Introduction

Management and Sharing of Construction Data

Computing in Construction

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Special needs of the construction sector

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Construction industry

All industries deliver products and/or services to their customers

How about the construction industry?

- What are the products like?
  - buildings, facilities
- What are the delivery processes like?
  - construction projects
- What is the construction lifecycle?
  - lifecycle stages
  - official approvals
- How are delivery processes organized?
  - delivery methods, contracts

Impacts on data management and sharing

Building construction

People need <u>protected, controlled, and usable space</u> for varied purposes

- residence, work, social gatherings, commerce, production, health care, sports, culture, storage, ...

Protection is needed from environmental factors

- rain, snow, sunlight, dust, wind, noise, ...
- intruders, outsiders' sight, ...

Conditions of spaces need to be actively controlled

- temperature, humidity, air quality, ...

Usability creates requirements for the space

- typically: horizontal floors, vertical walls, sufficient dimensions, entrances, natural light, ...

In addition, built environment serves other purposes

- esthetic – the look and feel of living
- social – natural contact with others

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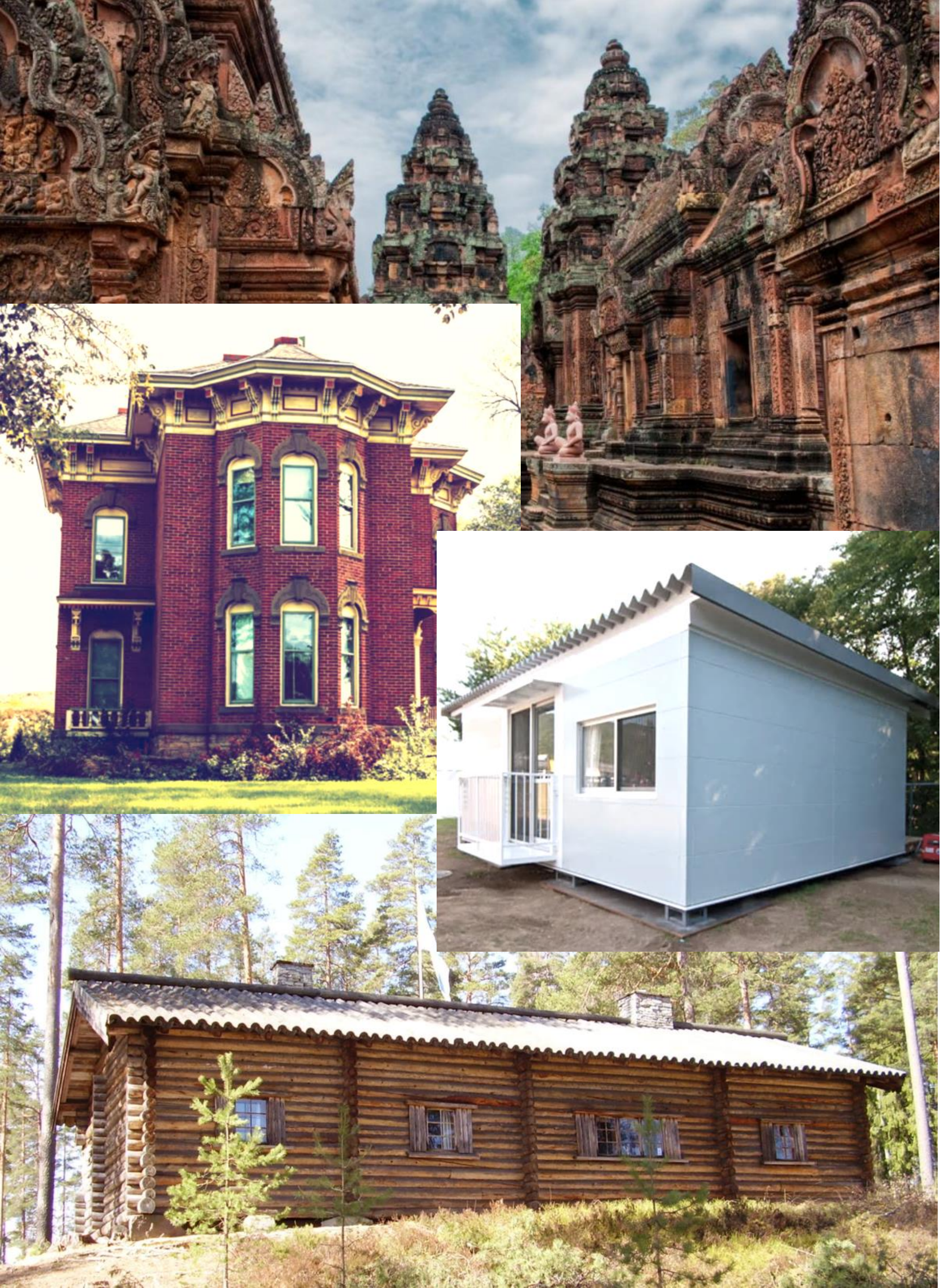


Lifespan of buildings

Buildings are normally designed to last at least 50 years

- the actual lifespan can be shorter or much longer
- buildings need maintenance and renewals over time

Many changes happen over building lifecycle

- type of use
- extensions
- spatial configuration
- building systems
- surface treatments

Lifespan of different parts varies

- renewals required at different time periods
- the more independently different aspects can be renewed, the more maintainable the building is

Material/component	Years
Paint	7-15
Appliances	5-20
Wood paneling	20-50
Water lines	50-70
Concrete walls	75+
Engineered lumber	80-100
Concrete foundation	100+

https://www.bhhomeinspections.com/building-materials-life-expectancy-chart/

Shearing layers

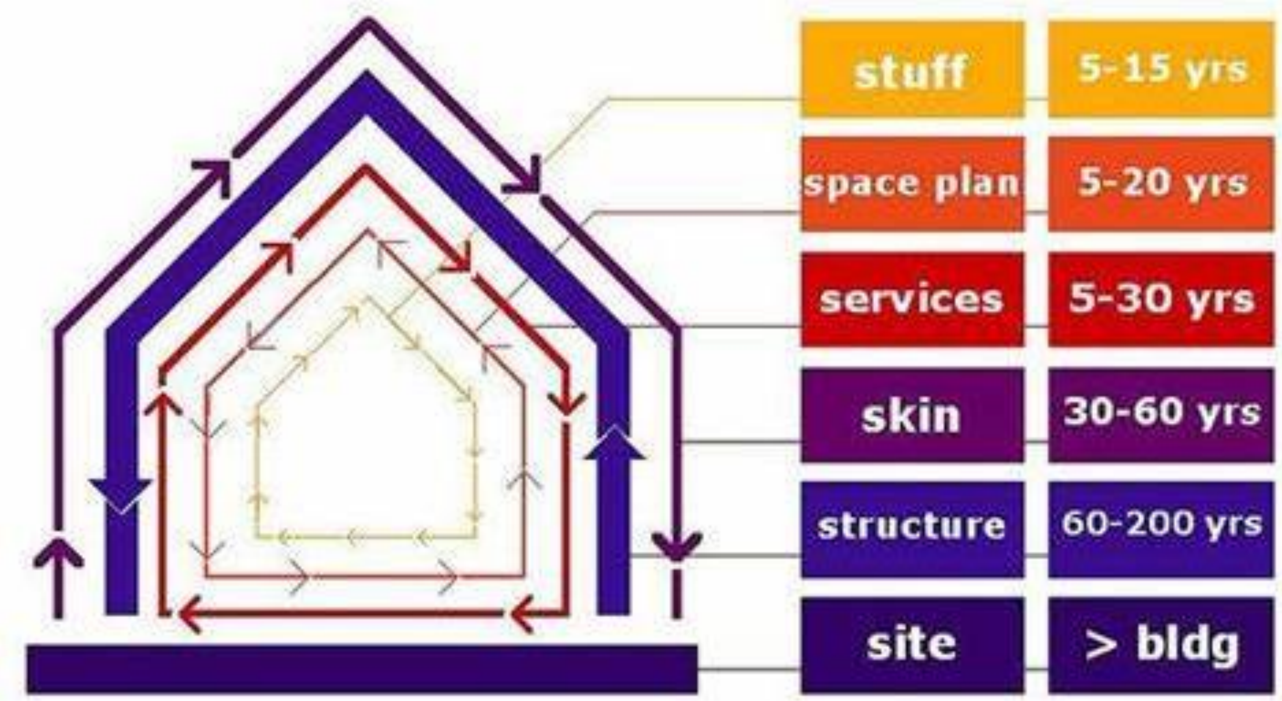
Long-lasting buildings allow the different layers to **change relatively independently**, as they have widely different lifespans

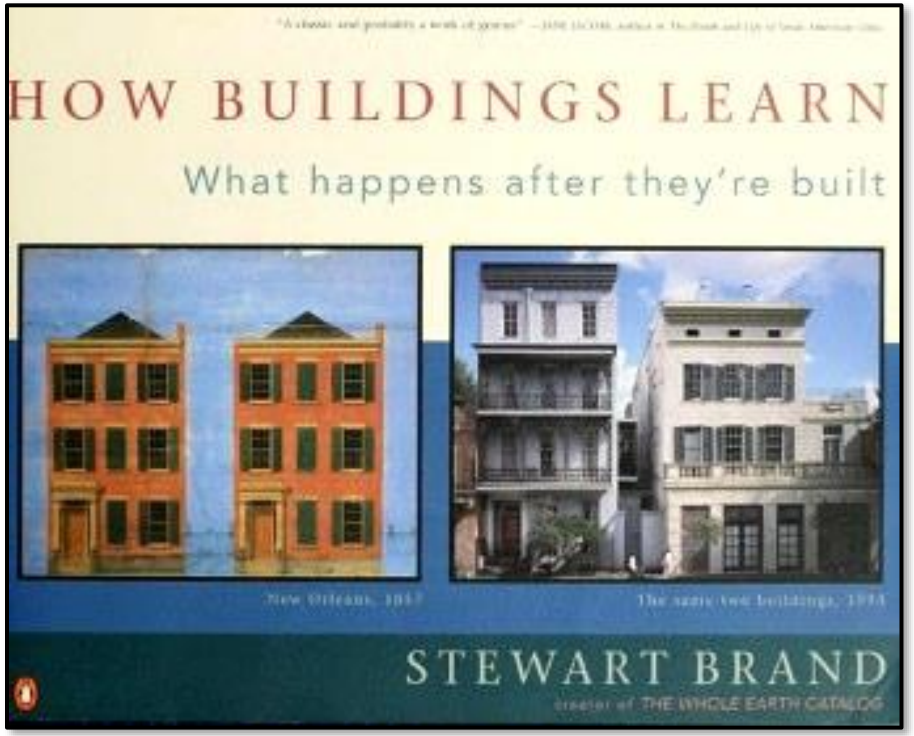
- loosely coupled layers
- flexible and adaptable: cheap, simple, robust components
- support for user-driven modifications
- evolutionary design over visionary design: design that grows and incrementally improves over time

"All buildings are predictions, and all predictions are wrong" - Stewart Brand

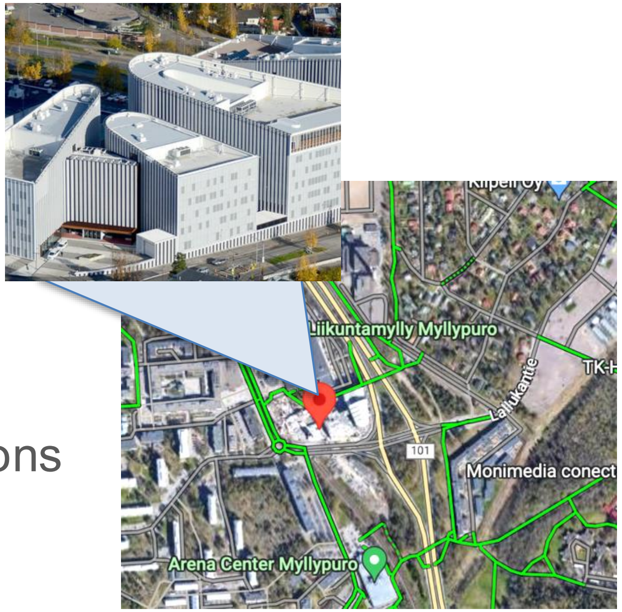
"Our basic argument is that there isn't any such thing as ***a building****. A building properly conceived is* ***several layers of longevity of built components"*** – Frank Duffy

(Stewart Brand, *How Buildings Learn: What Happens After They're Built*, Viking Press, 1994)



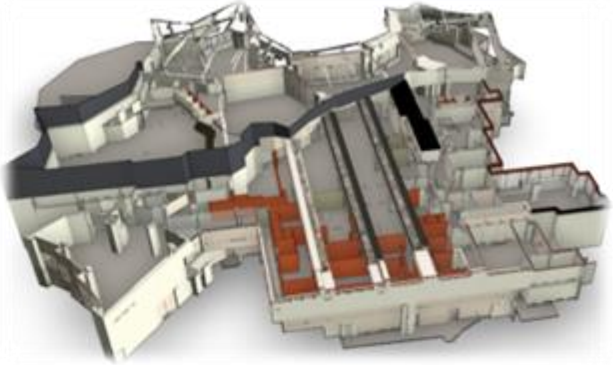


Buildings as products



Buildings are large and unique one-of-a-kind products

1. Own, exclusive geographical location
    - specific zoning, building codes, and other constraints
    - climate, environmental stress, site topography, ground conditions
    - existing buildings and infrastructure networks around the site
    - available pool of contractors and specific transportation needs
2. Different time period of construction and operation for each building
    - products, regulations, and practices all evolve over time
3. Individual customer needs
    - use of the building, spatial requirements, style, and esthetics
    - constraints on budget and time



→ Each building requires specific planning and design

– the need to satisfy the unique customer needs in unique circumstances

Buildings are constructed outside, on the construction site

– conditions are much more uncontrollable and varied than, for instance, in factory production

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Buildings are complex products

Number of parts

- A single-family home: ~ 3 000 parts
- An apartment building: ~ 30 000 – 300 000 parts
- For comparison:
  - a typical car: ~ 30 000 parts
  - a Boeing 737: ~ 300 000 parts

Interdependencies

- Parts are put together in a specific way, in a specific order, by dozens of different workers
- Assembly tasks require sequences of successful operations
  - a drywall: *frame erection* → *electrical wiring* → *plasterboards* → *plastering* → *painting*
- On site construction is difficult to parallelize
  - e.g., electrical wiring cannot be done before the frame has been completed
- Little resource flexibility due to the trade-specific nature of tasks
  - e.g., if a frame builder is absent, an electrician cannot replace him

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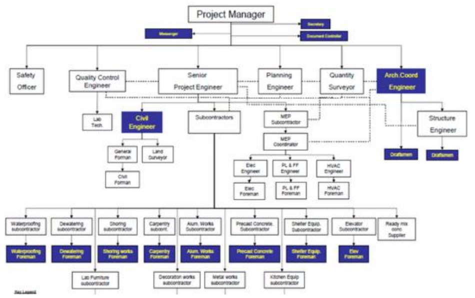
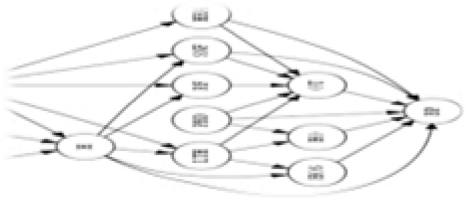
Characteristics of construction projects



- Project consortiums are fragmented
  - Each project is executed by a large and unique set of parties
  - Consortium is different in each project
- Uniqueness → uncertainty → changes → ripple effects
  - Unique product and often a unique consortium
  - Unexpected site circumstances
  - Unfamiliar coordination with partners
  - Delays and conflicts due to poor coordination create changes with ripple effects



- Contractual arrangements predispose to confrontation
  - Fulfilling one's own contract obligations is seen more important than the success of the whole project – a possible problem if there is a need to adapt to changes
  - Contract disputes and litigation are commonplace
  - Information is not shared for the fear that it may later be used against oneself
- Cost-driven culture
  - Quality, time, and sustainability are of secondary importance

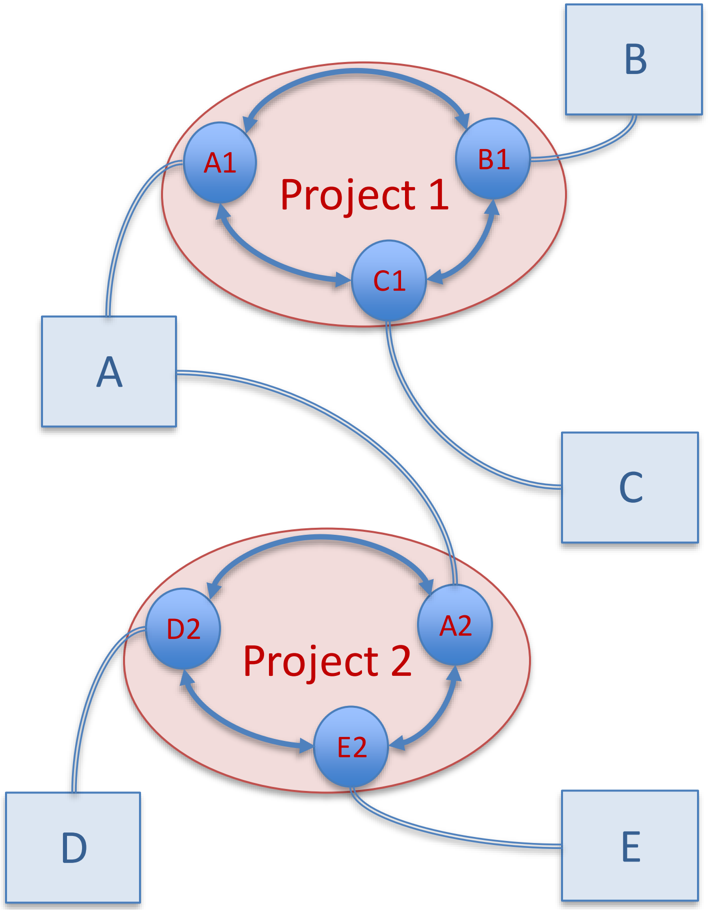
Loosely-coupled industry – tightly-coupled projects

In the construction industry, companies are loosely coupled

- companies in the same trade are broadly speaking exchangeable
- no company has much specific adaptation with other individual companies

But in construction projects, companies are tightly coupled

- highly interdependent task sequences involving different companies
- shared work locations and resources
- tight schedules



Coordination through the community of practice

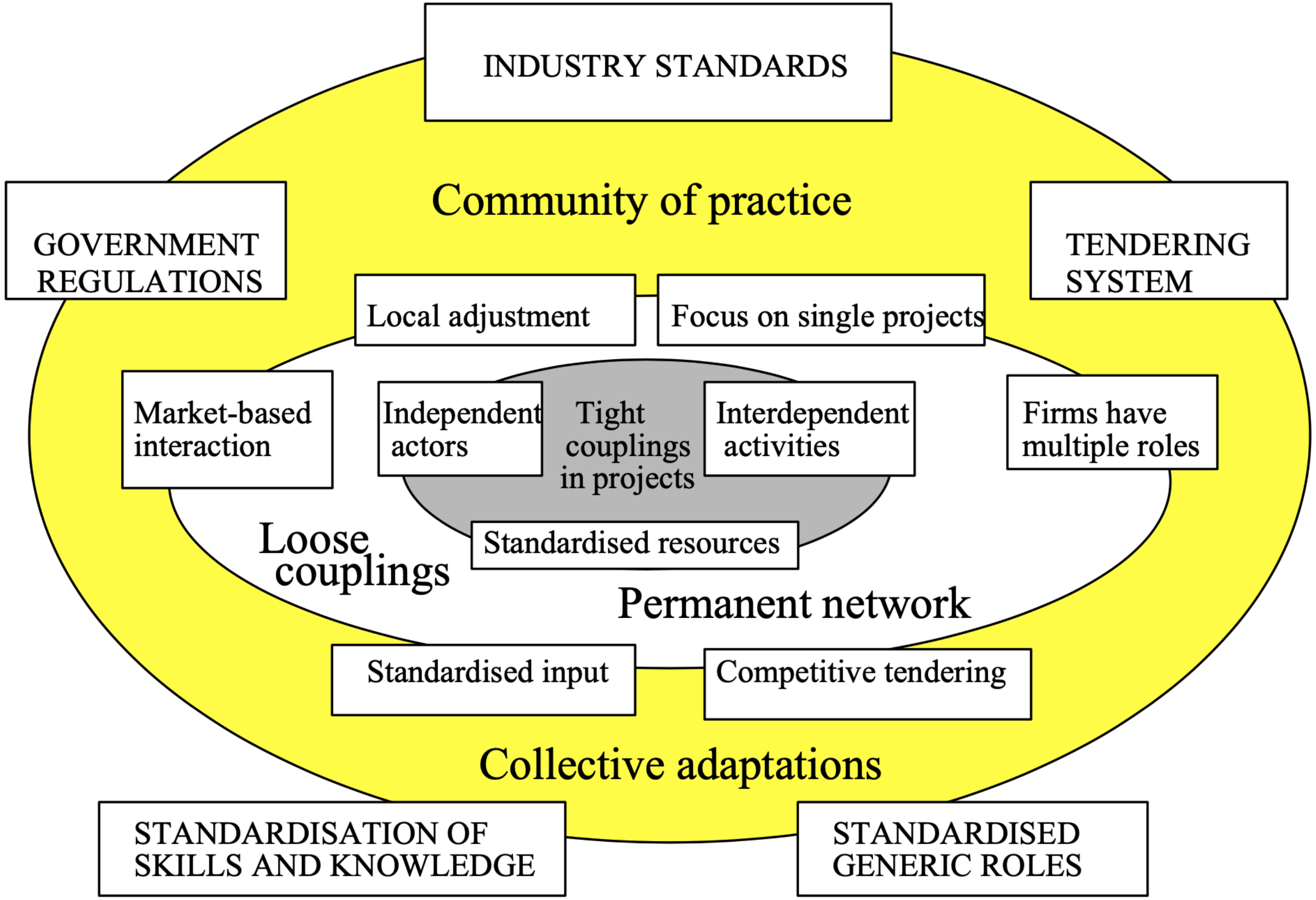
How to achieve sufficient coordination within projects without previous adaptations between the companies involved?
(*Or how can buildings be constructed in the first place?*)

→ Over time, collective adaptations (*a community of practice*) have formed, reflected in

- governmental regulations
  - building codes, norms, principles for housing subsidies
  - working environment and workers’ protection
- standards
  - contract formulas
  - components and systems
  - tendering processes require standardized offerings from suppliers
  - generic roles of companies in design, planning and construction
  - skills and knowledge: 'current standards of workmanship’
- common knowledge that everyone in construction knows
  - or soon learns after starting to work in construction

Dubois, A., & Gadde, L. E. (2002). The construction industry as a loosely coupled system: implications for productivity and innovation. *Construction management & economics*, *20*(7), 621-631.

Coupling patterns and related adaptations



Community of practice is a way to <u>enhance productivity and efficiency</u>:

- it facilitates tight couplings in projects, despite loose couplings in the industry
- stabilises conditions and therefore promotes short-term productivity

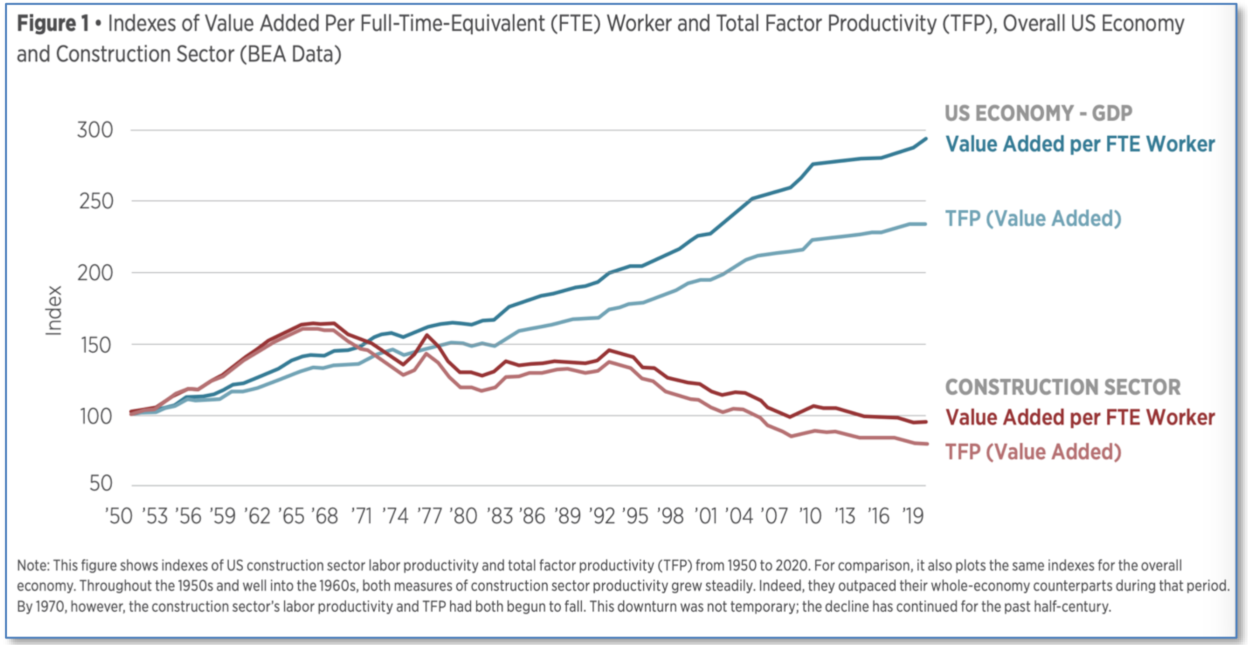
However, it also <u>hampers innovation</u> because it tends to make firms

- similar,
- independent, and
- slow to change, since change depends also on what other firms do

Dubois, A., & Gadde, L. E. (2002). The construction industry as a loosely coupled system: implications for productivity and innovation. *Construction management & economics*, *20*(7), 621-631.

Poor productivity in the construction sector

Productivity development has lagged far behind the average



Reasons (?)

- requirements for buildings and construction processes are increasingly complex
- community of practice, while handy in short-term, keeps the industry stagnant in long term
- slow adoption of prefabrication (partly due to nasty problems caused by tolerances, etc.)
- the weakest links may limit the productivity of complete workflows
  - all tasks in a workflow and the interoperability between them need to be improved in parallel

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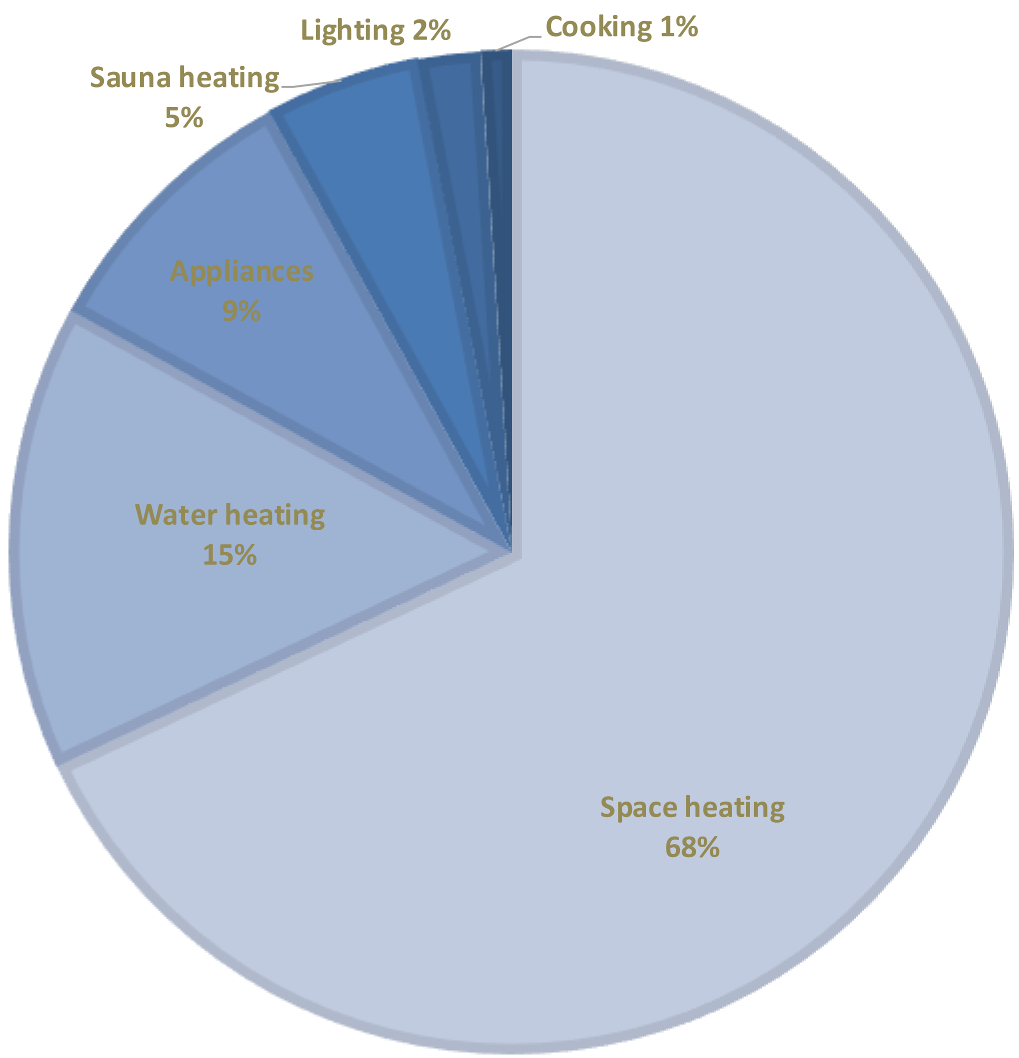
Climate impact of construction



- The construction and operation of buildings are responsible for ~40% of global energy-related CO_2 emissions
  1. **Embodied Carbon Emissions**: The total carbon emissions associated with the production and transportation of building materials.
  2. **Operational Carbon Emissions**: From the use of heating, ventilation, and air conditioning (HVAC) systems, lighting, and other building systems.
  3. **Waste and Resource Use**: The generated waste, including construction debris and discarded materials, contributes to carbon emissions through transportation and disposal
- Strategies to reduce the climate impact
  – Using low-carbon building materials
  – Increasing energy efficiency in buildings
  – Promoting sustainable building practices to reduce resource use and waste
  – Promoting recycling of building components

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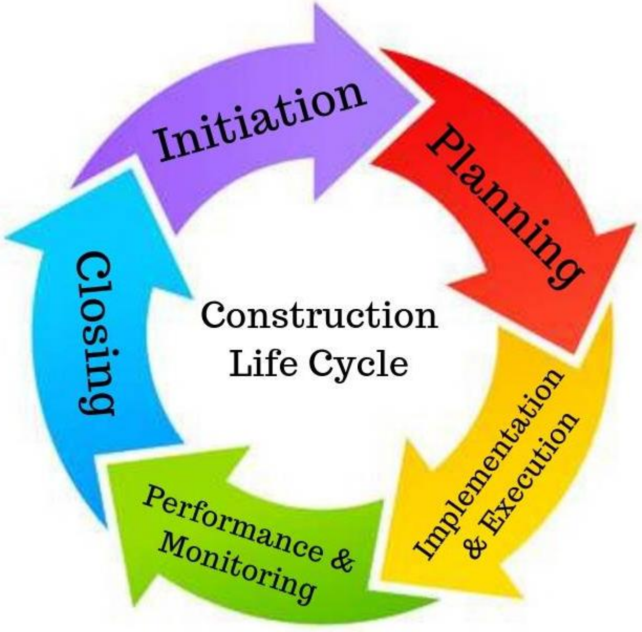
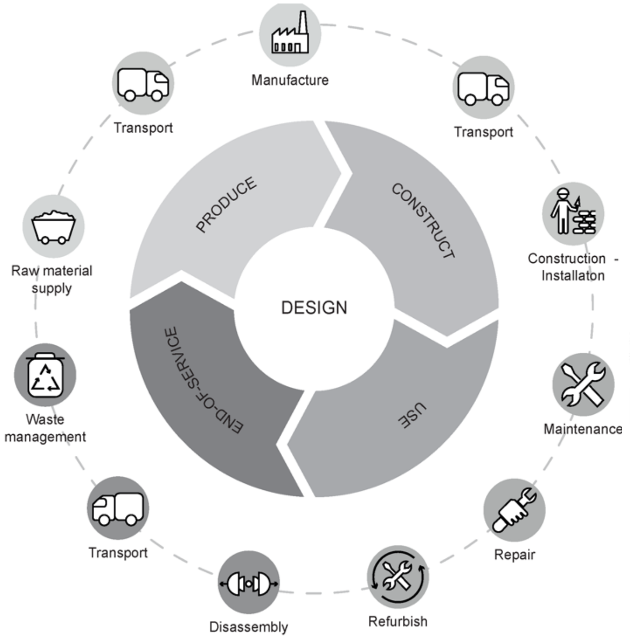
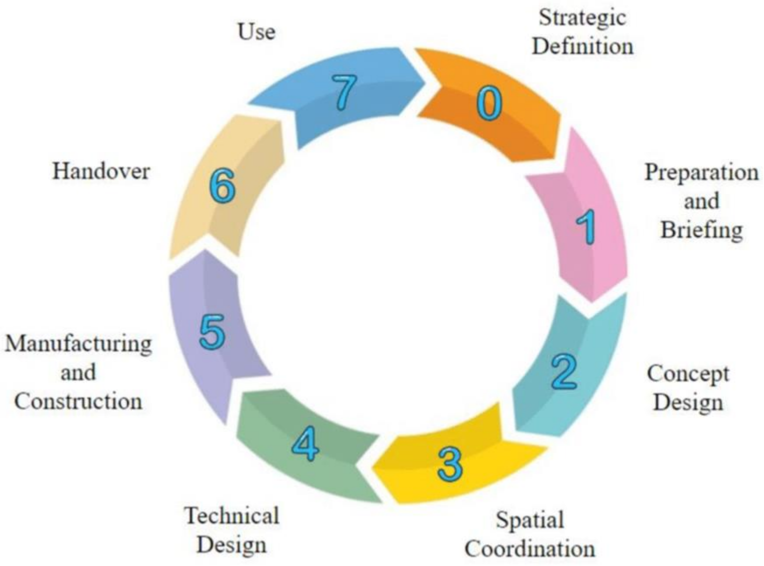
Construction lifecycle

Construction lifecycle



- The lifespan of a building consists of several stages characterized by different main functions
- The borders of the stages are not strict but there can be considerable overlap
- There are different models of building lifecycle stages
  - The models can be based on different perspectives
  - The stages can be grouped in different manner





RIBA Lifecycle model

John Messner (2019): [INTRODUCTION TO THE BUILDING INDUSTRY]

Standards / Stages	BS EN 16310:2013		HOAI	RIBA	ISO 22263
1	Initiative	Market study	Establish the base of the project	Strategic Definition	Inception
		Business case			
2	Initiation	Project initiation		Preparation and Brief	Brief
		Feasibility study			
		Project definition			
3	Design	Conceptual Design	Preliminary Design	Concept Design	Design
		Preliminary Design			
		Developed Design	Final Design	Developed Design	
		Technical Design	Building Execution Drawings	Technical Design	
		Detailed Design	Preparation of contract award		
4			Building permission applications		
5	Procurement	Procurement	Assisting the award process		
		Construction Contracting			
6	Construction	Pre-construction	Project Supervision (Construction Supervision)	Construction	Production
		Construction			
		Commissioning	Project control and documentation	Handover and Close Out	
		Hand Over			
		Regulatory Approval			
	Use	Operation		In Use	
		Maintenance			
	End of Life	Revamping			Demolition
		Dismantling			

Karlapudi, Menzel, Törmä, Hryshchenko (2020)

Standards relevant to building lifecycle

- BS EN 16310 – Engineering services terminology
- HOAI – A German Fee Schedule for Architects and Engineers
- RIBA – Work Plan of The Royal Institute of British Architects
- ISO 22263 – Organization of information about construction works — Framework for management of project information

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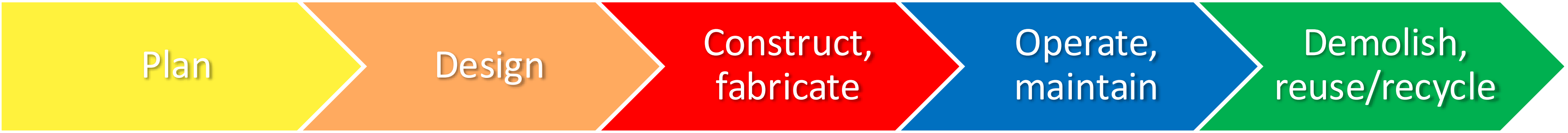
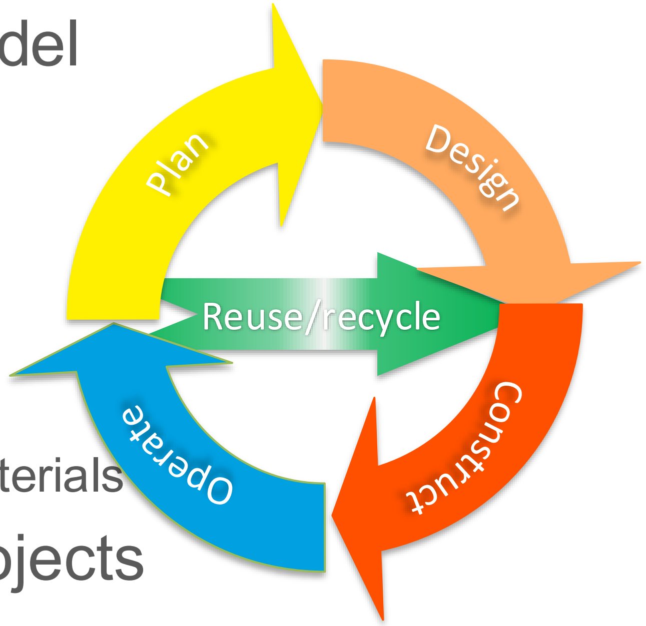
Building lifecycle stages



For the purposes of this course, a simple lifecycle model with five stages is adopted:

1. **Plan** – initiation, secured site, business case, delivery model
2. **Design** – several steps from concept design to detailed design
3. **Construct** – procurement/fabrication, logistics, site operations
4. **Operate** – use, operation, and maintenance of the built asset
5. **End of life** – demolition and reuse/recycling of components/materials



The Operation stage can include many renovation projects

- Lifecycle can therefore be seen as a cycle of repeating renewals of the built asset
- In the stage 5 Recycle, components or materials can leave the cycle, entering perhaps the lifecycle of another built asset

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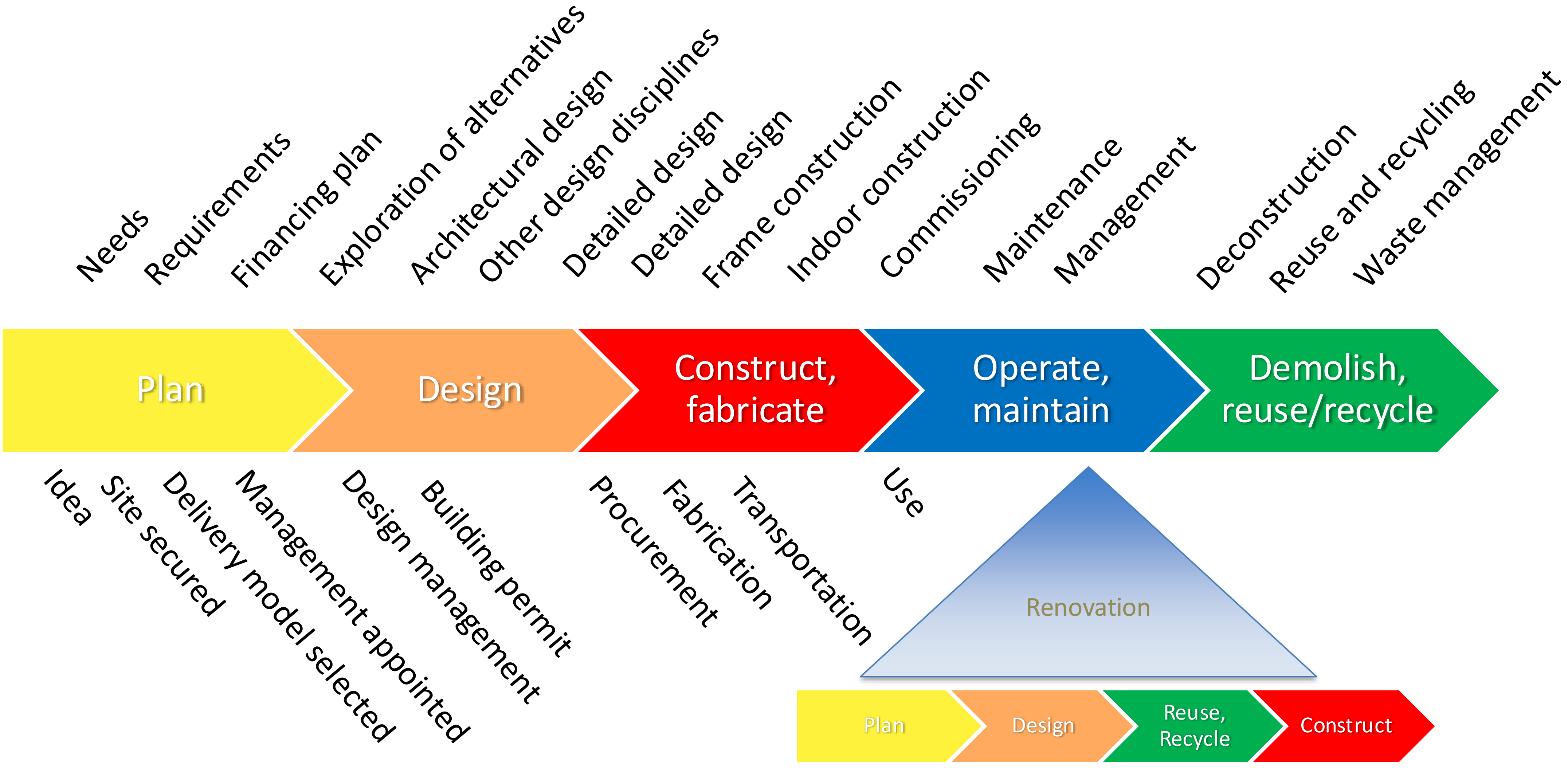
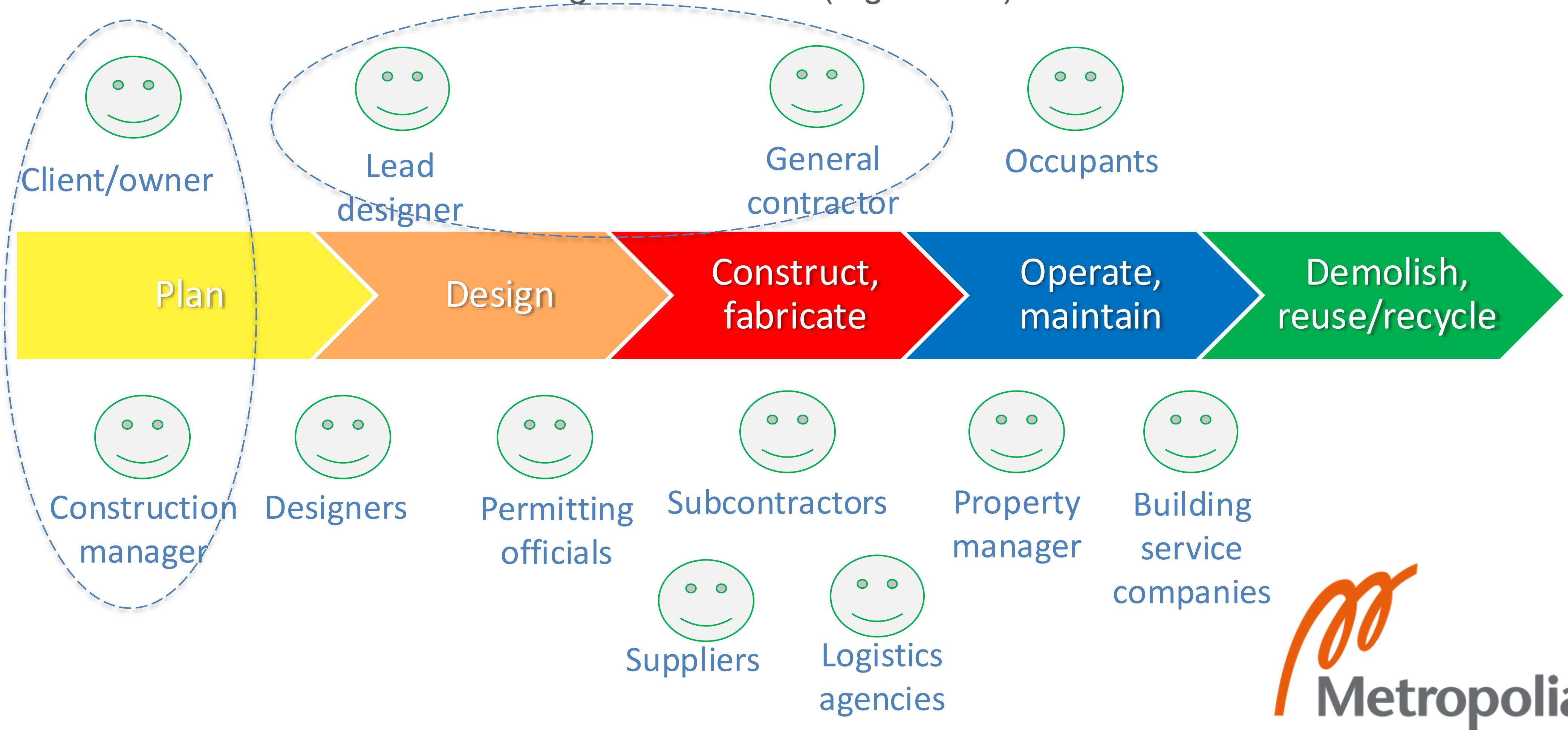
Building lifecycle – tasks and functions



Roles of actors and stakeholders

Agents can assume different roles over the lifecycle of a building

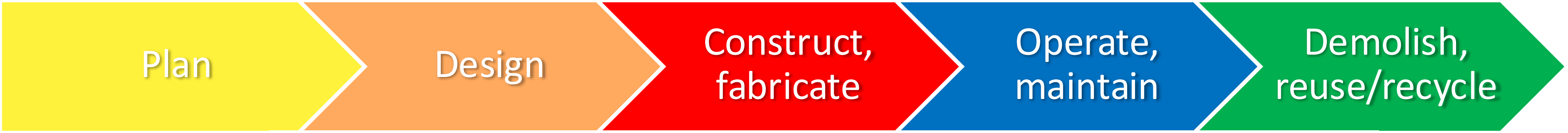
- same agent can take multiple roles
- roles can move from one agent to another (e.g. owner)



Lifecycle assessment (LCA)

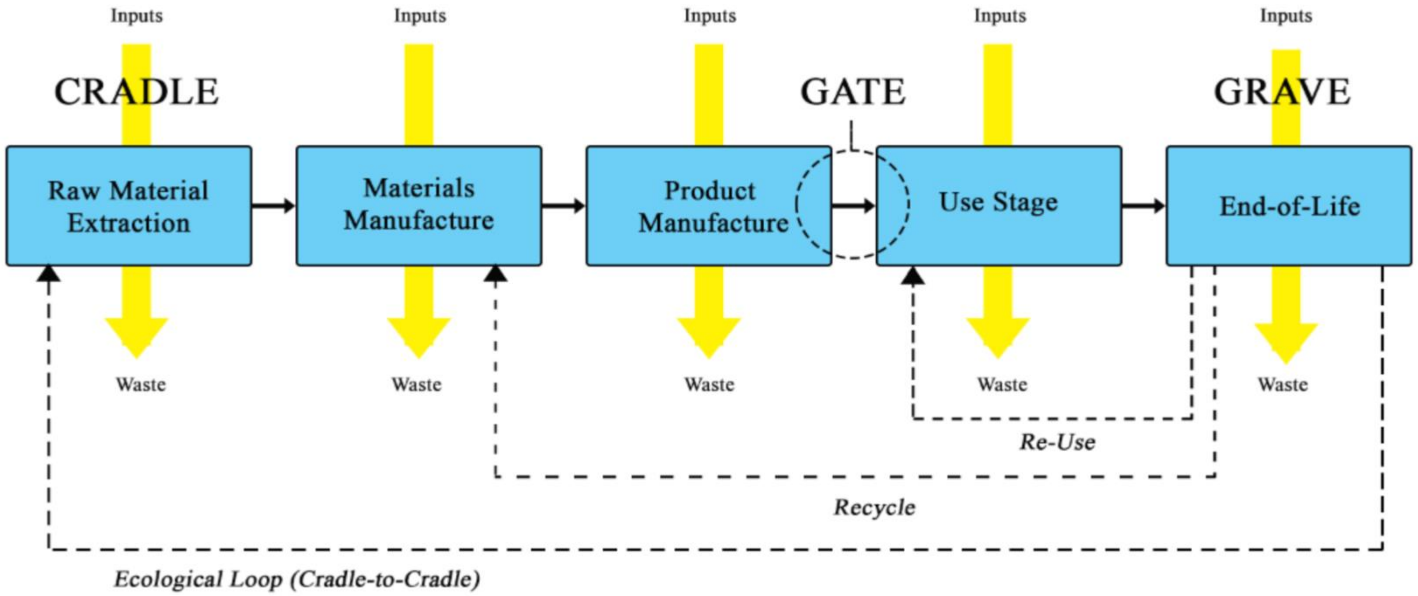
Building LCA is a methodology for assessing environmental impacts associated with all the stages of the building lifecycle

- Lifecycle Inventory (LCI) – identifying all material flows from and to the building
- Lifecycle Impact Analysis (LCIA) – evaluating the potential environmental and human health impacts based on flows of LCI



Three important points

- Cradle
- Gate
- Grave



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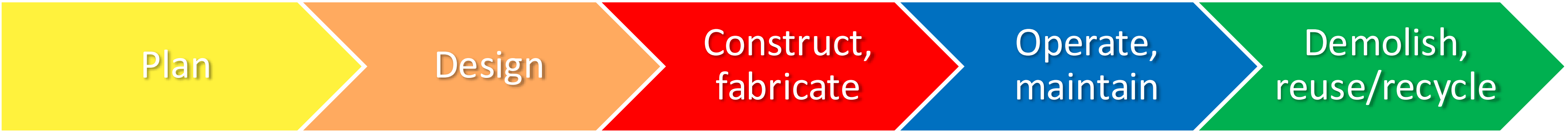
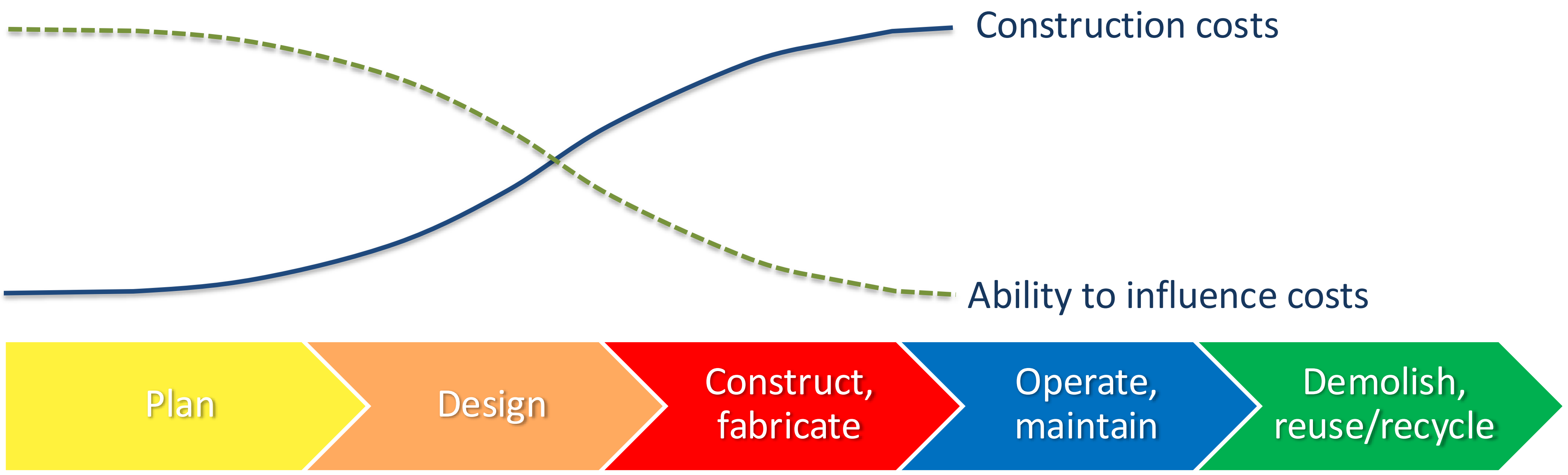
Lifecycle costing (LCC)



LCC is a method of evaluating the total cost of a building over its lifecycle

- aims to provide a comprehensive view of the costs and benefits associated with
  - different building materials,
  - design options, and
  - maintenance strategies
- enables owners to make informed decisions about the most cost-effective and sustainable approaches to construction
  - more robust than return of investment calculations
- helps the owners to
  - save money and
  - reduce their environmental footprint over the building's lifetime

Costs during construction project



Construction costs accumulate during the delivery phase

- Can be influenced mostly in the planning and early design stages and only very little after the construction begins

Operation stage is responsible of up to 80% of lifecycle costs

- Note that economic and social value of the use of the building can be tens of times the costs of construction and operation

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Building regulations

Regulation of construction

Unrestricted freedom to build can lead to chaos

- incompatible/interfering uses of land
  - mixing industry, traffic, residential areas, ...
- insufficient provision of
  - water and electricity supply
  - sanitation and waste management
- lacking transportation infrastructure
  - road network, public transportation, parking space, ...

→ Problems with
- safety
- health
- comfort

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Objectives for built environment

Safe
- stability of structures, fire safety, separation of transportation modes, ...

Healthy
- pure air and water, no harmful emissions, little noise or accumulation of moisture, ...

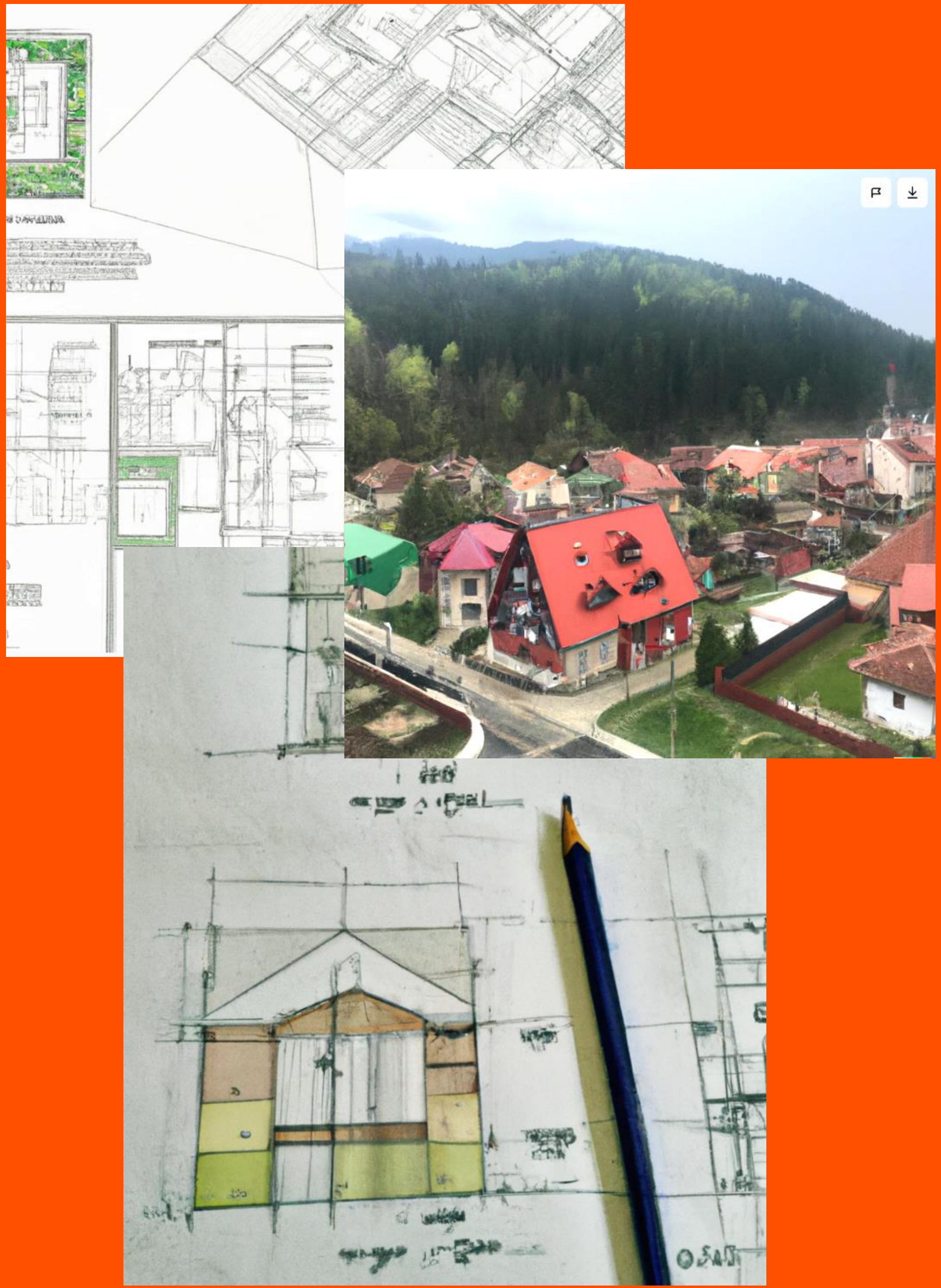
Comfortable
- pleasant temperature, esthetically pleasing, combines social interaction and privacy, ...
- essential services are easily accessible

Sustainable
- energy-efficient, low carbon

High quality
- no defects or broken systems

Demographically balanced
- avoids segregation of demographic groups

Finnish Building Code



Aspects of regulation

1. Land use planning
   - External: How should a building fit into its environment?
   - What is required from the use, size, form, and appearance of a building?

2. Building codes
   - Internal: How should a building be constructed?
   - What is required from structures, materials, space dimensions, escape routes, etc.?

Both can address all the previously mentioned objectives from their own perspectives

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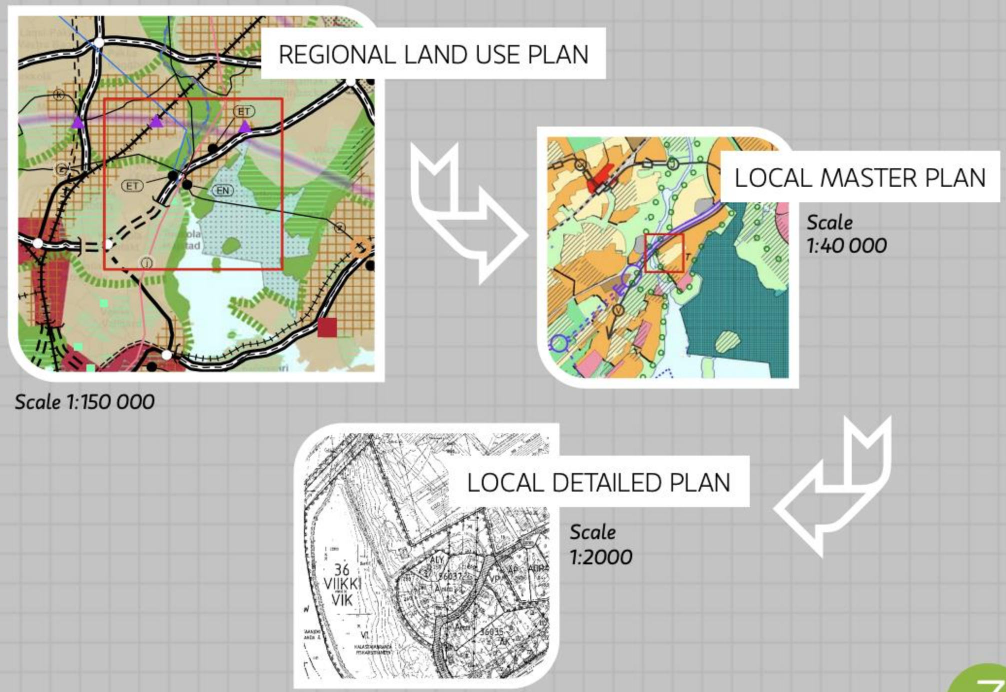

Uudenmaan liitto (2021). What is a regional land use plan?

Land use planning

- How can land be used for construction?
  - What can be built where?
- Most common method is *zoning*
  - Land is divided to designated areas based on the use of buildings (residential, industrial, commercial, ...)
- Multiple levels of land use plans (in Finland)
  - **Regional plan** ("maakuntakaava") – locations of functions at the county level, guides master planning at municipalities
  - **Master plan** ("yleiskaava") – the development of a municipality (zones, networks, services), guides detailed planning
  - **Detailed plan** ("asemakaava") – the possible locations and sizes of buildings, guiding building projects
- Possibly other regulations, e.g.,
  - Local building regulations ("rakennusjärjestys")
  - Temporary building restrictions ("rakennuskielto")

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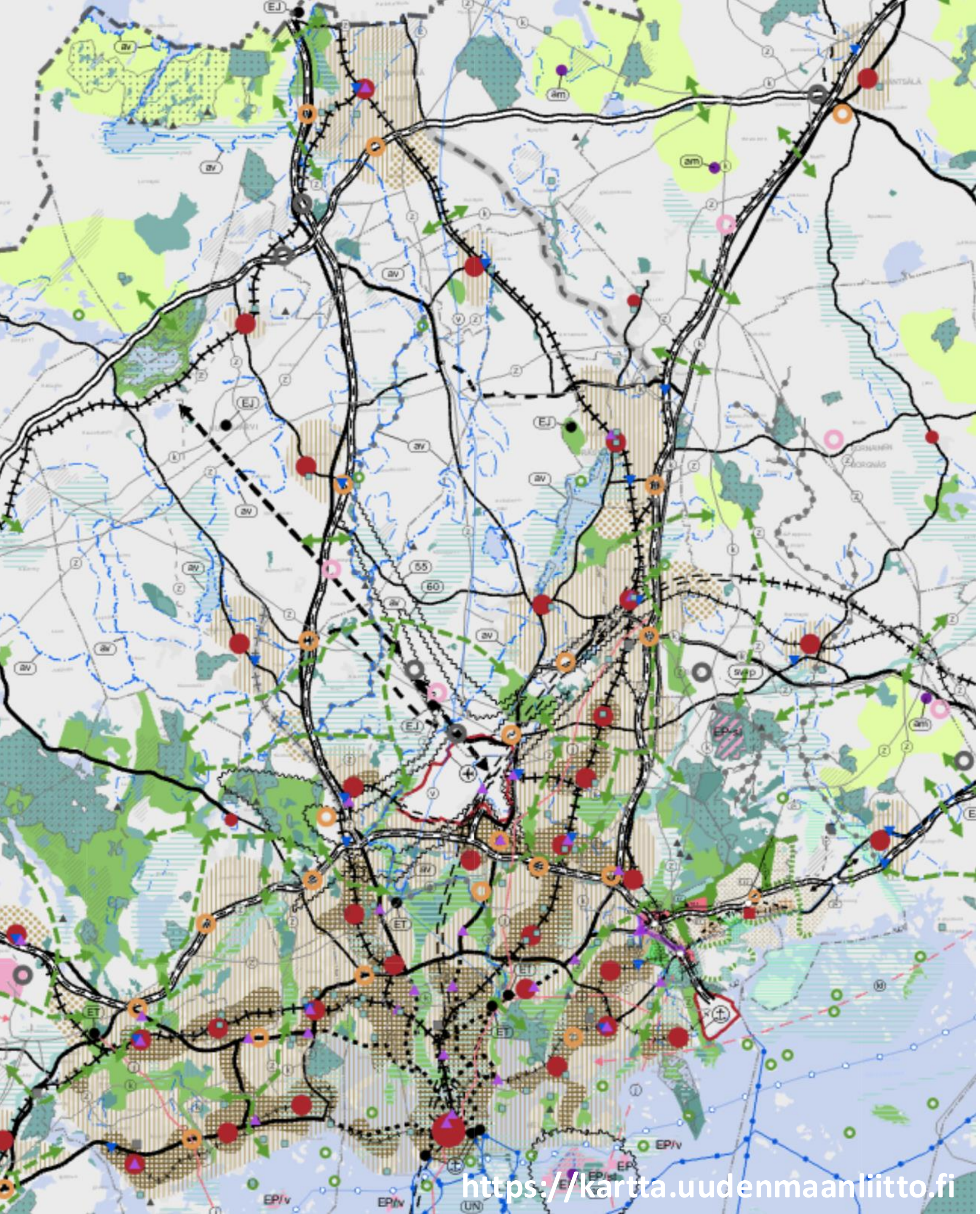

Example of a land use plan for the capital region of Finland

- Urban area
- Nature reserve
- Industrial area
- Workplace area
- Recreation area
- Urban area relying on rail traffic
- Central urban area
- Commercial center

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Building codes

A building code is a set of rules that specify the standards for buildings

- required to obtain building permission

Different types

- **National building code** that becomes a law formally enacted by the government
- **Model building code** that can be adopted by a local authority (municipality or urban area)

Example: International Building Code (US)

- Building occupancy classifications
- Building heights and areas
- Interior finishes
- Foundation, wall, and roof construction
- Fire protection systems
- Materials used in construction
- Elevators and escalators
- Already existing structures
- Means of egress (exit)

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The National Building Code of Finland

- Planning and supervision
- Strength and stability of structures
- Fire safety
- Health
- Safety of use
- Accessibility
- Noise abatement and noise conditions
- Energy efficiency of buildings
- Use and maintenance manual
- Housing design

https://ym.fi/en/the-national-building-code-of-finland

Health

When undertaking a building project it is to be ensured that the building is designed and constructed in such a way that it is healthy and safe with regard to indoor air, humidity, temperature and lighting conditions, and water supply and sewerage, as required by the intended use of the building and environmental conditions. The building must not cause risk to health because of impurities in indoor air, radiation, water or soil pollution, smoke, wastewater, the insufficient processing of waste, or the humidity of the building elements or structures.

Products used in construction work must be such that during their planned service life they do not cause emissions that cannot be considered acceptable into the indoor air, drinking water or the environment. Building systems and equipment must be suitable for their intended use and maintain healthy conditions.

Decree	Further material
782/2017 Decree of the Ministry of the Environment on Humidity (pdf) Responsible person Timo Lahti	
1047/2017 Decree of the Ministry of the Environment on Water and Sewerage systems of buildings PDF 173kB Responsible person Tomi Marjamäki	
1009/2017 Decree of the Ministry of the Environment on the Indoor Climate and Ventilation of New buildings (pdf) Responsible person Pekka Kalliomäki	

Personal email addresses are of the form firstname.lastname@ym.fi

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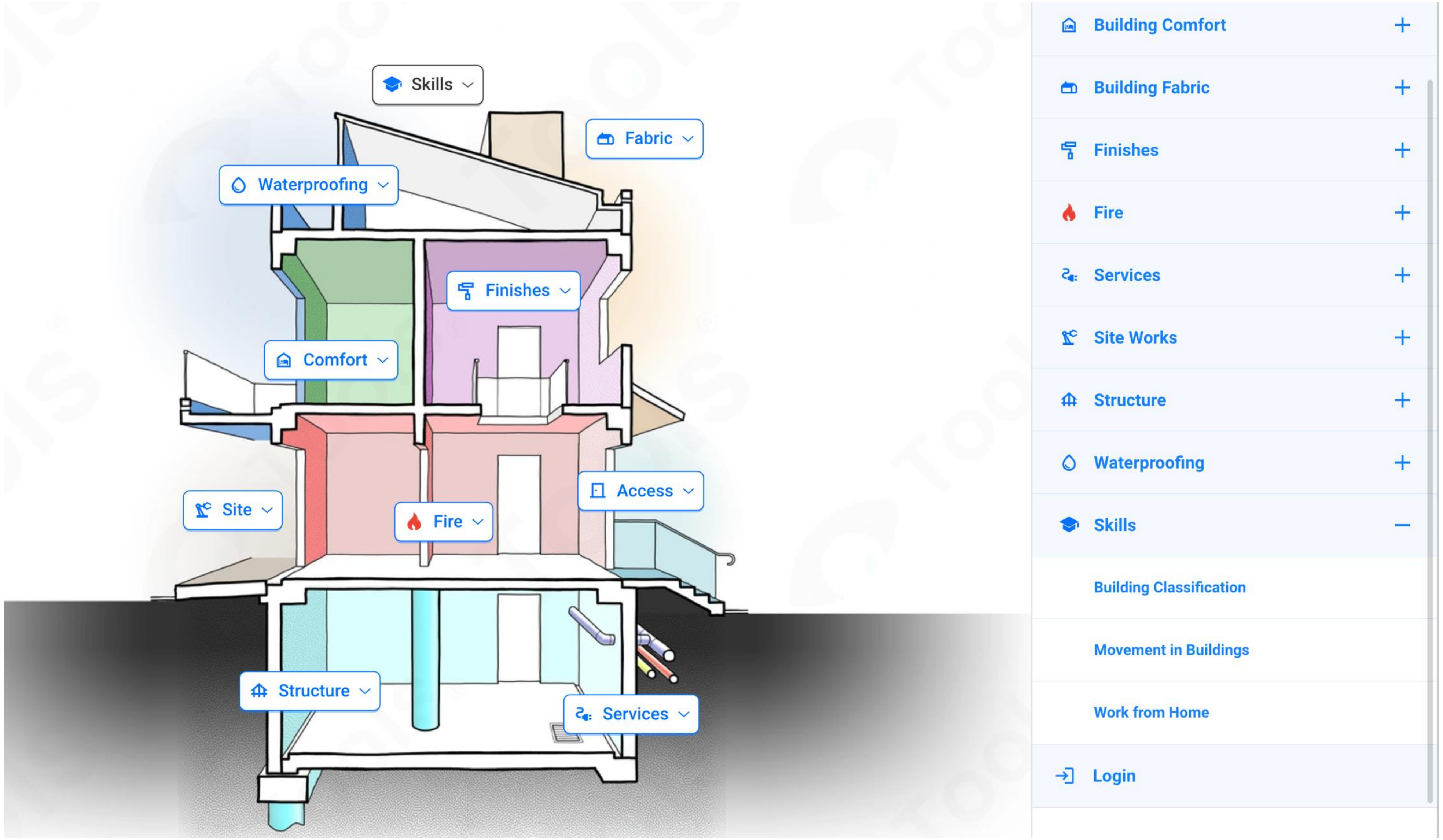
Building code of Australia



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Building permit

Building permit is an official approval to construct a building

Application of a building permit may require

- description of the building
  - master drawings or
  - building information model
- additional reports
  - climate impacts
  - building materials
  - proof of ownership of the real estate

Application process can be carried out

- with paper documents
- with electronic documents (pdf)
- with structural data (BIM models, spreadsheet data, and such)
- using a digital permitting service

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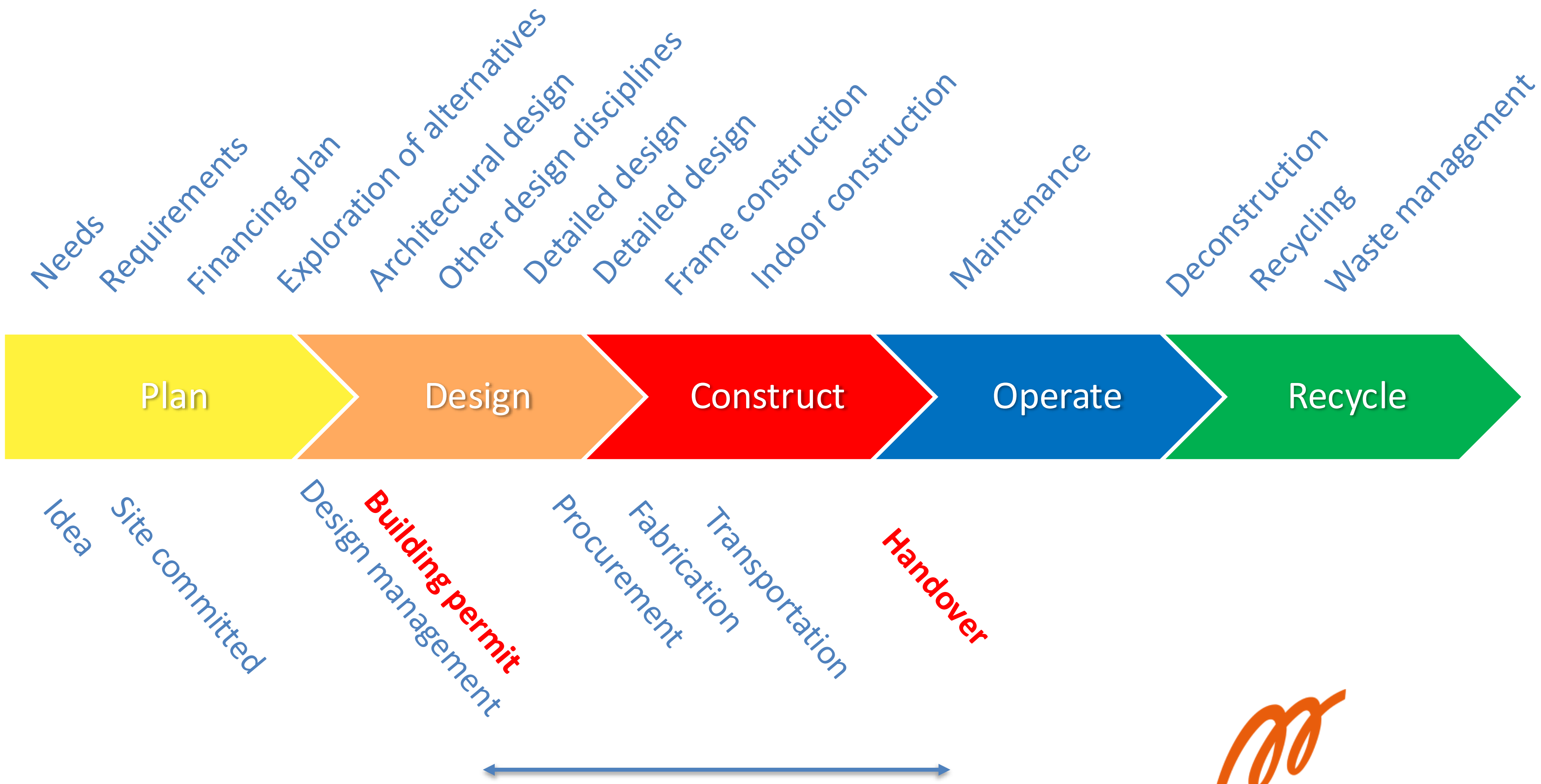
Building lifecycle – official approvals



Delivery methods

Construction project delivery methods

The overall methods to

1. organize and finance
2. the design, construction, operations, and maintenance for a building
3. by entering into legal agreements with one or more parties

Before deciding on the delivery method, the scope of a project must be defined

- for instance, if there are multiple buildings, are each of these a separate project or is there just one large project

Core decisions about the delivery method

1. Organizational structure

- the approach to organize the parties
- can have a significant impact on team responsibilities, roles, level of risk, and interactions
- is created through the contracts between the parties (in a different way in different methods)

2. Contracting methods

- the payment terms: how payments are made from one party to another
  - lump sum, cost plus a fee, unit cost, ...

3. Award method

- how to select the other party of a contract
- competitive bid, prequalification, best value selection, negotiated selection

> These decisions are related to each other, and there are some typical combinations

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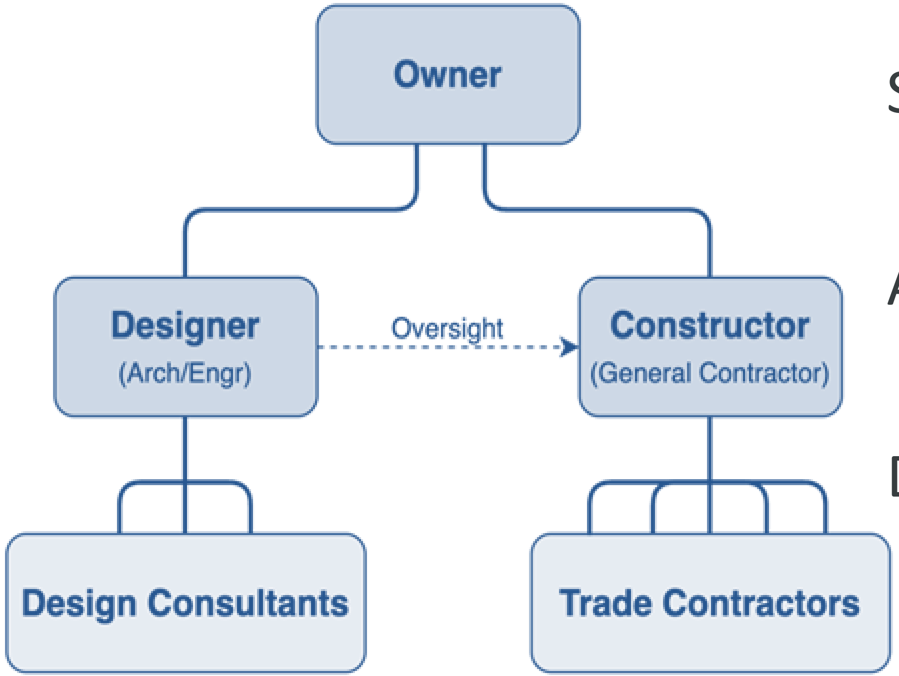
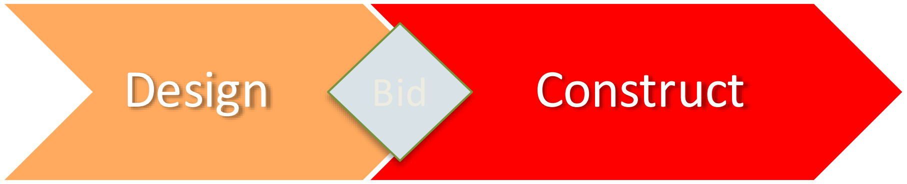
Design-Bid-Build





One party designs then the constructor(s) are chosen based on competitive bidding

- Designer has a oversight of the work of the constructor(s)

Suitability

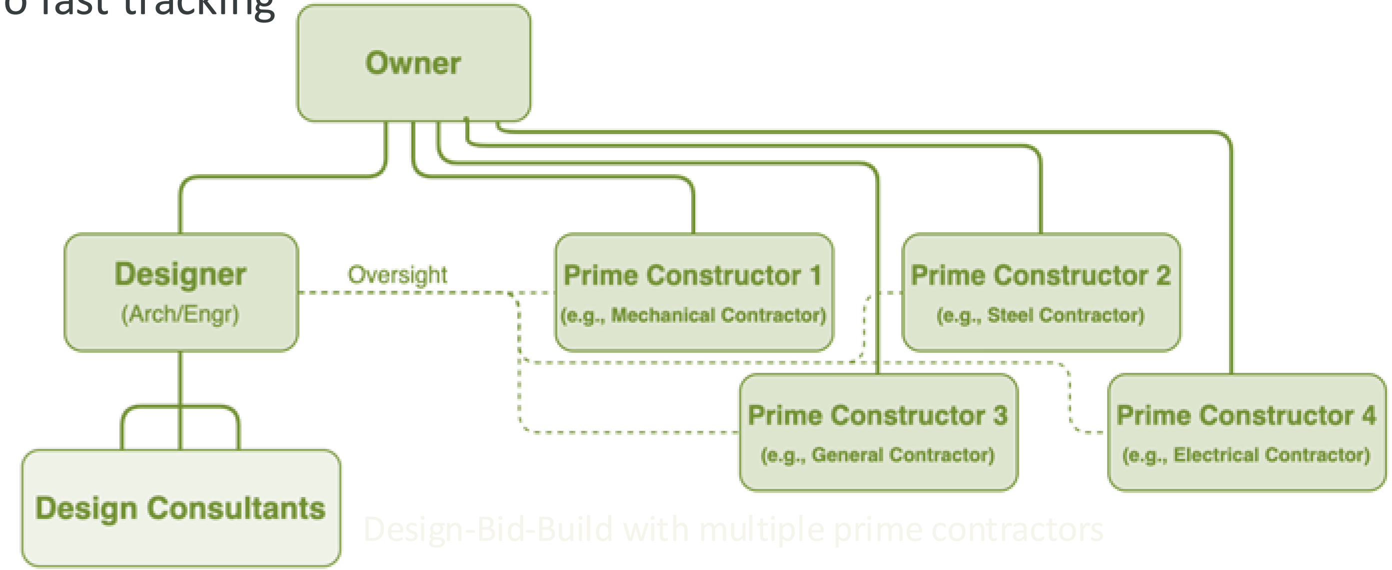
- Straightforward projects, where no changes are expected
- Public projects (assume to promote fair competition)

Advantages

- clear responsibilities
- construction costs are known in advance (assuming no changes)

Disadvantages

- changes will lead to delays or additional costs
- no fast tracking



Design-Bid-Build with multiple prime contractors

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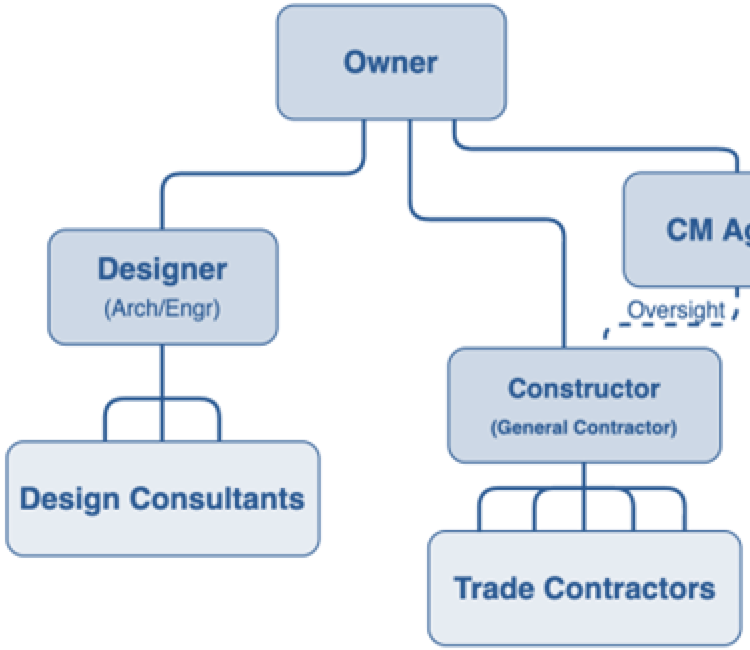
Construction management

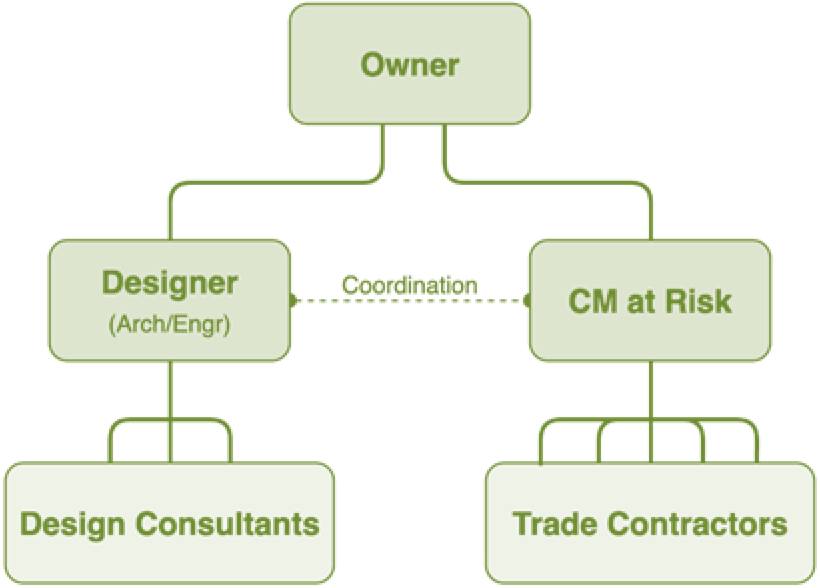
Construction management agency

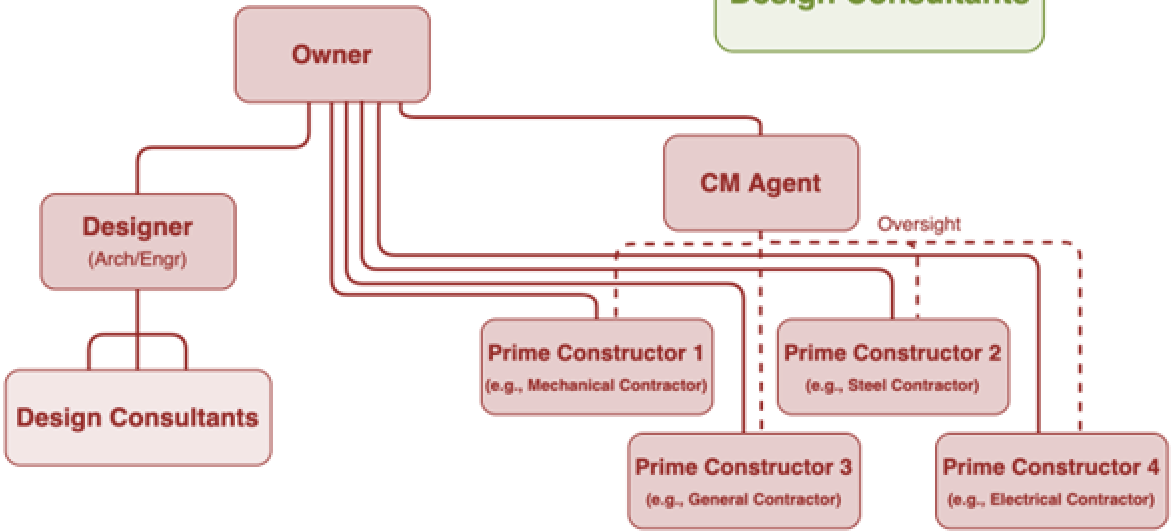
An intermediary (consultant) providing the expertize and/or capacity that the owner lacks



Construction management agency at risk

Makes the contracts with trade contractors and sharing the profit/loss of the project





CM Agent as an intermediary in a split project

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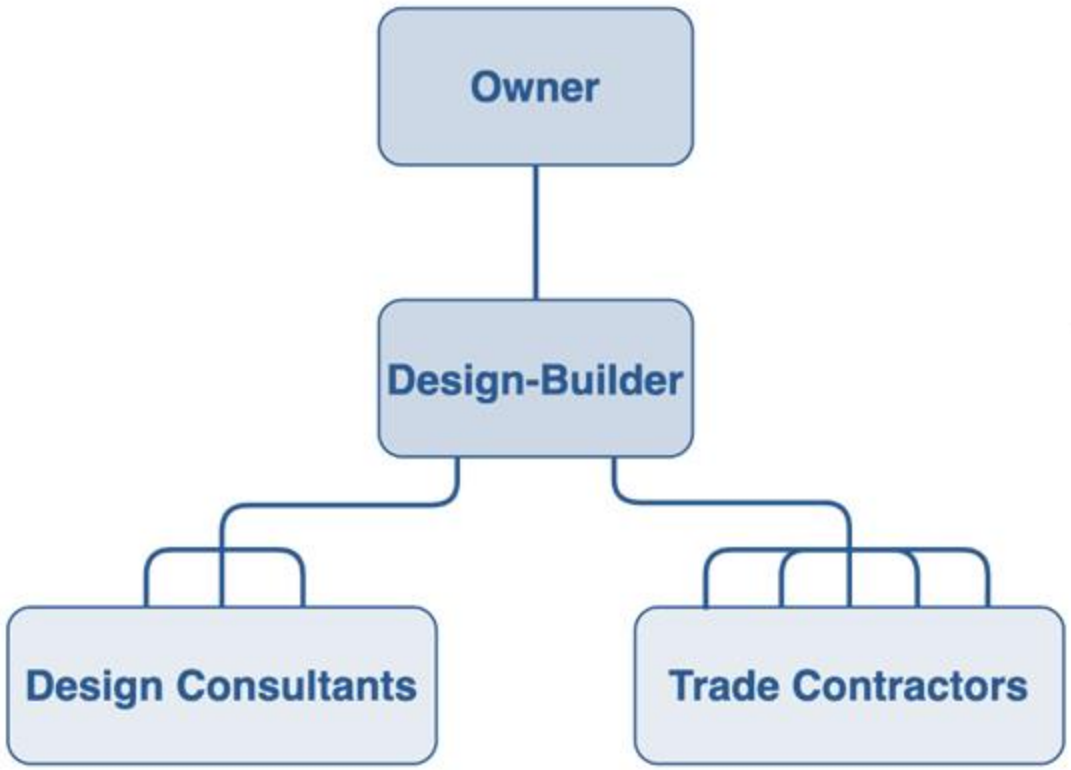
Design-Build



The same party takes responsibility for both design and construction

- Smooth coordination between designer and constructor
- Less coordination with owner needed

Suitability

- Unique, technically demanding projects

Advantages

- Enable the faster execution of the project

Disadvantages

- Construction costs are not known in advance
- Owner may have less control that desired

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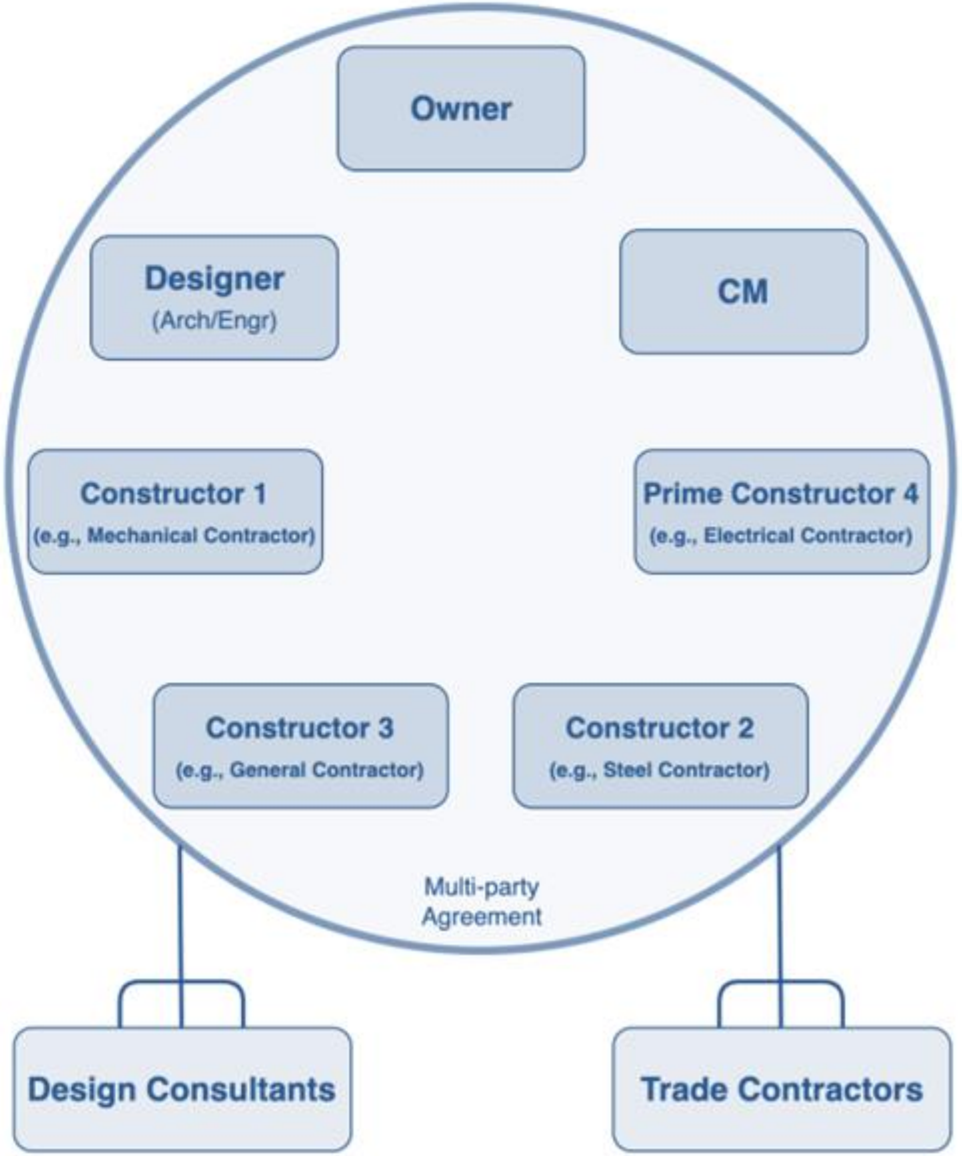
Alliance and integrated project delivery



The primary partners (within the circle)

- enter in a multi-party agreement
- share the profit and risks of the project
- adopt a non-adversarial approach: no blame / no disputes
- can hire additional consultants and trade contractors

Suitability

- highly complex and large projects
- willingness of partners to use collaborative practices (lean, big room, BIM, etc.)

Advantages

- incentive for successful completion of the whole project
- higher productivity, job satisfaction, loyalty

Disadvantage

- suitable only to large projects

Construction project delivery methods

Design-Bid-Build ("traditional")

Construction management

Design-Build

Alliance / Integrated Project Delivery

simple project	low	**Complexity**	high	complex project
no changes expected	low	**Change frequency**	high	many changes expected
clear responsibilities	low	**Collaboration**	high	tight collaboration
delivery time unimportant	low	**Strictness of constraints**	high	short delivery time needed

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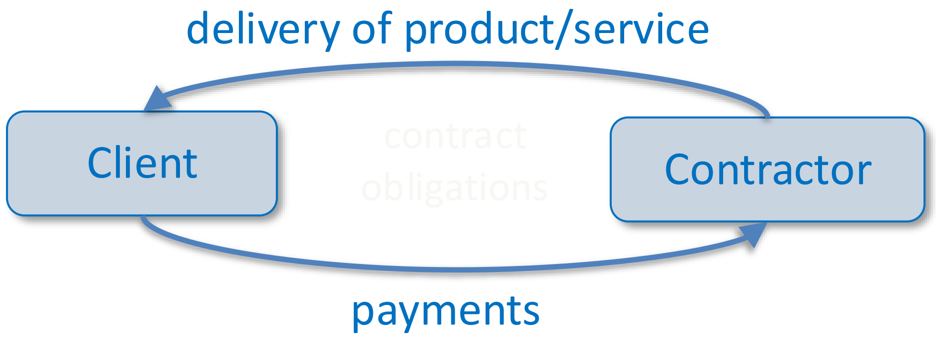
Lifecycle-based delivery models

- Typically (but not necessarily)
  - used in large-scale infrastructure projects
  - owner is from the public sector and contractor from the private sector
- The contractor has a role also in the operational stage of the construction lifecycle
  - usually, the right to operate the asset for a set period of time
  - operation fees are used to recover its investment and maintenance expenses in the project
  - motivates the contractor to do high-quality work in design and construction

- Numerous different models, with different obligations and rights for the contractor
  - BOO – Build, Own and Operate
  - BOOT – Build, Own, Operate, and Transfer
  - BOT – Build, Operate, and Transfer
  - DBO – Design, Build, and Operate
  - DBFO – Design, Build, Finance, and Operate

Contracting methods



Payment terms define how payments are made

- Lump sum
  - the client pays a fixed amount to the contractor, as defined in the contract
  - the amount is typically divided into monthly payments
  - works well with the Design-Bid-Build model
- Cost plus a fee
  - the client pays for all costs of the contractor: labor, materials, equipment, ...
  - on top of that the client pays an agreed-to fee: fixed sum or a percentage
  - open book: the contractor will share their accounting with the owner
- Cost plus a fee with a Guaranteed Maximum Price (GMP)
  - a cap to total price of the cost plus a fee contract
  - if the costs of the contractor exceeds GMP, it will still just get the GMP
- Unit price
  - the contractor is paid by the units of work completed
  - e.g., cubes of excavated material

Different ways to divide the risk

- for the contractor about the uncertainty of the scope (amount of work)
- for the client about the total price of the work

Create different incentives for the contractor to save costs and work efficiently

Award methods

- Competitive Bid
  - select the lowest cost contractor in a competitively bid arrangement

- Prequalified Competitive Bid
  1. prequalify a subset of the potential bidders (e.g., on competence, experience, quality)
  2. select the lowest cost bidder from the prequalified contractors

- Best Value Selection
  1. define a weighted set of criteria (cost, competence, experience, quality, ...)
  2. select the best bidder according to the weighted criteria

- Negotiated Selection
  - select a partner based on previous experience
  - negotiate a contract with the chosen partner
  - not typically allowed in public projects

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Management and sharing of construction data

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Impacts on data management and sharing

- Central systems for the whole project are difficult to establish
  - What is the center of the project? Owner, client, architect, constructor, alliance, ...
  - Data is created by many parties in a decentralized manner
    - What happens to the ownership of data if it is shared in a centralized system
    - How to maintain clear responsibility of data?
  - How to provide project-level data management policies that embrace the data sovereignty of parties?
- Contracts, warranties, etc. can create incentives to not share data with a partner who may later on use it against you – or even not collect the data
  - What are the policies and rules governing the interaction of companies?
  - Collaborative delivery methods are more friendly to information sharing
- Different parties have different competencies or willingness to use digital technologies
  - Regulations can have a big impact to establish common requirements and to level the playfield
- Each project has a new consortium of companies with different systems
  - Problem of interoperability: How can different systems play together?

Managing and sharing construction data – special needs

Characteristics of construction sector

- **One-of-a-kind products**
- **Construction in-place and outside**
- **Long and variable lifespan of buildings/components**
- **Complexity of products**
- **Loosely-coupled companies, tightly-coupled projects**
- **Large and evolving project consortiums**
- **Labor shortage in construction**
- **Adversial contract incentives**
- **High impact on environment**
- **Part of critical infrastructure (bridges, hospitals, military facilities, water treatment plants)**
- **Privacy and sensitivity of data (sensor data from apartments, competitive information, IPRs of designs)**
- **Soft targets for attacks (schools, shopping malls, stations)**

Technical solutions

- **Interoperability technologies**
  - Data standards and ontologies
    - openBIM, Peppol, GS1, CityGML, BrickSchema, ...
- **Interorganizational data sharing environments**
  - Common data environments
  - Decentralized data management
  - Data ownership / sovereignty
  - Methods for establishing trust
- **Enforced data sharing and linking between siloes**
  - Linking design models and data
  - Detailed and visual data sharing for collaboration
- **Data gathering and sharing in construction stage**
  - Emerging sensor and scanning equipment
    - drones, robots, positioning, RFID/QR, helmet cameras
  - Shared coordination data among parties
  - Regular scanning of installations for as-built modeling
- **Data gathering in the operational stage**
  - As-maintained BIM, digital twins, building logbooks, digital product passports
- **Enforced cybersecurity practices**
  - Wide security-minded approach
- **Collaborative delivery methods and contracts**

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Characteristic	Implications	Data management concerns	Solution proposals
One-of-a-kind products	• Project includes planning and design • Many unknowns due to bespoke designs • Design adapts to as-built	• Disconnected phases and data flow • Inevitable changes with ripple effects • Need for as-built modeling	• Data standards/environments • Shared coordination data • Regular scanning → as-built
Construction in-place and outside	• Uncontrolled conditions • More variability in the end results • Work disruption due to harsh conditions	• Data gathering for quality control • Revisions to shared plans and designs	• Emerging sensor and scanning equipment (drones, robots, ...) • Shared coordination data
Long and variable lifespan of buildings and components	• Expect future modification in the building • Avoid slow changing-layers to prevent changes in fast-changing layers	• Create, store and share data • Expect surprises and changes • Loosely-coupled but linked designs	• As-maintained BIM, digital twins, building logbooks, DPPs • Link design models / data
Complexity of products	• Many specialized disciplines and trades • Work fragmented to many companies	• Siloed information, lack of data sharing, non-interoperable systems	• Enforce data sharing and linking between siloes
Loosely-coupled companies, tightly-coupled projects	• Collective adaptations: regulations, standards, and a shared culture of practice	• Less innovation and development • Allows for poorly specified designs • Systems not interoperable	• Detailed, frequent, visual and collaborative data sharing • Interoperability technologies
Large and evolving project consortiums	• Multiple data producers and consumers • Changing center of a project (owner, architect, builder, owner)	• No single central data environment • Data ownership / sovereignty • Linking data across companies	• Decentralized data management • Interoperability technologies • Establish trust and cybersecurity
Labor shortage in construction	• Lack of resources • Need to use unfamiliar resources	• Unknown and low-skilled workforce/companies	• Use commonly available tools • Cybersecurity practices
Adversial contract incentives	• Local optimization • Fear of litigation limits data sharing	• Smooth adaptation to changes is difficult	• More collaborative delivery methods and contract forms
High impact on environment	• Carbon footprint (30-40%) • Energy consumption (30-40%) • Use of virgin raw materials (30-40%)	• More diverse data contents • Support circular economy with data gathering and sharing	• Use of standards for data contents; increase data gathering in operational stage

Interoperability

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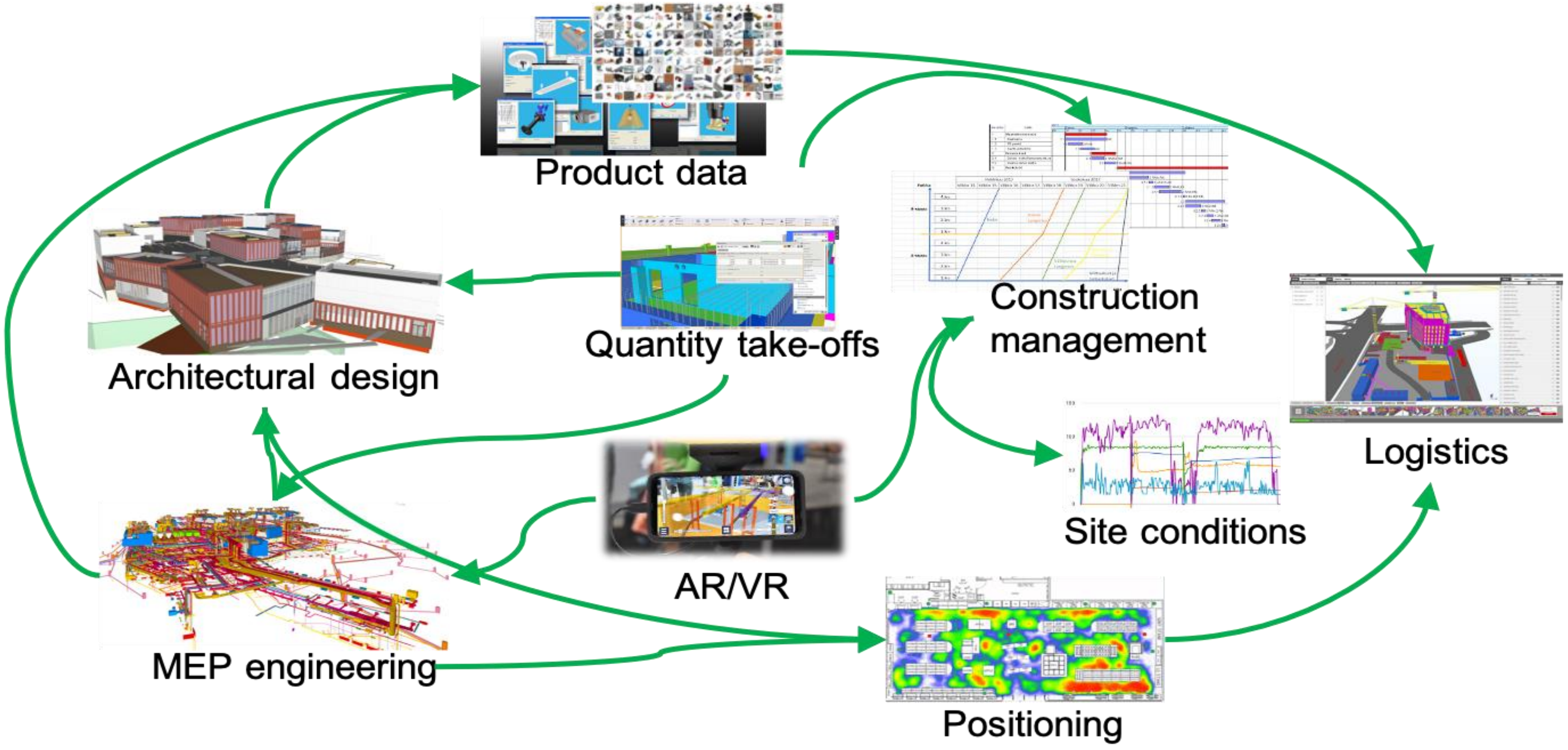
From point solutions to interoperable systems



"The costs caused by poor software interoperability in the capital sector are at least 15.8 billion US$/year" (US NIST, 2004)

Productivity depends on what happens both

1. inside tasks and
2. between tasks

There is a need for

- Interoperability between systems
- Smooth information flows
- Automation of workflows

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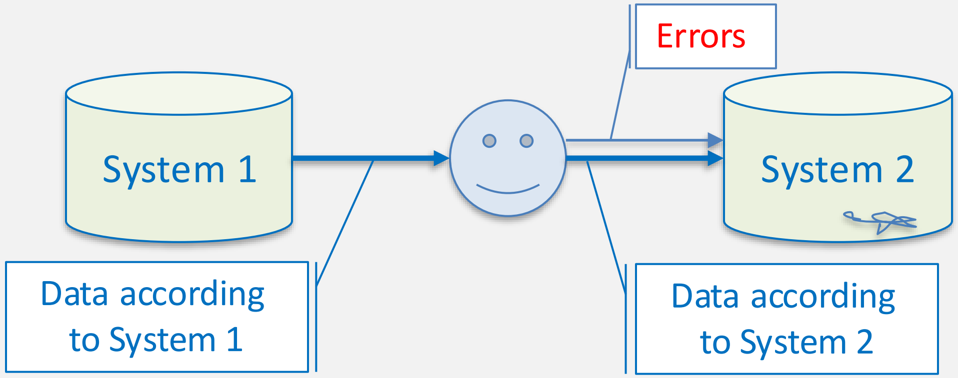
The need for interoperability

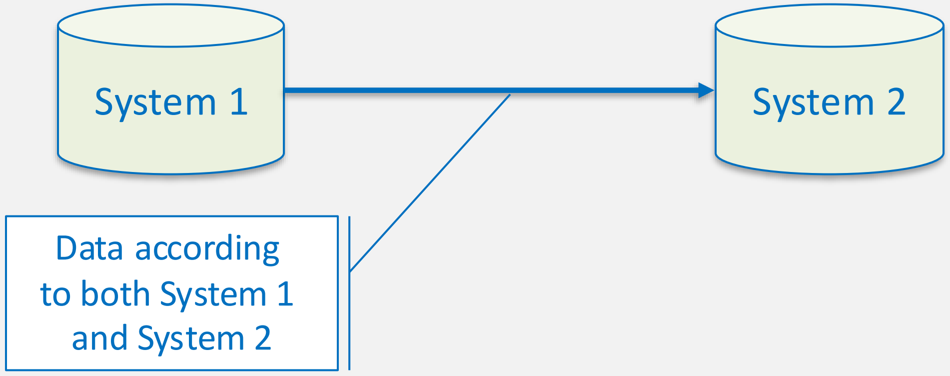
Manual transformation and exchange of information

- orders of magnitude slower than systems
- produces additional errors
- requires repetitive and unmotivating tasks from people
- people become bottlenecks in processes
- systems are easier to implement



Interoperable transfer of information

- requires work to adapt to standardized formats and interfaces
- faster (no additional delays)
- better quality (no additional errors)
- increases potential for automation
- allows new kinds of dynamic applications (e.g., redoing the transformation every few seconds)



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Definition and demarcation of *interoperability*

Interoperability is the ability of **systems** to

1. exchange information and
2. **act on the information exchanged**

Interoperability is not same as **integration**

Integration

- tightly-coupled systems
- closed and static settings

- «putting diverse concepts together to create an integrated whole»

Interoperability

- loosely-coupled systems working together
- open and multi-directional collaboration

- *«systems work together by sharing appropriate messages and using narrow, agreed-upon, interfaces, but without any single conceptual integration»*

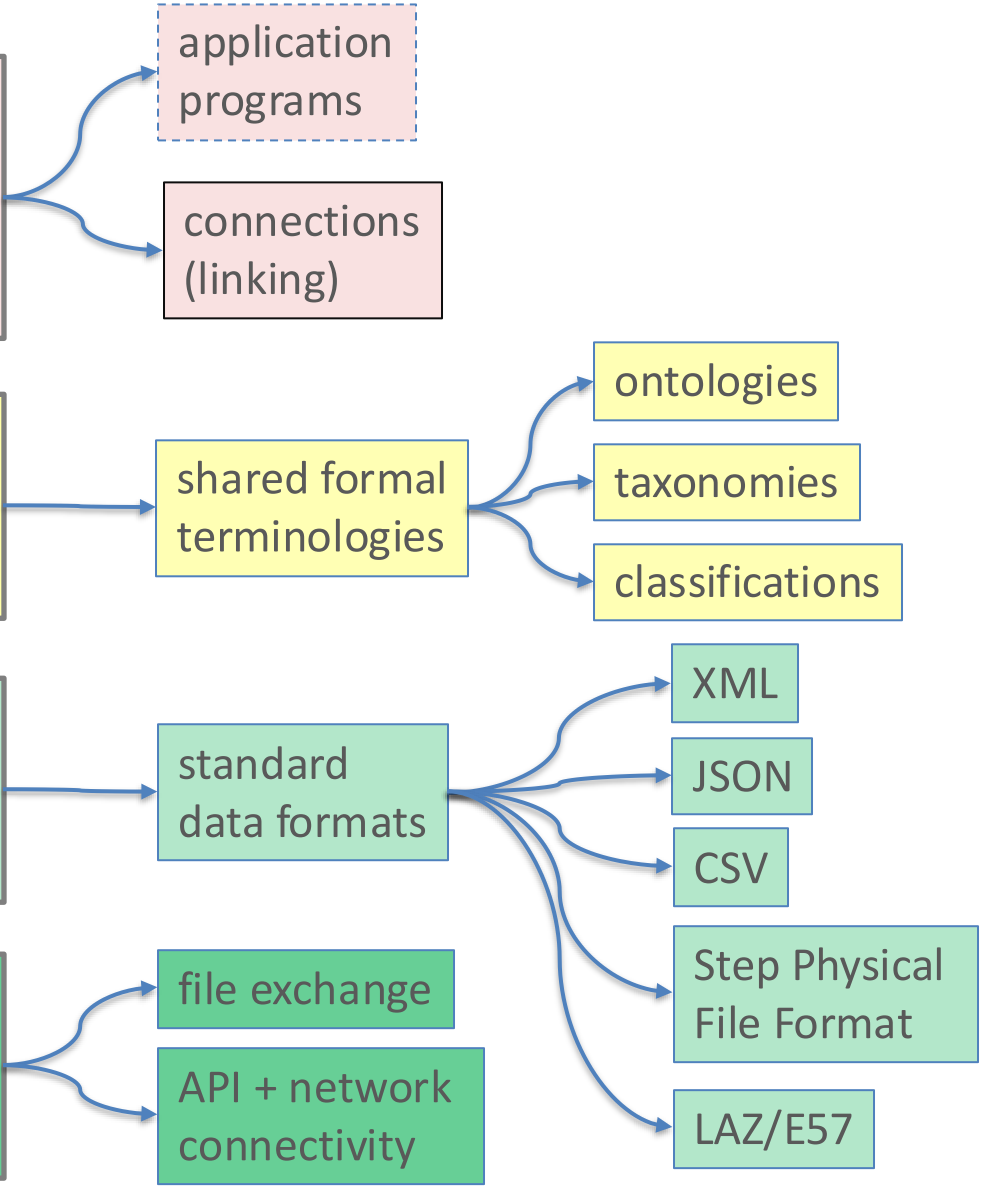
Levels of interoperability

4. Pragmatic interoperability
The context of data usages is understood across systems
- organizational: organizational structures/processes
- legal: regulations, contracts, disputes, ...

3. Semantic interoperability
The terms used in data are understood across systems
(what is a “window”, “wall”, “task”, “history”, ...)

2. Syntactic interoperability
The structure of data is understood across systems
(how to parse the data)

1. Technical interoperability
Bits and bytes can be transferred across systems



Cybersecurity

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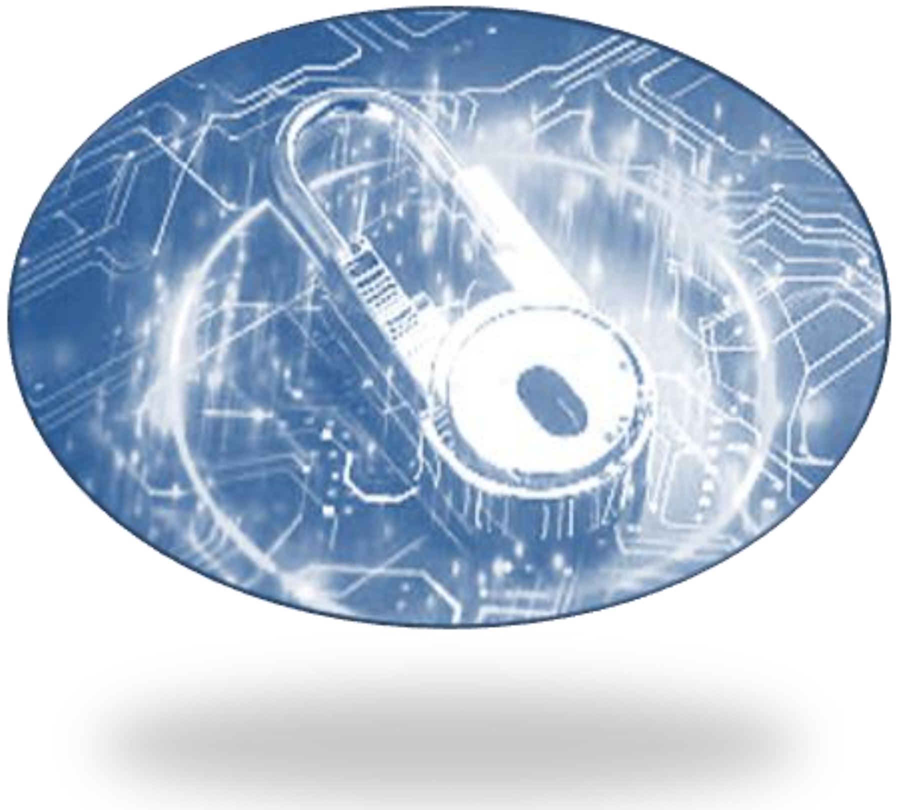
Importance of cybersecurity



- Cybersecurity is a necessary concern, whenever data is managed and especially when it is shared
  - information security
  - sensitive and confidential data
  - access rights of people
- Cybersecurity challenges
  - physical safety and security at the construction site
  - intellectual property rights of designs
  - privacy of occupants
  - information related to competition (prices, delivery times, quality levels, ...)
- Security concerns need to be addressed
  - regardless of the way data is managed and shared in a project
  - with a wide security-minded approach

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Impact of digitalized construction on cybersecurity

- Regulations on BIM-based building permits and as-built BIM models
  - More BIM models will be created with rich information contents
  - Models will be regularly uploaded to an online permitting systems
  - → More attack surface
- Proliferation of centralized Common Data Environments
  - Dependence on networks and cloud services
  - → Centralized, high-value attack target
- Growing number of APIs in BIM software
  - BIM data will be retrieved with other software (procurement, energy analysis, ...)
  - → Backdoors to BIM data
- Complex and large subcontractor networks
  - Small subcontractors often have mediocre IT skills and low cybersecurity competencies
  - Short-term project consortiums do not build competencies or create loyalty
  - → Potential new vulnerabilities brought by each party
- BIM-based digital twins at the operational stage
  - Connecting sensor observations and actuation to a BIM model
  - →Operational stage vulnerabilities (e.g., concerning privacy)

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Thank you!