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Adaptable buildings – why and how

circular economy,
digitalisation of construction,
and its industrialisation

Prof. Ivanka Iordanova, Ph.D.

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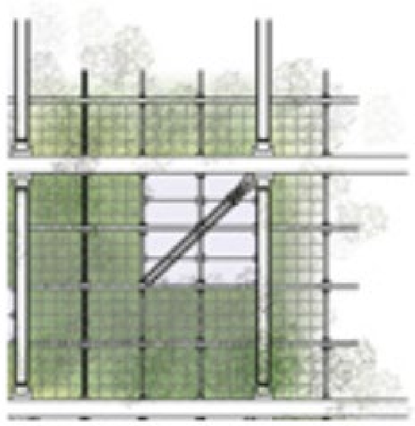
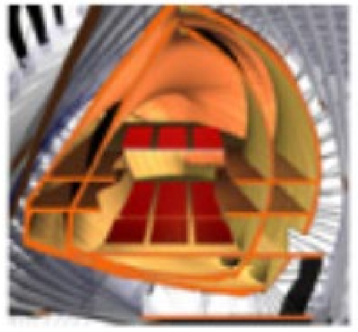
A bit about me

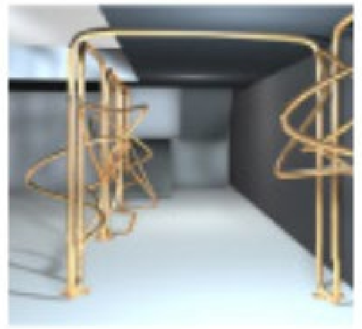
Associate Professor - ETS, Montreal

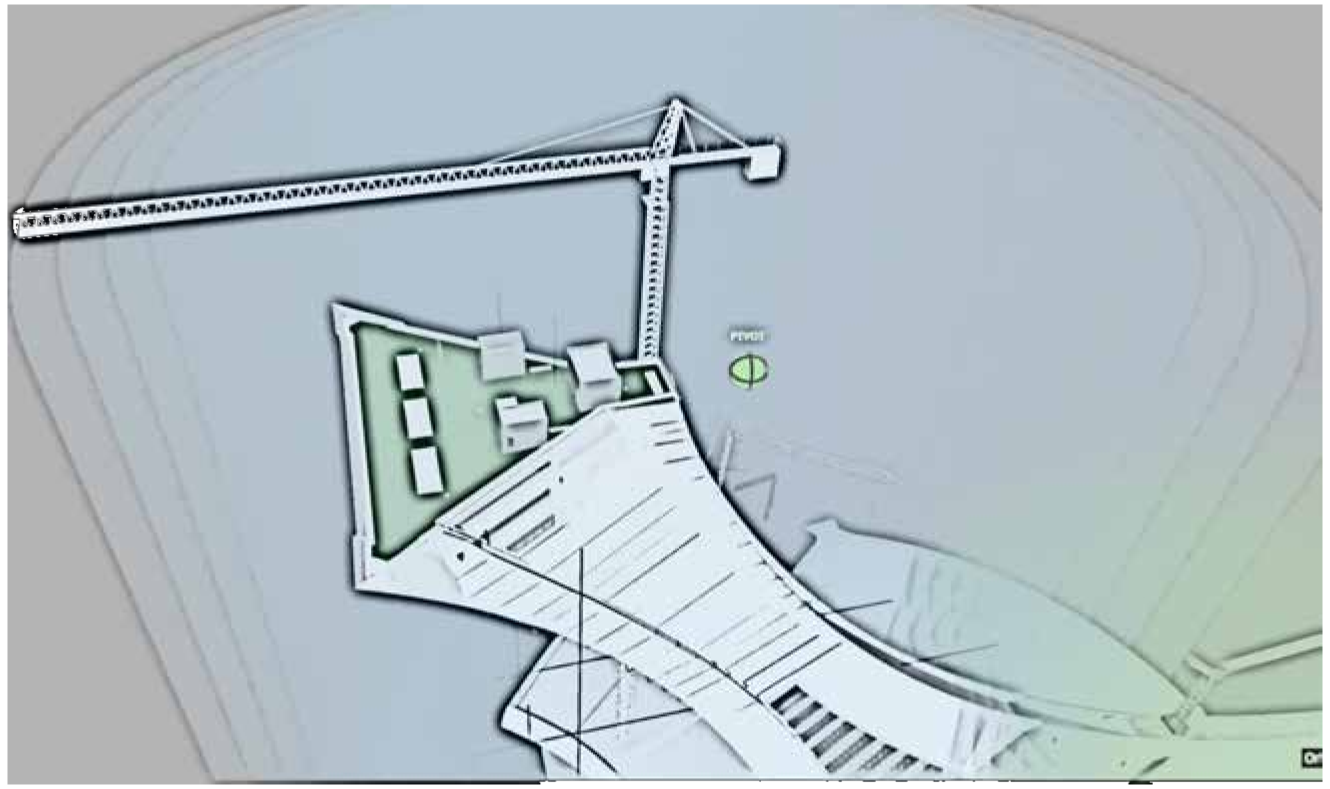
- Architecture – UASEG, Sofia, Bulgaria
- MScA, PhD – Université de Montréal
  teaching, research in architecture
- Post-doc – École de technologie supérieure (ÉTS) teaching, research - GRIDD
  BIM & digital transformation of AECO

- Pomerleau Inc. – Canadian General Contractor
  BIM, VDC, Innovation Director

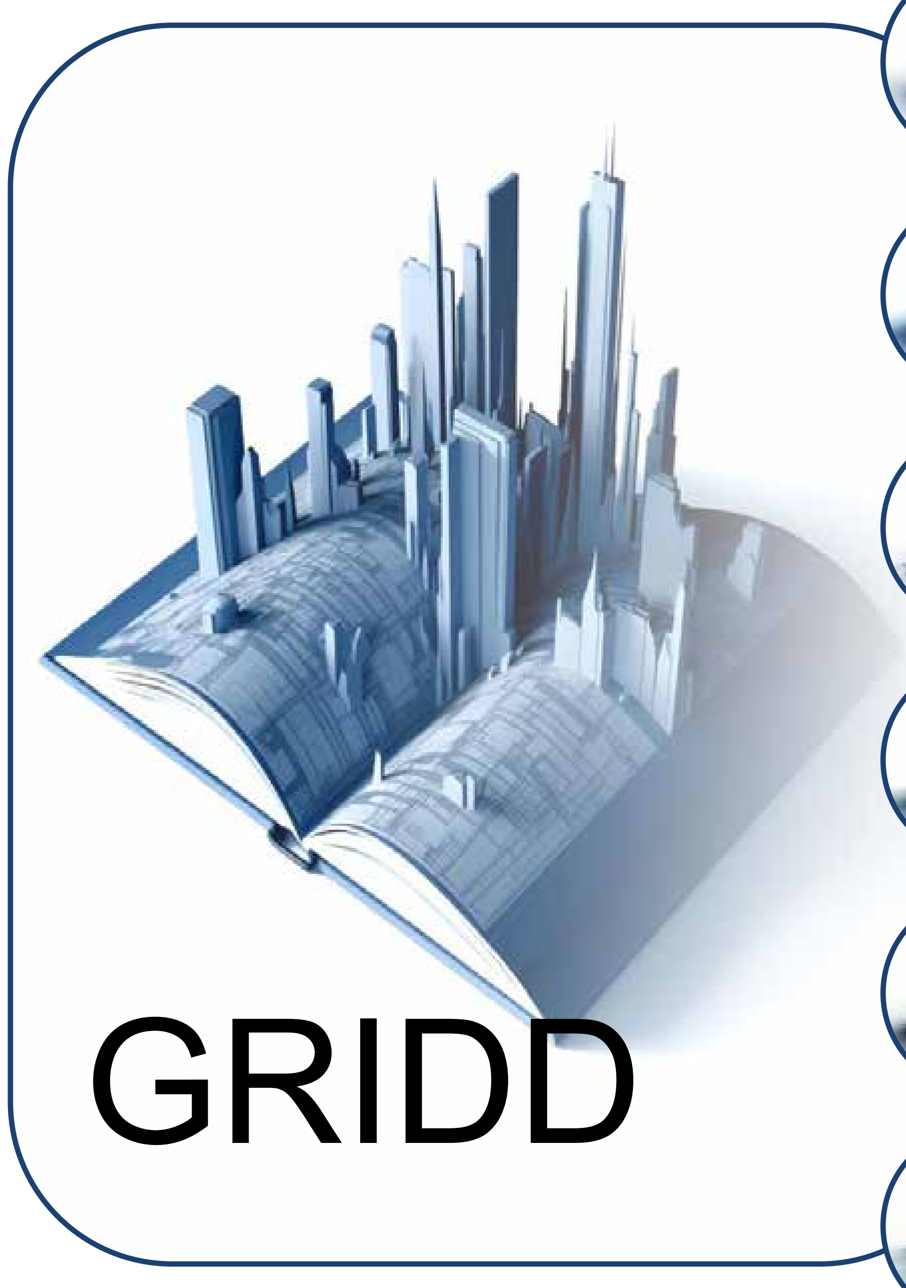






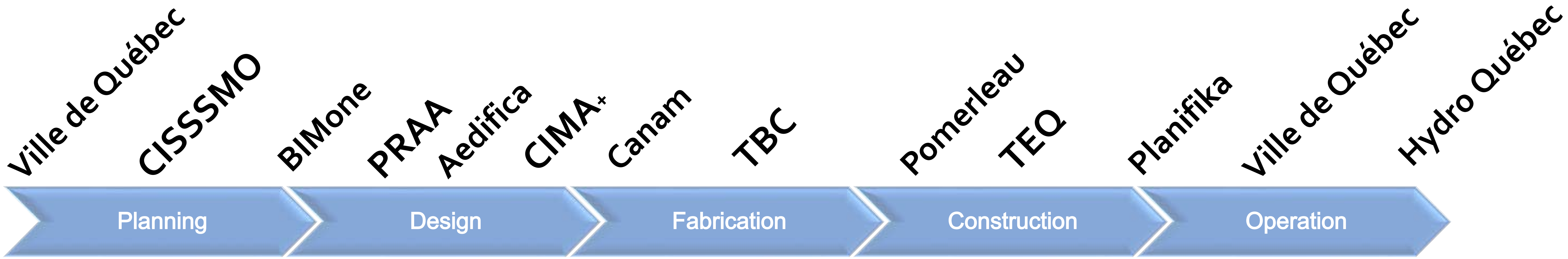


GRIDD – Research Group in Integration & Sustainable Development in Construction



- BIM & information lifecycle management
- Digital Twin and AI
- Industrialization & automation of construction
- Legal framework & contractual language
- Integration, collaboration & Lean Construction
- Sustainable development & Circular Economy

Industrial Research Chair on digital technologies in construction



Groupe BIM du Québec

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Ædifica PROVENCHER_ROY CIMA+ POMERLEAU TBC BIMOne PLANIFIKA TEQ GROUPE CANAM Hydro Québec VILLE DE QUÉBEC

Why change?
What is an adaptable building?
What does it take to favour adaptability?
How can we design for future adaptability?

Why AECO needs to change?

- Lack of skilled labor
- Poor productivity

Building & construction responsible for:

40% of the world's extracted materials
39% of all carbon emissions
11% comes from embodied carbon emissions
Almost the entire waste stream comes from demolition

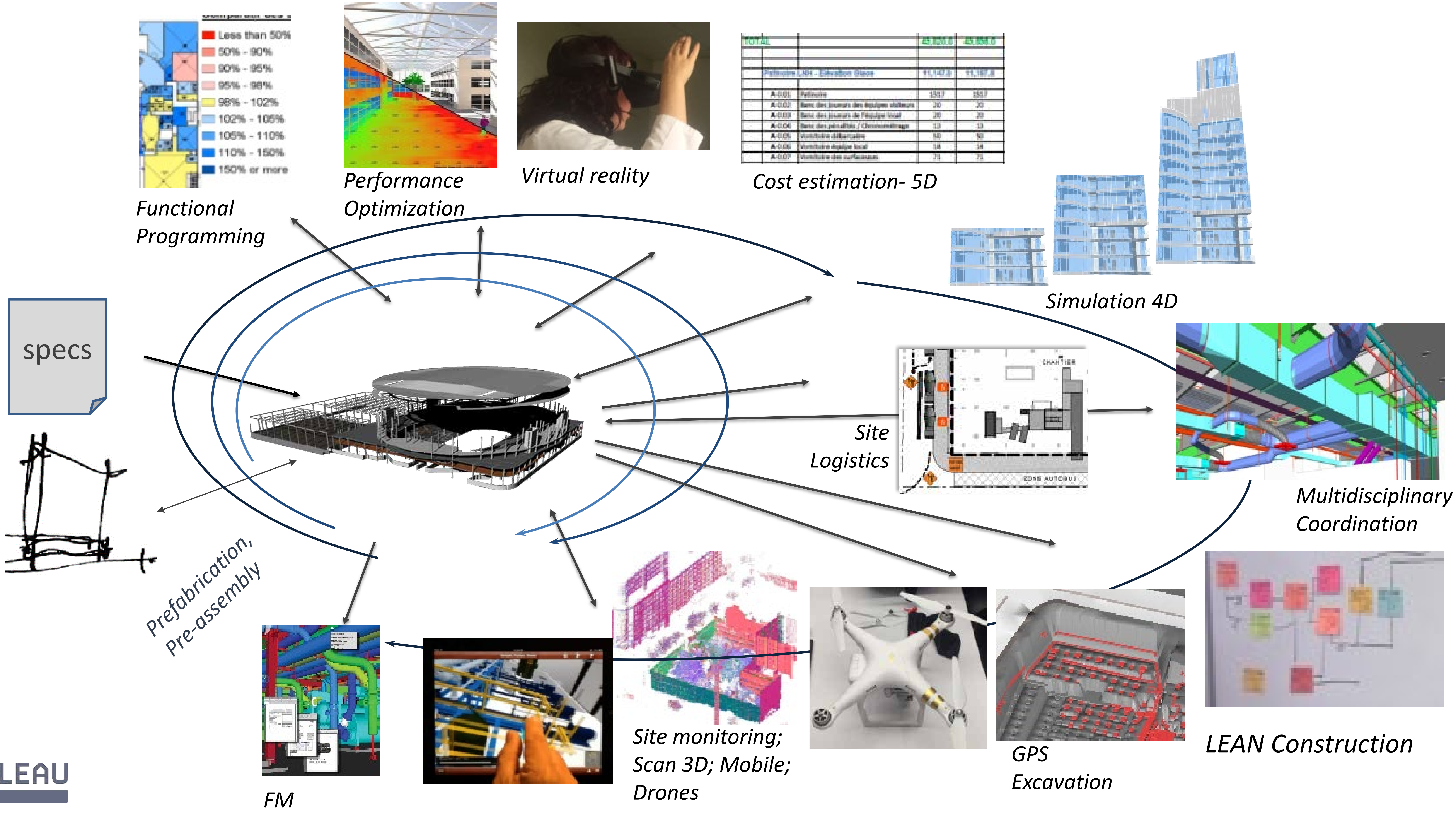
- Environmental crisis

- Housing crisis
- Affordability
- Quality & customer satisfaction

Potential answers

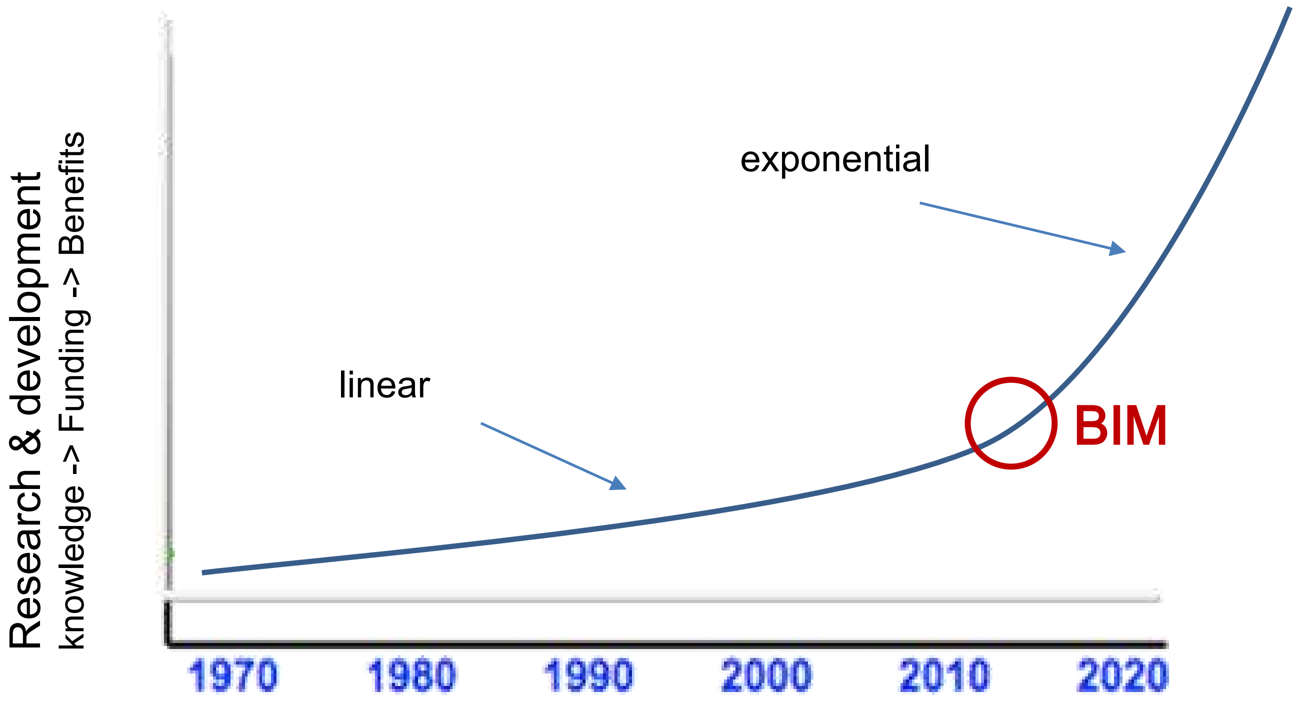
- Digitalisation of the AECO industry
- Industrialisation of construction
- Circular economy strategies for buildings:
  - Réuse and adaptation
    of the existing and future built assets

BIM – BUILDING INFORMATION MODELING



Digital Transformation of AECO industry

BIM (Building Information Modelling)
& accelleration of innovation



BIM VDC
Virtual and augmented reality
Digital Twins
Smart Building Lean construction
Automatisation Smart Cities
Robotisation DfMA
Artificial Intelligence Offsite construction
Digital Fabrication 3D printing
Exosqueletons Circular economy
IoT DfD
Construction 4.0

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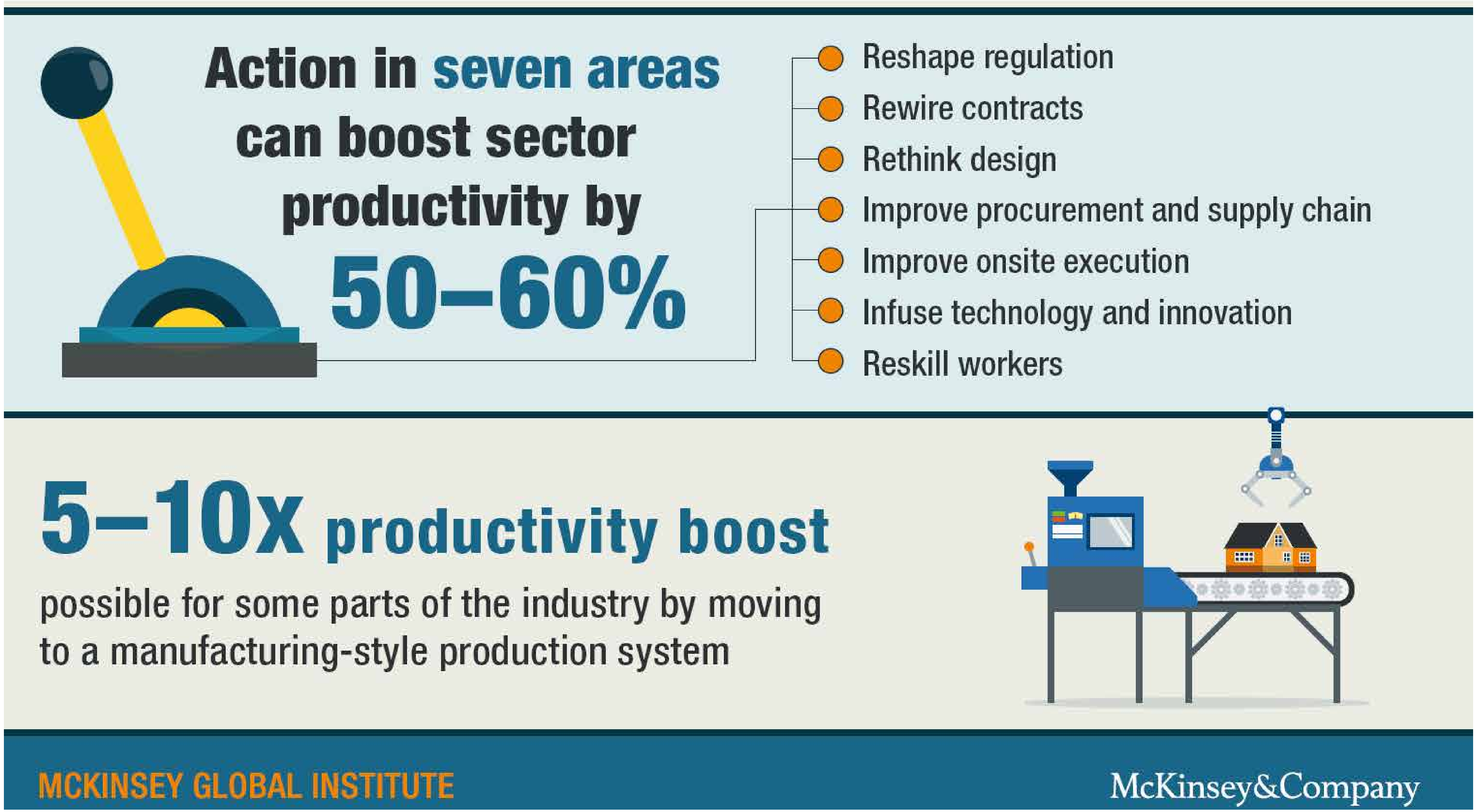
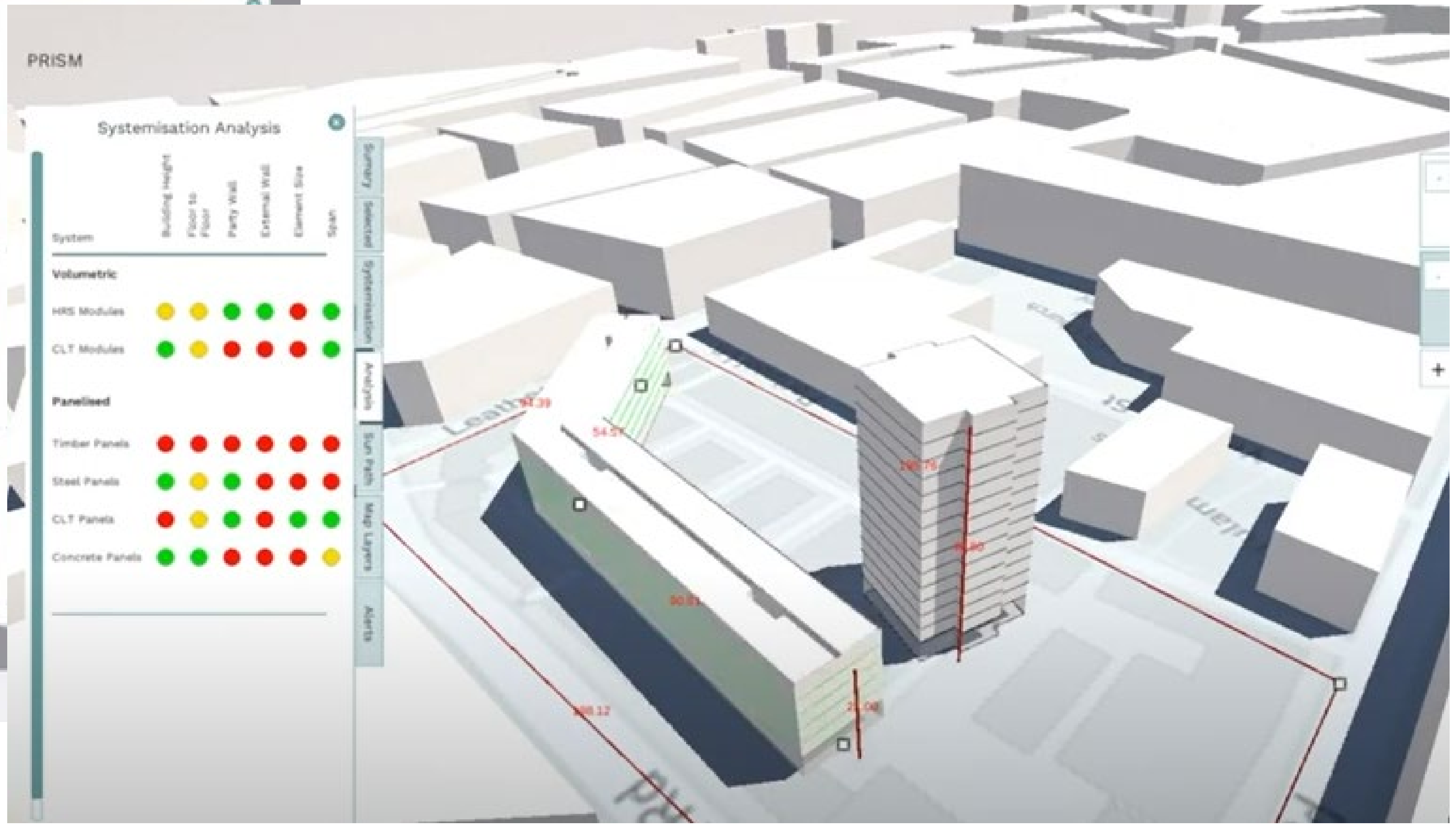

Action in seven areas can boost sector productivity by
50–60%
Reshape regulation
Rewire contracts
Rethink design
Improve procurement and supply chain
Improve onsite execution
Infuse technology and innovation
Reskill workers
5–10x productivity boost
possible for some parts of the industry by moving to a manufacturing-style production system
MCKINSEY GLOBAL INSTITUTE
McKinsey&Company

Transition to industrialised construction - city of London residential projects

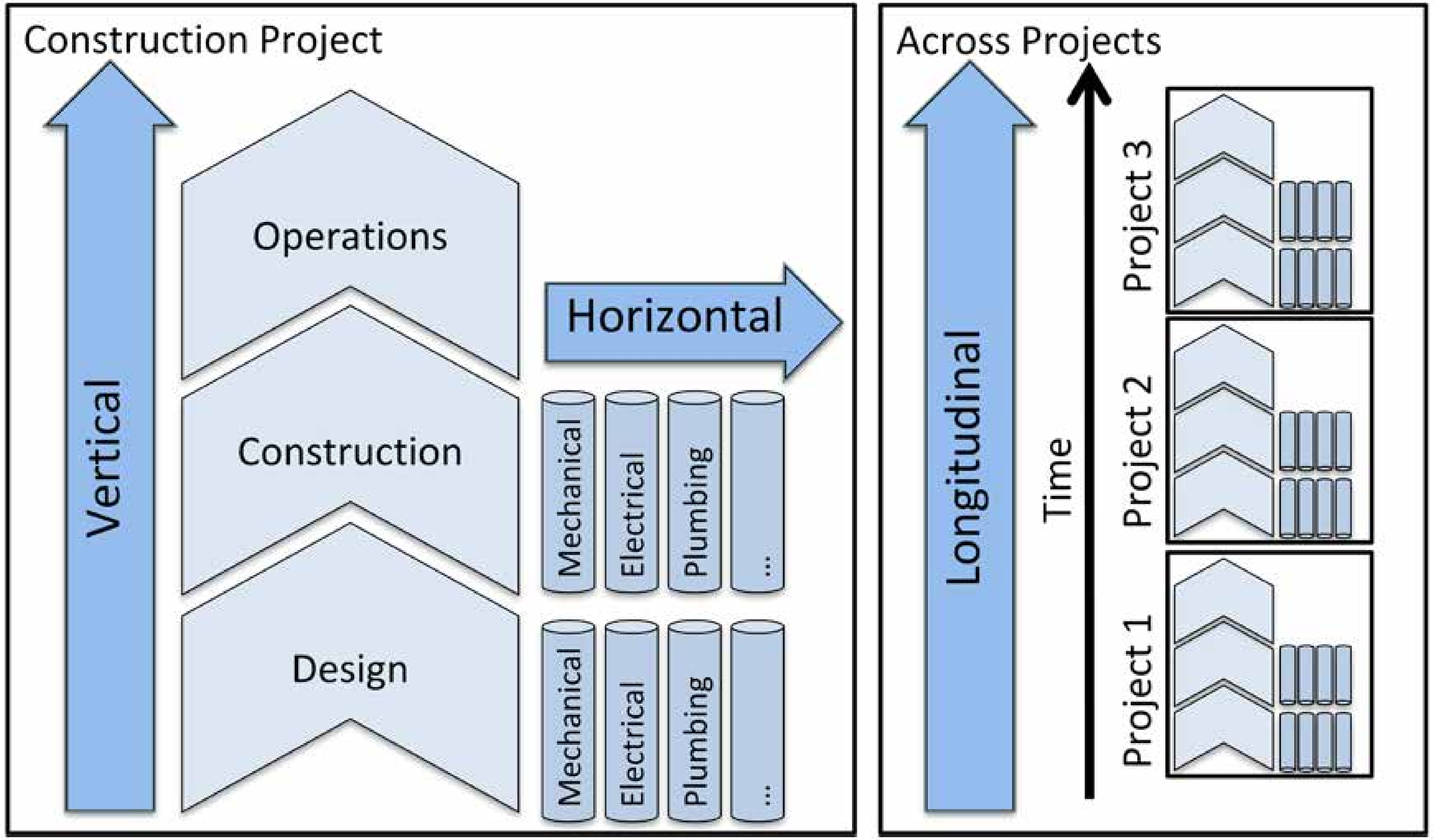
Published: 18 July 2019

The London Mayor's office has sponsored the development of a free application for developers to help conform to London's spatial planning rules and assist in deciding which rapid off-site construction technology best fits their design.



https://www.youtube.com/watch?v=_dzskvz4Yew

Innovation problem: Industry fragmentation



Three Dimensions of Fragmentation in the AEC industry (Sheffer 2011; adapted from Fergusson 1993)

(ref: Hall et al (2014)
www.researchgate.net/publication/281064102

Advantages associated with off-site construction (and industrialized construction)

- Increased productivity
- Shortening of construction time
- Cost predictability and reliability
- Quality improvement

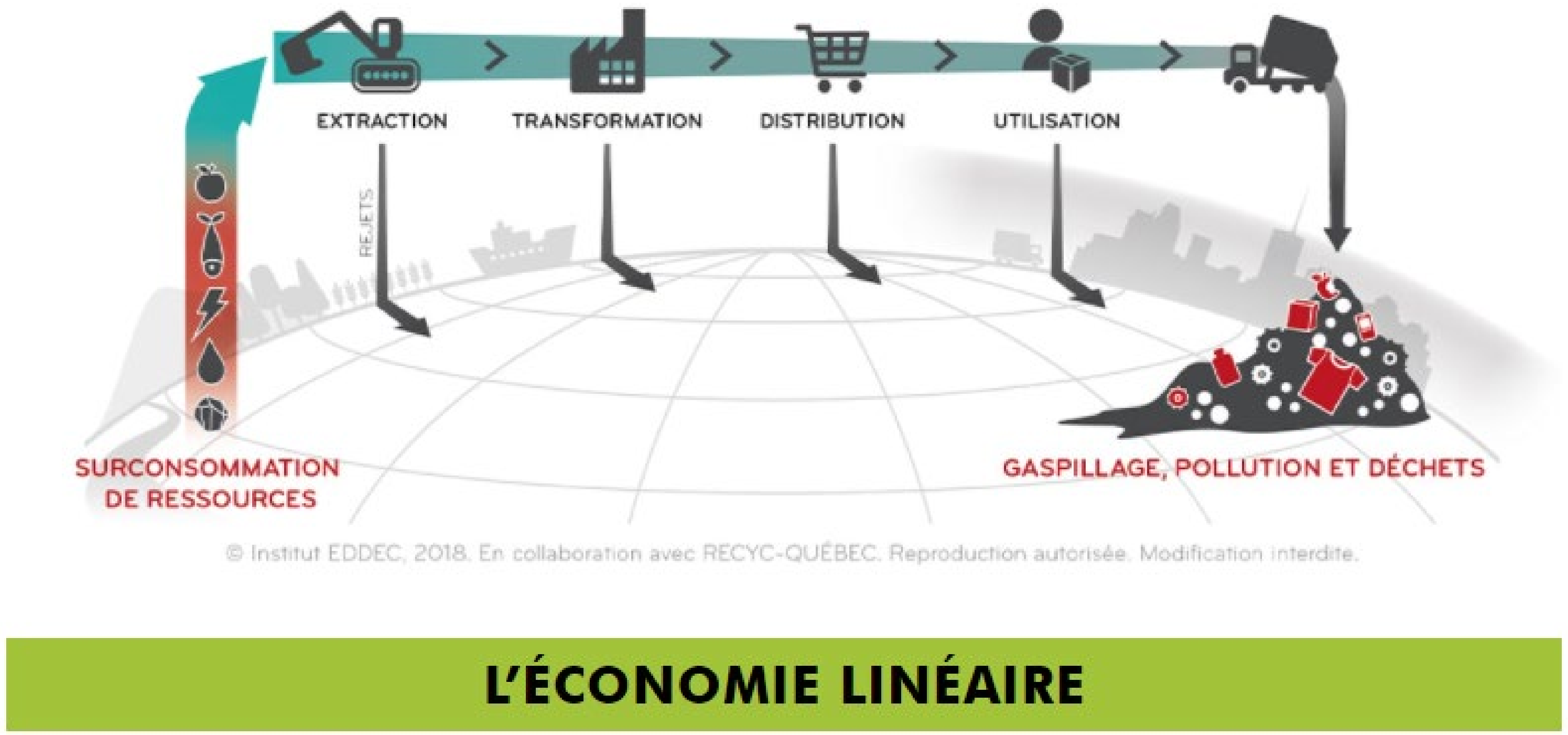
Environmental advantages

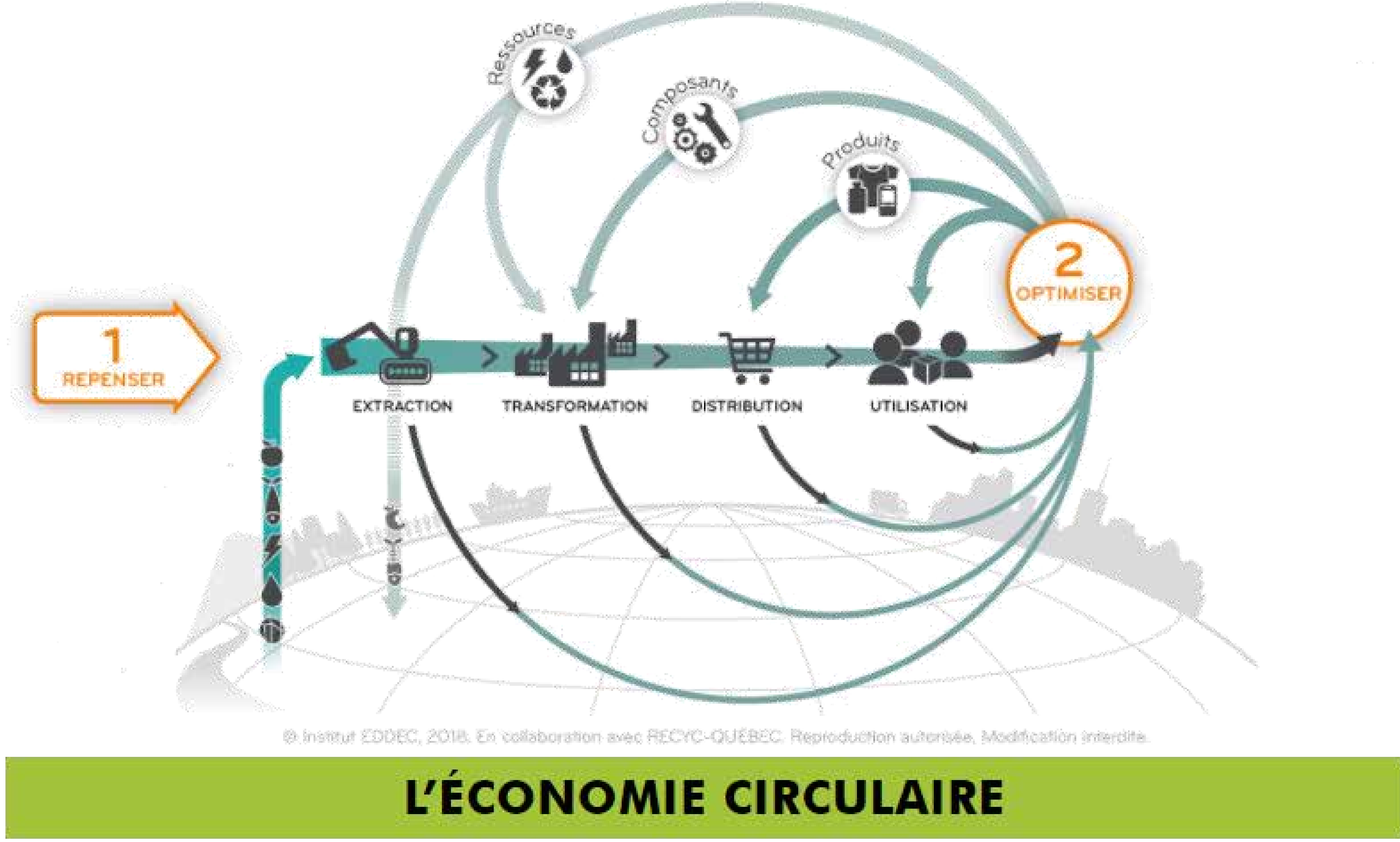
- Supporting sustainable development: Reducing the waste of labor and materials
- Creating better conditions for circular economy: Dry mechanical joints, productization, modularity

Social advantages

- Better conditions for learning and continuous improvement
- Improvement of working conditions
- Positive impact on occupational health and safety
- Possibility to retire later (no heavy impact on the body)
- Favors mental health

Circular economy – a scheme





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Source: Recyc-Québec

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Design for Adaptability (DfAd) - Definitions

- Adaptability : Is the ease with which buildings can be physically modified, deconstructed, refurbished, reconfigured, or repurposed
  (Ross et al. 2016)

- Adaptable Architecture: how to prolong the useful life of buildings by designing them to be more adaptable, creating a more sustainable built environment.
  (Schmidt and Austin, Adaptable Architecture 2016)

Why refurbish, change, adapt?

Physical	Economic	Functional
Weathering	Market fluctuations (real estate values)	Ownership/user needs
Wear and tear	Budget shifts	Organisational expansion/shrinkage
Vandalism	Ownership/use least cost alternative	Type of work (ways of working)
Incompatibility factors (chemical)	Reduction in lease lengths	Quality of workplace (employee comfort)
	Global competition	Flexible employment arrangements
Technological	**Social**	**Legal**
Information technologies	Fashion (aesthetics)	General legislation
Construction methods	Demographics (life expectancy)	Building ordinances (safety regulations)
Material performance	Lifestyle – mobility, density (urbanisation)	Construction standards
Product life cycles	Social agendas, trends	Government grant incentives
Transport facilities	Skills (sophistication of user)	Planning
		Environmental controls

(Schmidt and Austin, Adaptable Architecture 2016)

Circular economy strategies

Increased circularity

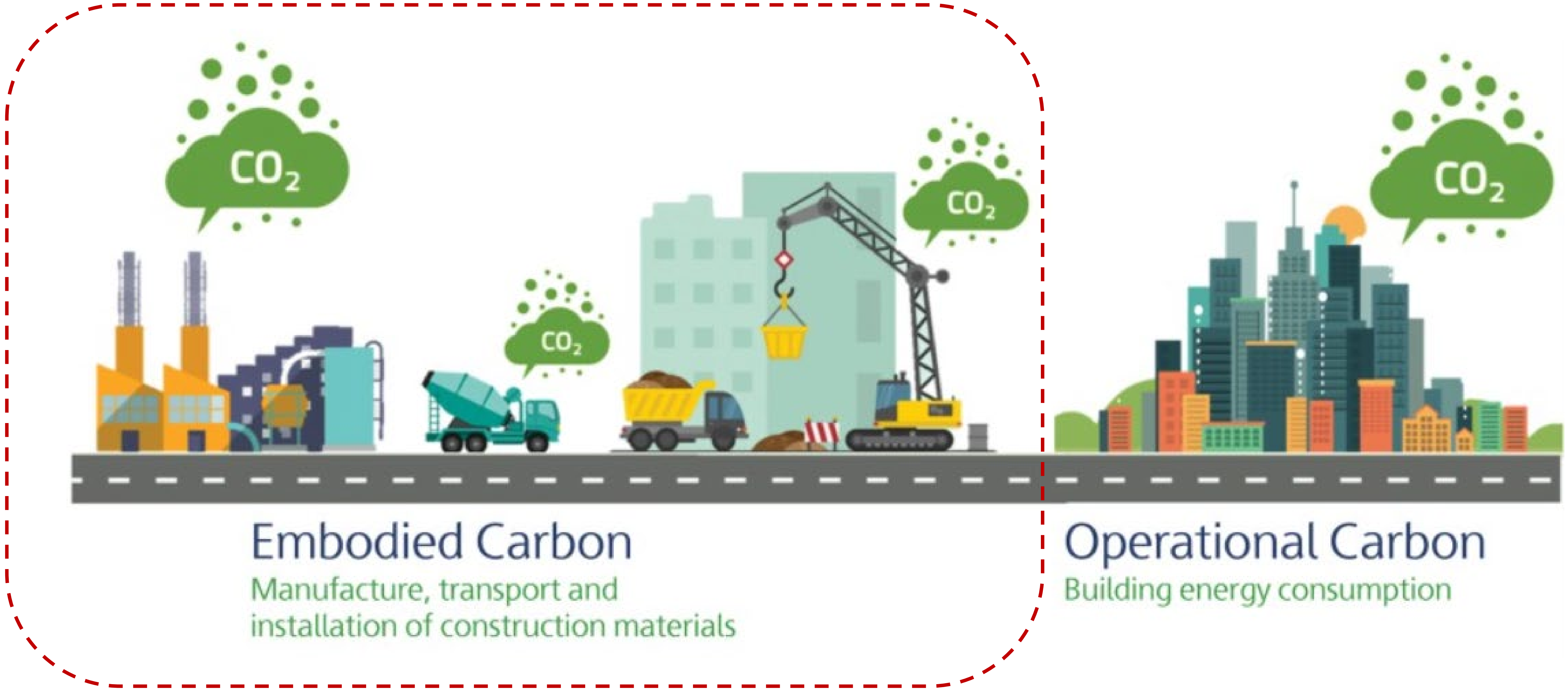
Linear economy

Smarter product use and manufacture	**R0**	**Refuse**	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	**Rethink**	Make product use more intensive (e.g. through sharing products or by putting multi-functional products on market).
	R2	**Reduce**	Increase efficiency in product manufacture or use by consuming fewer natural resources
Extend lifespan of product and its parts	**R3**	**Reuse**	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	**Repair**	Repair and maintenance of defective product so it can be used with its original function
	R5	**Refurbish**	Restore an old product and bring it up to date
	R6	**Remanufacture**	Use parts of discarded product in a new product with the same function
	R7	**Repurpose**	Use discarded products or its part in a new product with a different function
Useful application of materials	**R8**	**Recycle**	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	**Recovery**	Incineration of material with energy recovery

Potting et al. (2017)

Circular economy and industrialized construction?

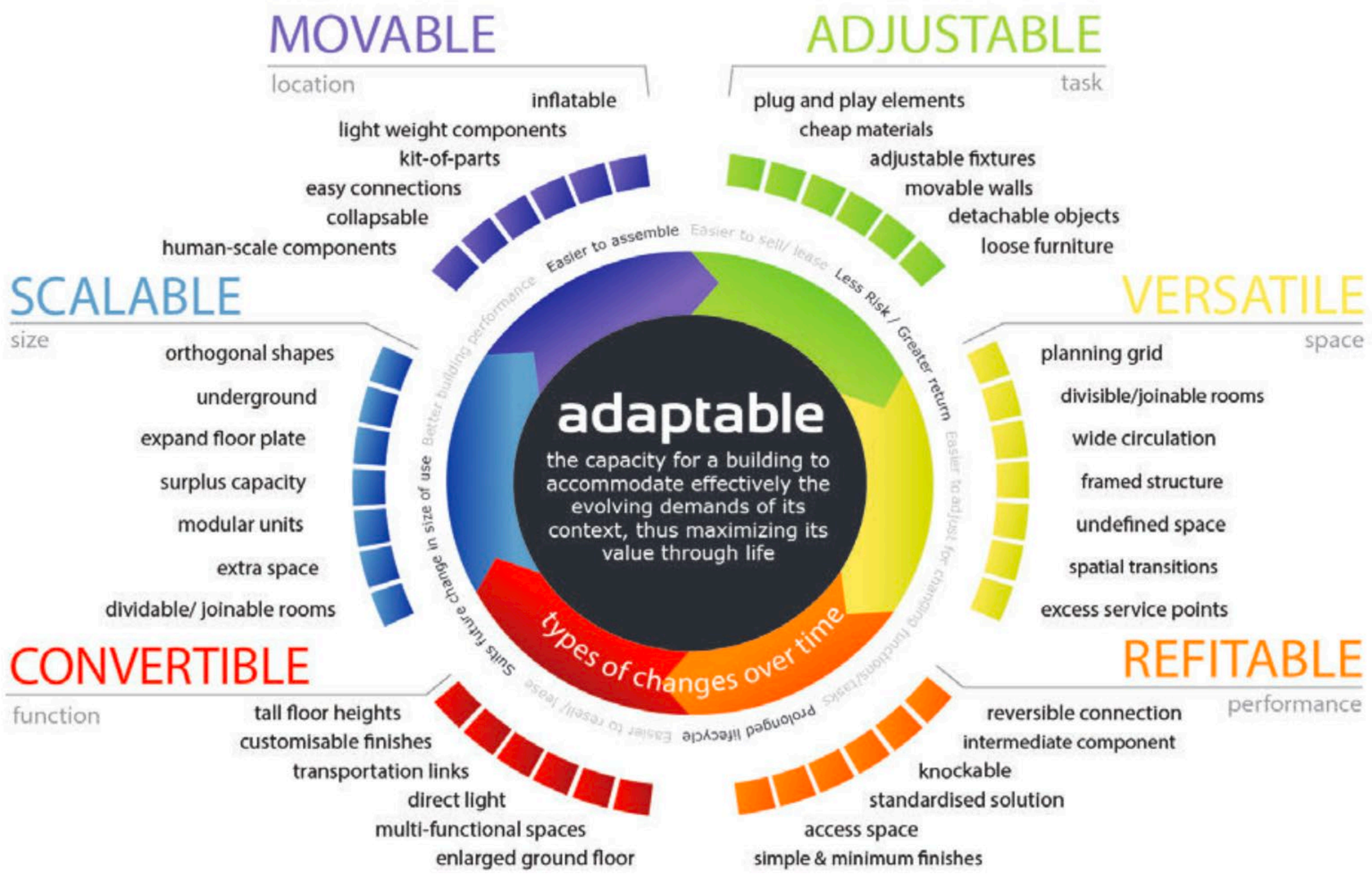
- Reduce material waste
- Potential for adaptability and deconstruction
- Less transport (of materials and of people)
  - Smaller carbon footprint



Typology of building's adaptability

(Schmidt and Austin, Adaptable Architecture 2016)

Adaptability Typologies



Source: Adaptable future 2012

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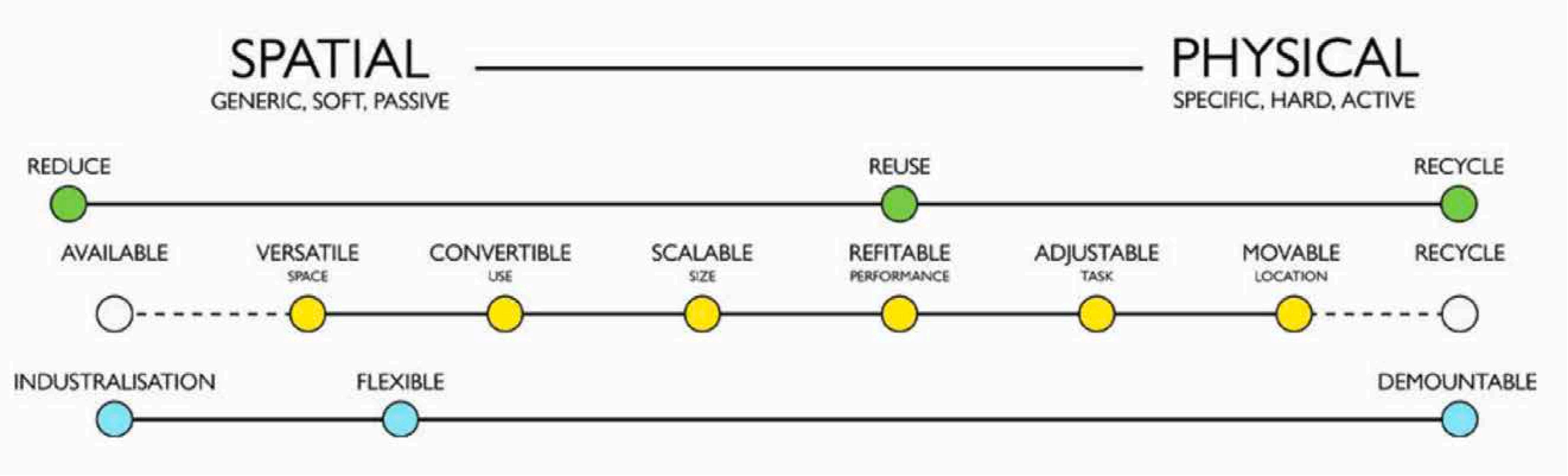
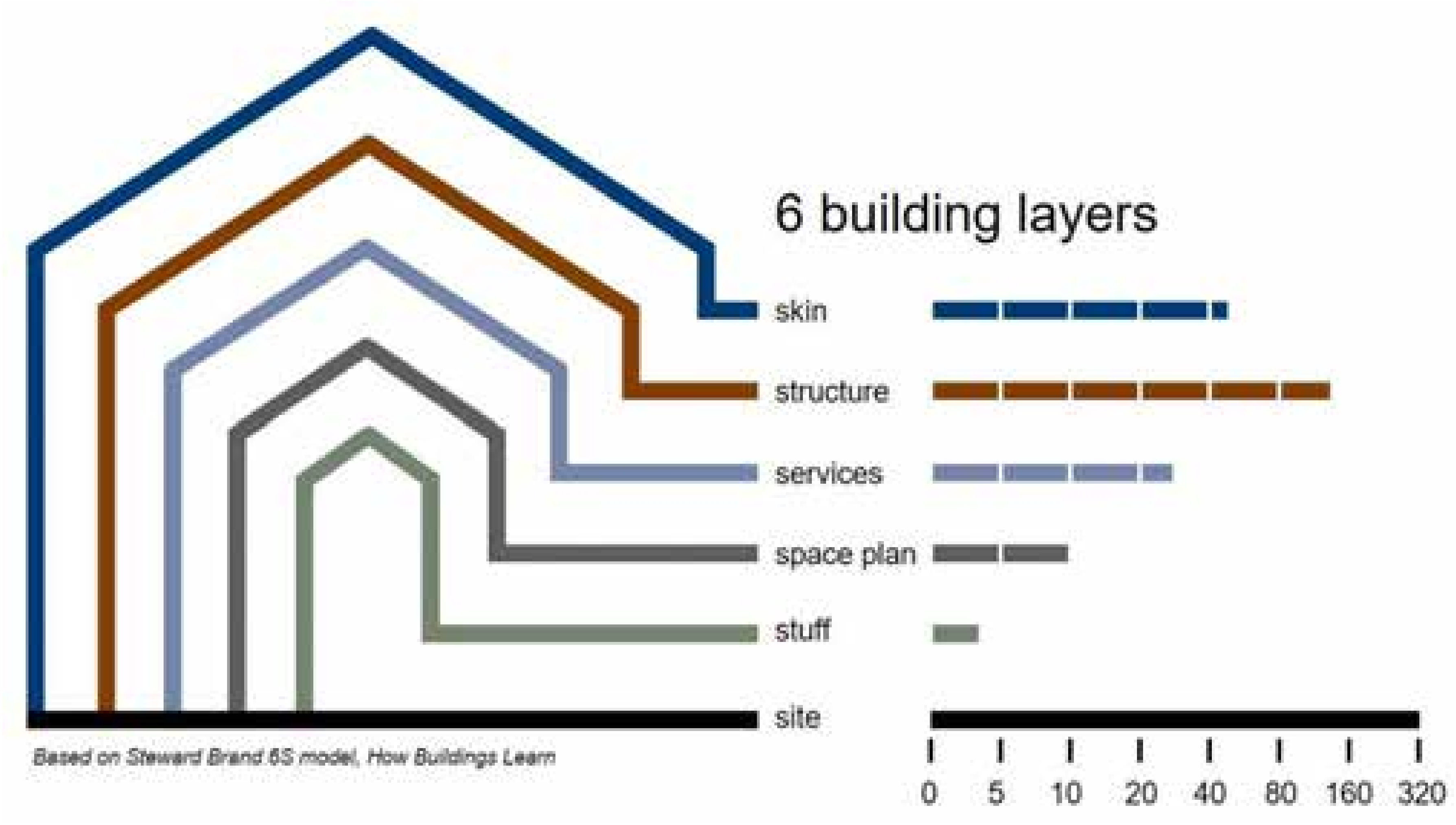
Relations between building aspects, CE strategies and adaptability strategies



(Schmidt and Austin, Adaptable Architecture 2016)

Building Layers (shearing layers)



- Layers provide a way of thinking about the building that link both time and the building's material form, conceiving components as different 'layers' of longevity.

Design strategies:

- Separation of systems depending on their life-length
- 'Dry' mechanical connections
  - Modular construction
  - IBS (Industrialized Building Systems)
- Structural decomposition 'Super Skeleton & Intelligent Infill'
- Open Building concept
- Systemic multilevel grids
- Open engineering systems

Source: Building layers and time (adapted from Brand, 1994)

Some high level design strategies

Physical elements	Spatial aspects	Building character	Contextual
DS01: Modularity	DS05: Loose fit	DS11: Aesthetics	DS12: Multiple scales
DS02: Design 'in' time	DS06: Spatial planning		
DS03: Long life	DS07: Passive techniques		
DS04: Simplicity and Legibility	DS08: Unfinished design		
	DS09: Maximise building use		
	DS10: Increased activity		

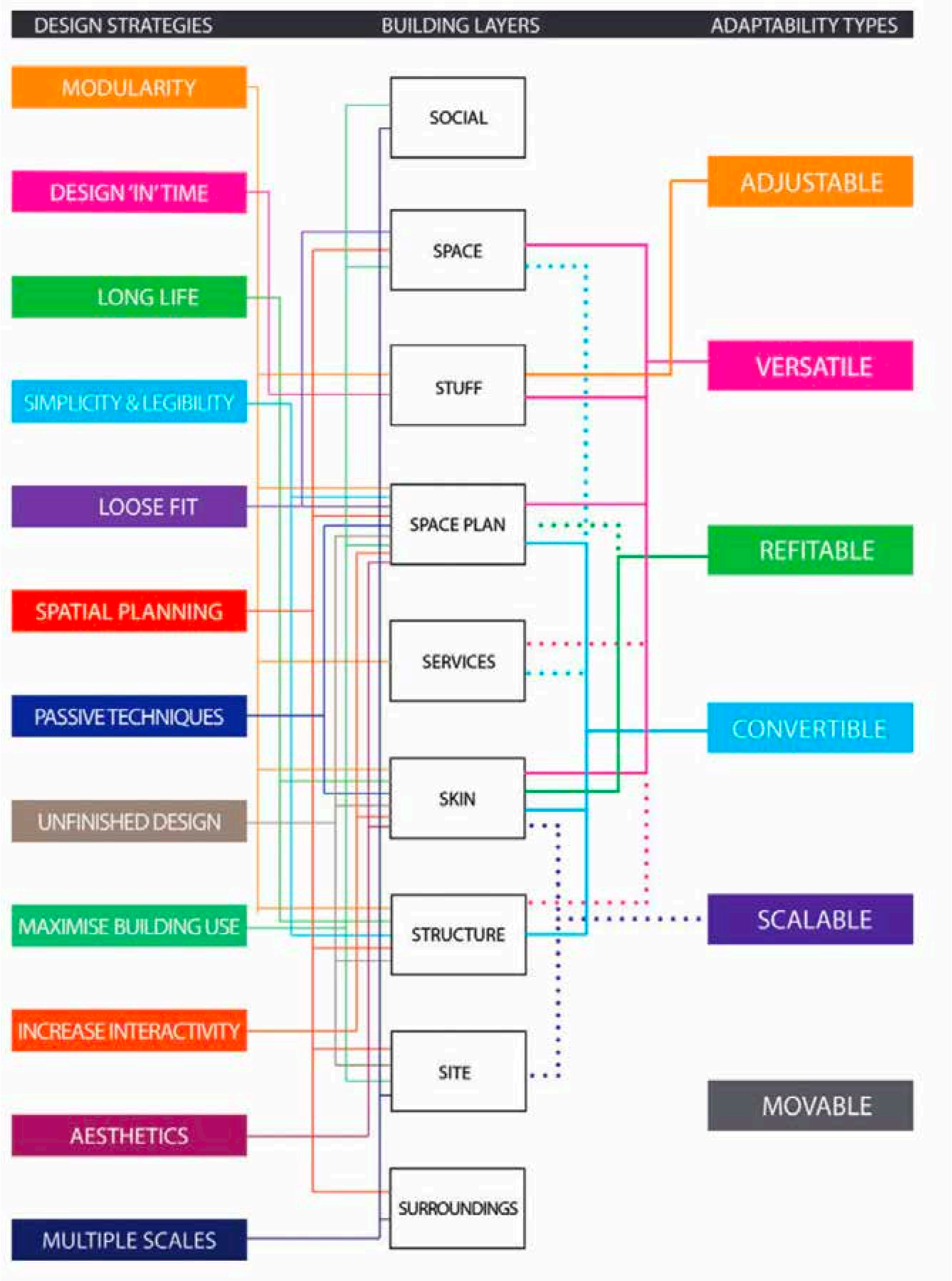
(Schmidt and Austin, Adaptable Architecture 2016)

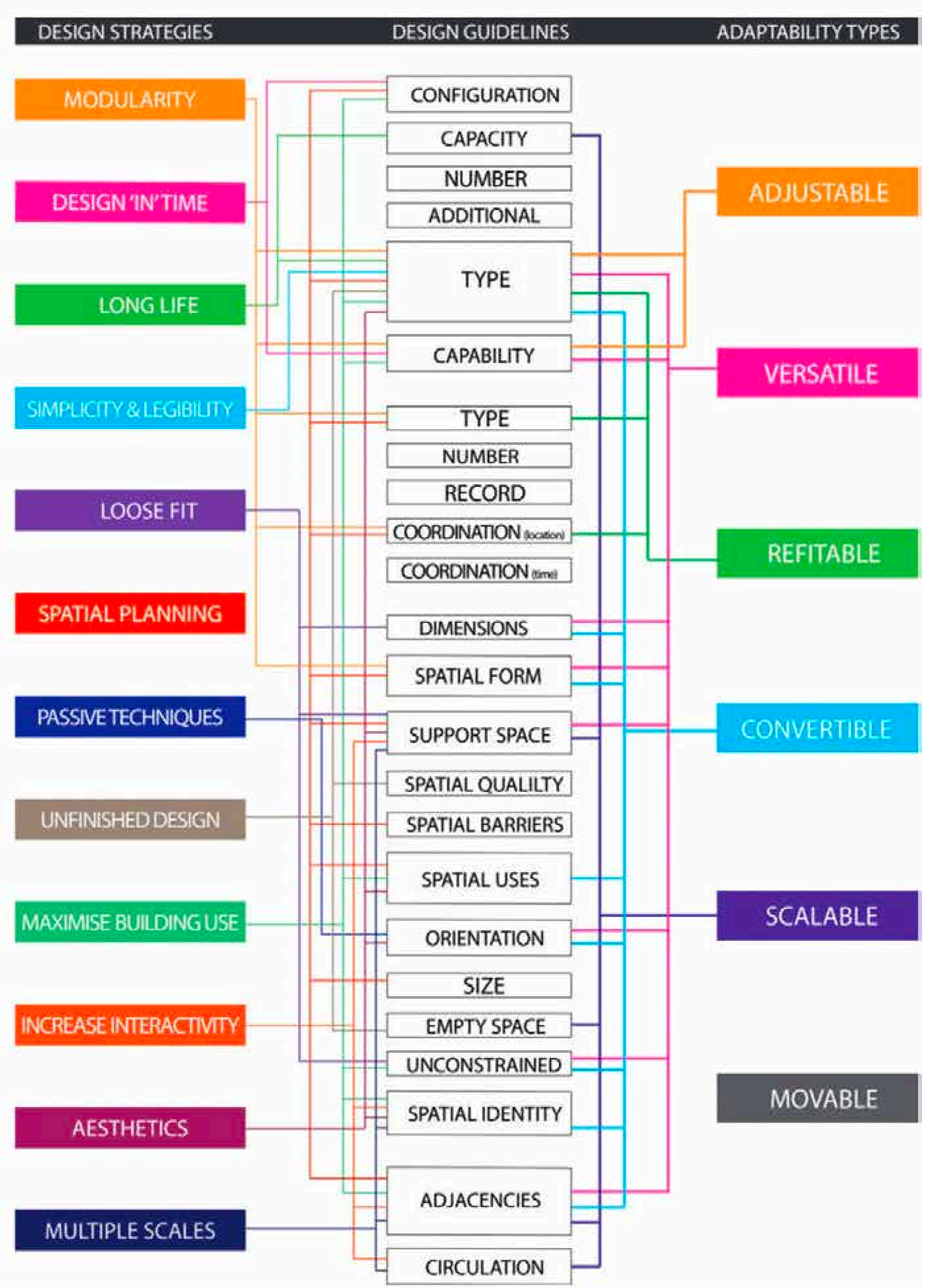
On modularity

DESIGN STRATEGIES x12	BUILDING CHARACTERISTICS x60		
DS1 MODULARITY separation of the physical parts of the building into defined functional entities	**CAR1**	**Reversible**	capacity for the construction to be separated into its constituting parts (with minimum if any damage)
	CAR2	**Movable Stuff**	furniture, equipment or fixtures that can be moved throughout the building freely
	CAR3	**Component Accessibility**	components within the building are easily accessible; other components are not damaged in the process
	CAR4	**Functional Separation**	separation of functions into different constituting parts; 1:1 function to component relationship
	Design tactics		DT1–9
	Case studies		A4, A5, A14 and A15

(Schmidt and Austin, Adaptable Architecture 2016)

Meta model





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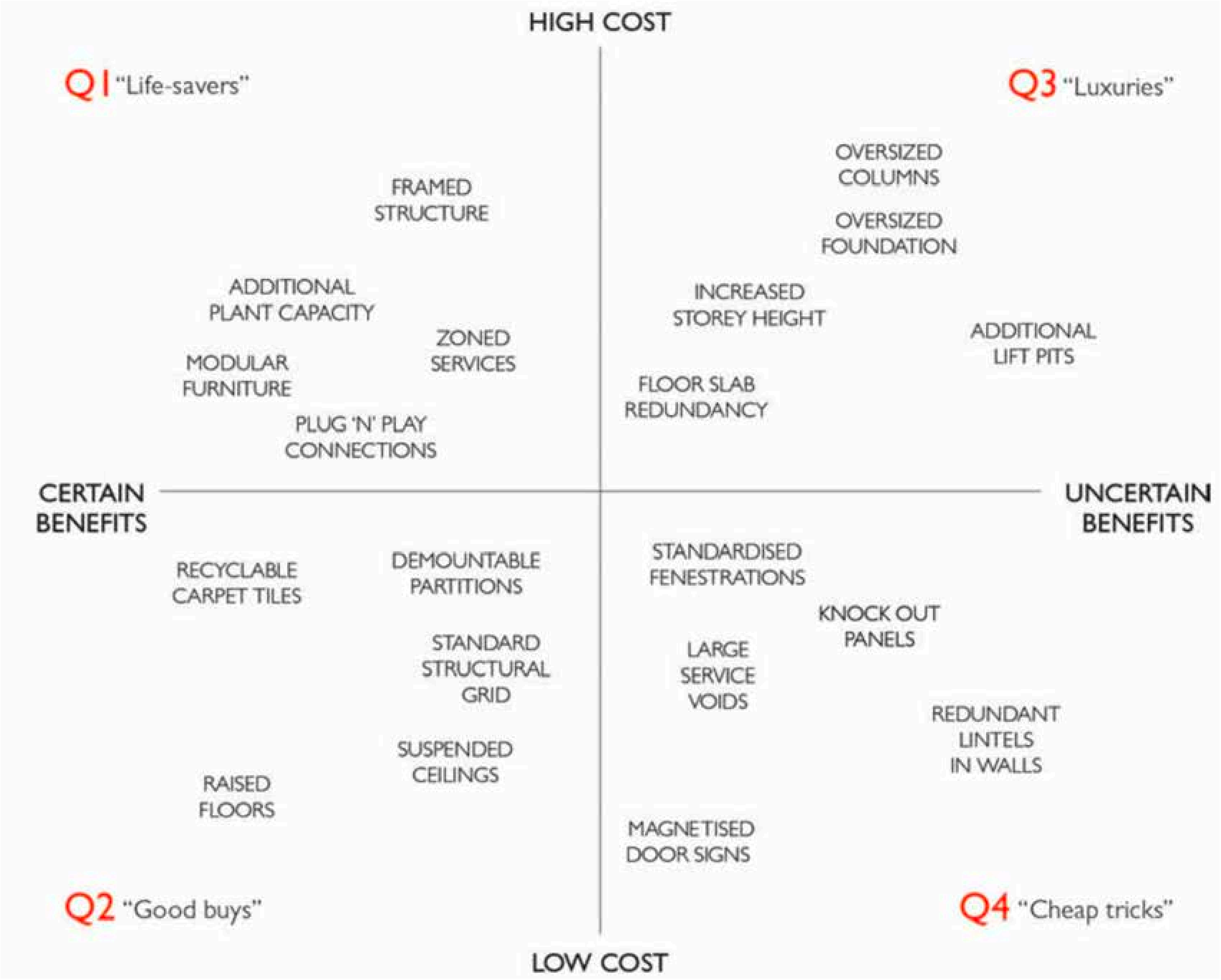
Cost certainty meta-model



(Schmidt and Austin, Adaptable Architecture 2016)

Design for adaptability principles

- Layering Building Components & Systems
- Reserve Capacity
  (accommodate a potential increase in future loads)
- Design for Deconstruction (DfD)
  to be able to reuse the elements after deconstruction
- Mechanical Connections
- Modularization
  (standardization of components *sizes* and *interfaces)*
- Commonality
  (using the same component sizes and construction details throughout a building)
- Accurate Information
  (plans, BIM)
- Access for Assessment
  (layers; visual and remote sensing)
- Simplicity
  (provides certainty for designers working on adaptation)
- Appropriate Materials
  (durable, non-toxic)
- Open Plan Layouts

The prerequisits – digitalisation + industrialisation

Benefits of digitalisation
(among others)

- Precise coordination (BIM)
- Simulation of the adaptability
- DfMA – DfMAd (*Design for Manufacturing and Adaptability*)
- Information tracking diring the building's lifecycle (*Digital thread*)

Benefits of industrialisation
(among others)

- Mechanical (dry) connections
- Standardisation of the interfaces between parts
- Modularisation
- Simplified assembly (*Plug-and-play*)

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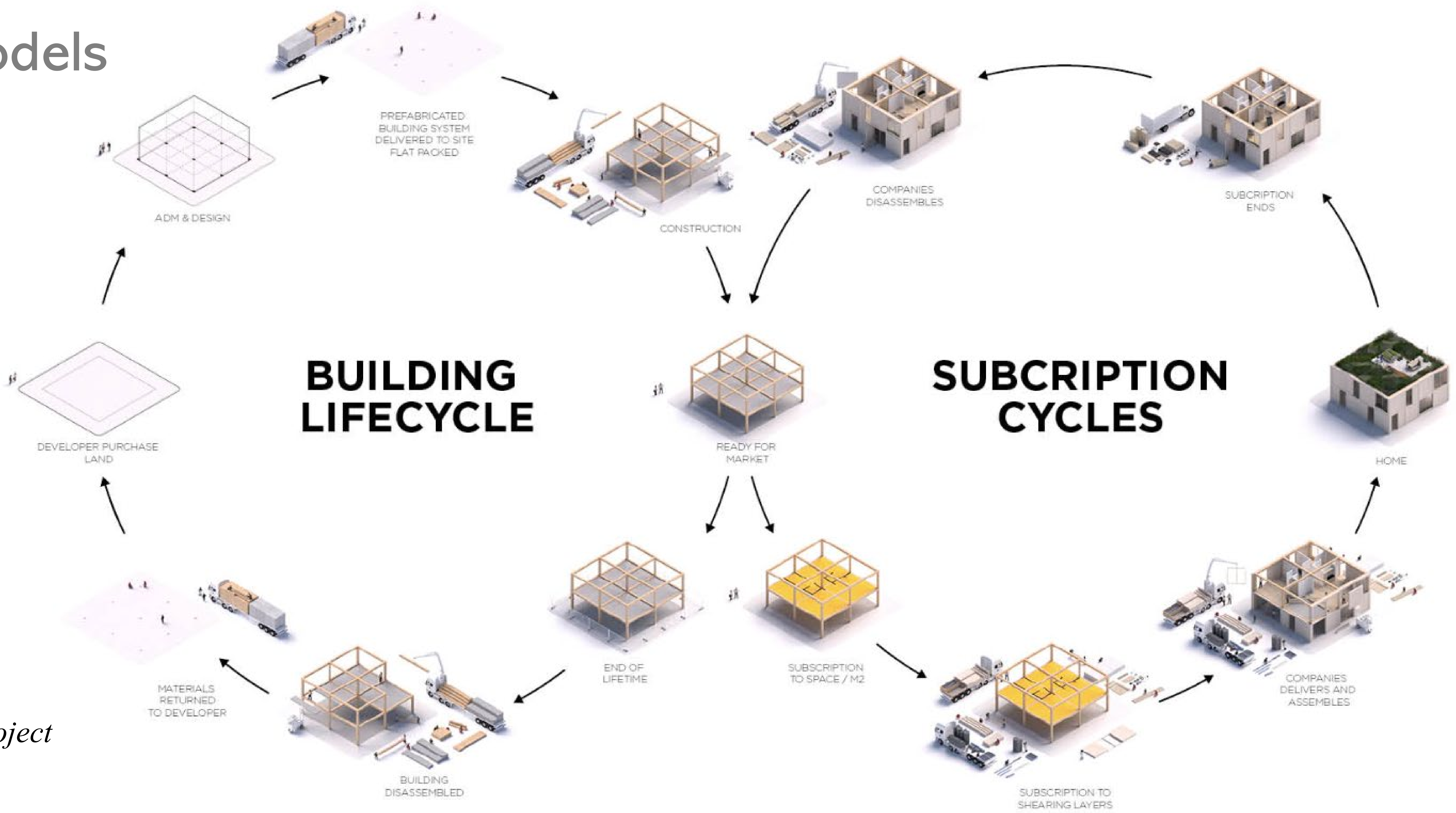
Change in the business models



The Urban Village Project

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https://www.effekt.dk/urbanvillage

Some examples of modularity and adaptability

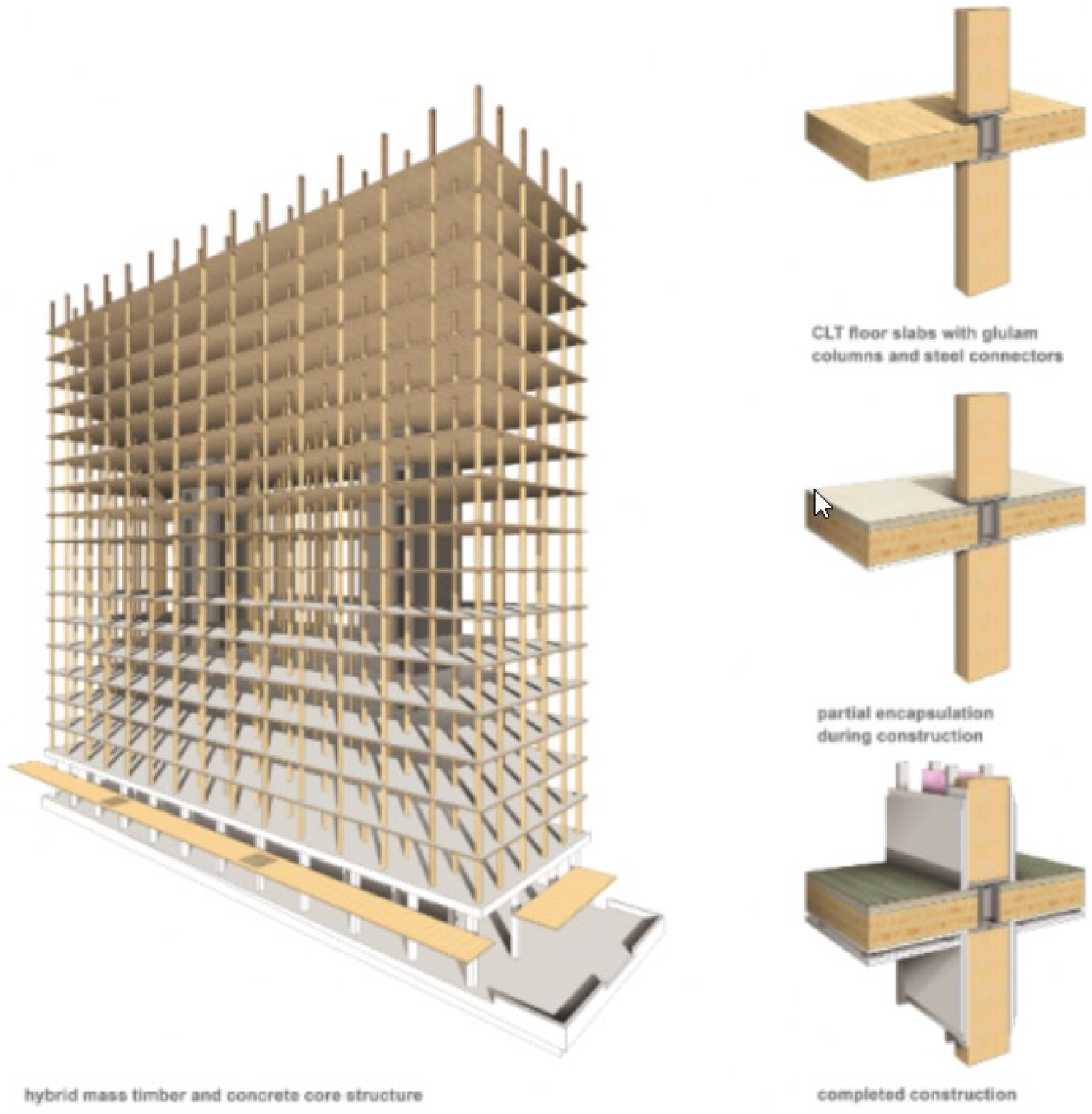
Modular & deconstructable buildings

- Extension modulaire de l'hôpital Maisonneuve-Rosemont
- Certains stades du FIFA-22

Stadium 974 by Fenwick Iribarren Architects

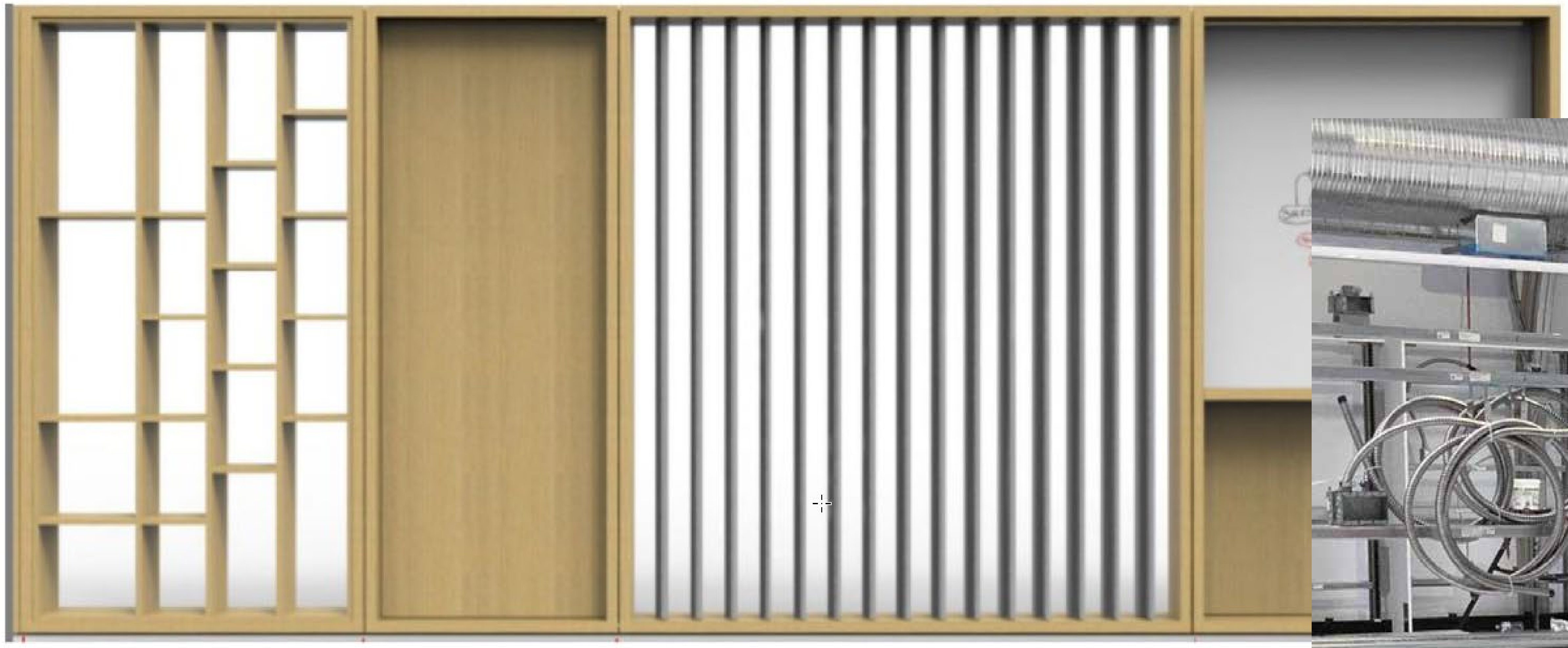
https://lefil.ciusssestmtl.net/survol-dun-batiment-tout-neuf/

Engineered wood
UBC – Brock Commons, Vancouver

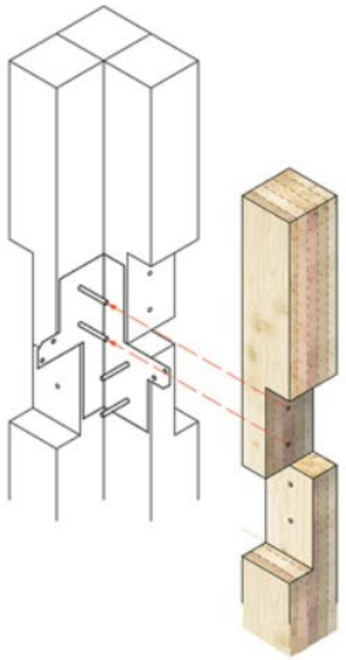


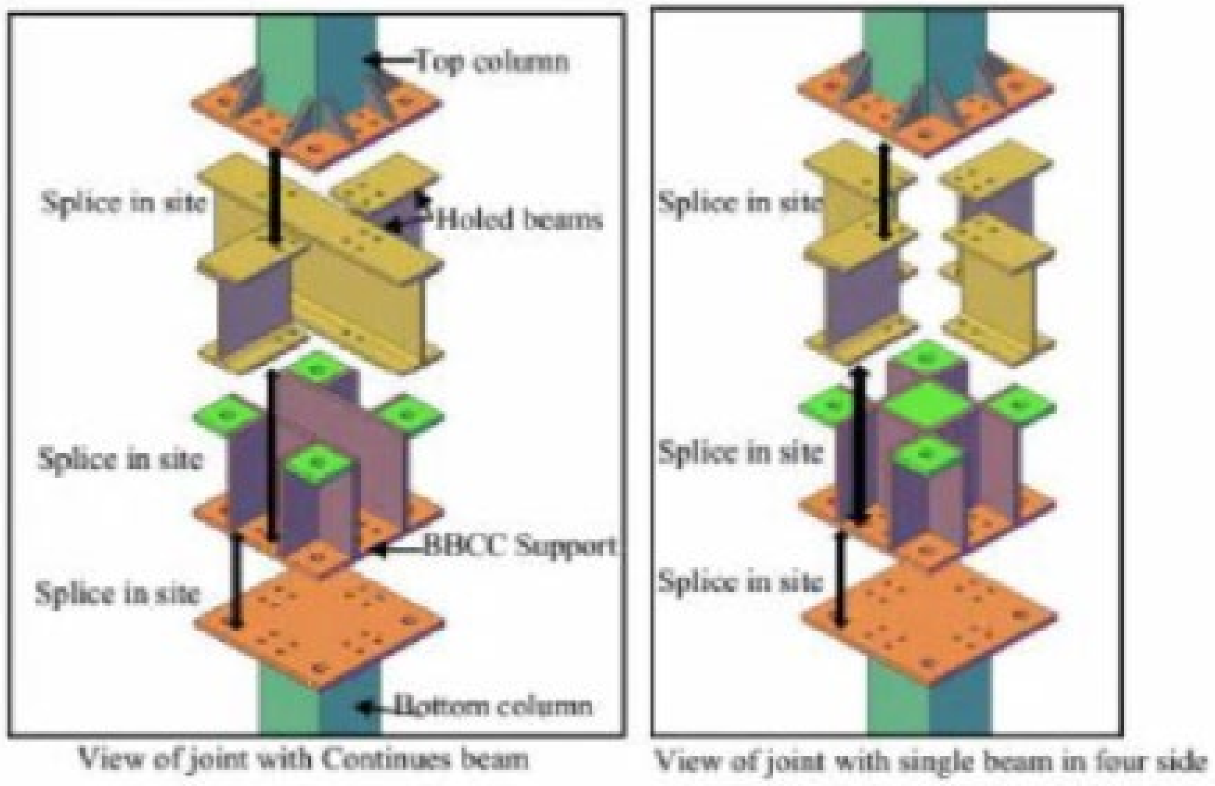
www.canadianarchitect.com/brock-commons-acton-ostry-standing-tall/

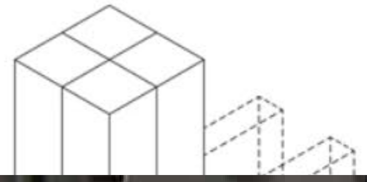
Modularity and standardised interfaces



Dry mechanical connections







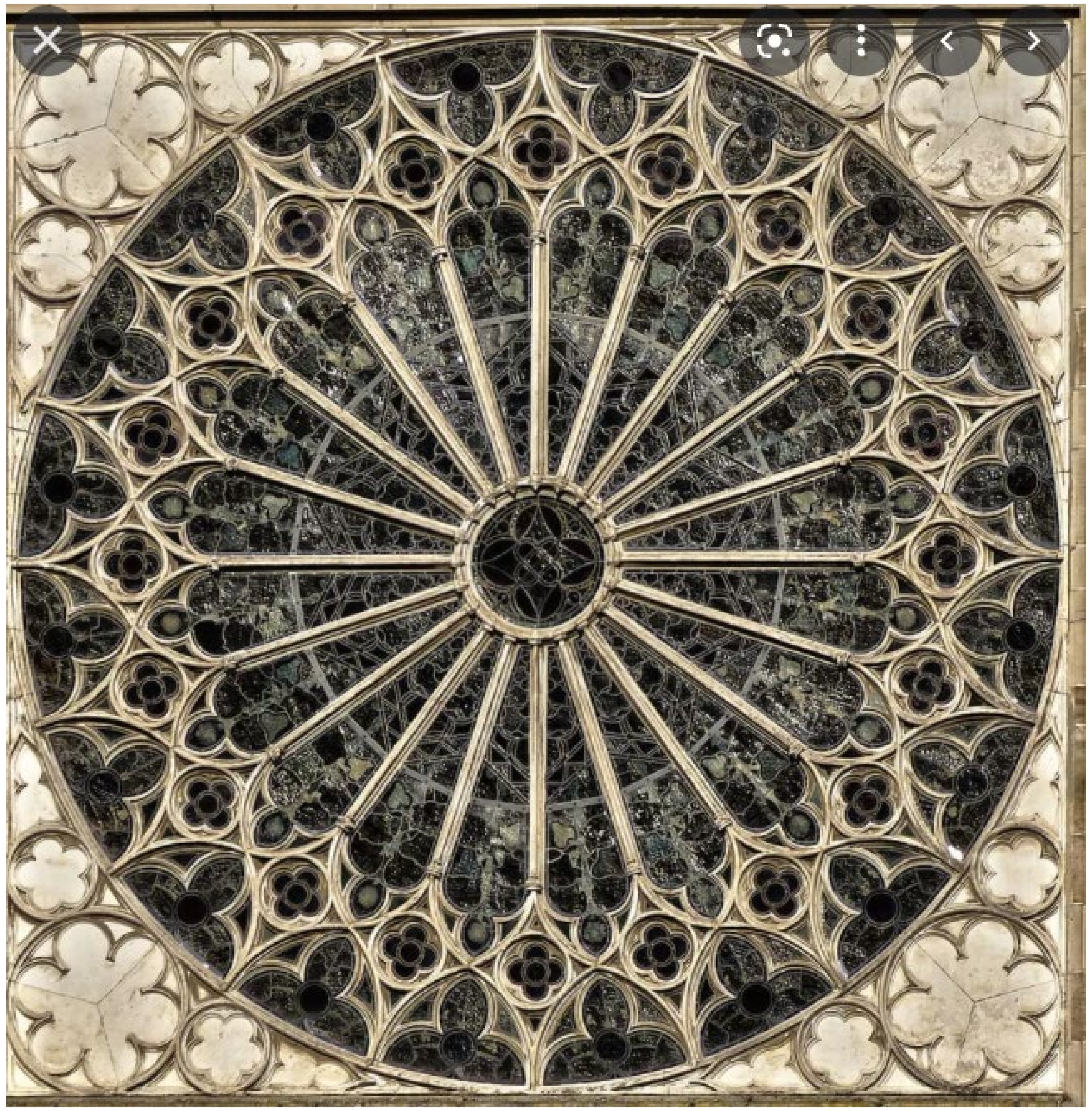
Source: ArchDaily

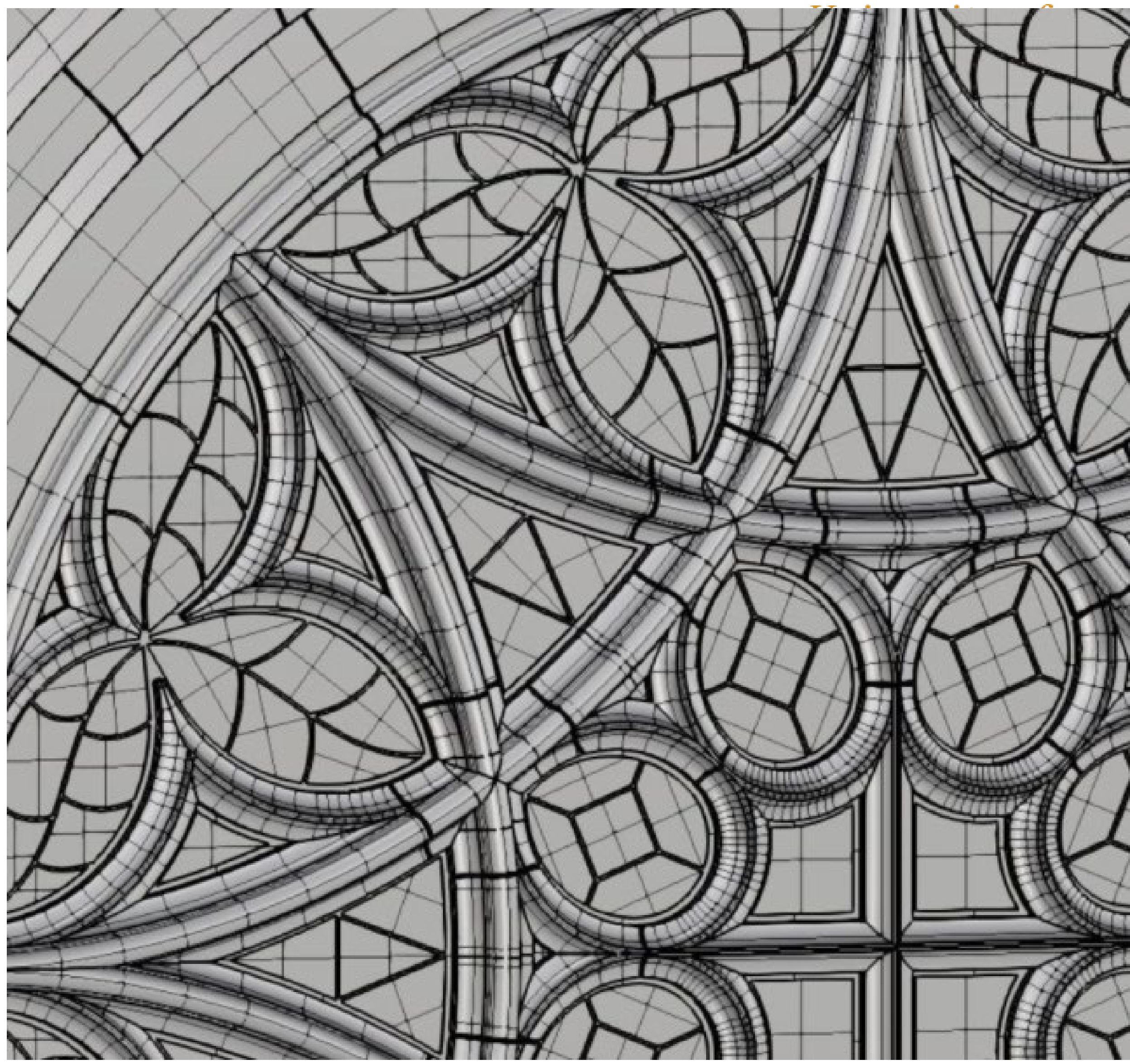
The challenges

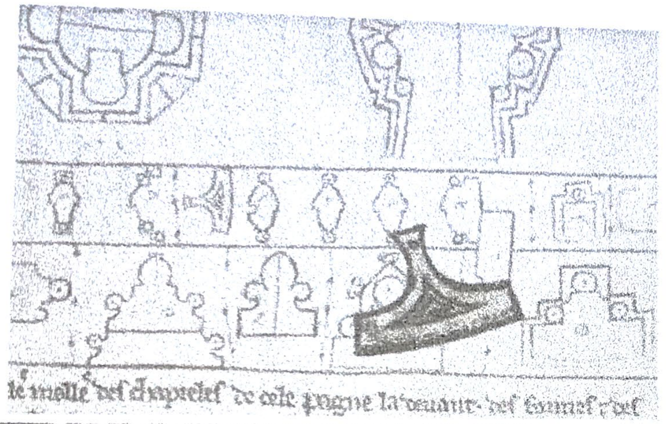
- Perception of repetitive & monotonous architecture
- Needs change in the business models
- Provoques changes in the traditional roles
- Suffers from the fragmentation of the AECO industry

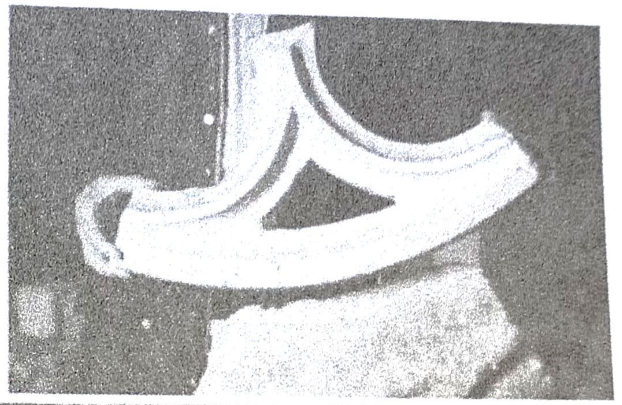
Can we rehabilitate
the notion of 'standard'?

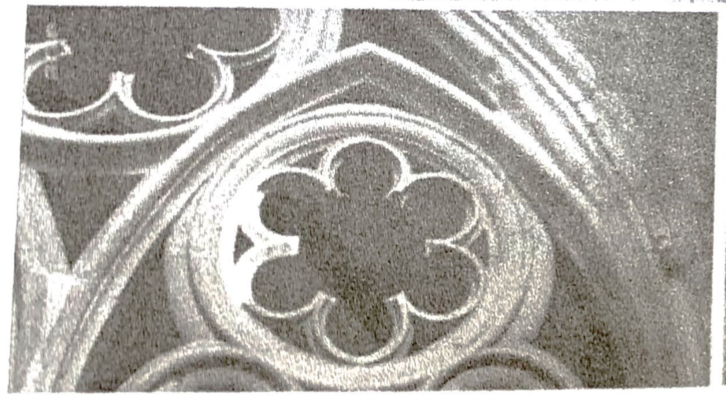
The Gothic rose

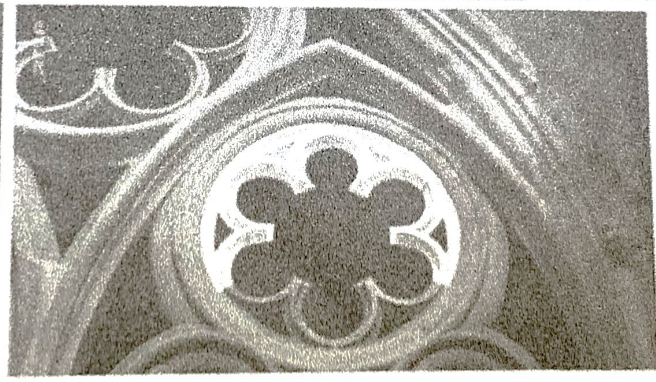












‘Rodin: Transforming Sculpture’

Rodin’s small model of ‘Three Shades’ (1897).

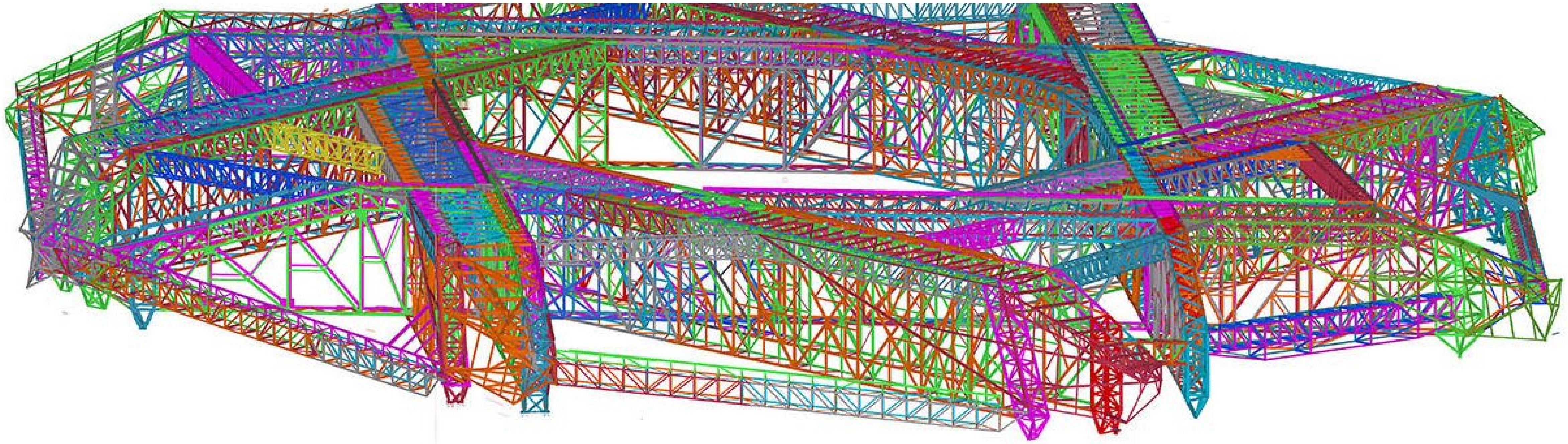
PHOTO: CHRISTIAN BARAJA/MUSÉE RODIN

https://www.wsj.com/articles/rodin-transforming-sculpture-review-reinventing-an-art-form-1470258143

Rodin’s most radical innovation: the recombinant figure

Rodin used the term bozzetti for his beloved “pieces” or sculptural studies of tiny arms, heads, legs, hands and feet, which he modelled in clay before having several casts of them made in plaster. He thus built up a repertory of forms, into which he readily delved to complete his fragmentary figures, composing new groups and assemblages in a totally unprecedented manner. (musee-rodin.fr)

Steel structures



The challenges- repetitive and monotonous architecture

- Mass ccustomisation
- Flexibility
- Adaptability

- Digitalisation & robotisation

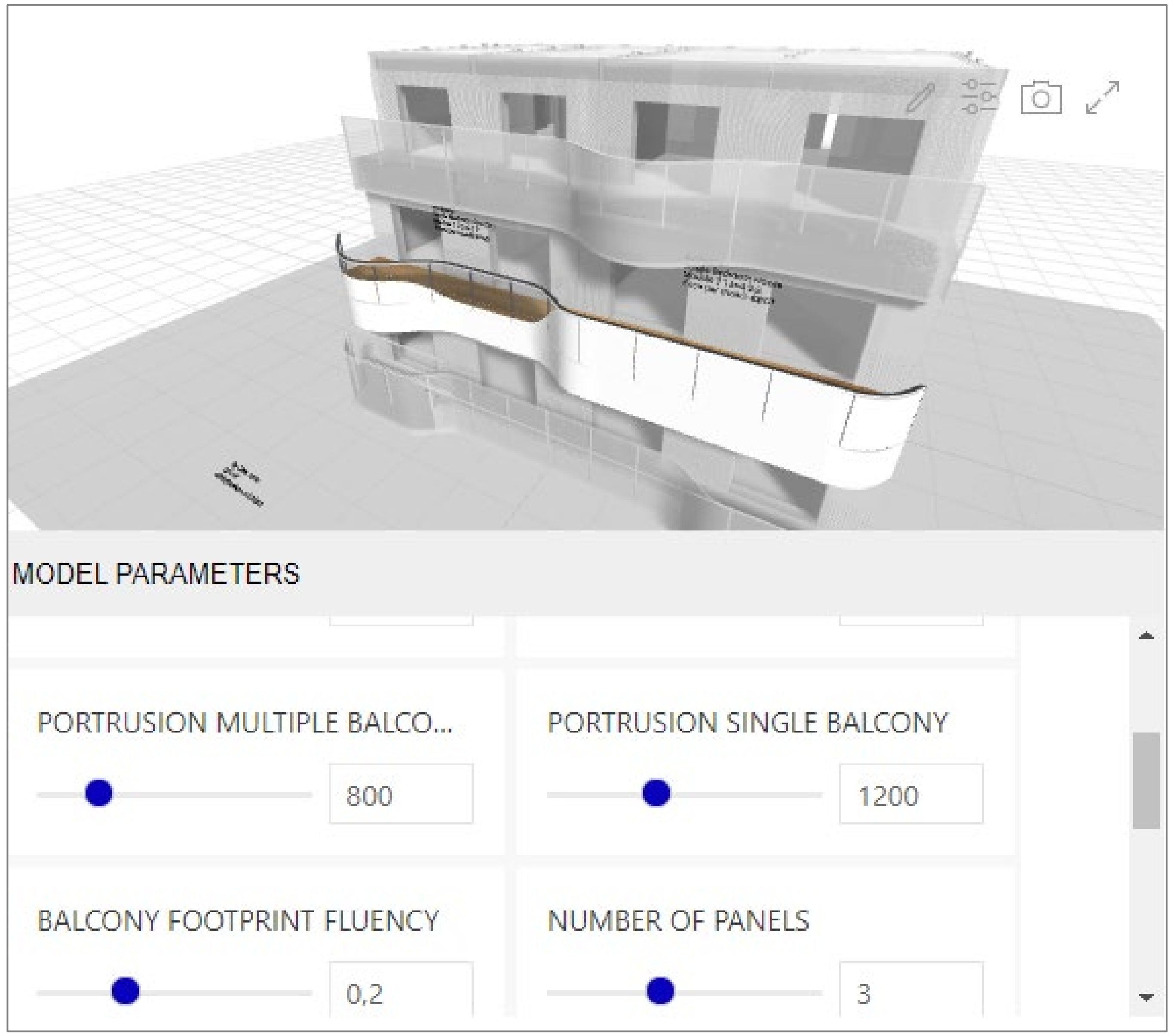
The Sydney Opera house

https://robbievanleeuwen.github.io/engineering%20journalism/sydney-opera-house/

www.designweek.co.uk/issues/april-2014/building-the-sydney-opera-house/

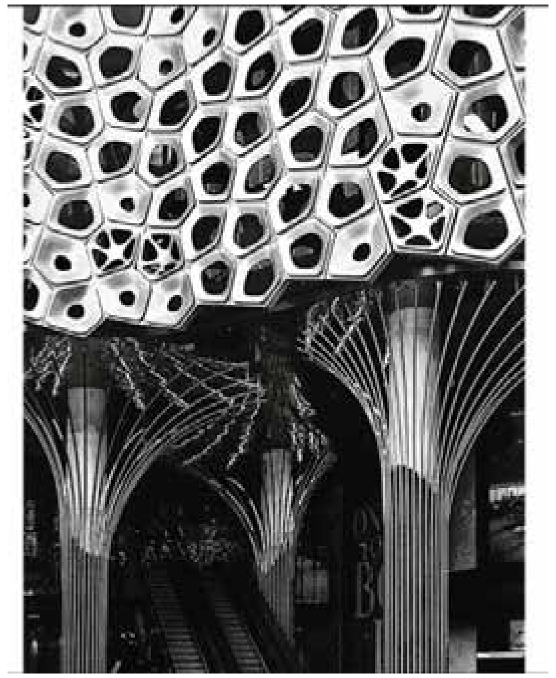
www.reddit.com/r/architecture/comments/kmyzaa/sydney_opera_house_under_construction_1973/

Mass customization



www.aplusv.solutions/systems/

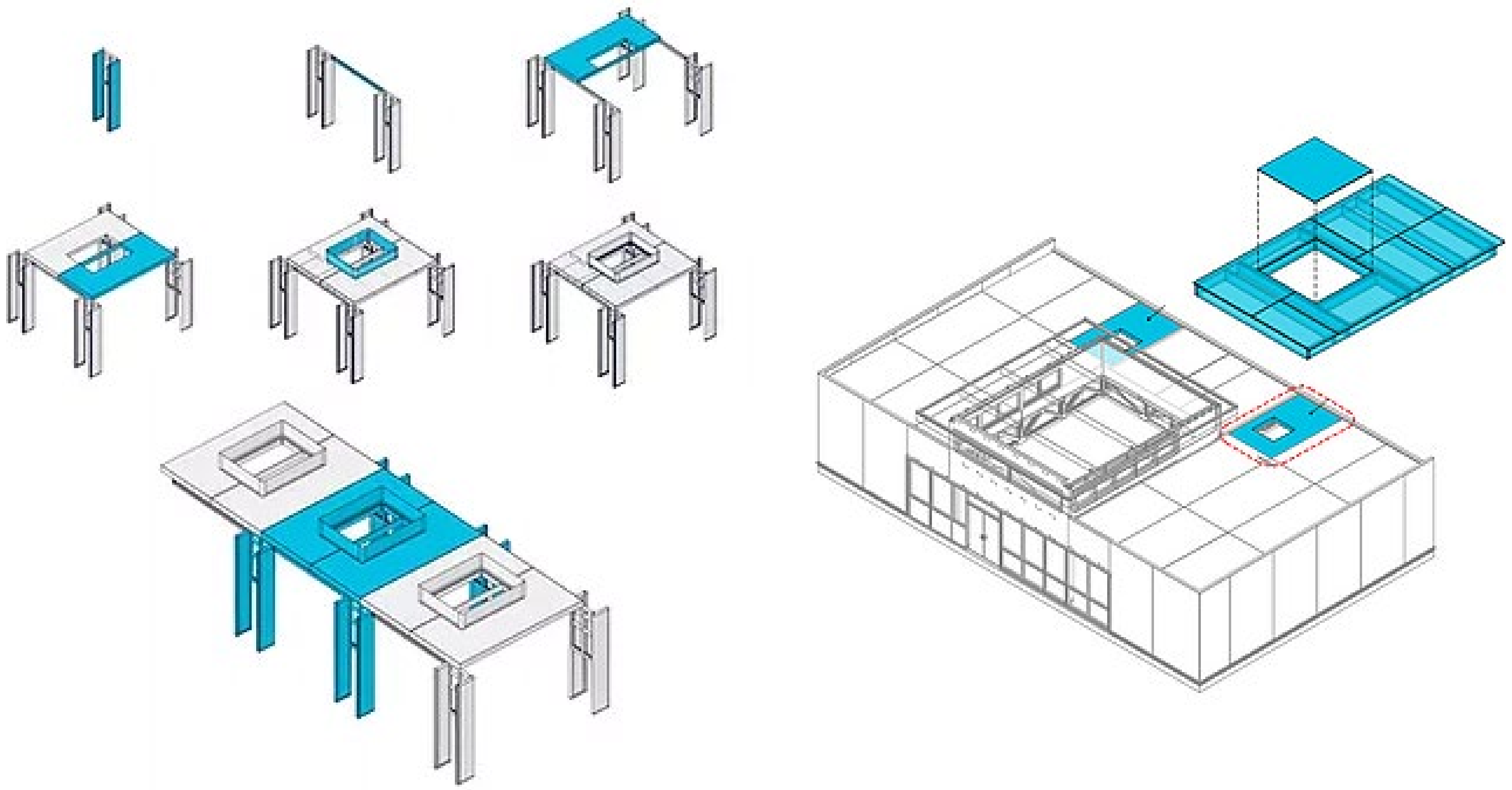
https://inhabitat.com/prefabricated-broadway-stack-apartments-break-ground-in-manhattan/gluck-broadway-stack/



www.sightline.org/2018/08/02/modular-construction-a-housing-affordability-game-changer/

Open systems, plateforms, kits of parts

OpenBuilding.co

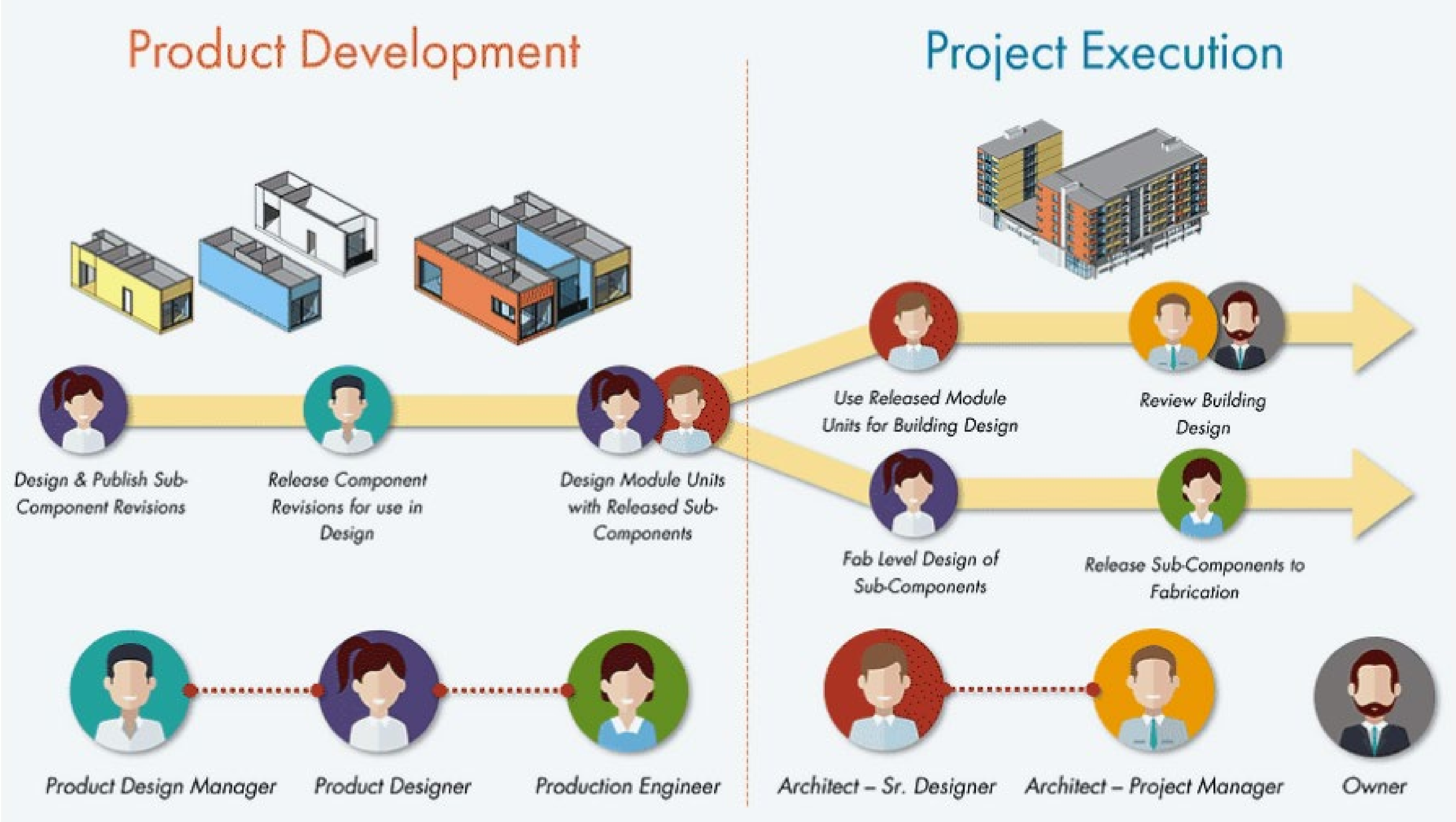


https://www.projectfrog.com/kit-of-parts

Industrialized system for schools

Kitconnect

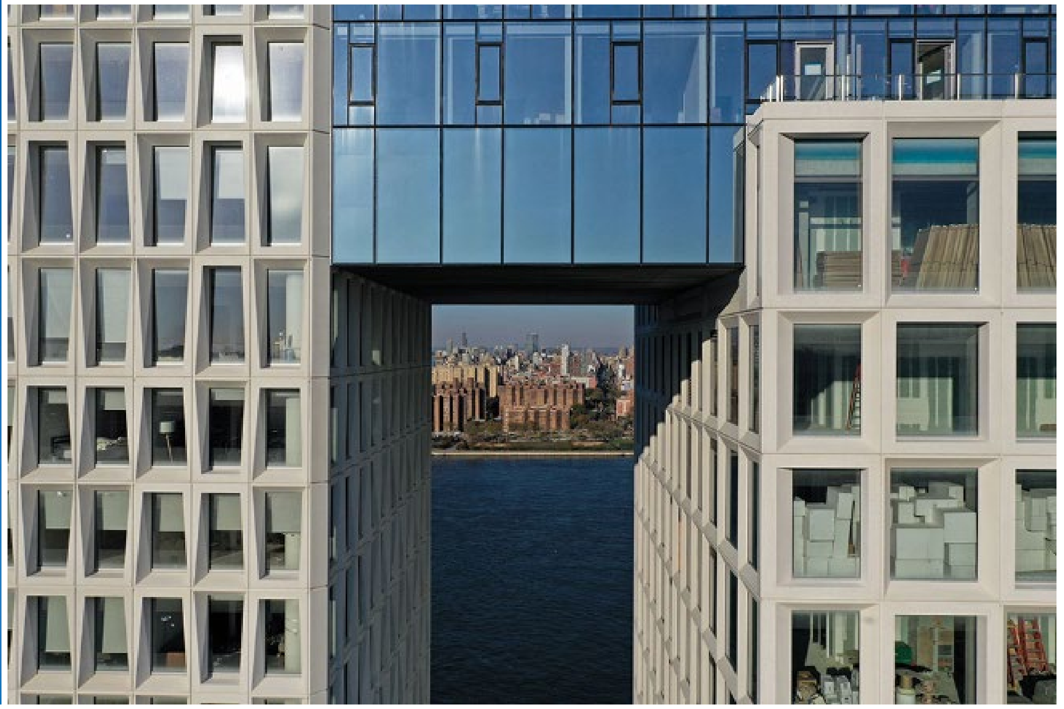
www.projectfrog.com/flex-building-program



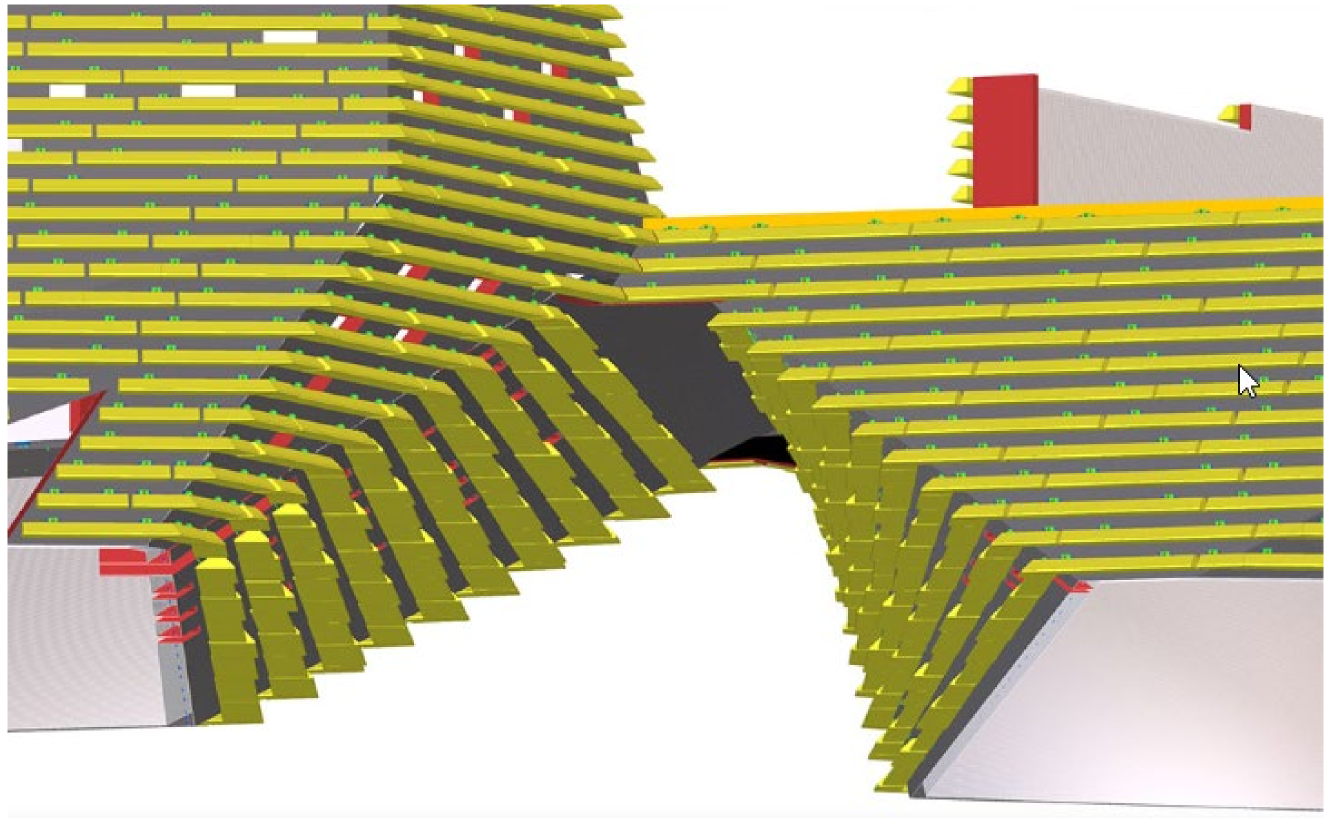
https://builtoffsite.com.au/news/kitconnect-taking-it-to-the-cloud-mmc-and-a-standardised-kit-of-parts/

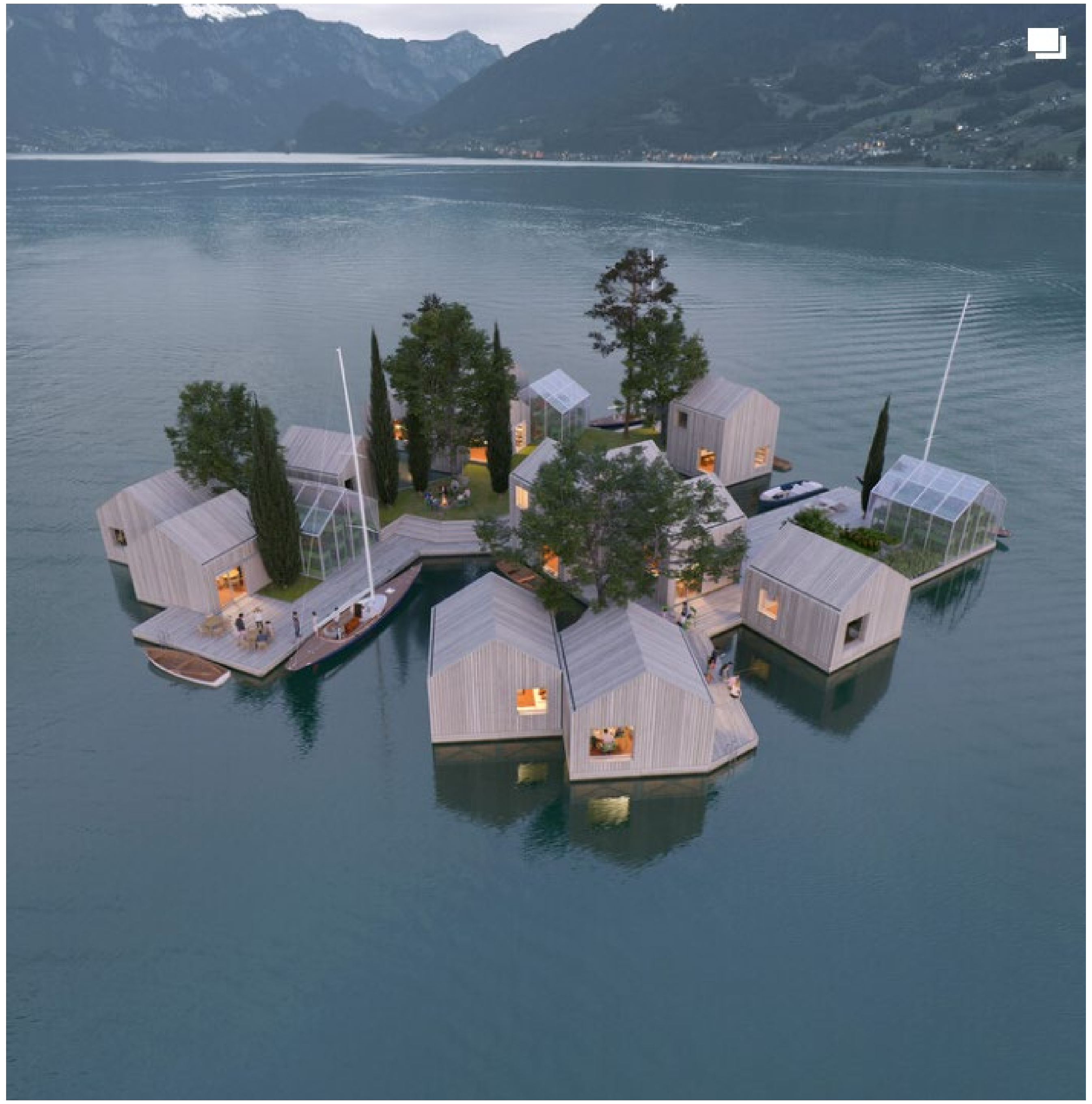
Automatisation & robotisation

Pouring these precast punched windows for the Domino Sugar Refinery apartment complex was a large job for Gate Precast, requiring multiple concrete casts in three different profiles. Durable 3D-printed molds for concrete casting made with Big Area Additive Manufacturing (BAAM) printers have enabled the company to deliver quality precast pieces within a shorter timeline than wooden forms.



Creativity & integration, DfMA





https://www.archdaily.com/991029/mast-designs-a-sustainable-modular-system-for-building-floating-architecture

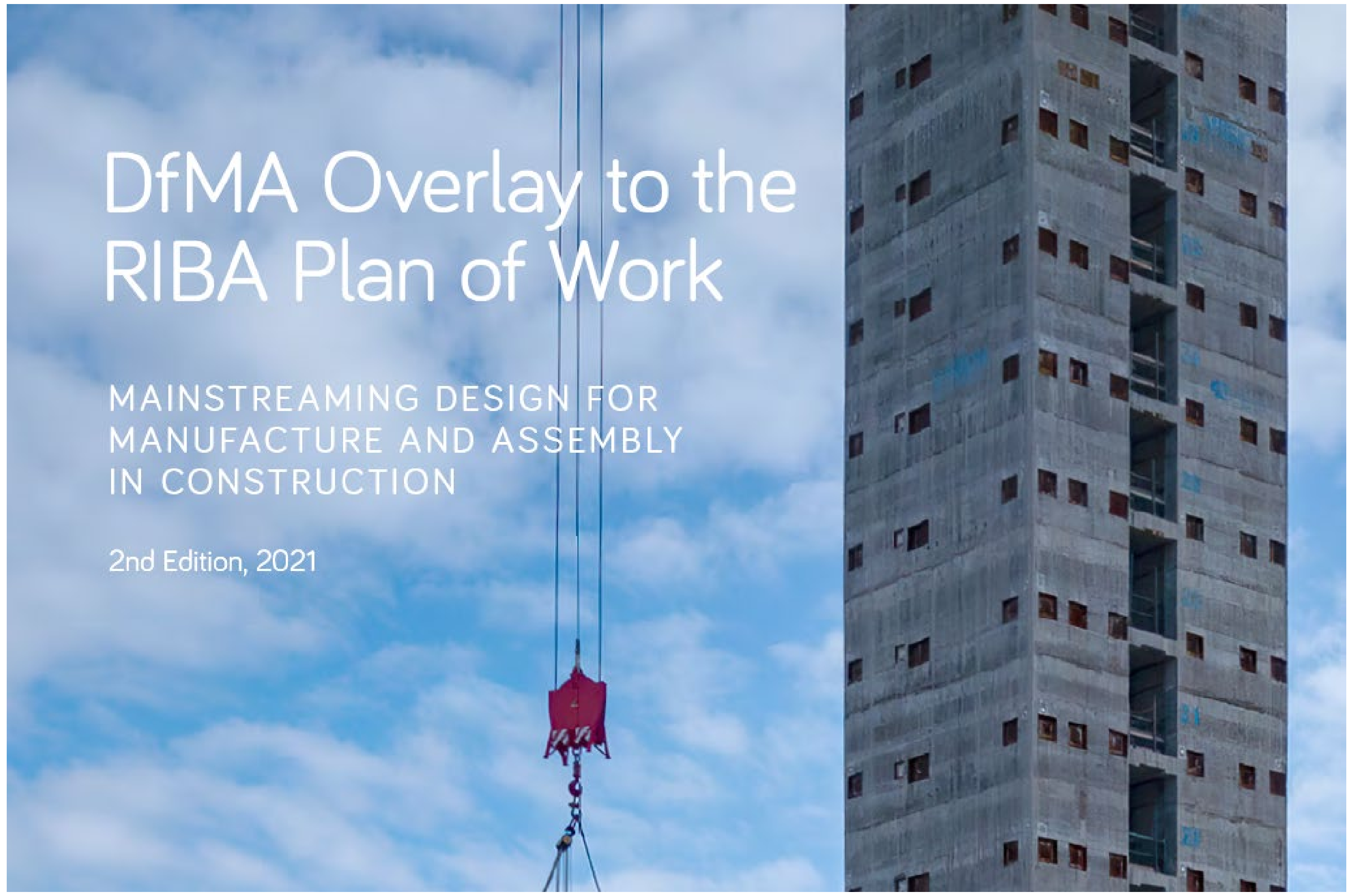
https://precast.org

ÉTS ÉCOLE DE TECHNOLOGIE SUPÉRIEURE Le génie pour l'industrie Université du Québec

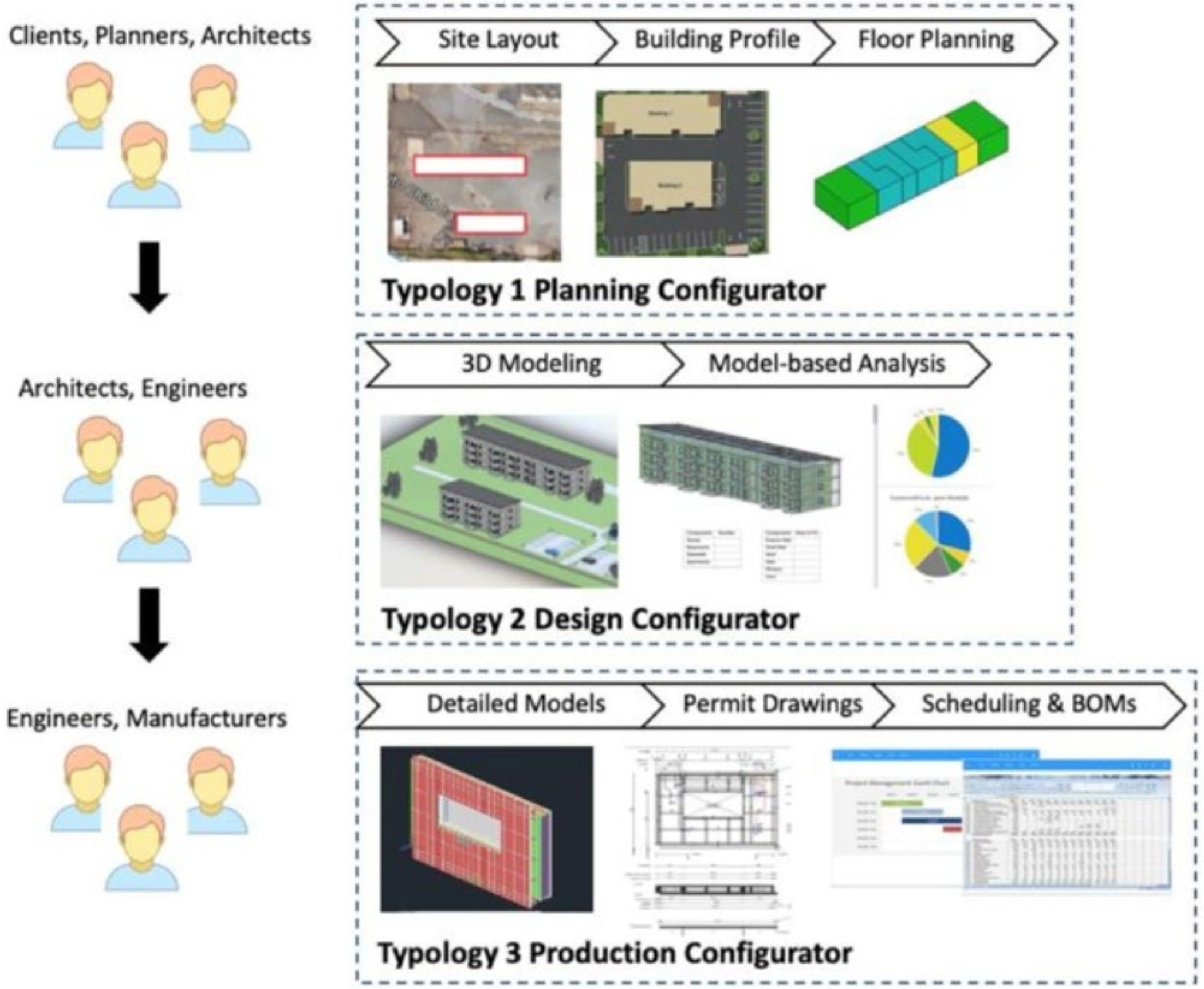
GRIDD GROUPE DE RECHERCHE EN INTÉGRATION ET DÉVELOPPEMENT DURABLE EN ENVIRONNEMENT BÂTI

DfMA – Design for Manufacturing and Assembly

Design for Manufacture	Design for Assembly
• Design for productivity	• Minimize and manage interfaces including templates / jigs
• Design for logistics	• Simplify and reduce sub-assemblies and component parts
• Design to be modular	• Reduce assembly risks
• Design to facilitate manufacturing	• Make sub-assembly easy
• Optimize design for supplier capabilities	• Design for easy handling
• Use common parts and materials	• Use efficient methods of joining
	• Prototype and perform first run studies



Configurators



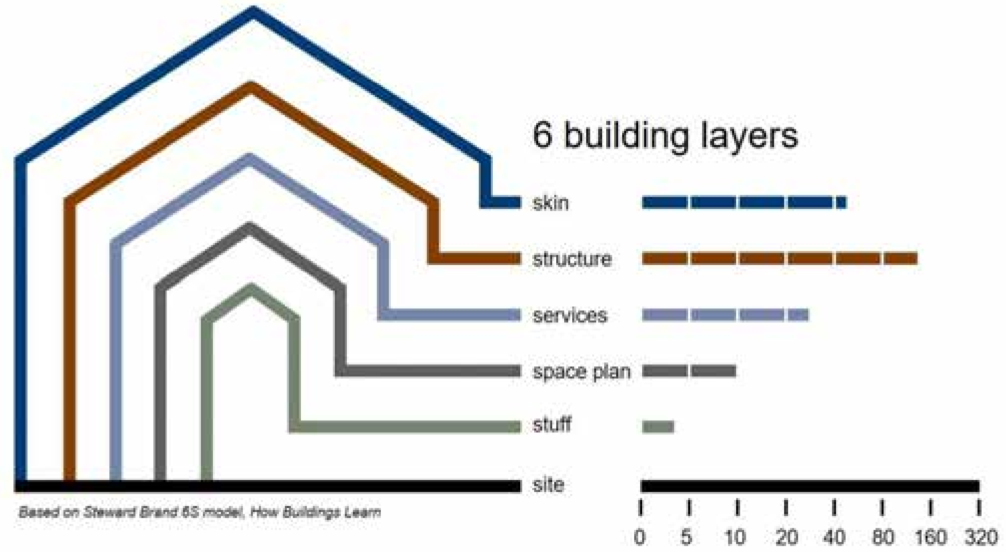
Source: Daniel M. Hall

Prism-app.io – la mairie de Londres

A framework for Design of adaptable buildings

Genesis of the proposed framework

A.Structural requirements			
A.1 Access	A.2 Measurement Systems	A.3 Facade	A.4 Function
A.1.1 Access to building	A.2.1 Floor height	A.3.1 Insulation of the façade	A.4.1 Daily multifunctionality
A.1.2 Specified acccess for disablers	A.2.2 Surplus of building space	A.3.2 Material	A.4.2 Seasonal multifunctionality
A.1.3 Reuse of stairs and elavators	A.2.3 Modular coordination	A.3.3 Movability of the façade components	A.4.3 Dual functionality
A.1.4 Location of of the vertical access	A.2.4 Fire resistant load bearing	A.3.4 Daylight facilities	
	A.2.5 Extendible building/ Horizontal unit	A.3.5 Maintenance access	
	A.2.6 Extendible buildig/ Vertical unit	A.3.6 Digital integration	
	A.2.7 Insulation between stories and units	A.3.7 Accessibility to utilities	
	A.2.8 Shape of columns	A.3.8 Heritage preservation	
	A.2.9 Independency of unit	A.3.9 Regulatory compliance	
	A.2.10 Location of the core of the building	A.3.10 Community engagement	
	A.2.11 Material	A.3.11 Attachment system	
	A.2.12 Assembly sequences		
	A.2.13 Installation equipment		
	A.2.14 Dissassembly		
	A.2.15 Structural grid		
	A.2.16 Load bearing foundation for extending stories		



B.Technical Requirements					
B.1 Energy saving	B.2 Water consumption	B.3 Light	B.4 Air quality	B.5 Insulation	B.6 Connections
Optimise material use for heating / cooling	Waste water treatment and local reuse	Using natural ligh for interior spaces	Fine dust/ Exhaust system	Fire safety/ resistancy	Bolted connections
natural ventilation	Local water collection	Optimize color use to light absorption/reflection	Natural ventilation	Energy modeling	Interchangable fixtures
local cooling	Grey water recycling	Location and size/shape of daylight facilities	Green lungs	Moisture control	Plug- and- play Services
local energy/heat storage	Rainwater harvesting	Lighting control	Façade windows to be opened	insulation material durability	Labling and documentation
Optimize color use to heat absorption/reflection	Water metering	Smart lightning system	Smoke control	insulation integrity	User training
Eliminate Energy losses through façade	Smart water control	Lightning zoning	Wellness certification	Green roof insulation	
Insulation and acoustics system	Plumping accessibility	Daylight harvesting	Maintenance protocols	High insulation R-values	
Glazing and shading		Emergency Lightning	Indoor plants	Climate responsive insulation	
Orientation of the building		LCC analysis	Ventilation system design	Air sealing	
Maintenance access			Air filteration		
Scalability					
Remote control and automation					
Energy storage					

C. Spatial
Distinction between infills
Dividing by flexible partition or movable walls
Prosity of spaces (Open building theory)
Material selection
Spatial capacity
Natural lightning
Natural ventilation
ceiling system
Adaptable core areas
Efficient circulation
Modular design
Flexibility
Interface geometry

D. Site
Expandable site
Multifunctional site
Safety and security
Quality of mobility
Natural landscape
Walkability
Distances to the entrance
Diversity
Cultural and heritage preservation
Community engagement
Sustainable transportation

E. Social
Privacy
Occupants engagements
Affordability
Community well-being
Cultural preservation
Youth and Elderly-Friendly
Safety and security
User centered design

Proposed framework

Layers	Criteria	Numbers	Sub-criteria	Explanation
Services	A. Access	A.1	Access to building	Access to a building plays a crucial role in enhancing its adaptability. Adaptable buildings are designed to evolve over time, accommodating changes in use, technology, and the environment. Easy and flexible access to different parts of a building facilitates this adaptability. It allows for easier renovations, modifications, and repurposing of spaces without major disruptions or structural changes. This flexibility in access helps in extending the building's economic viability, reducing maintenance costs, and addressing changing socio-economic needs. Moreover, adaptable buildings, through their flexible access features, can respond more effectively to the needs of diverse user groups, thereby contributing to a more inclusive and sustainable built environment.
		A.2	Specified acccess for disablers	In the context of accessible or adaptable buildings, the focus is typically on providing features and facilities that ensure equal access and usability for individuals with disabilities. Such as Ramps and Elevators, Accessible Restrooms, Accessible Parking.
		A.3	Reuse of stairs and elavators	Refers to designing or retrofitting a building in a way that allows existing staircases and elevators to continue serving their intended purposes efficiently, even as the building undergoes changes or adaptations to meet evolving needs or regulations.
		A.4	Location of of the vertical access	refers to the strategic placement or positioning of elements such as stairs, elevators, ramps, and other vertical circulation mechanisms within a building to ensure ease of movement and accessibility for occupants and visitors
	B. Insulation	B.1	Fire safety/ resistancy	Fire safety and resistance in insulation significantly contribute to a building's adaptability by ensuring enhanced safety, regulatory compliance, reduced damage, lower insurance costs, and greater flexibility for various uses. Fire-resistant insulation materials slow down the spread of flames, enhancing occupant safety and reducing structural damage in case of a fire. Building codes and regulations often mandate fire-resistant insulation, ensuring legal compliance and reducing the risk of costly retrofits. Lower insurance premiums for buildings with effective fire safety features provide financial adaptability. Fire-resistant insulation also promotes sustainability, resilience, and durability, making buildings better equipped to face various challenges.
		B.2	Energy modeling	Energy modeling is a powerful tool that can significantly contribute to the adaptability of a building in several ways. By simulating and analyzing energy performance under various scenarios, it helps inform design decisions and optimize energy-efficient features, which can lead to long-term adaptability benefits.
		B.3	Moisture control	Moisture control in insulation significantly contributes to a building's adaptability. It prevents issues like mold growth, structural damage, and reduced insulation performance, ensuring the longevity of the structure. Effective moisture control also supports energy efficiency, making the building adaptable to changing energy regulations and market demands. Furthermore, it facilitates renovations and modifications, as well as enhances indoor comfort and occupant satisfaction. Overall, proper moisture management in insulation is a fundamental aspect of creating a resilient and adaptable building.
		B.3	Insulation material durability	Insulation material durability greatly contributes to a building's adaptability. Durable insulation lasts longer, reducing maintenance needs and costs. Durability enhances a building's resilience, enabling it to withstand adverse conditions. Durable insulation also helps maintain the building envelope's integrity, making the structure comfortable and adaptable for various uses.
		B.4	insulation integrity	Insulation integrity significantly contributes to a building's adaptability by ensuring sustained energy efficiency, thermal comfort, and moisture control. It supports the structural integrity of the building, enhancing its overall stability and longevity. Maintaining insulation integrity reduces the need for frequent repairs, optimizing long-term cost-effectiveness and adaptability. Proper insulation management is crucial for creating a comfortable, durable, and efficient building that can easily adapt to varying climates and purposes.
		B.5	Green roof insulation	Green roof insulation, which involves planting vegetation on a building's rooftop, offers several benefits that contribute to the adaptability of the structure. Firstly, it enhances
		B.6	High insulation R-values	High insulation R-values, which represent the thermal resistance of a building's insulation materials, offer numerous advantages that significantly contribute to a building's adaptability. Firstly, they enhance energy efficiency by minimizing heat transfer, reducing heating and cooling costs, and allowing the building to meet evolving energy efficiency standards and regulations .Secondly, higher R-values contribute to consistent indoor comfort by preventing temperature fluctuations and drafts, making the building adaptable for various climates and occupant preferences.
		B.7	Climate responsive insulation	Climate-responsive insulation plays a pivotal role in enhancing a building's adaptability by tailoring insulation solutions to specific climate conditions. Such an approach allows for better control of the indoor environment, leading to several benefits. Climate-responsive insulation optimizes energy efficiency by adapting insulation strategies to local climate patterns, reducing the building's reliance on mechanical heating and cooling systems and aligning with evolving energy efficiency regulations. It fosters year-round comfort by mitigating temperature extremes, ensuring the building remains adaptable to seasonal changes and variable weather conditions .
		B.8	Air sealing	Air sealing in insulation significantly contributes to a building's adaptability by enhancing energy efficiency, indoor comfort, and overall building performance. By preventing unwanted drafts and air leaks, air sealing minimizes heat loss in cold weather and heat gain in hot weather, reducing heating and cooling costs and ensuring the building meets evolving energy efficiency standards .

The conceptual framework is derived from the theory of shearing layers. This refinement offers a more detailed array of strategies, simplifying the process of accessing approaches for adaptable buildings.

Evaluation method

Layers	Criteria	Numbers	Sub-criteria	Quantitative Questions	Qualitative Questions
Services	Accessibility	A.1	Access to building	Are the entry points to the building adaptable to accommodate different modes of access, such as mobility devices, walkers, or strollers?	
		A.2	Specified acccess for disablers	1. What percentage of the building's total area is wheelchair accessible? 2. How many parking spaces are dedicated to individuals with disabilities, and what is their proportion in relation to the total number of parking spaces?	1. Is there a feedback mechanism in place for continuous improvement in accessibility features based on user experiences? 2. How adaptable is the building to emerging needs and technologies for enhancing accessibility?
		A.3	Reuse of stairs and elavators	How often do the elevators and stairs require maintenance, and what are the associated costs?	How do the stair and elevator designs impact the flow of people and congestion during peak hours?
		A.4	Location of of the vertical access	What is the average distance from key areas (like entrances, common areas, emergency exits) to the nearest vertical access point?	How do occupants and visitors perceive the convenience and accessibility of the current vertical access points?
	Insulation	B.1	Fire safety/ resistancy	1. What percentage of the building's total area is covered by the automatic fire sprinkler system? 2.What is the average time (in minutes) required for complete evacuation of the building during fire drills?	1. Are there any special considerations or safety features in place for individuals with mobility impairments during a fire emergency? 2. What fire-resistant materials and construction techniques were used in the design of this adaptable building? 3. Are there any environmentally friendly or sustainable fire-resistant materials or systems used in the building's construction?please explain about the strategies.
		B.2	Energy modeling	1. How closely do the actual energy usage metrics align with the energy modeling predictions? 2. What level of greenhouse gas emissions reduction is projected by the energy model, and how does this compare to actual reductions achieved?	1. How does the energy model accommodate the integration of renewable energy sources? 2. How does the energy model take into account climate variability and potential future climate change impacts?
		B.3	Moisture control	1. How does the building handle moisture control in areas that may experience high humidity, such as bathrooms or kitchens? 2. How has the building's design taken into account the potential for moisture infiltration or leakage during adaptation phases? 3. Can you describe the moisture-resistant materials and construction techniques used in the building's envelope, such as roofing and exterior walls?	1. What are the challenges in maintaining and operating the moisture control systems? 2. How does the building's moisture control strategy comply with health and safety standards and guidelines?
		B.3	Insulation material durability	1. What insulation materials have been used in the construction of the building, and how do they contribute to its energy efficiency and thermal performance? 2. What strategies are in place to ensure that insulation materials maintain their thermal resistance (R-value) over the building's lifespan? 3. Are there any insulation materials that are designed to be easily removed and replaced during adaptation phases to ensure ongoing performance?	1. How do the insulation materials affect the indoor environmental quality, including factors like air tightness, moisture control, and indoor air quality? 2. What is the environmental impact of the insulation materials, considering factors like production processes, embodied energy, and disposal?

Evaluation of the adaptability of Gaston Miron library

	Sub-criteria	Questions	Answers	Best condition	Worst condition	1	2	3	4	5
1	Diversity of the environment and site	How is the diversity of functions in the environments (e.g., commercial, residential, recreational) ?	It is located in city center and surrounded by residential, commercial and religious buildings.	The ideal stage of diversity in adaptable buildings is characterized by flexibility and inclusivity.	The least favorable stage in adaptable buildings is marked by isolating the building with limitted building with different funtionality					
2, 3	Cultural and heritage preservation	.How does the adaptable building's design contribute to the preservation and integration of local cultural and heritage values? . What strategies are in place to ensure that any adaptive changes to the building remain sensitive to its cultural and historical context?	In the process of renovating a historic library, established in 1960 and situated centrally in the city, efforts were made to preserve its original function. This included the temporary relocation of all books to an alternate site during the renovation phase, with the intention of restoring them to their original location upon completion of the building work. Structural elements, particularly the walls featuring opals and glazing, were largely maintained, with modifications limited to certain sections for aesthetic or functional enhancements. All columns within the structure were retained, undergoing refurbishment to align with modern standards. The majority of the alterations were focused on updating the building's services and spatial layout to meet contemporary requirements, ensuring both the preservation of its historical integrity and the adaptation to current functional needs.	In the best scenario, building modifications respect and preserve the historical and cultural significance of the structure. This involves retaining key architectural features and historical elements that define the building's character. Renovations are carried out sensitively, blending modern functionality with historical aesthetics.	In the worst scenario, building modifications disregard the cultural and heritage value of the structure. Key historical features are often removed or altered beyond recognition to make way for modernization, leading to a loss of the building's original character and historical significance.					
4	Multifunctionality	Do you think this building has th potential to change the function over time? If yes,What design strategies are employed to ensure that the adaptable building can effectively serve multiple purposes over its lifecycle?	Currently, the building no longer serves as a library, with plans underway to repurpose its function. However, the extensive renovations and refurbishments carried out in 2011 and 2012 have enhanced its adaptability. Featuring an open space plan and a robust structural framework, the building is well-suited to accommodate a variety of other uses. This versatility stems from the strategic updates made in the past decade, which have not only preserved the building's integrity but also expanded its potential for diverse applications in the future.	An adaptable building features spaces that can easily transform to serve multiple purposes, catering to a wide range of activities and user needs. The design includes modular elements and smart systems that allow for quick and efficient reconfiguration. Such buildings effectively balance functionality, comfort, and aesthetics, making them highly efficient and user-friendly.	an adaptable building fails to offer genuine multifunctionality, with spaces being rigid, difficult to reconfigure, and limited in their use.					
5	Expandable site	How is the building's site designed to accommodate possible future expansion or downsizing?	The expansion of the building, either vertically or horizontally, is constrained due to several factors. Its status as an older structure poses limitations on vertical additions, ensuring the preservation of its original architectural integrity. Similarly, horizontal expansion is not feasible, given the surrounding urban landscape, which includes adjacent streets and buildings.	An adaptable building is designed with the potential for easy expansion, both vertically and horizontally, to accommodate future growth or changing requirements.	An adaptable building lacks any real potential for expansion, with a rigid structure that cannot be easily modified or extended.					
6	Building Codes and Regulations	What types of building codes and regulations are applicable to modifications in adaptable buildings?	some regulations in 2011 and 2012 were followed. (the detail were not reminded to interviewee	Adaptable buildings are designed and modified in strict adherence to current building codes and standards, ensuring safety, accessibility, and environmental sustainability.	Adaptable buildings fail to comply adequately with existing building codes and standards, compromising safety, accessibility, and environmental performance.					
7	Energy modeling	What energy modelling software or tools were used to design and analyze the building's energy efficiency?	For this building, no form of energy analysis was conducted.	Energy modeling is extensively utilized in adaptable buildings, guiding design and operational decisions to maximize energy efficiency and sustainability. This proactive approach involves simulating various scenarios to optimize building performance, leading to reduced energy consumption and lower environmental impact.	Energy modeling is either overlooked or inadequately used in the design and operation of adaptable buildings. This neglect results in inefficient energy use, higher operational costs, and a larger carbon footprint.					
8		How does the building's energy performance compare to industry standards or benchmarks for similar adaptable structures?								
9	Remote control and automation	1. Do you have a Building Management System (BMS) installed in your adaptable building? 2. Is your building's lighting system remotely controllable? 3. Does your adaptable building feature automated HVAC controls? 4.Is your building equipped with remote-controlled smart windows or shades?	The building lacks any remote control systems for its services or structural elements. All lighting systems are manually operated, and there are no remotely controlled shading devices. However, it is equipped with an HVAC system, which, to some extent, may have remote control capabilities, although this detail is not precisely recalled.	Adaptable buildings are equipped with advanced remote control systems that manage various building functions like lighting, temperature, and security efficiently.	Adaptable buildings lack effective remote control systems, leading to manual management of essential functions like lighting and HVAC, which is less efficient and more time-consuming					
10	Daylighting	How do the occupants perceive the visual comfort provided by the daylight harvesting system (e.g., light levels, glare control)?	The majority of the lighting fixtures and their placements have been retained from the building's previous incarnation as a library, where the lighting design was specifically tailored for that purpose. However, no formal analysis was conducted on the effectiveness of this lighting setup, and feedback regarding lighting satisfaction was not systematically gathered from the building's occupants.	Adaptable buildings are designed to maximize daylight harvesting, using strategically placed windows, reflective surfaces, and skylights.	An adaptable building fails to effectively utilize daylight, resulting in reliance on artificial lighting and increased energy consumption.					

Educating 'change agents'

SHORT MASTER'S PROGRAM IN (BIM)

DESS
IN BIM & DIGITAL INNOVATIONS

Thank you !

ivanka.iordanova@etsmtl.ca

QUESTIONS?

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Références

- Beddiar, Karim, Aurélie Cléraux, and Pascal Chazal. 2021. *Construction hors-site: DfMA, modulaire, BIM l'industrialisation du bâtiment*. Malakoff: Dunod.
- Bourgault, M., Iordanova, I., Perrier, N., Rankohi, S., Denis, M. (2021). Les modes de réalisation comme moyen d'orchestrer les projets de construction : concepts et exemples nationaux. In Brunet, M., Romero-Torres, A. (éd.). La gestion de projets au Québec : des cas pour illustrer une expertise en croissance. Les Éditions JFD. ISBN 978-2-89799-101-2.
- Hosseini, M. R., Martek, I., Zavadskas, E. K., Aibinu, A. A., Arashpour, M., & Chileshe, N. 2018. Critical evaluation of off-site construction research : A Scientometric analysis. *Automation in Construction*, *87*, 235-247.
- McKinsey & Company. (2020). *The next normal in construction : How disruption is reshaping the world's largest ecosystem*. https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Operations/Our%20Insights/The%20next%20normal%20in%20construction/The-next-normal-in-construction.pdf?shouldIndex=false
- Messa Sokoudjo, Virginie Raissa (2021). Barrières à l'utilisation de la préfabrication modulaire volumétrique de bois au Québec : étude de cas du passage d'un système préfabriqué unifamilial au multifamilial. Mémoire de maîtrise électronique, Montréal, ÉTS.
- Rankohi, S., Bourgault, M., Iordanova, I., Carbone, C., (2022), C-DFMA Framework: A Construction-Oriented DFMA Deployment Framework, Journal of Construction Management and Economics
- Richard, R. & I. Iordanova, (2021) Complicities between Industrialised Building Systems and Building Information Modeling. In : Lu, W. et Anumba, C. (ed.) Scientific Companion to Building Information Modeling, Edward Elgar Publishing.
- Speight, V. 2020, juillet 9. Le DFMA, la clé de la réussite dans la construction Hors-site. *HORS SITE: LE MAGAZINE DE LA CONSTRUCTION MODERNE*, *9*. https://hors-site.com/le-dfma-la-cle-de-la-reussite-dans-la-construction-hors-site/

http://gridd.etsmtl.ca/fr/

https://quebecwoodexport.com/

https://precast.org/