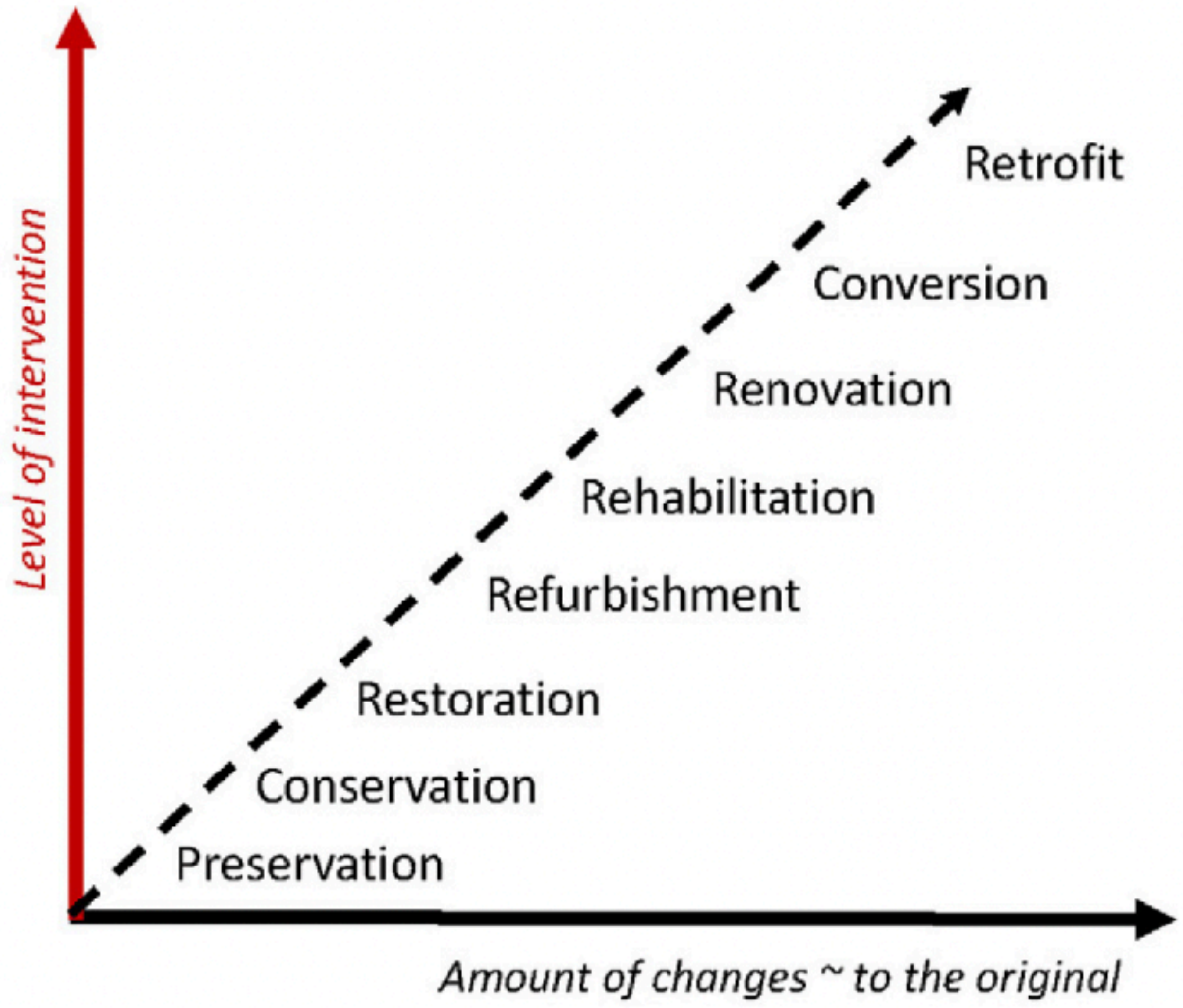


Fig. 1 Overview of building interventions in the spectrum of adaptive reuse.
Drawing: Els De Vos

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

[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

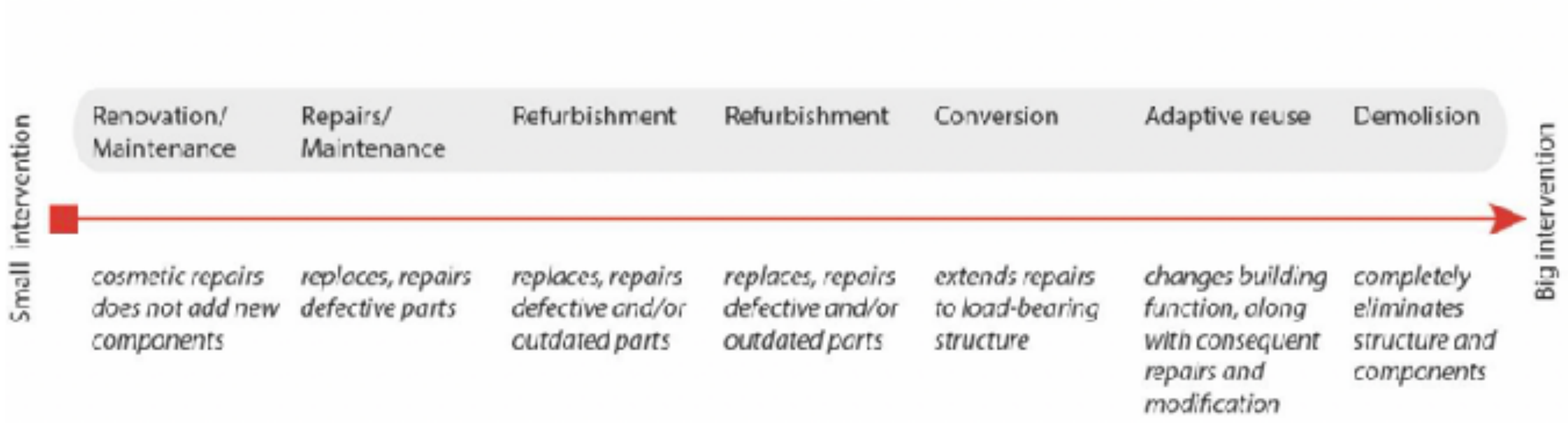
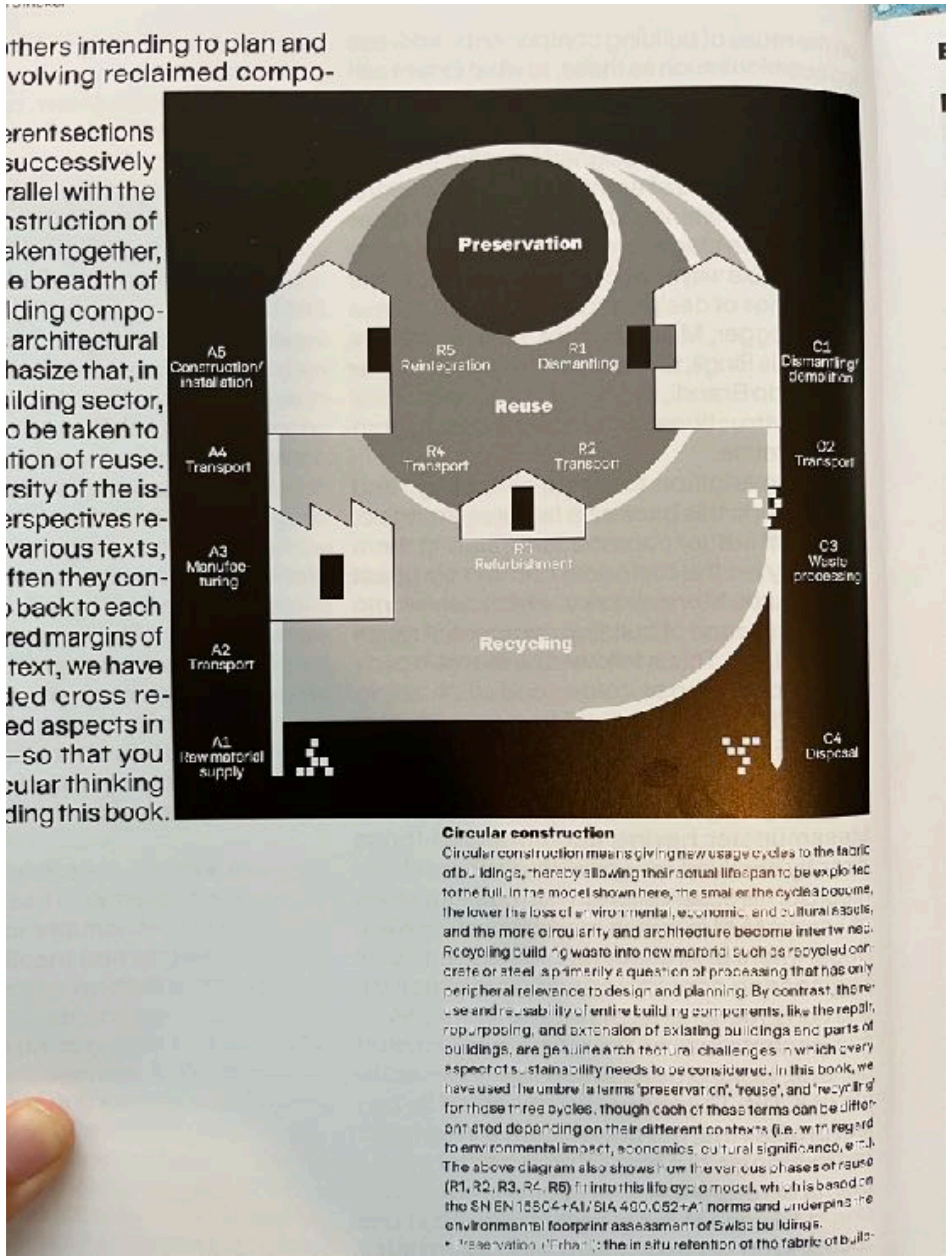


Figure 8 Level of interventions *(Giebeler et al., 2009)*



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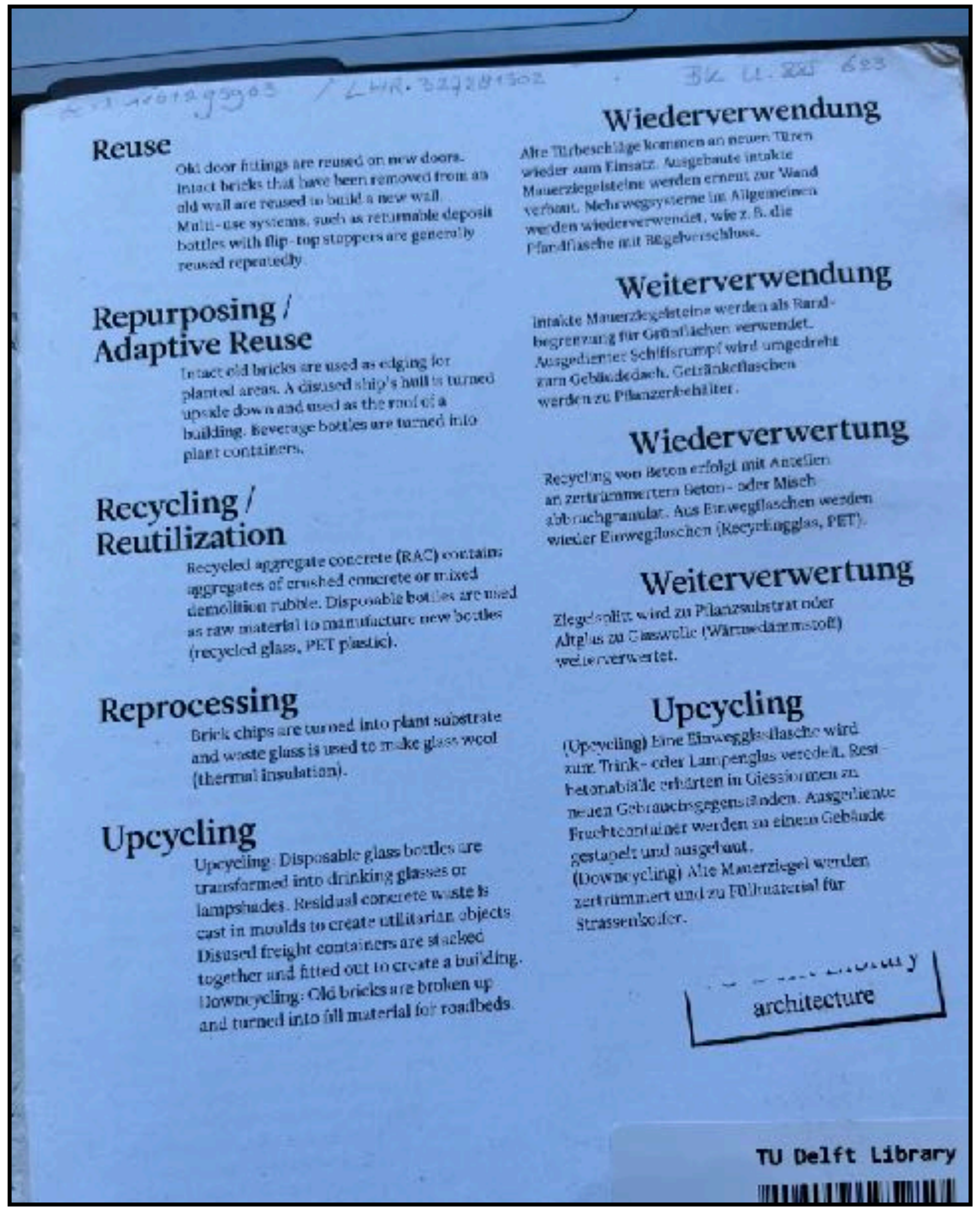
Circular construction
Circular construction means giving new usage cycles to the fabric of buildings, thereby allowing their actual lifespan to be exploited to the full. In the model shown here, the smaller the cycles become, the lower the loss of environmental, economic, and cultural assets, and the 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 these 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 buil-



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).

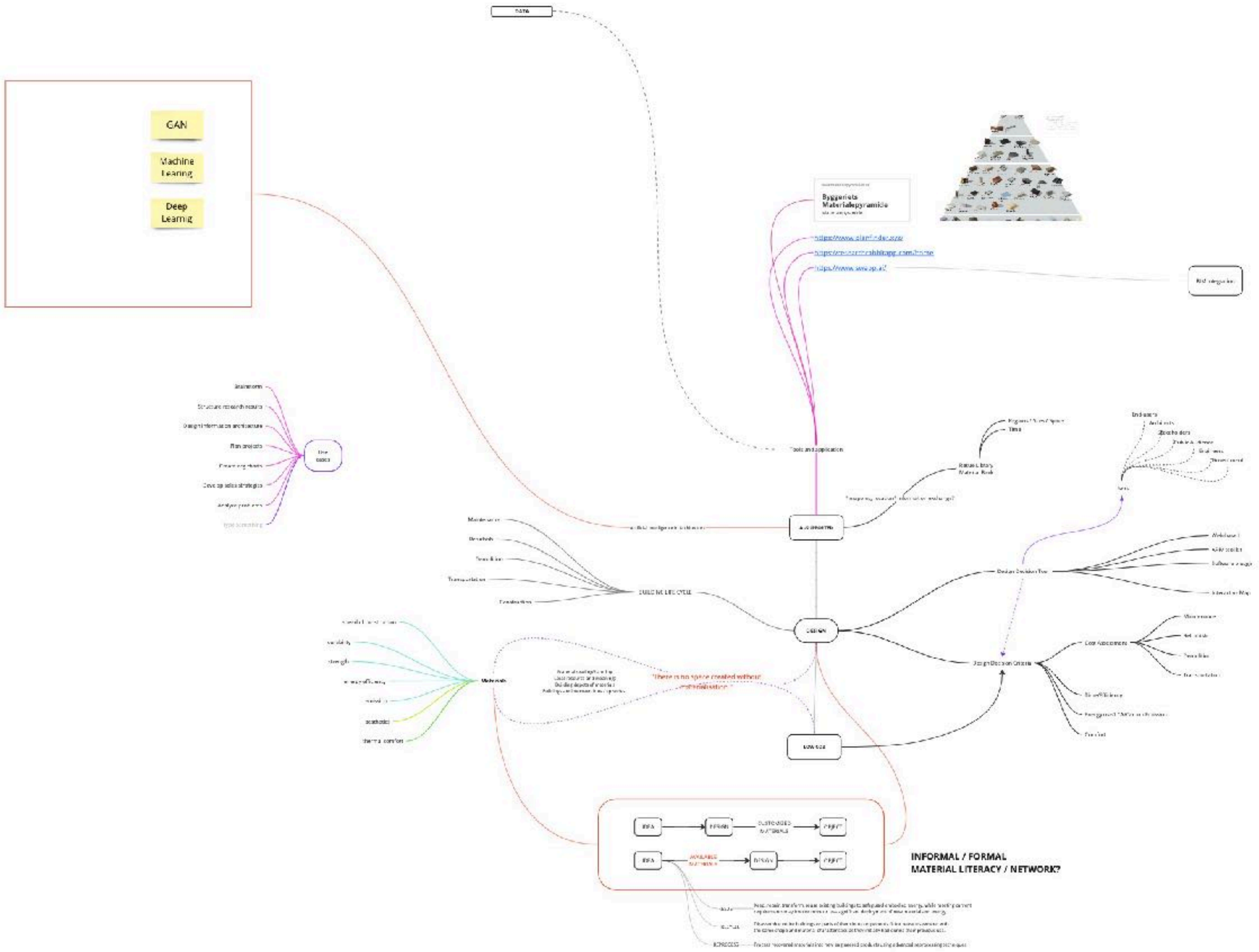
Wiederverwertung
Recycling von Beton erfolgt mit Anteilen an zertrümmertem Beton- oder Mischabbruchgranulat. Aus Einwegflaschen werden wieder Einwegflaschen (Recyclingglas, PET).

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 Frachtcontainer werden zu einem Gebäude gestapelt und ausgebaut.
(Downcycling) Alte Mauerziegel werden zertrümmert und zu Füllmaterial für Strassenkoffer.



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Tools and application
"There is no space created without
materialisation."
INFORMAL / FORMAL
MATERIAL LITERACY / NETWORK?