Towards Net Zero
Technology Advances & Human Factors

Building Energy Efficiency Lecture Series

11th March 2024

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Speakers

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Towards Net Zero:

Technology Advances & Human Factors

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Outline

01 From Industry 4.0 to Industry 5.0
Technology Innovation and Adoption trajectory for net zero

02 BIM · Digital Twin · Green Artificial Intelligence
Data-Driven Smart Sustainable Urbanism

03 Case study - Al Rayyan Stadium, Qatar

04 Case study - Hepworth Art Gallery, UK

05 Future Directions

Industry 4.0 ›› Industry 5.0

Industry 4.0

- Digitalisation

Industry 5.0

- Cyber-Physical Cognitive Systems
- Green Manufacturing
- Cultural Collaboration
- Mass Customisation

Adapted from (Adel 2022)

➢ **Industry 4.0 – integration of smart, connected, autonomous digital and physical technologies**

➢ **Industry 5.0 – human-machine collaboration**

- Integration of AI and robotics technology with human creativity for problem-solving and value-adding for customers
- LCA impact on manufacturing, consumption, sustainability, and CE
- Business intelligence and social implications of mass personalization
- Impact on careers and skills and organizational change

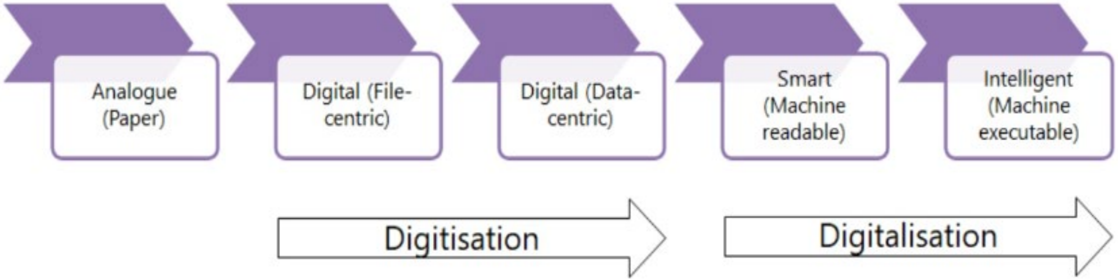
(Adel 2022)

(EU Directorate-General for Research and Innovation 2021)

(Turner & Oyekan 2023)

Towards Digital Intelligence

Digital Process Maturity



- *DT in manufacturing, aerospace, automobile, healthcare, sports, retails, AEC, asset & facilities management, etc.*

- **A Digital Twin need not always be in 3D**
- **BIM, RFID, GPS, GIS, IoT, VR/AR/MR, photogrammetry, laser scanning, AI, 3D printing, robotics, big data analytic and blockchain for DT & off-site Construction**

Shaun Farrell
@ Buro Happold, 2021

Towards Digital Intelligence

Identified technologies	
BIM	Digital fabrication on-site
AI	Design simulations
Design automation	Blockchain
Big data	Digital twin of city
IoT asset management	Distributed off-site production
IoT energy consum	
AR on-site and ma	
VR and immersive	
Future materials	
CAVs and tunnels	

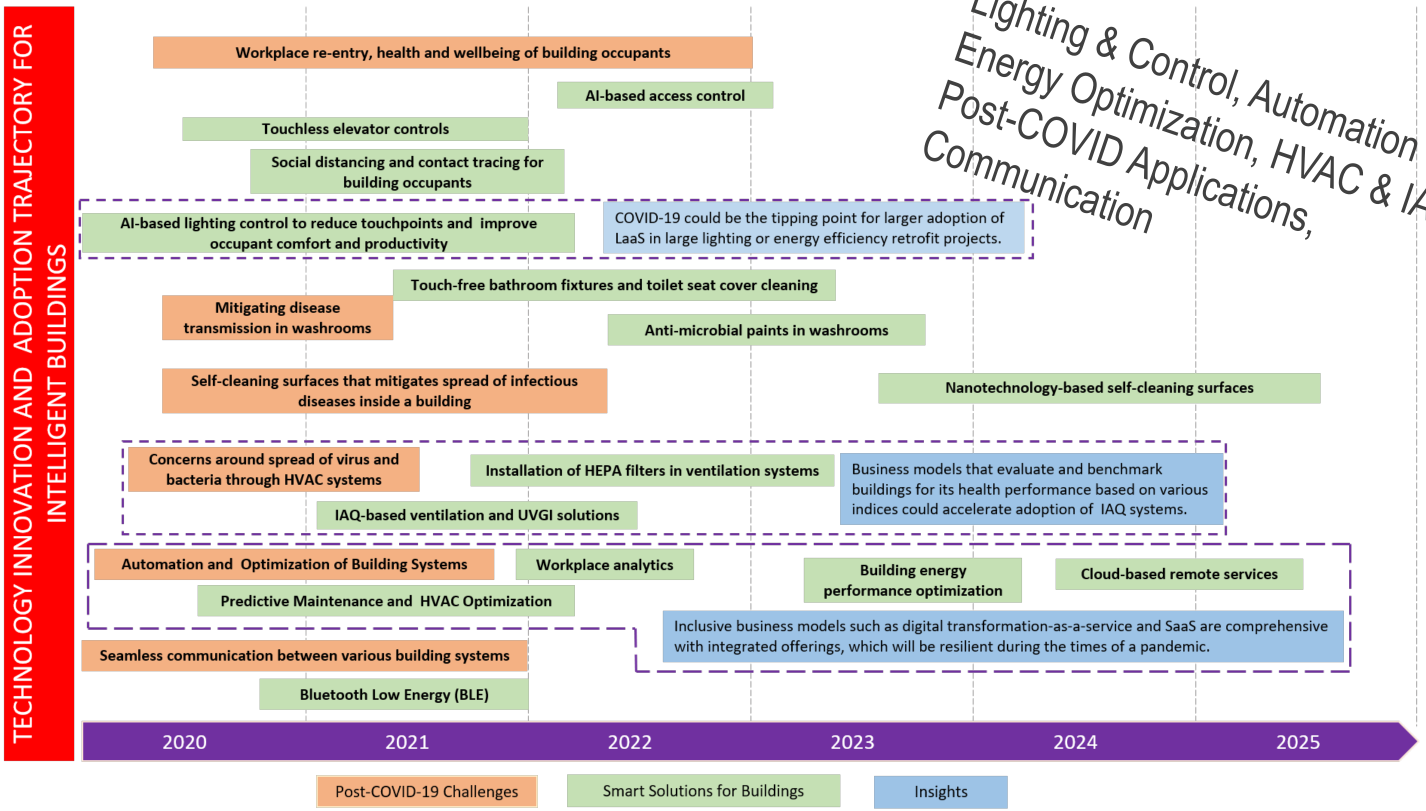
Identified trends
Lean processes
Alliancing business models
Standardization
Safety on-site
No disruption
Sustainability
End user focus
tomation
ıpanies

- **Boosting construction efficiency**
- **Value-driven computational design**
- **User-data-driven built environment**
- **Intelligent Construction Equipment and Robotics (IER) for enhancing safety and improving productivity**
- **Addressing skilled worker shortage**

Ernstsen et al. (2021)

Technologies for Intelligent Buildings

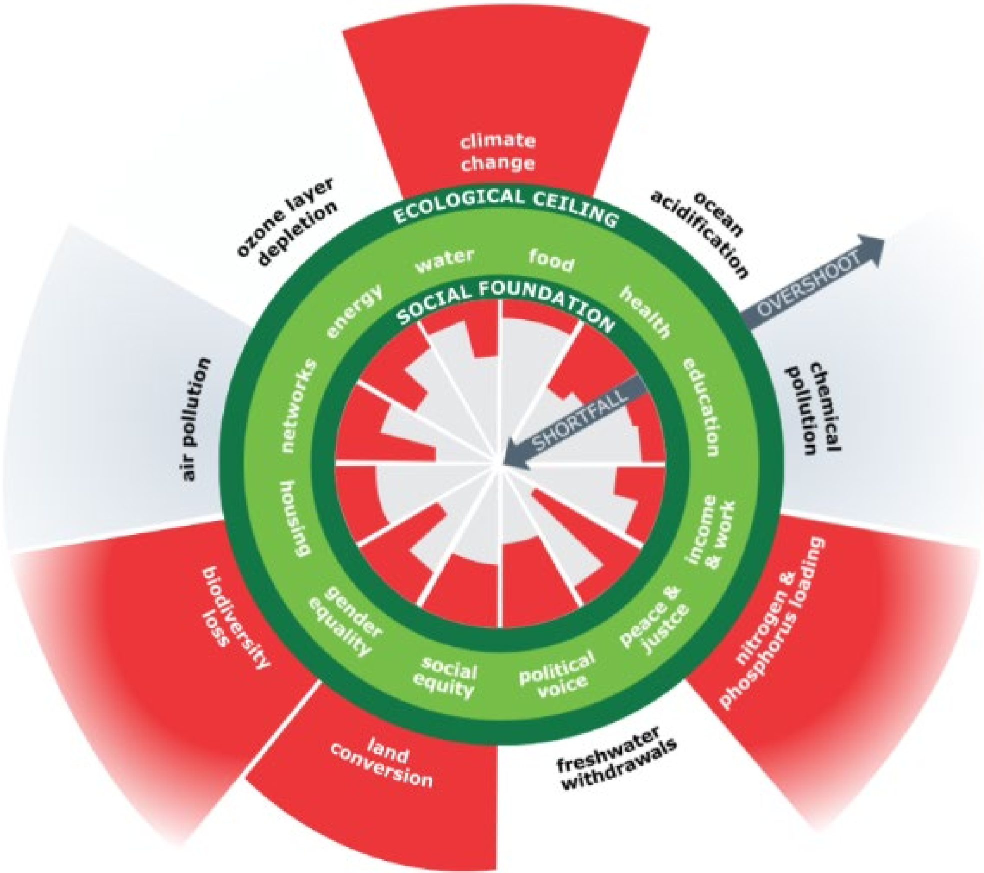
Lighting & Control, Automation & Energy Optimization, HVAC & IAQ, Post-COVID Applications, Communication



Frost & Sullivan, Intelligent Buildings and COVID-19 Impact review, technology potential and future readiness assessment, CABA Report 2021

➢ **Technology innovation and adoption trajectory**

The Doughnut of social and planetary boundaries (2017)



Nine planetary boundaries

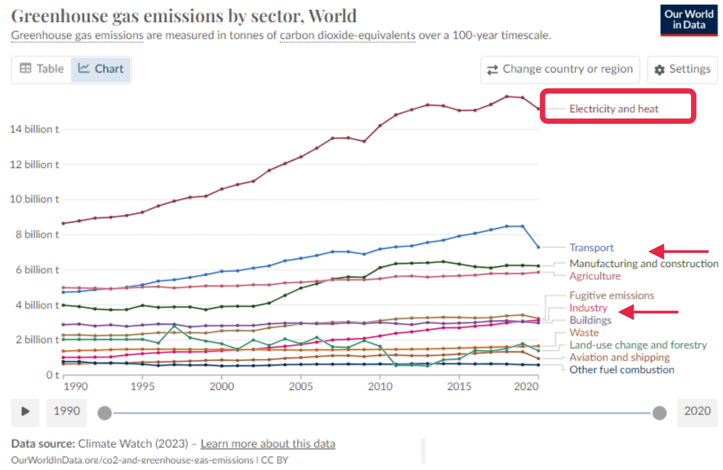
1. Climate change
2. Change in biosphere integrity (biodiversity loss and species extinction)
3. Stratospheric ozone depletion
4. Ocean acidification
5. Biogeochemical flows (phosphorus and nitrogen cycles)
6. Land-system change (e.g. deforestation)
7. Freshwater use
8. Atmospheric aerosol loading (microscopic particles in the atmosphere that affect climate and living organisms)
9. Introduction of novel entities (e.g. organic pollutants, radioactive materials, nano-materials, and micro-plastics).

Rockström et al. (2009)

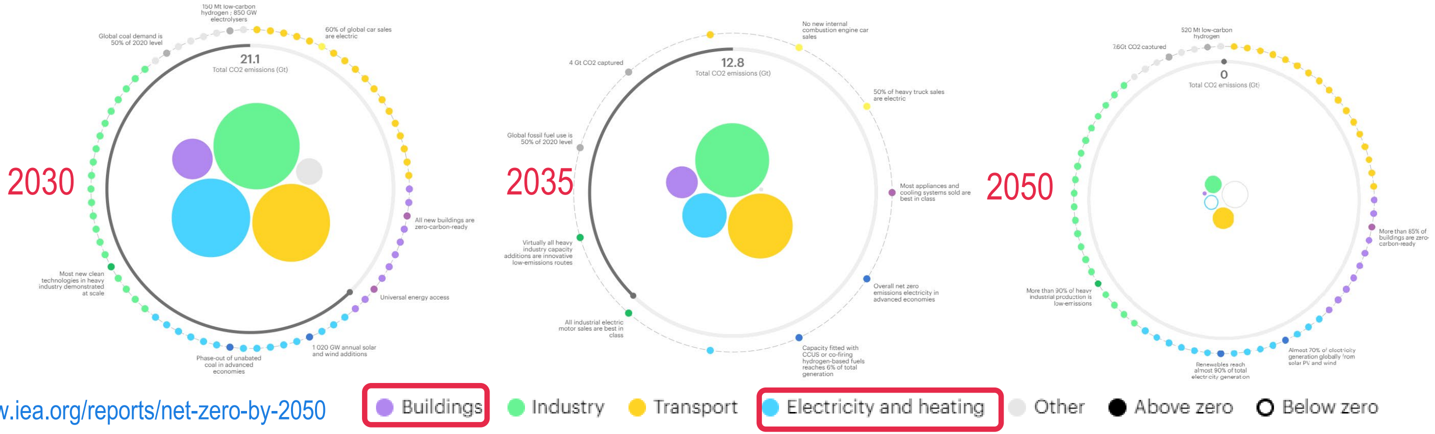
Raworth (2017)

https://www.kateraworth.com/doughnut/

Greenhouse Gas Emissions



https://ourworldindata.org/emissions-by-sector



Climate Watch (2023)

IEA (2021)

https://www.iea.org/reports/net-zero-by-2050

RIBA Guide

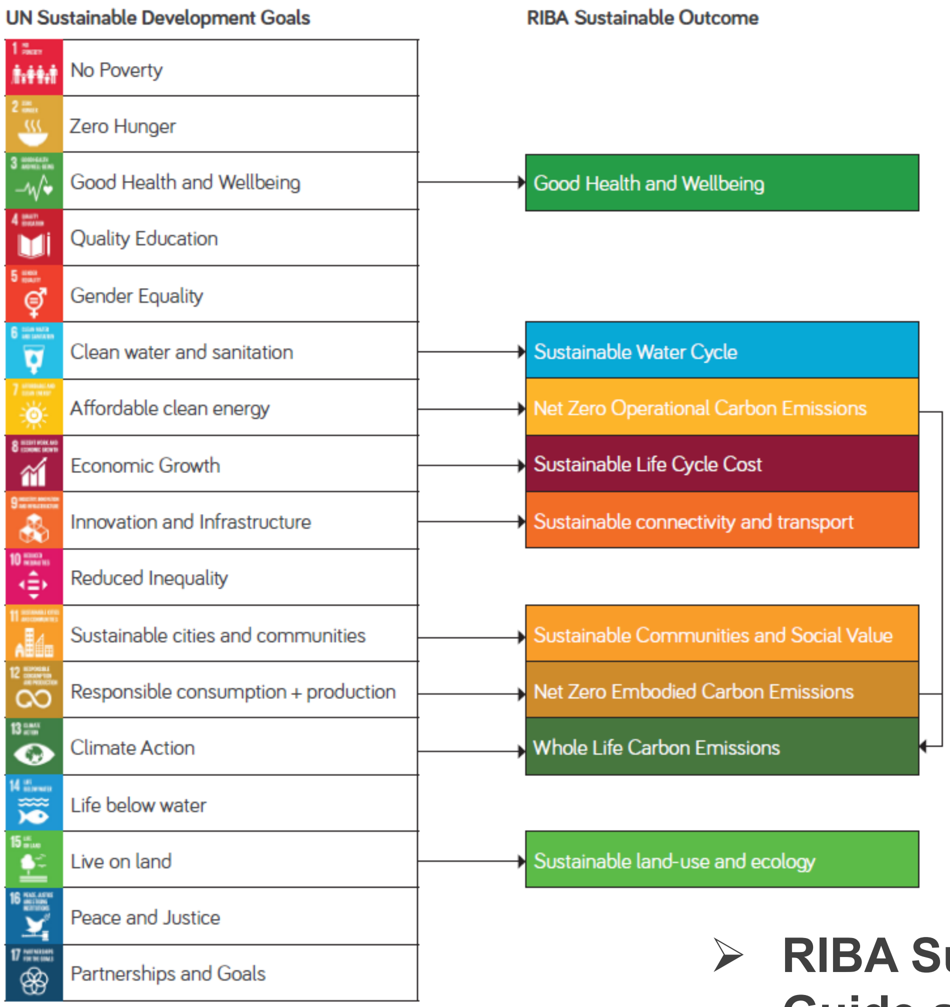
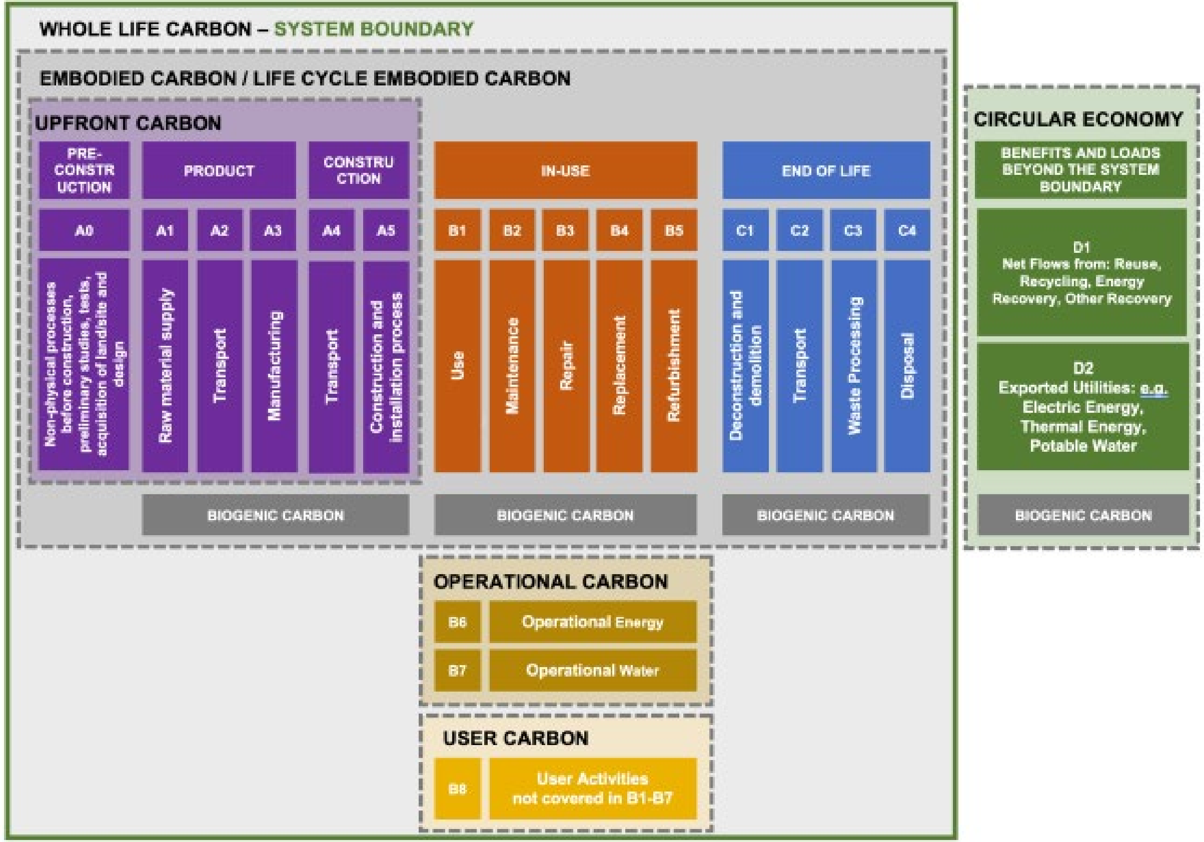


Diagram 1: UN Sustainable Design Goals Outcomes Map, Gary Clark

- **RIBA Sustainable Outcomes Guide aligns with UN SDGs**

RIBA (2019)

Life-Cycle Assessment

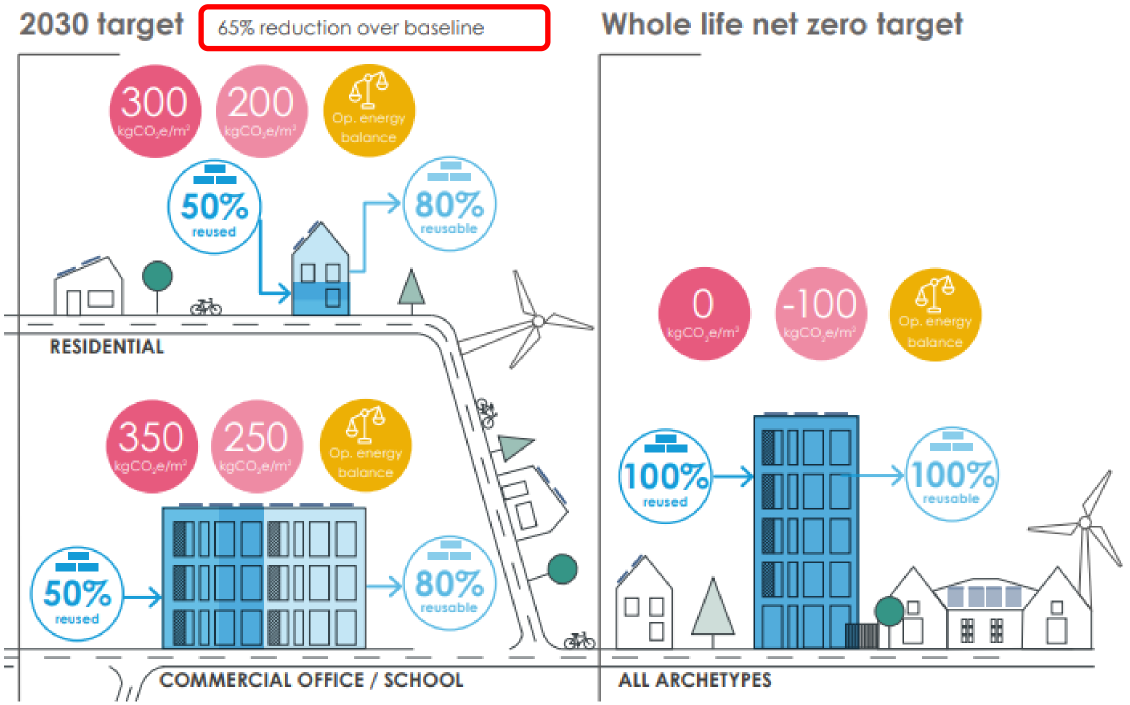


- Carbon definitions for the built environment, buildings & infrastructure (2023)

Whole Life Net Zero Carbon

20 Sept. 2023
(GOV.UK)

UK to Net Zero by 2050
reduce carbon emissions by 68% by 2030 compared to 1990 levels, a target of 77% for 2035.



LETI (2020)

- **LETI embodied carbon reduction targets towards whole life net zero**
  - by 2030 all new buildings must operate at net zero

Energy Performance Gap

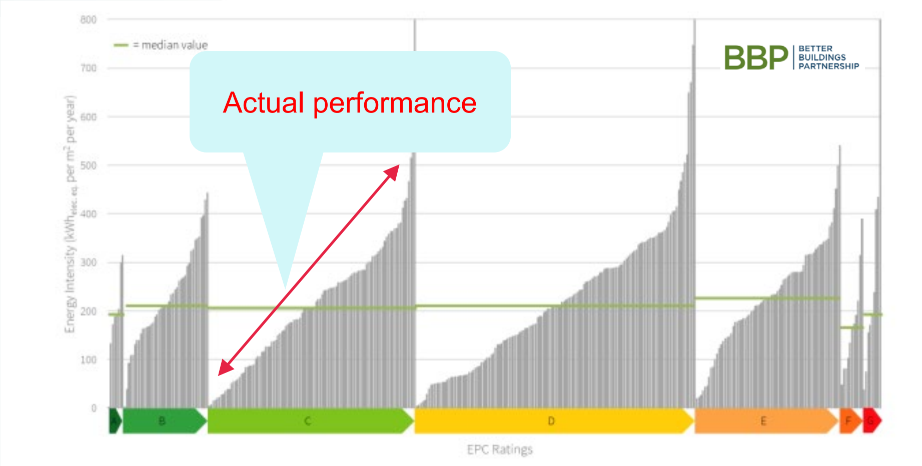


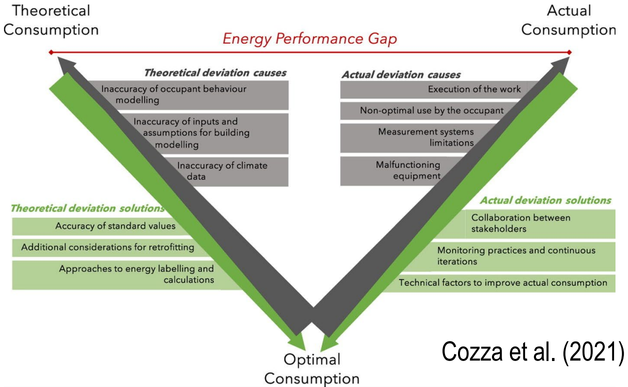
Figure 1 Office energy intensity (kWh$_{elec. eq.}$ per m² (NLA) per year) by EPC rating. Each grey bar represents a single office building's energy intensity over the course of a year. (Source Real Estate Environmental Benchmark 2017, Better Buildings Partnership)

BBP (2018)

Coyne & Denny (2021)

Cozza et al. (2021)

LETI (2021)



Cozza et al. (2021)

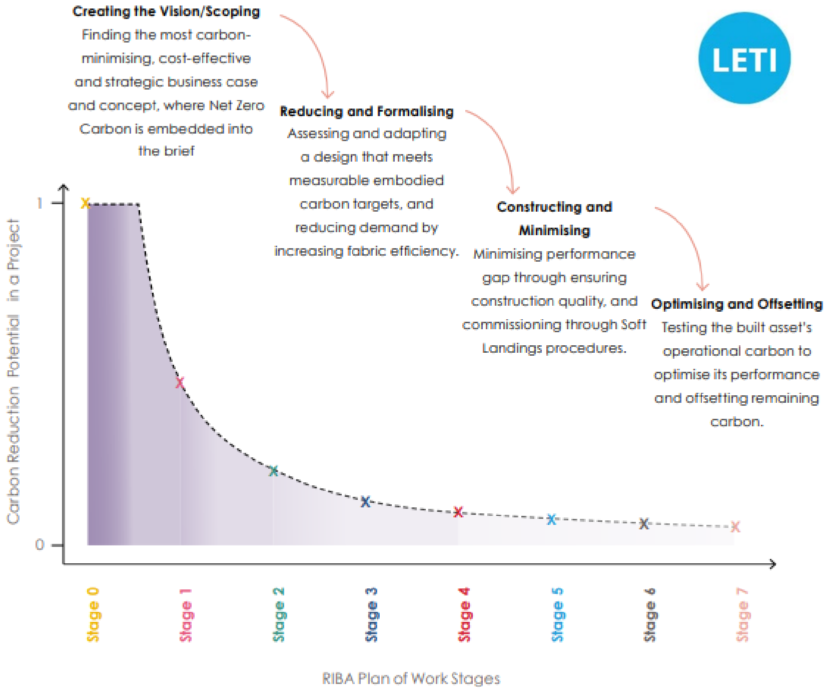


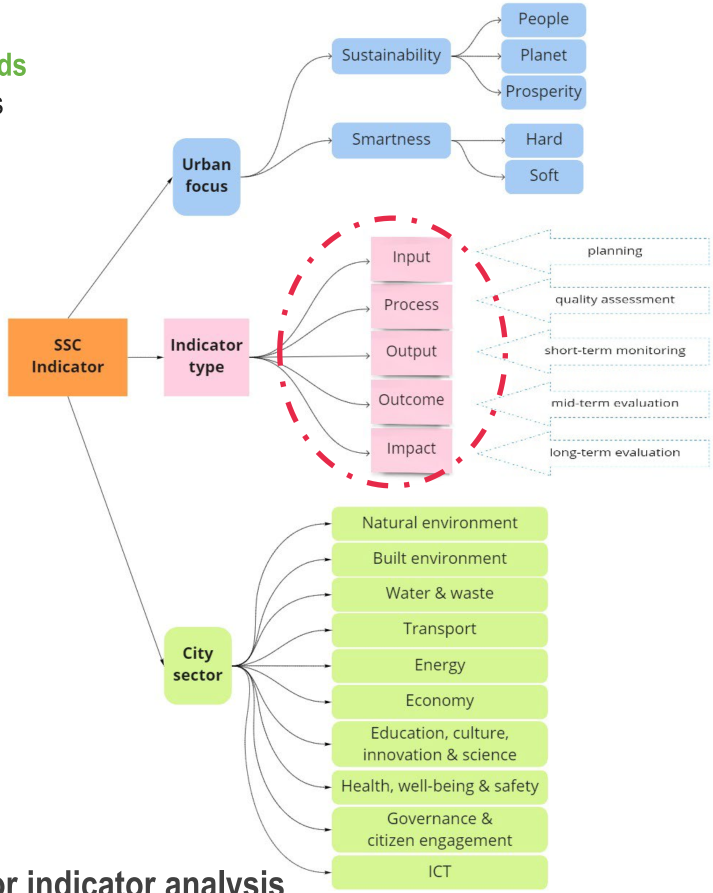
Figure 7 - Carbon Reduction Potential as Project Progresses

- **Energy performance gap**
- **Carbon reduction potential**

Smart Sustainable Cities Indicators

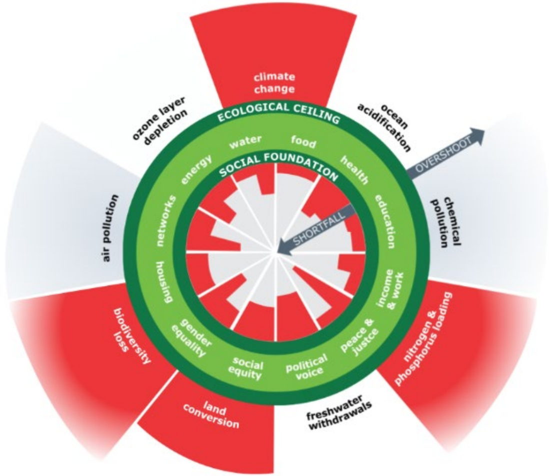
SSC standards

413 indicators



Taxonomy for indicator analysis

The Doughnut of social and planetary boundaries (2017)



https://www.kateraworth.com/doughnut/

Huovila et al. (2019)

Raworth (2017)

Technologies for SSC

OrganiCity Experimentation as a Service

- **OrganiCity – Co-creation of Digital Solutions for Citizen-Centric Smart Cities**

Harbor Research CABA Report (2020)

Frost & Sullivan, CABA Report (2021)

- **Technology Radar 2020-2025**
  - 12 technologies in 5 categories: Lighting & Control, Automation & Energy Optimization, HVAC & IAQ, Post-COVID Applications, Communication

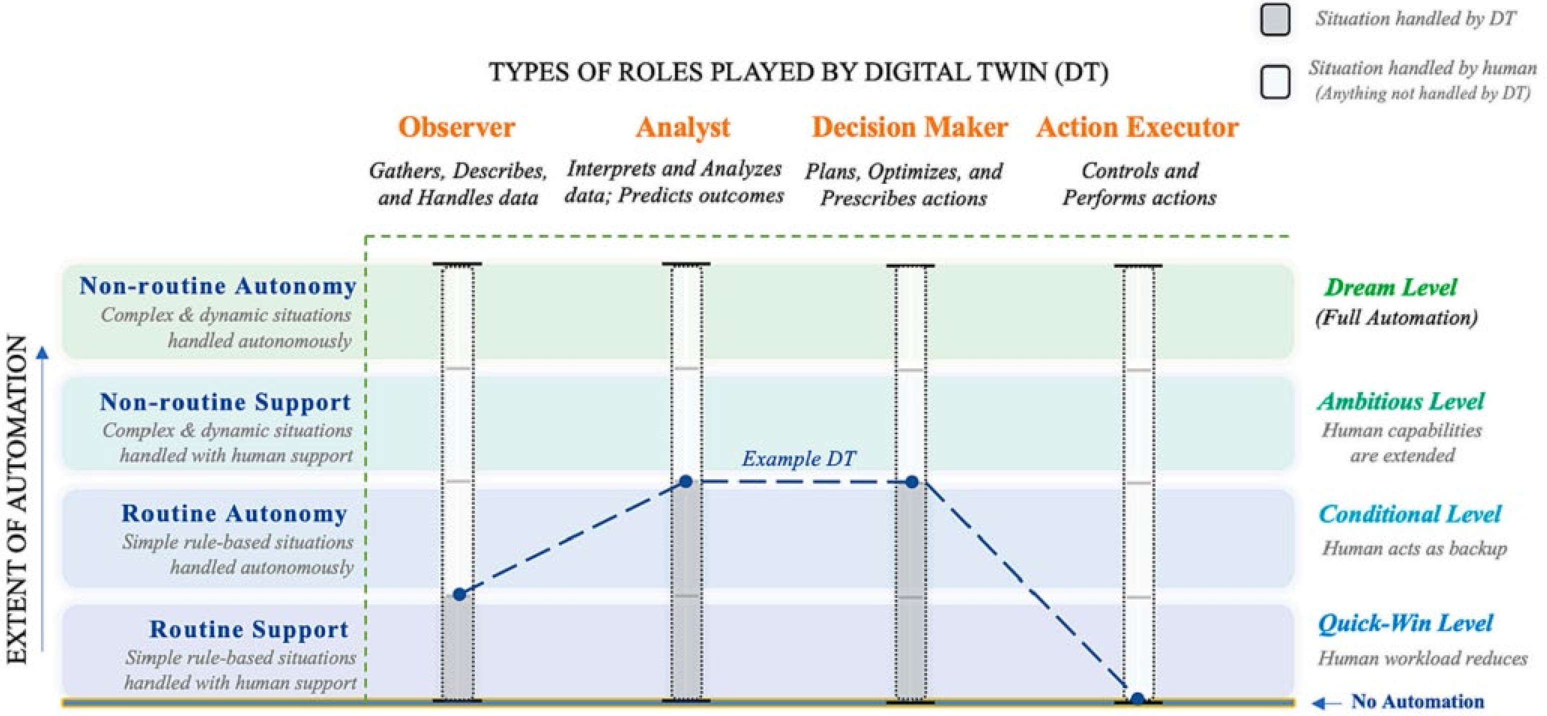
Dong et al. (2021)

- **Occupant behaviour modelling methods - Resilient Building Design, Operation and Policy at Urban Scale**

Gartner (2021)

- **Interfaces and Experiences** – Digital Twin, AI, IoT Platforms, Smart Personalization, etc.
- **Business Enablers**
- **Productivity Revolution**

Digital Twin ↔ Human



Agrawal et al. (2023)

Levels of Digital Twin framework

-- The extent of automation for role distribution by DT or human

BIM Dimensions

- ***3D*** **BIM - Live model in CDE**
- ***4D*** **BIM (*3D* BIM + Time) - Scheduling**
- ***5D*** **BIM (*4D* BIM + Cost) - Estimating & Cost**
- ***6D*** **& *7D* BIM (Sustainability & FM)**
- ***8D*** **BIM (Overlay of health, safety & welfare consideration into the BIM process)**
- ***nD*** **BIM – a holistic view of information & insights**

Building Information Modelling (BIM)

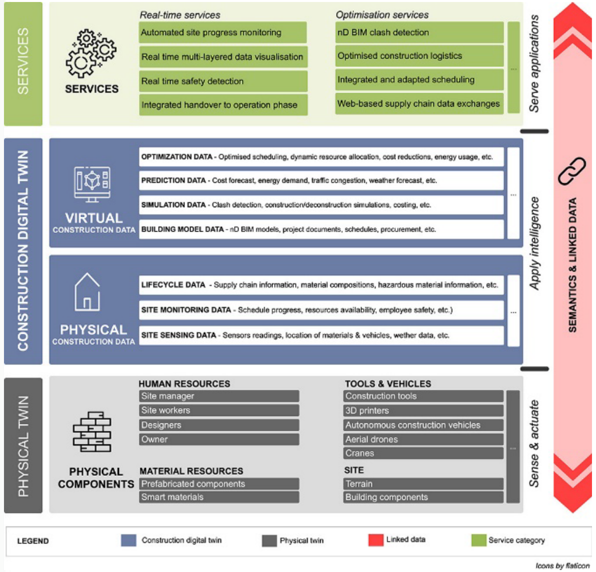
"use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions"

BS EN ISO 19650-1:2018

(Ellis 2023)

(Hamil 2021)

BIM-DT in AECO Industry



(Boje et al. 2020)

➢ Opportunities & challenges

- Technology-enabled construction safety management
- RFID, GPS, pressure sensors and laser scanners aid real-time data in pre-fabrication.
- Real-time carbon emissions monitoring in prefabrication.
- Blockchain, AI, robotics and visualized tools improve prefabrication digital twin.

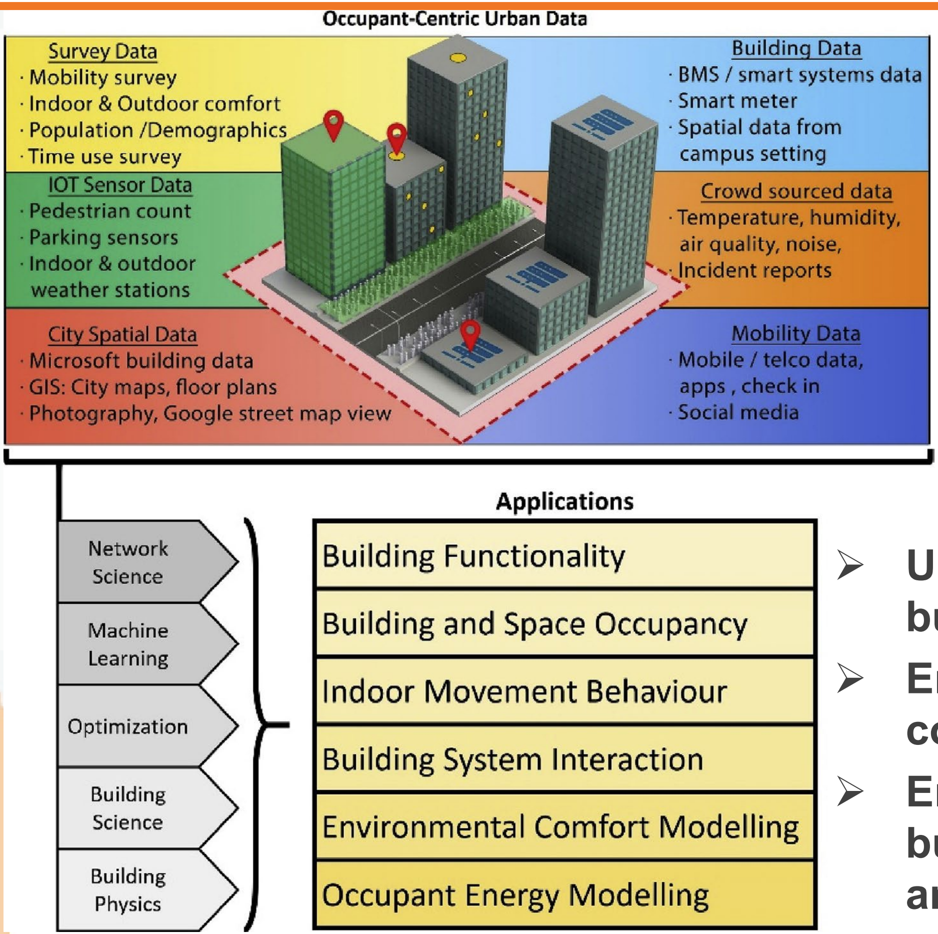
- Harness the transformative power of digital technologies for sustainable urbanization and future-proof adaptation
- Outcome-based planning, design and implementation of digitization projects and outcomes monitoring
- Data-driven decision-making for leading and governing digital value creation for all stakeholders

(World Economic Forum 2022)

Yevu et al.. (2023)

Zhang et al. (2023)

Urban-scale Occupant Behaviour



Future work models
Behbahani (2023)

- **Urban-scale human-building interactions**
- **Environmental comfort interference**
- **Energy use at buildings, districts, and city scales**

Salim et al. (2020)
Leprince et al. (2023)

Energy System Digital Twin

- Supporting decision-making and energy system design i.e. intuitive, visually-assisted communication between decision maker and DT
- Integrating technological and non-technological (e.g. governance, economic, social, environmental, spatial, legal/regulatory) solutions to be adaptable for local context, also vary from planning stage to implementation stage.
- Systematic generation of integrated process and energy system configurations
- Encourage high involvement of stakeholders i.e. flexible integration of user-defined preferences for selection of solutions
- Facilitate community learning towards net zero carbon and involve crowd-sourcing climate action together and green innovations e.g. Earthshot, Ashden climate champions.

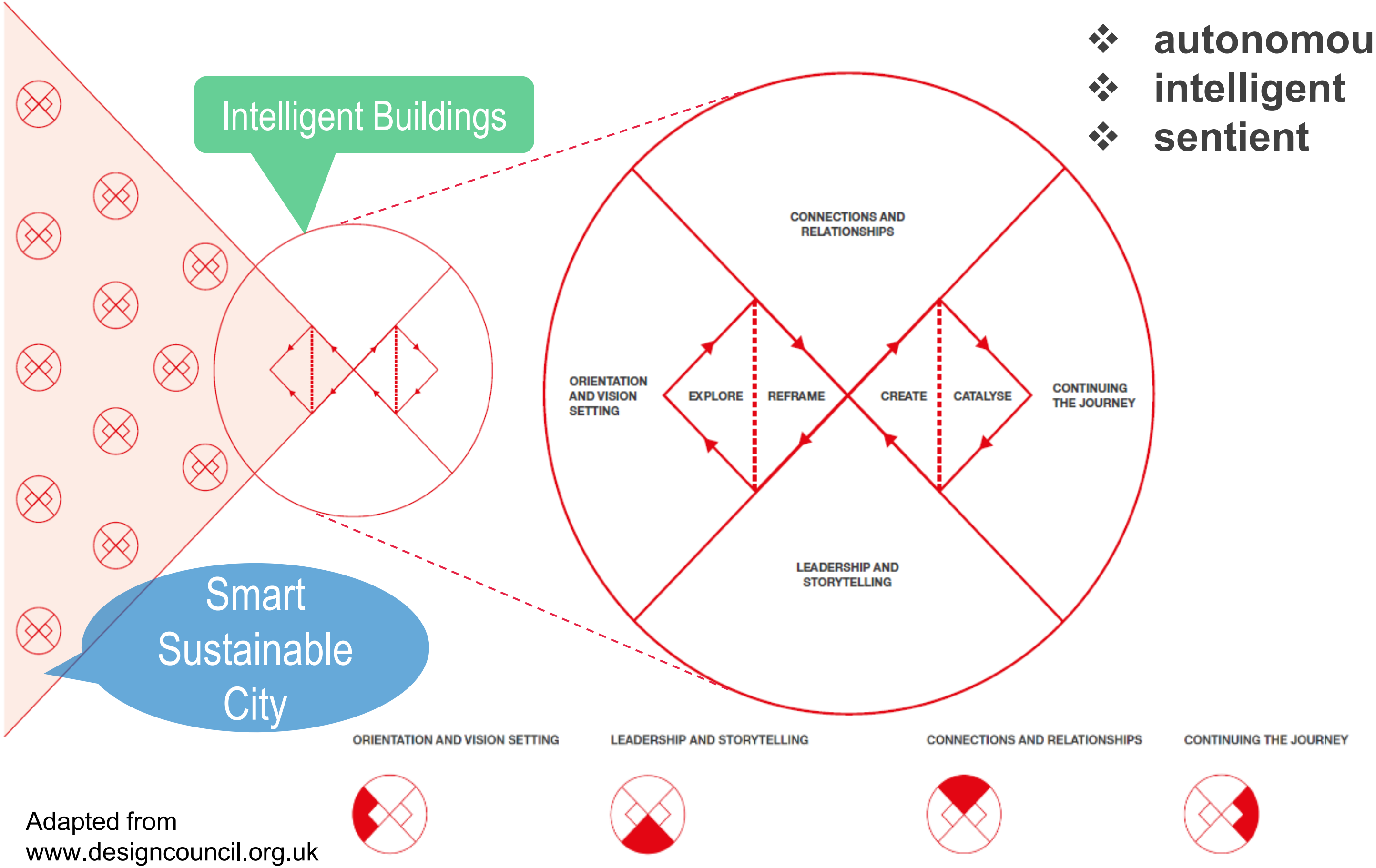
(Zhang et al. 2021)

(Yigitcanlar, T., et al. 2021)

(Granacher et al. 2022)

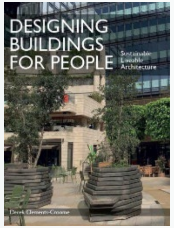
Holistic Design Framework for Innovation

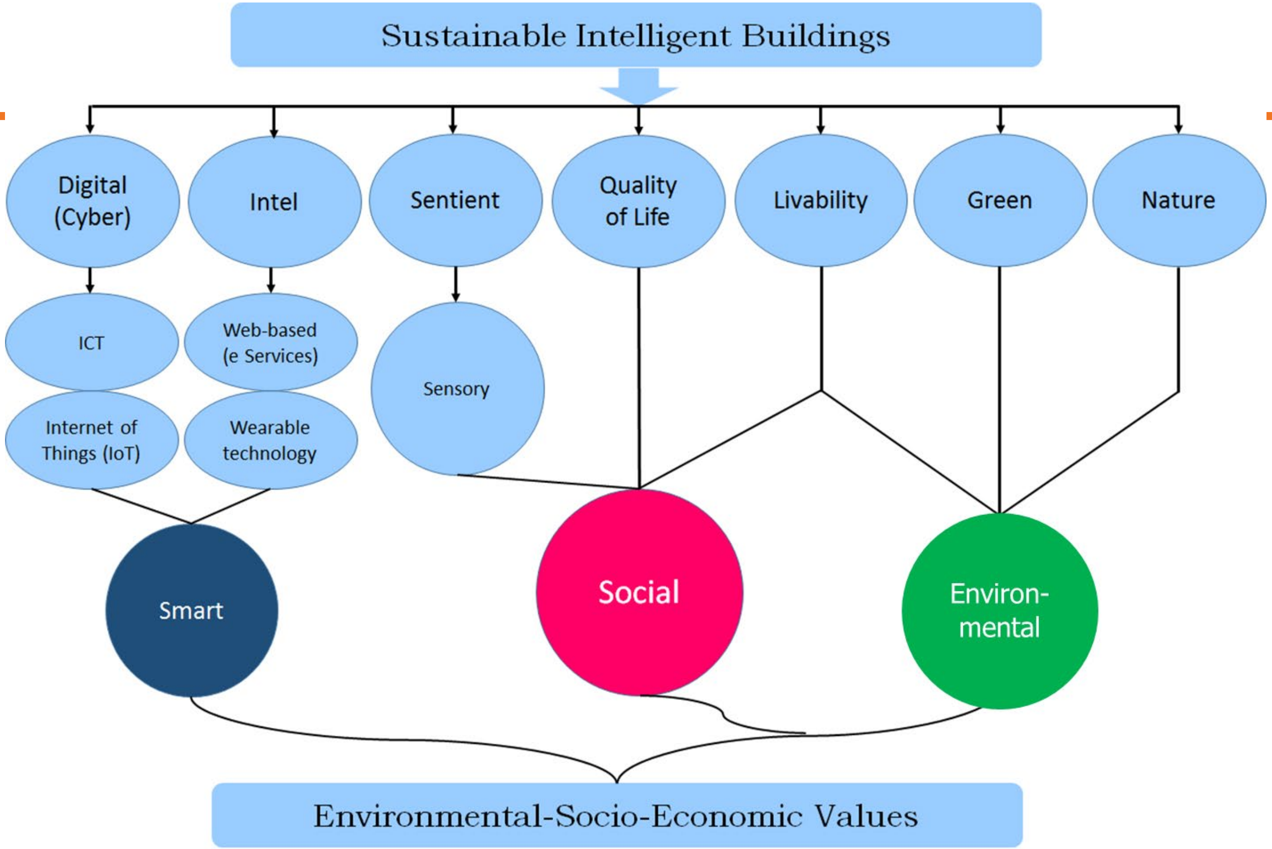
- autonomous
- intelligent
- sentient



Adapted from www.designcouncil.org.uk

Design Council (2004, 2019 and 2021)





- Key constituents of Intelligent Buildings

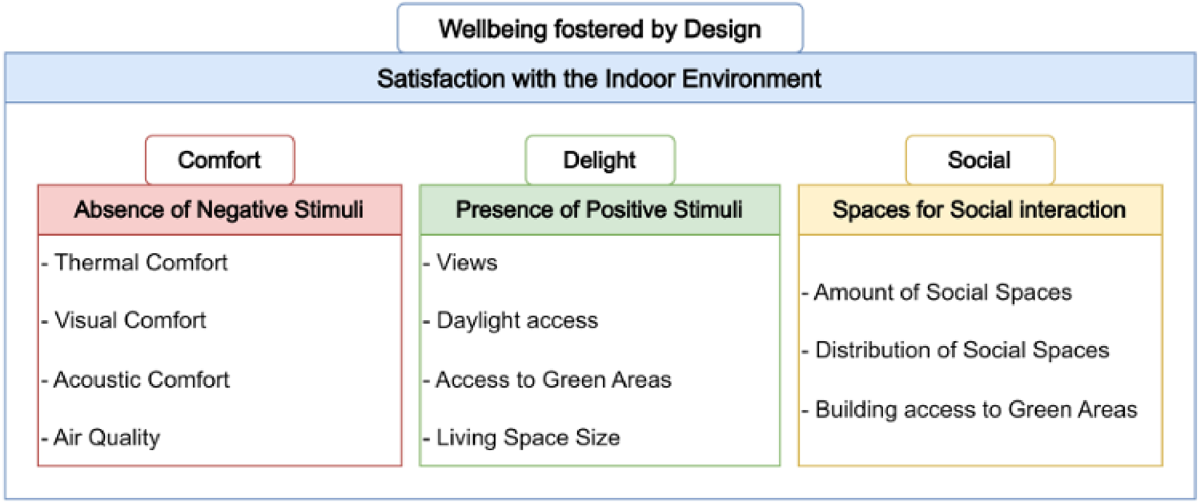
"Intelligent Buildings and Cities should provide a multi-sensory experience"

Derek Clements-Croome

Clements-Croome (2000, 2011, 2013, 2020)

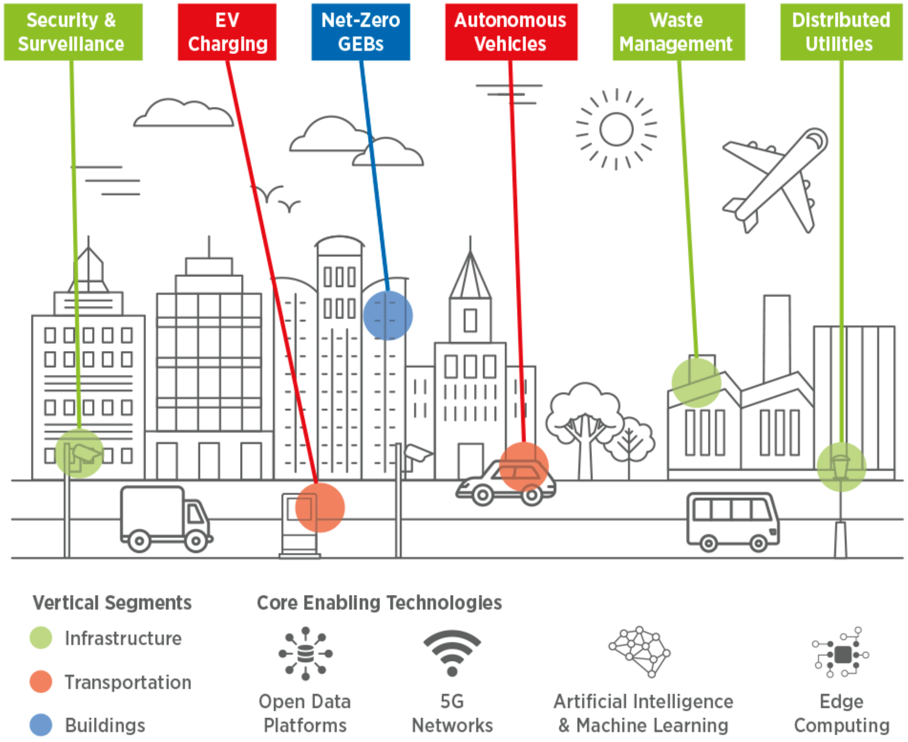
Biophilic Wellbeing Framework

Abazari et al. (2022)



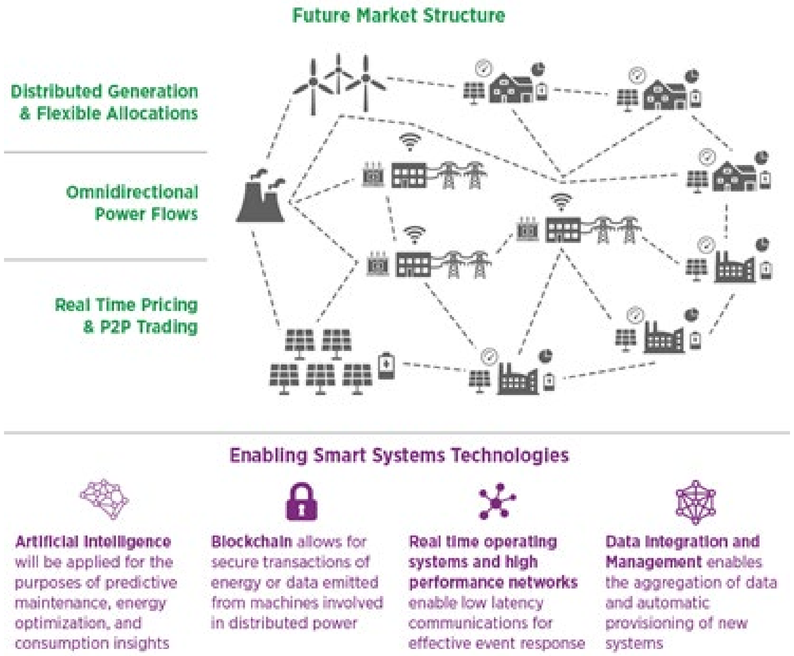
Croffi et al. (2023)

Data-driven Smart Sustainable Urbanism



Citizen-centred cities co-creation

Harbor Research
CABA Report 2020



Intelligent energy management & distributed smart grid interactivity

Big Data • BIM-DT Enhanced Circular Economy

- **Design big data management systems with analytic tools;**
- **Data is collected from wearables; services systems; questionnaires; interviews;**
- **Data is about resource use; health and wellbeing; predictive maintenance;**
- **Refresh and recycle for Circular Economy - use smart waste system;**
- **Have effective facilities management processes in place.**

Xu et al. (2021)

Ellen MacArthur Foundation (2022 & 2023)

…realising a net zero and nature-positive future…

① Build Only What You Need	② Build With The Right Materials	③ Build Efficiently	④ Build For Long-Term Value

A circular economy could reduce global CO_2 emissions from building materials by 38% in 2050

Case Studies

Al Rayyan Stadium – Qatar

- One of the FIFA World Cup 2022
- Located in Al Rayyan area and also named as Ahmad bin Ali Stadium
- Gross seating Capacity +40,000
- Challenging Sustainability KPIs

Al Rayyan Stadium – Qatar

scalemag.online; Pattern Design; Ramboll

Al Rayyan Stadium – Qatar

- Two Rating Systems: GSAS Rating (4 Stars) & LEED (Certified)
- Reduce embodied carbon (CO2-eq): **15%**
- Operational GHG emissions reduction (BAU): **30%**
- Energy demand reduction (ASHREA 90.1): **30%**
- Onsite energy supply from Renewables: **15%**
- Reduce potable water use: **60%**
- Diverting construction waste from landfill: **90%**

Hepworth Art Gallery

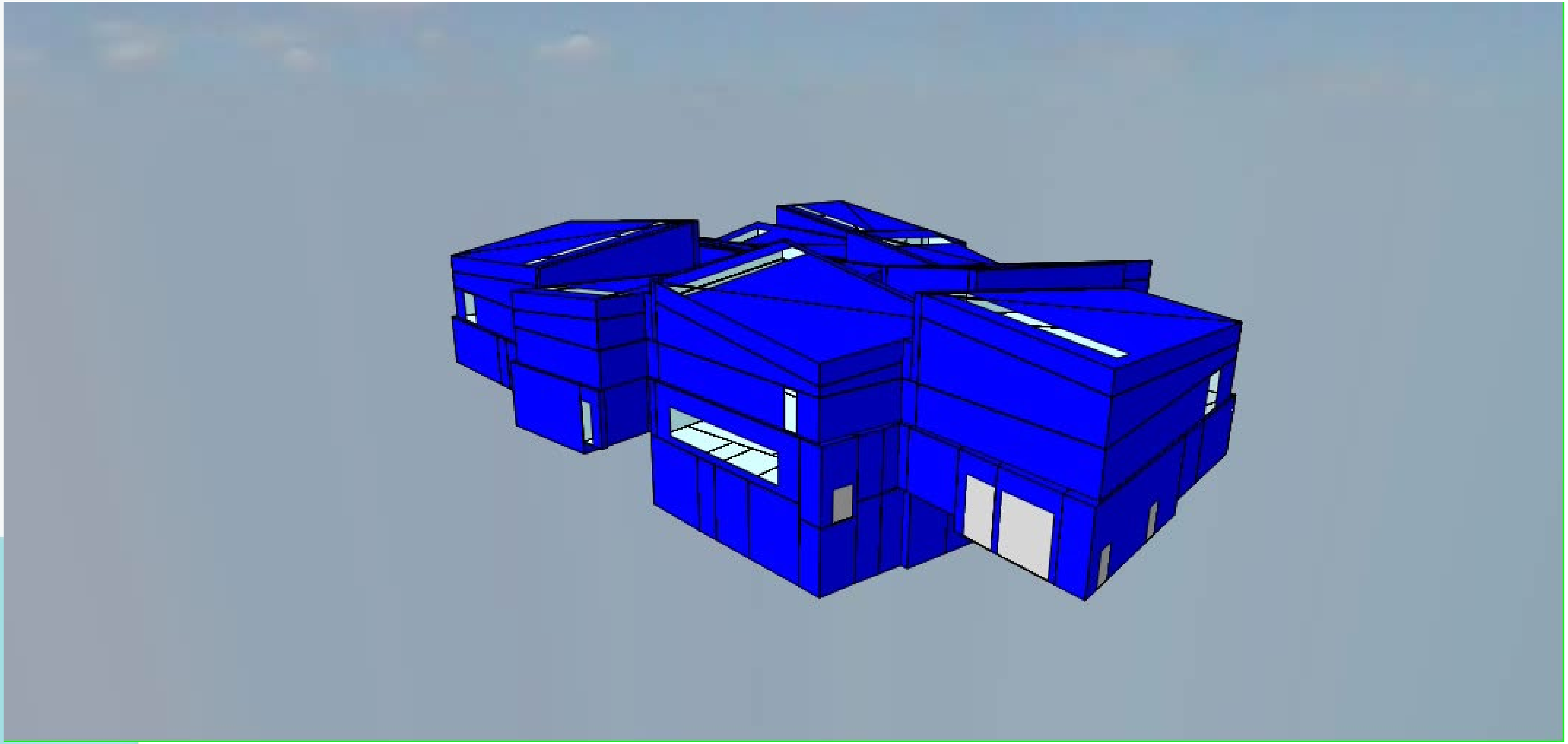
- 10 Galleries with Unique Architectural Design
- Located is Wakefield City, Yorkshire
- Complex Geometry
- GSHP for nearby water stream (River Calder) to provide *heating, cooling* and *DHW preheating*

https://hepworthwakefield.org/

Building Overview

Hepworth Art Gallery

3D Model



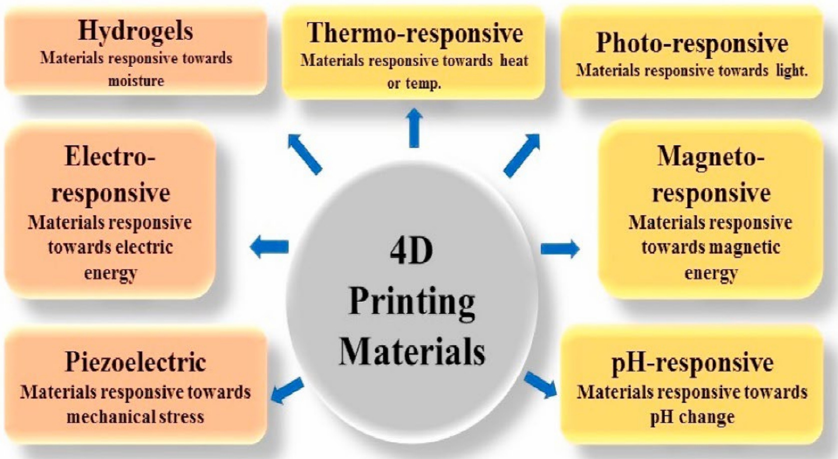
GSHP – Heating & Cooling

Winter

Summer

Hepworth Art Gallery

4D Printing with Smart Materials



Types of materials used for 4D printing schematics (Ahmed et al. 2021)

4D printing technologies

- 1D strand > 2D surface > 3D shape & morphing between different dimensions
- transformation is influenced by external stimuli, such as light, heat, electricity, magnetic field, etc.
- adaptability and dynamic response for structures and systems of all sizes

Applications

- designing and fabricating 4D garments as knitwear that considers comfort during body movement
- creating flat-pack parts would automatically assemble e.g. tables and chairs
- biocompatible devices sufficient to expand/contract an entity e.g. surgical procedure

Ahmed et al. (2021)

Haleem et al. (2021)

Liu et al. (2021)

4D Printing in Civil Engineering

3D printed steel bridge,
Amsterdams.
Arup, MX3D,
Joris Laarman Lab (2018)

Key aspects

- material selection, design, printing process, and external stimuli
- energy and time consumption, direct and indirect costs

Opportunities

- Adaptive & energy-efficient infrastructure - respond to external stimuli, e.g. temperature, moisture, load, sun, fire, water – safe, resilient, and efficiency
- Sustainable construction – eco-friendly structures – minimize waste, reduce energy consumption, disassembly and recycling
- Self-assembly and self-healing structures – reduced maintenance and extend the service life
- Disaster-resistant structures – adapt and respond to extreme forces
- Smart transportation system – urban planning and development - design flexible and dynamic urban spaces for evolving community
- Workforce development and upskilling

Ahmed et al. (2021)

Firoozi & Firoozi (2023)

Future Directions

- Close the Energy Performance Gap - integrated system to connect different digital or data technologies.
- Address aging or existing built assets without a BIM-based data source.
- Implement circular design framework for futureproof construction and regenerative cities.
- Design for biophilia and circularity with nature-based carbon-storing materials systems.
- Integrate novel technologies to enhance adoptions of Design for Manufacturing and Assembly (DfMA) and Design for Deconstruction (DfD) methods.
- Improve scalable urban planning with decentralized renewable energy management systems for resilient communities.
- Support community climate action network and boost green innovations.

Arup and
Ellen MacArthur Foundation (2022)

Kriegh et al. (2021)

Roxas et al. (2023)

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Thank You