Resource Wise Lean Design Managment Framework

Current State of Understanding

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Supervisor: Prof. Lauri Koskela and Prof. Roode Liias

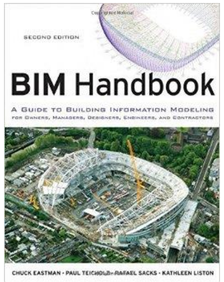
EDUCATION

- **2014 - … Aalto University and Tallinn University of Technology**
  – PhD Candidate
  – Early stage researcher
- **2010 – 2012 Technion – Israel Institute of Technology**
  – MSc in Civil Engineering, Construction Management
  – Research on BIM for construction engineering education
- **2006 – 2010 Tallinn University of Applied Sciences**
  – Exchange student in Denmark
  – Thesis in England
  – Crussel Bridge case study for BIM Hanbook
  – Co-Founder of Estonian Group for Lean Construction

TECHNION Israel Institute of Technology

TALLINNA TEHNIKAKÕRGKOOL

EESTI TIMMITUD EHITUSE TUGIRÜHM ETET

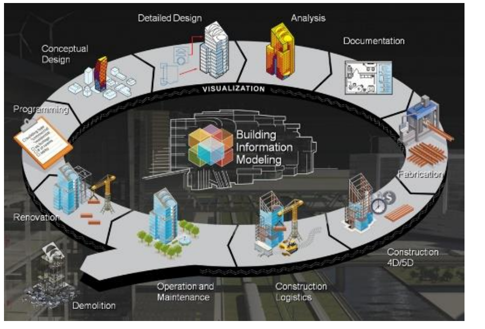


PROFESSIONAL EXPERIENCE

- **2015 - … Startup company Leansite OÜ**
  - One of the owners
- **2012 - … Gravicon EE OÜ**
  - One of the owners
  - BIM consulting and services
- **October 2012 – January 2015 Ministry of Economic Affairs and Communications**
  - Chief Executive Specialist
- **June – October 2010 University of Salford and Health and Care Infrastructure and Innovation Centre**
  - Research Assistant
- **May – June 2010 Nordecon Construction AS**
  - Site planning engineer
- **March – September 2009 Telora-E AS**
  - Owner's supervisor assistant on site

RESEARCH INTERESTS

- Digitalization of AEC industry (especially BIM)



- Cost and energy efficient design and engineering of buildings

- Design and construction management

BACKGROUND

NATURE OF DESIGN AND DESIGN MANAGEMENT

- The delivery of better value to the client with a reduced lead time and less resources has become the primary focus of design management (Morgan and Liker, 2006).
- Design management has been criticized for its inadequacy by many different practitioners and academics
- Due to the division of master builder within the last twenty and more years, the lack of communication and collaboration have been considered as a common issue for underperforming construction design and engineering (Latham 1994)
- For overcoming these barriers, new methods, tools and collaborative aspects have been instantiated into different forms within the three domains of projects' (Thomsen et al. 2009): commercial terms, organization and operating/production system.

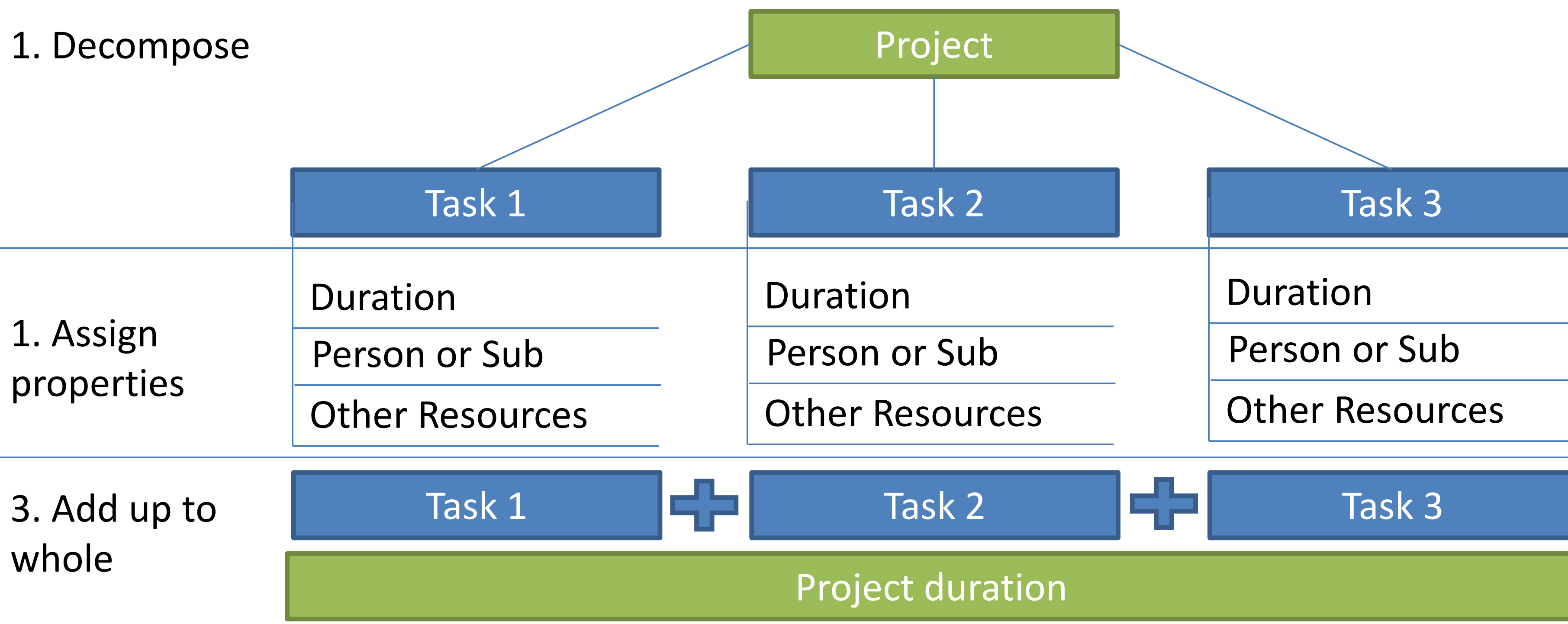
PROBLEMS IN DESIGN AND ENGINEERING

INEFFICIENCIES OBSERVED IN THE DESIGN OFFICE - **DESIGN MANAGEMENT INEFFICIENCIES**

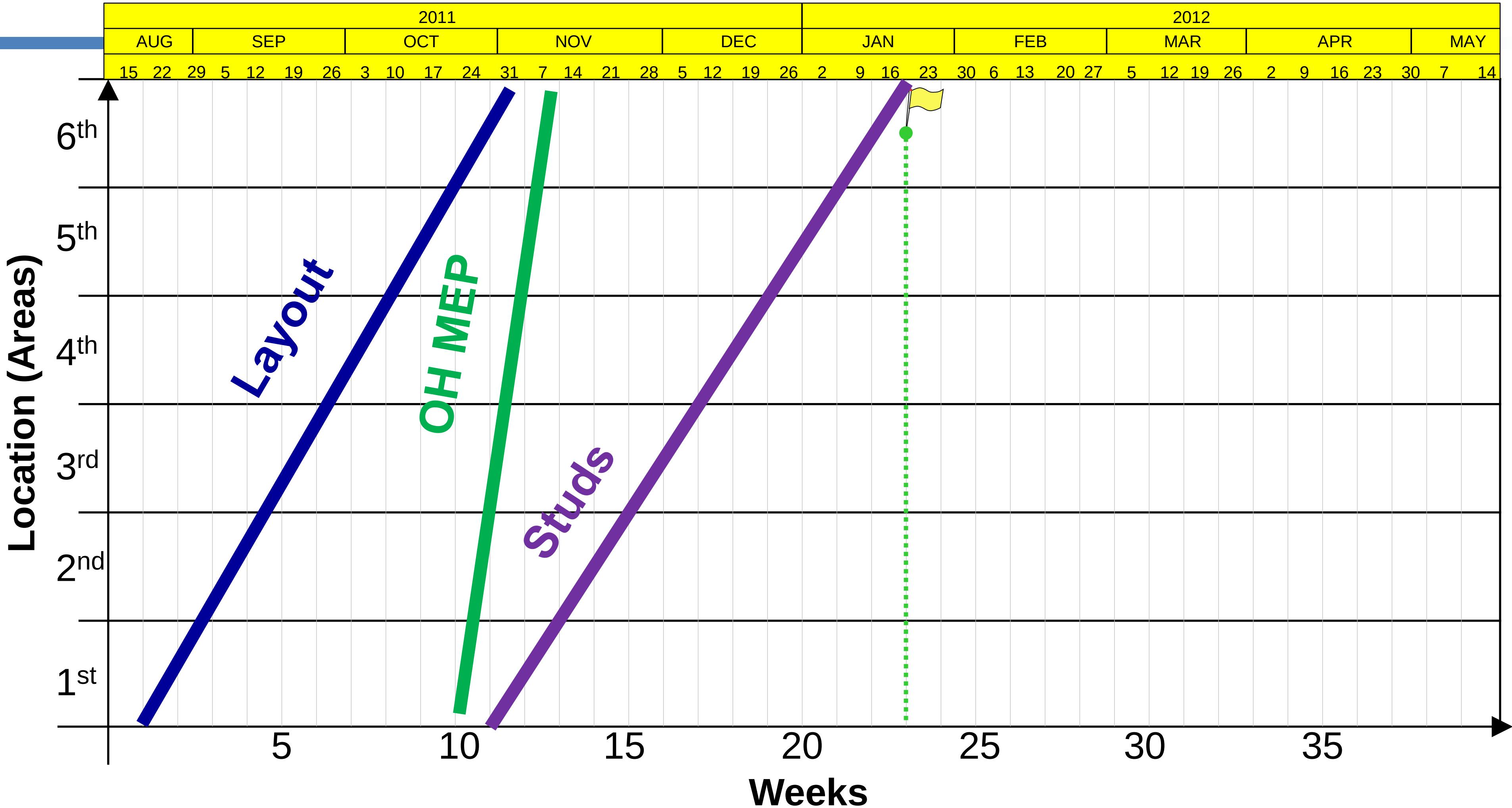
- **Design as project management and its dual nature**
  - Tasks are managed and optimized in isolation, the flow and value generation aspects of the design tasks are left for informal consideration by designers and engineers.
  - Design management and organization have a dual nature, as these two are separate (Koskela et al., 2014b).

DESIGN "PROJECT" MANAGEMENT IS BASED ON TRANSFORMATION VIEW

- Three steps method as in sciences is the basic method for planning project work!



Optimise the whole instead of piece



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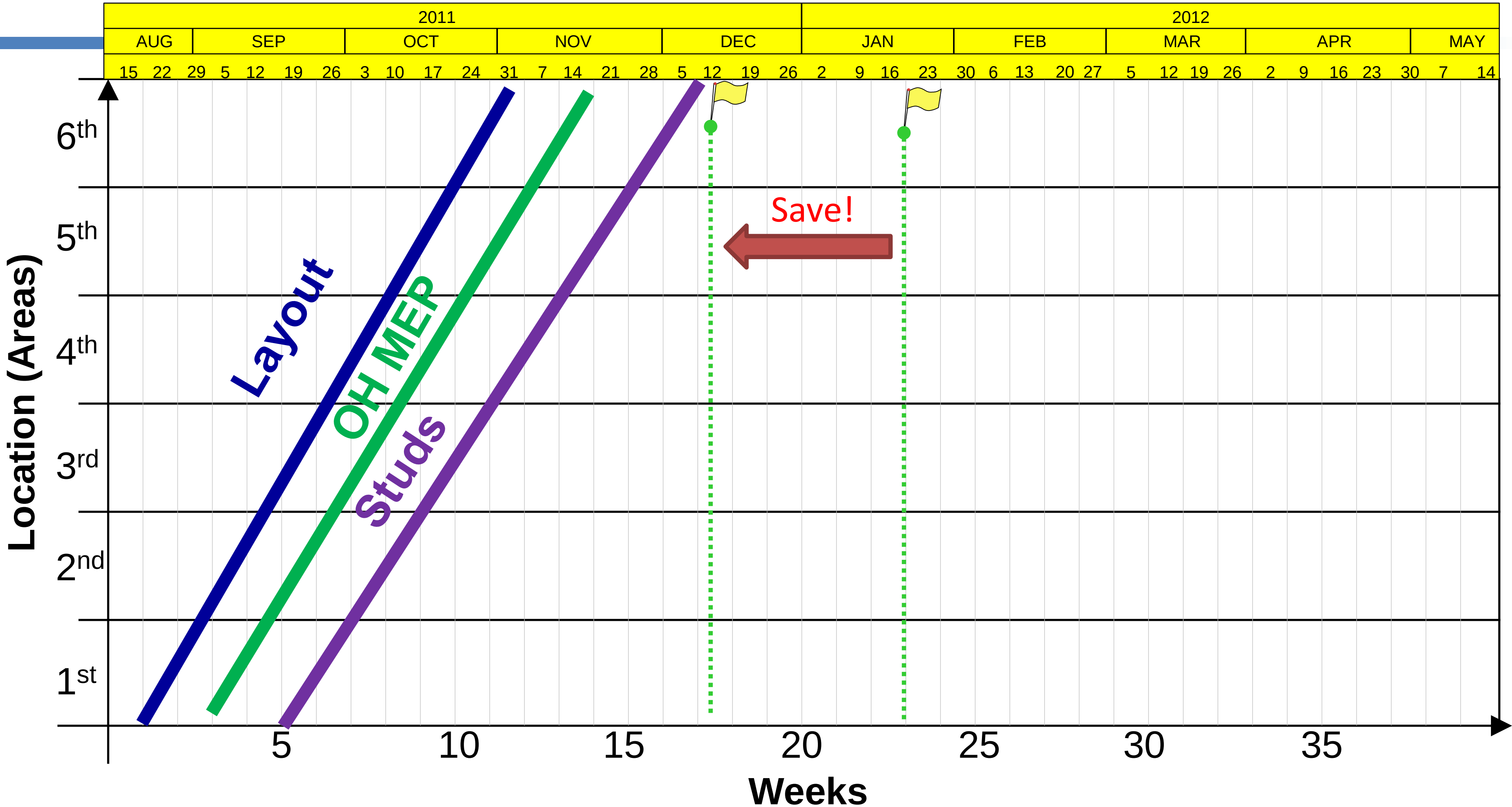

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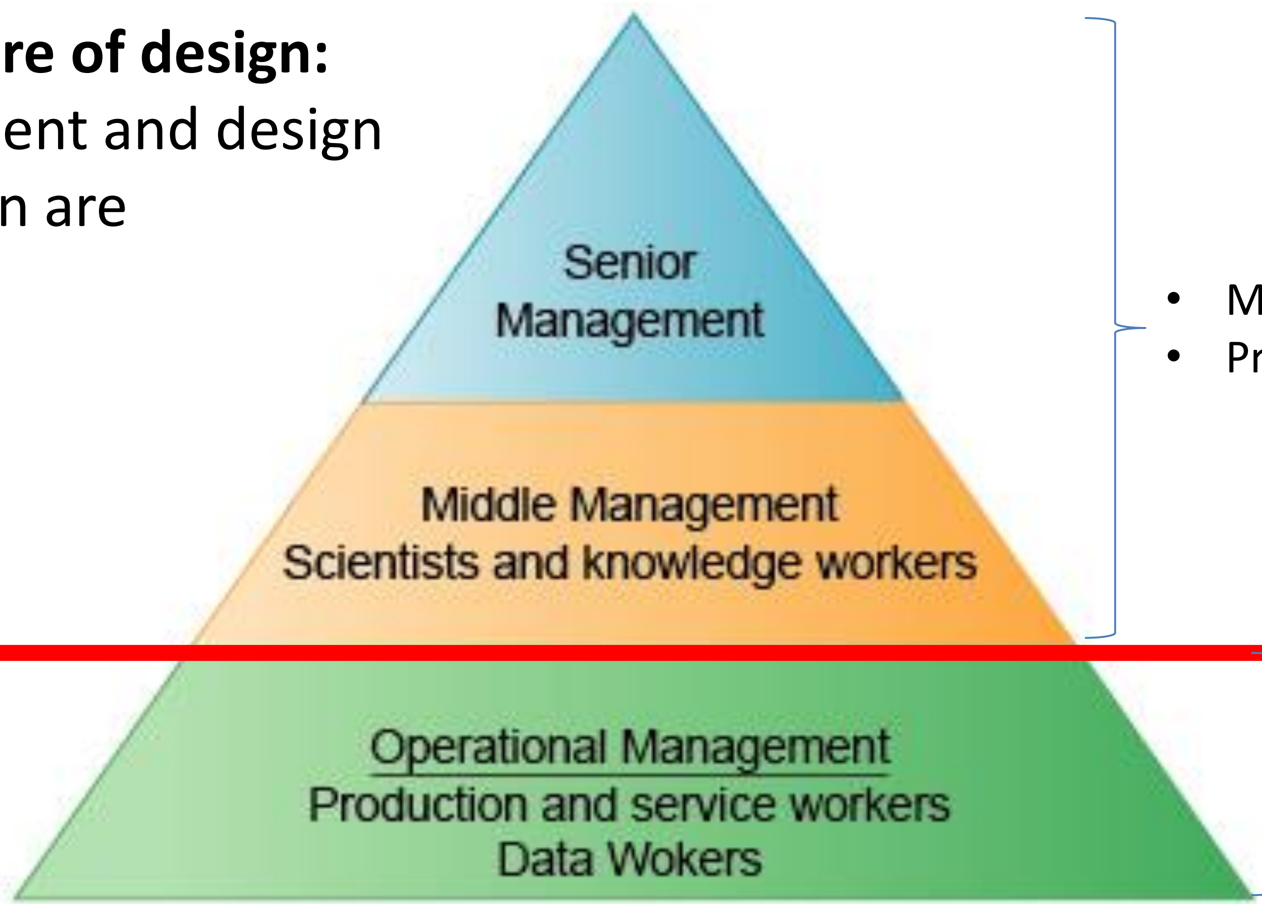
THE OTHER ASPECTS OF TASK HAVE BEEN LEFT TO INFORMAL CONSIDERATIONS BY DESIGNERS!

Dual nature of design: management and design production are separated



- Managers
- Project managers

- Designers
- Engineers

INEFFICIENCIES OBSERVED IN THE DESIGN OFFICE - **DESIGN MANAGEMENT INEFFICIENCIES**

- **Poor planning and avoidance of iterations**
  - Project schedule is complied in a top-down approach, plans are developed first and then pushed down the hierarchy to the designers. Only two dependency types are used: sequential and concurrent (Eppinger, 1991).
  - Design iterations are avoided, even in the case of clear interdependencies (Koskela, 2007; Ballard, 2000b).

DESIGN PRODUCTION IS SERIALIZED

<table>
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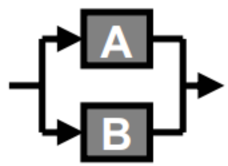
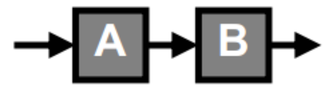
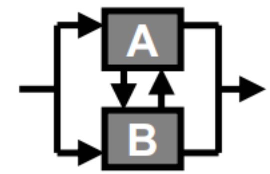
<tr><td>Graph Representation</td><td>
</td><td>
</td><td>
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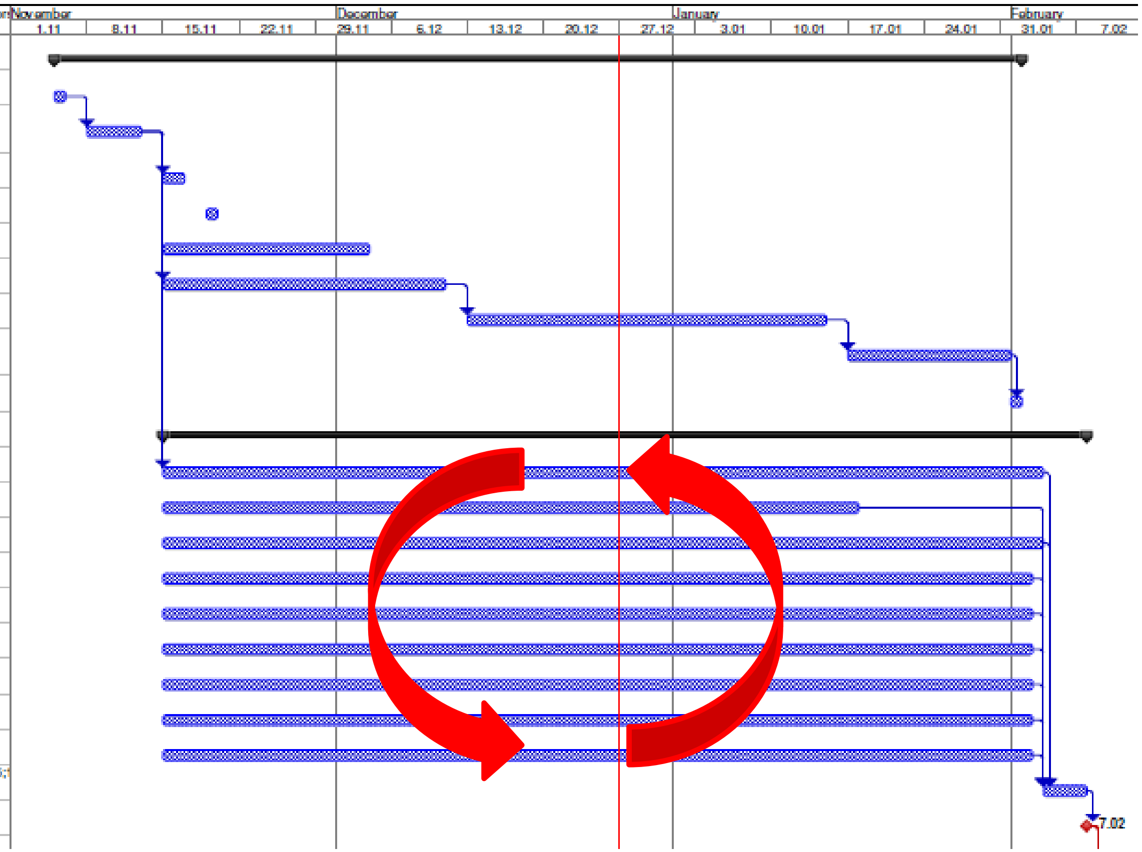
EXAMPLE OF DESIGN SCHEDULE WITH GENERIC AND CONCURRENT TASKS

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Eelprojekt (EP) ja ehitusluba**	**63 d**	**Fri 5.11.10**	**Tue 1.02.11**	
2	EP ja meditsiinitehnoloogia üleandmine Tellijale	1 d	Fri 5.11.10	Fri 5.11.10	
3	Tellija tutvumine EP-ga ning märkuste ja ettepanekute esitamine OÜ-le Innopolis Insenerid (IPI)	5 d	Mon 8.11.10	Fri 12.11.10	2
4	IPI kommentaarid Tellija märkustele/ettepanekutele	2 d	Mon 15.11.10	Tue 16.11.10	3
5	**Eelprojekti kiinitamine Tellija poolt (sh ruumiprogrammi lõplik kinnitamine)**	1 d	Fri 19.11.10	Fri 19.11.10	
6	Haljastus, teed-platsid PP koostamine	15 d	Mon 15.11.10	Fri 3.12.10	
7	Eelprojekti korrigeerimine (vajadusel) eelprojekti kooskõlastamine vajalike ametkondadega	20 d	Mon 15.11.10	Fri 10.12.10	3
8	Ehitusloa menetlus Pärnu Linnavalitsuses	25 d	Mon 13.12.10	Fri 14.01.11	7
9	EP korrigeerimine vastavalt Pärnu Linnavalitsuse märkustele ja ehitusloa taotluse täiendav menetlemine	11 d	Mon 17.01.11	Mon 31.01.11	8
10	Ehitusloa väljastamine	1 d	Tue 1.02.11	Tue 1.02.11	9
11	**Põhiprojekt (PP)**	**61 d**	**Mon 15.11.10**	**Mon 7.02.11**	
12	arhitektuur (ARH)	59 d	Mon 15.11.10	Thu 3.02.11	3
13	sisekujundus (SK)	46 d	Mon 15.11.10	Mon 17.01.11	
14	konstruktsioon (EK)	59 d	Mon 15.11.10	Thu 3.02.11	
15	Elektrivarustus ja automaatika (EL-AUT)	58 d	Mon 15.11.10	Wed 2.02.11	
16	Nõrkvoolu paigaldis (NV)	58 d	Mon 15.11.10	Wed 2.02.11	
17	Küte-ventilatsioon, jahutus (KVJ)	58 d	Mon 15.11.10	Wed 2.02.11	
18	Vesivarustus ja kanalisatsioon (VK)	58 d	Mon 15.11.10	Wed 2.02.11	
19	ravigaasid	58 d	Mon 15.11.10	Wed 2.02.11	
20	Hooldusraamatu (ELKIS) koostamine	58 d	Mon 15.11.10	Wed 2.02.11	
21	Põhiprojekti komplekteerimine	2 d	Fri 4.02.11	Mon 7.02.11	12;13;14;15;
22	**Projekti üleandmine Tellijale**	**0 d**	**Mon 7.02.11**	**Mon 7.02.11**	21
23	**Põhiprojekti ekspertiis**	**56 d**	**Mon 3.01.11**	**Mon 21.03.11**	



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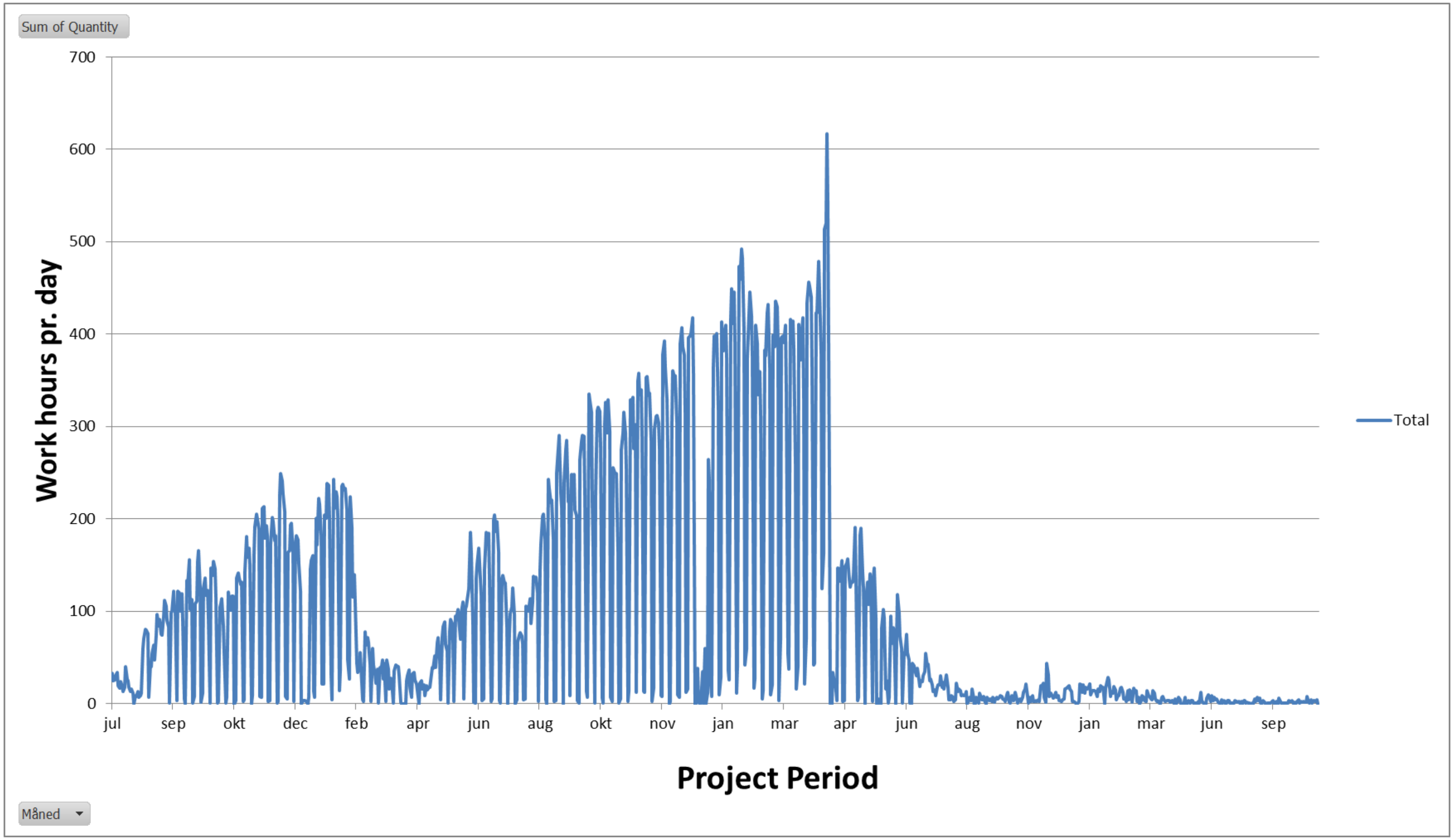
THE FOCUS IS ON DOCUMENTATION NOT ON DELIVERING CLIENT VALUE

VS

PROBLEMS WITH DESIGN MANAGEMENT



(Niels Treldal, 2016)

EXAMPLE OF STANDARDIZATION AND ISOLATED DECISIONS

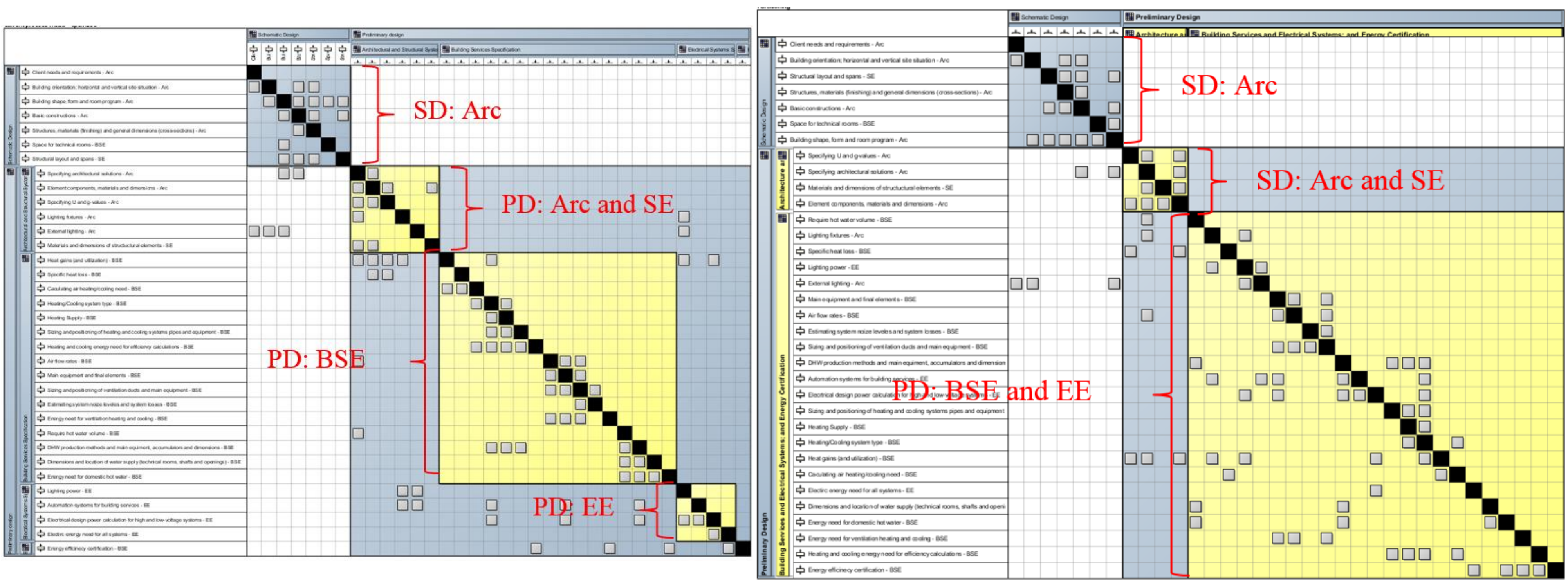
Structure	Building A				Building B			
	U-value, W/(m^{2}K)	Area A, m^2	Specific heat loss H, W/K	% of total	U-value, W/(m^{2}K)	Area A, m^2	Specific heat loss H, W/K	% of total
EW	0.20	1417.4	283.5	25.5	0.18	1069.9	190.7	12.4
Roof	0.10	315.2	31.5	2.8	0.11	509.5	54.5	3.5
EF above air	0.13	34.9	4.5	0.4	0.17	435.5	75.1	4.9
EF towards ground	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]
IS b/w garage and 1st floor	[illegible]	[illegible]	[illegible]	7.0	[illegible]	[illegible]	[illegible]	[illegible]
Windows	[illegible]	[illegible]	[illegible]	35.9	[illegible]	[illegible]	[illegible]	[illegible]
Doors	[illegible]	[illegible]	[illegible]	1.9	[illegible]	[illegible]	[illegible]	[illegible]
Thermal bridges[b]	[illegible]	[illegible]	[illegible]	9.9	[illegible]	[illegible]	[illegible]	[illegible]
Infiltration[c]	[illegible]	[illegible]	[illegible]	16.5	[illegible]	[illegible]	[illegible]	[illegible]
Total/ weighted average	0.43	2602.1	1111.4	100	0.55	2787.5	1543.0	100

INEFFICIENCIES OBSERVED IN THE DESIGN OFFICE - **DESIGN ORGANIZATION INEFFICIENCIES**

- **Poor integration of design disciplines and decisions in the early design stages**
  - Often architect makes his/her decisions in isolation without considering how it influences other designers and engineers
  - Problem solving is pushed downstream with the belief that appropriate engineered systems can be developed.

DESIGN SOLUTIONS HIGHLY STANDARDIZED

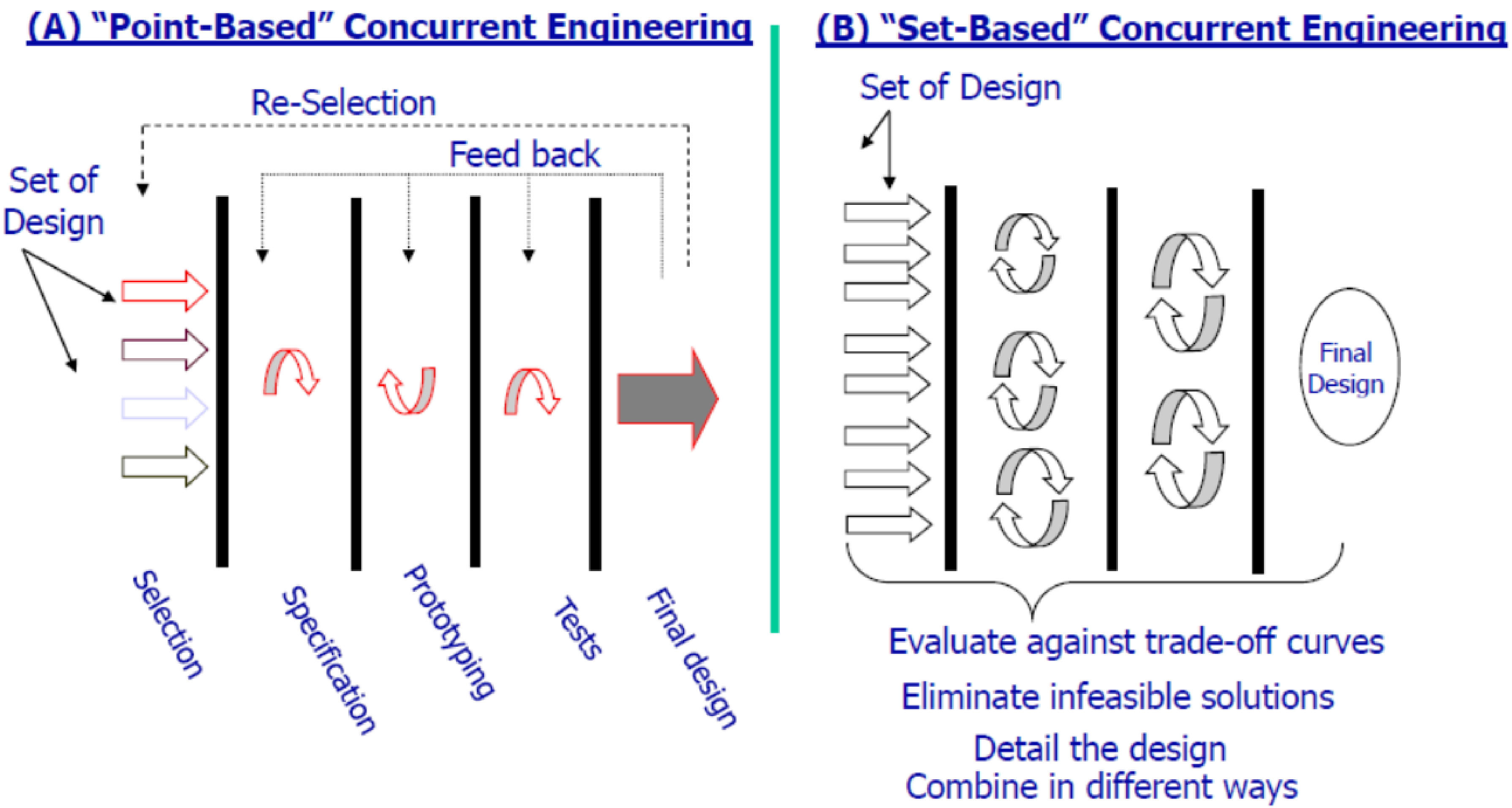
- Designers and engineers have learned to cope with problems by standardization and buffering!



INEFFICIENCIES OBSERVED IN THE DESIGN OFFICE - DESIGN ORGANIZATION INEFFICIENCIES

- **Poor specification of client needs and requirements**
  - No clear specification of client needs and requirements in relation to use functions
  - Focus on the spatial and functional aspects of the building
  - Architects start with some conceptualization of the building already in mind
  - Point-based design method (Sobek et al., 1999)
  - Lack of common understanding within design and engineering team regarding client values and needs

POINT-BASE VS SET-BASED CONCURRENT DESIGN



(Sobek et al., 1999)

FEW KEY IDEAS FOR BETTER DESIGN MANAGMENT

HOW IS AXIOMATIC DESIGN THEORY USEFUL

According to Pennanen, the design process can be divided into three orthogonal perspectives (Pennanen 2004):

- Programming (determination of needs, use functions, use properties and workplace planning)
- Shape and connections (connecting activities to spaces and shape determining the flows of resources and use processes)
- Components (Materials, details, equipment…) – embodiment

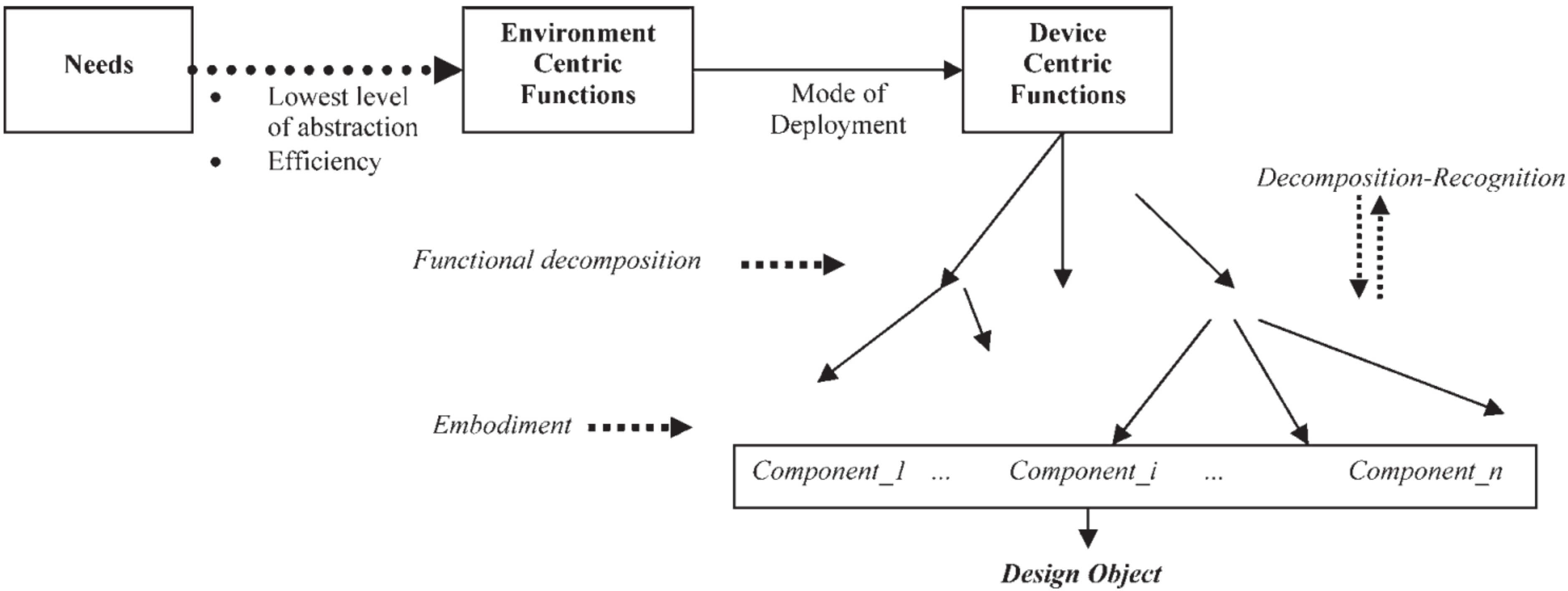
Combining orthogonal variables cause more iterations and can be called unnecessary complexity (Pennanen 2004).

RELATIONS BETWEEN NEEDS, FUNCTIONS, AND DESIGN OBJECT

1. Planning - Purpose of an artefact (telology)

2. Programming – Use Functions

3. Design conceptulization though Ditailed Design – From concept to component design



(Erden, Komoto et al., 2008)

SIMPLE EXAMPLE

1. Purpose of an artefact (telology) - Need

Measure and track time

2. Programming – Use Functions

Person measures the change of time

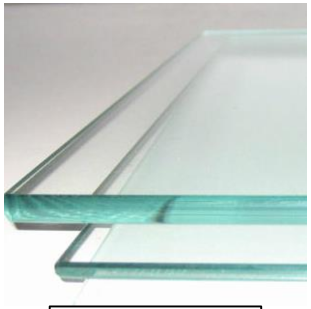
3.1 Design– Artefact functions

Keep time (Verb + Noun)

3.2 Concept and Form

3.3 Embodiment

Sand

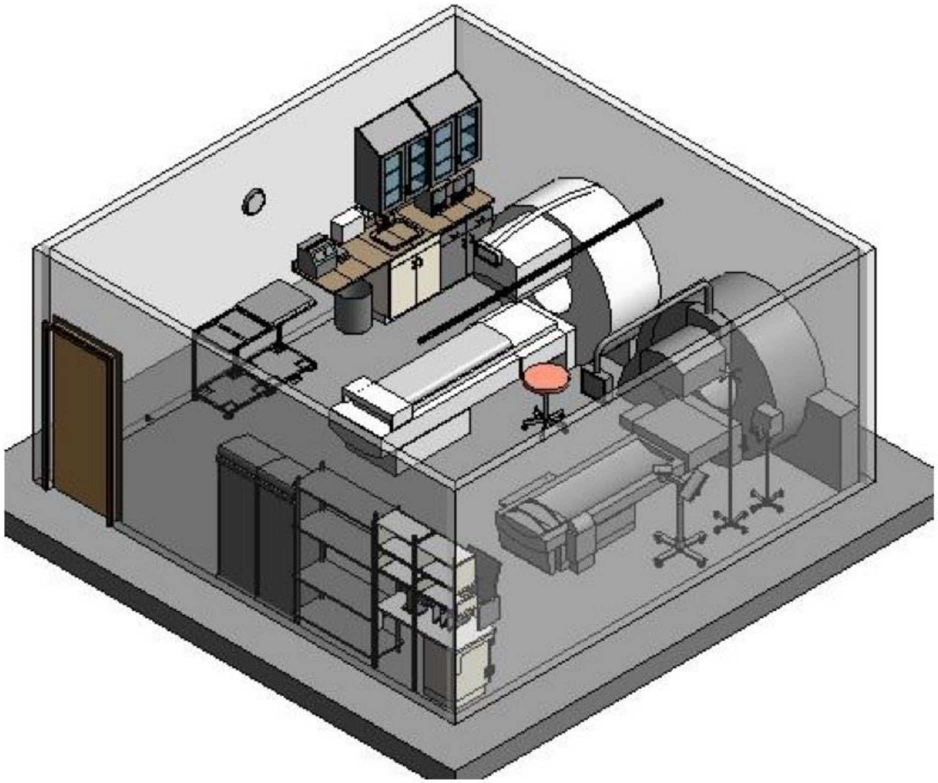


Glass

Expected behavior

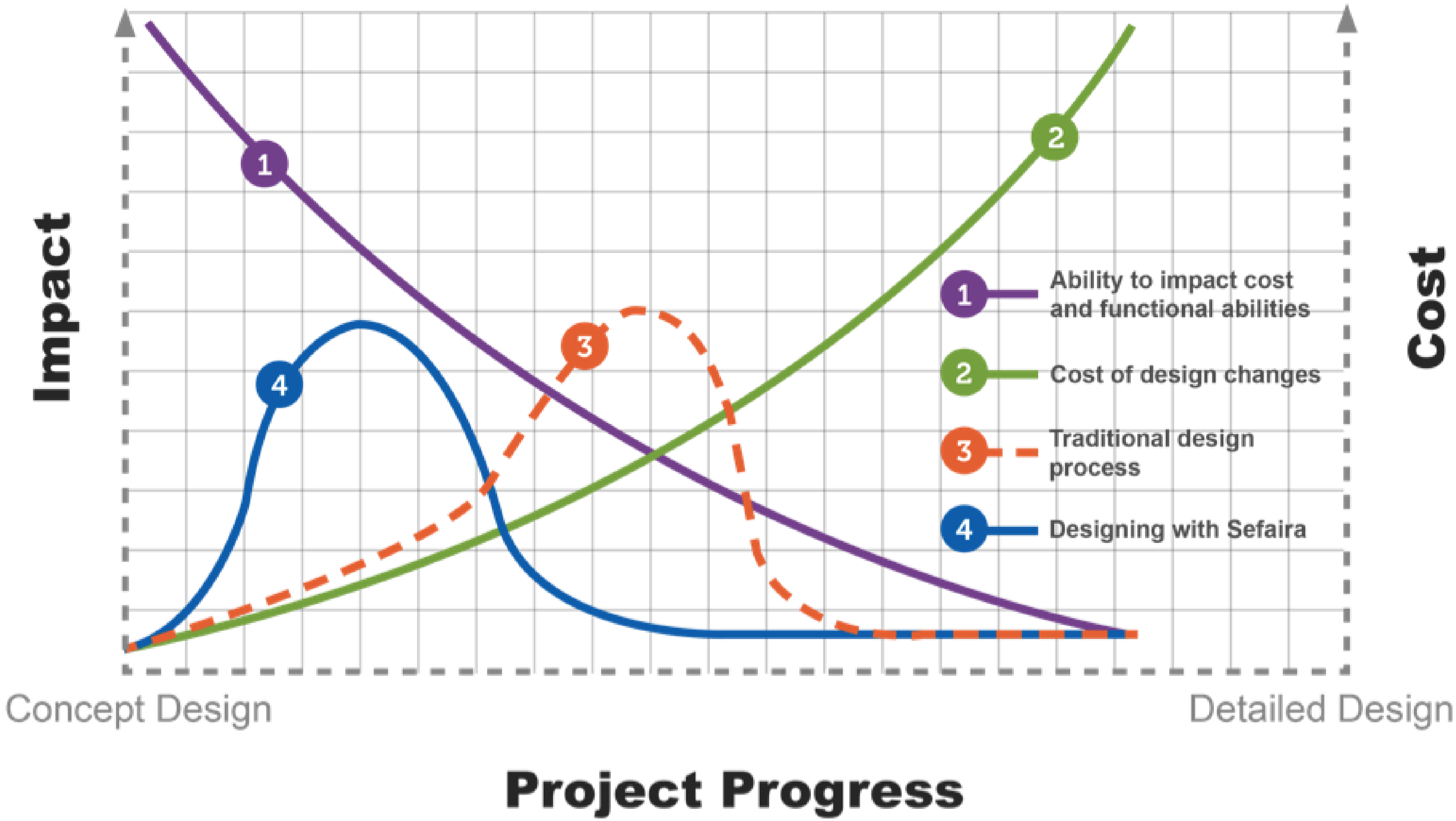
Actual behavior

ILLUSTRATION OF THE USE FUNCTIONS

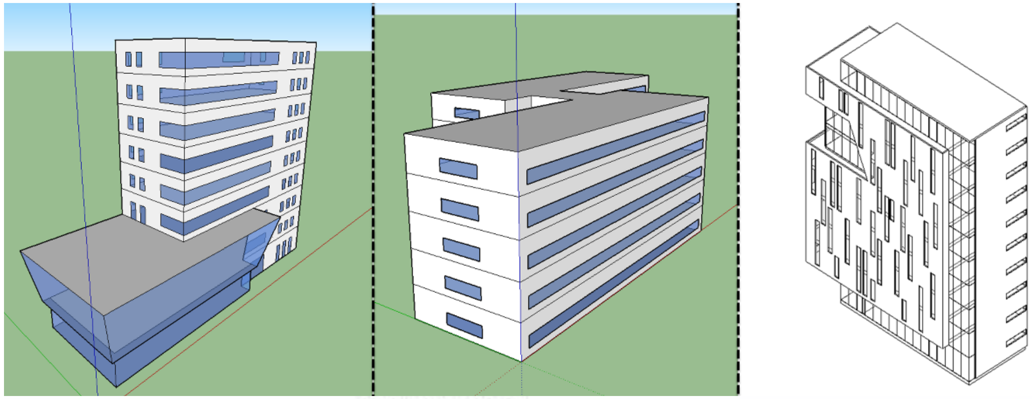


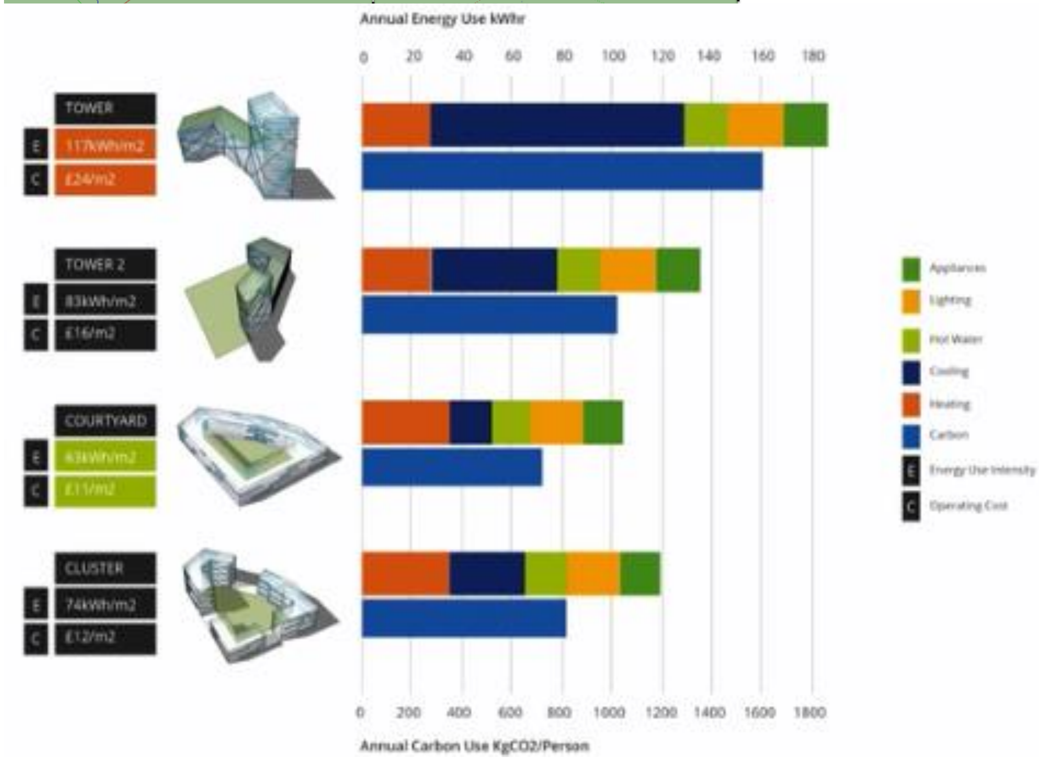
SEPS 2BIM TEMPLATES

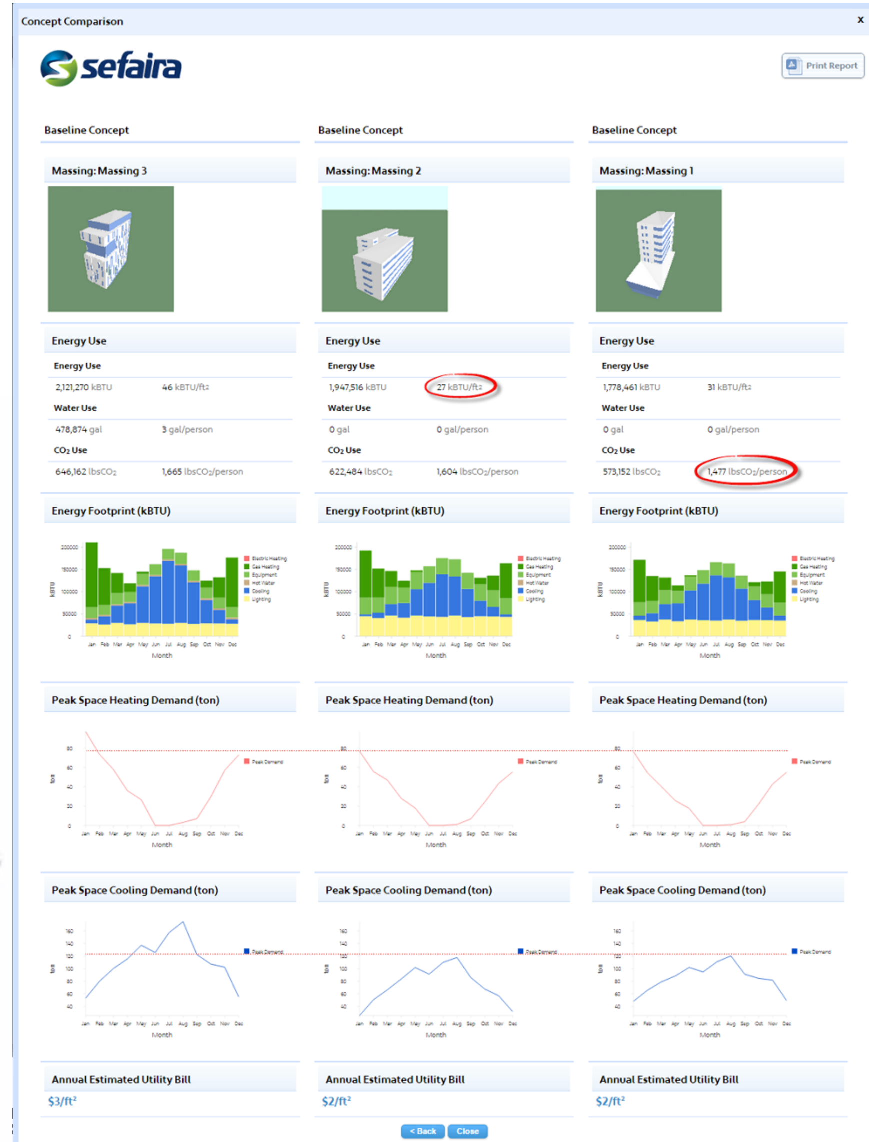
PERFORMANCE BASED DESIGN



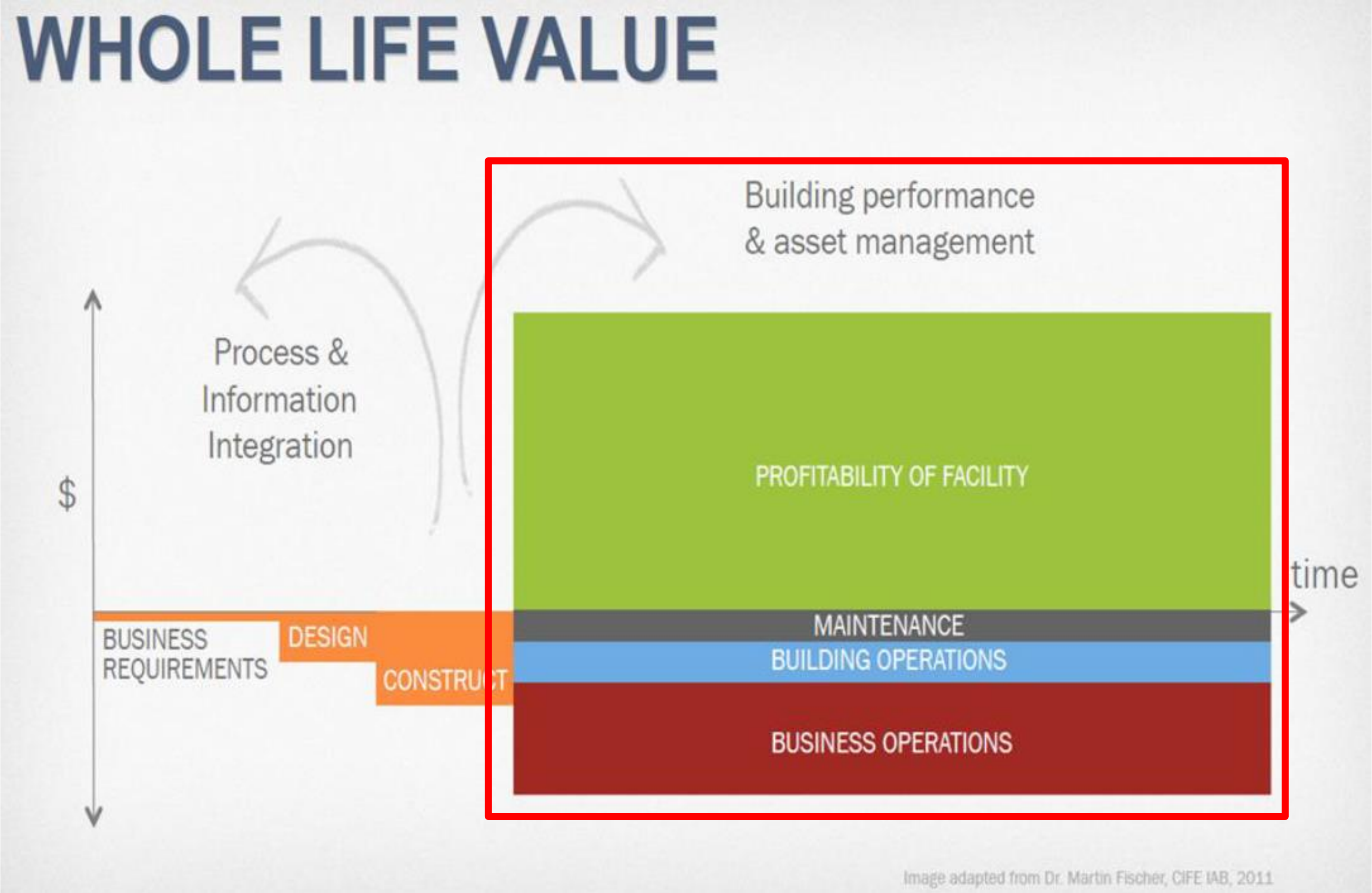
SET-BASED PERFORMANCE DESIGN



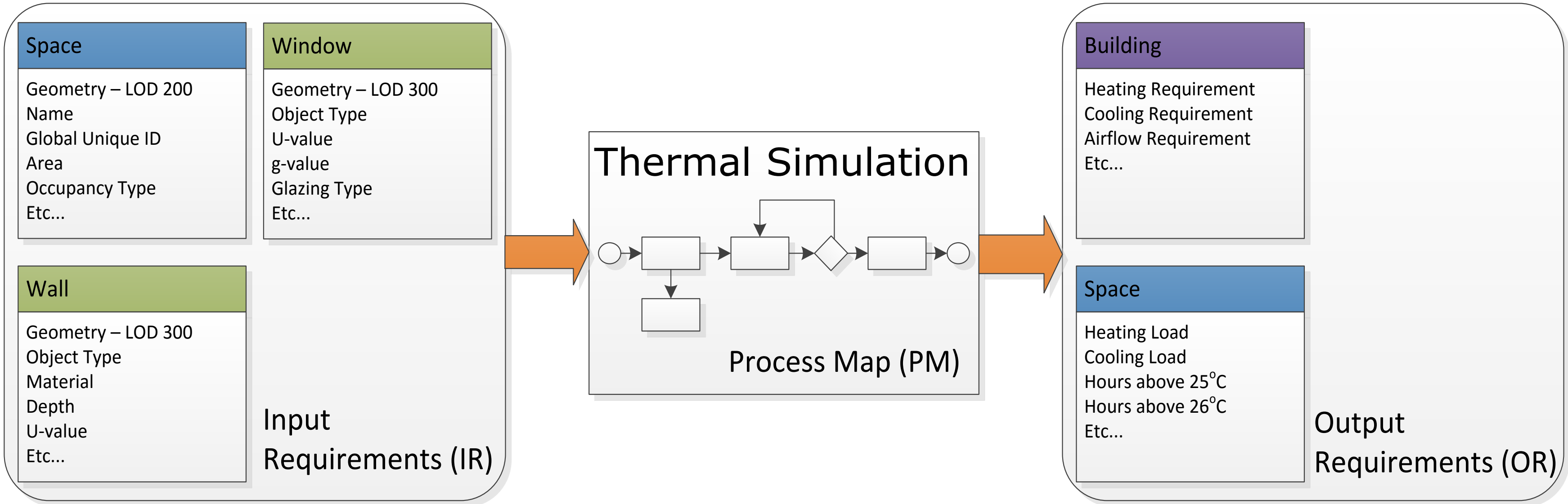




OPTIMISE THE WHOLE INSTEAD OF PIECE

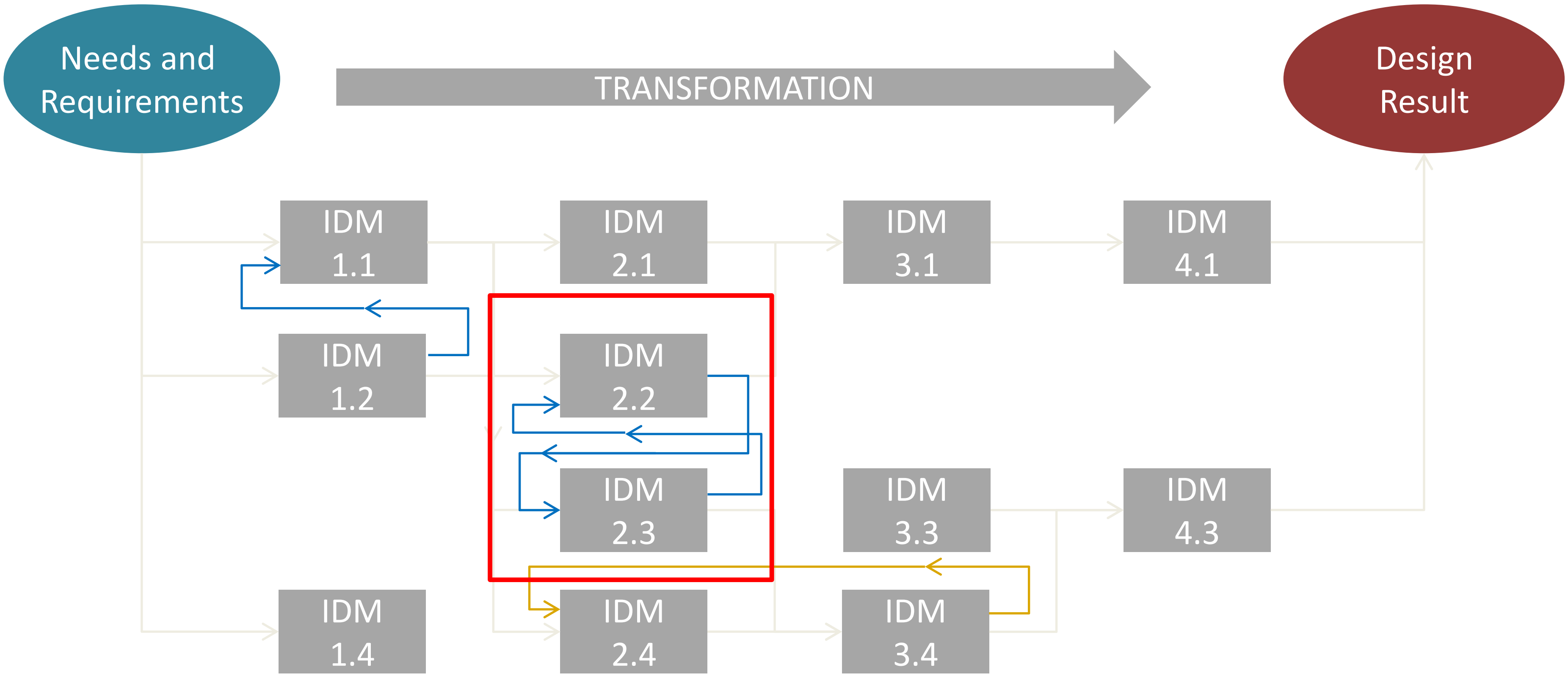


Information Flow Managment



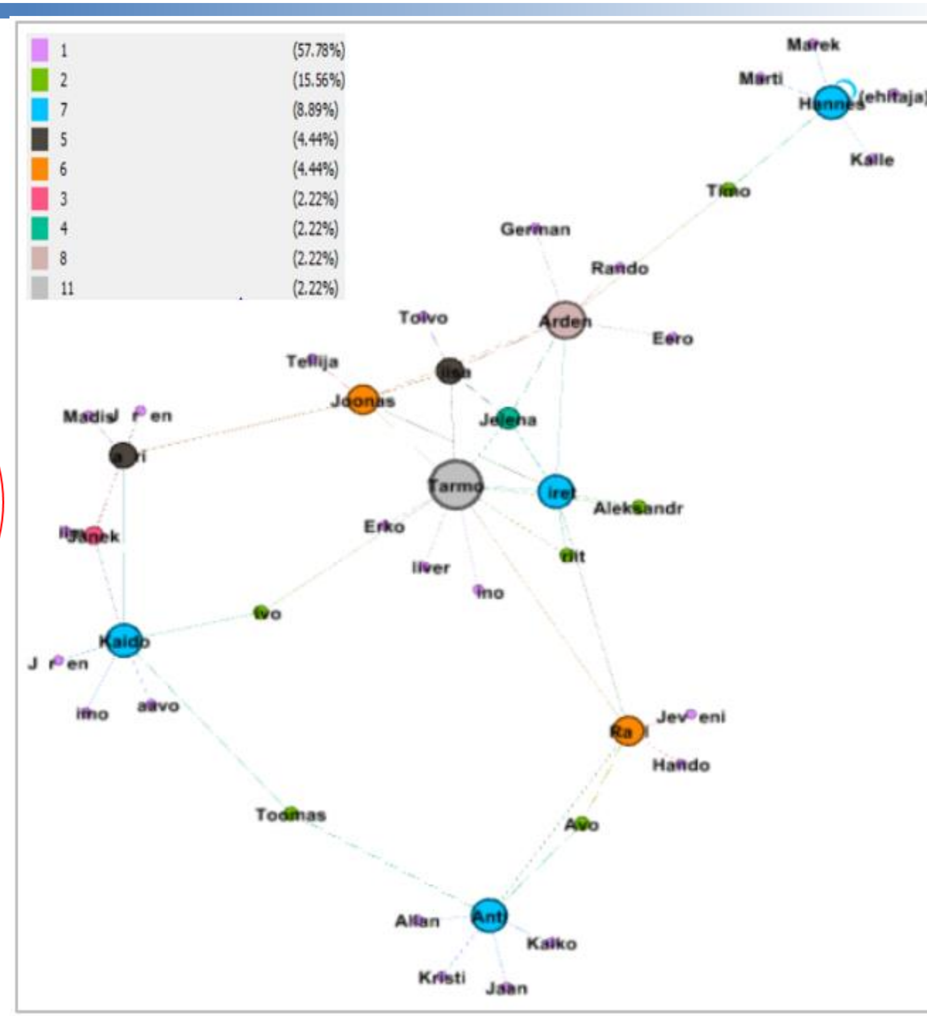
(Niels Treldal, 2016)

Information flow



(Niels Treldal, 2016)

MECHANICAL VIEW OF ORGANIZATIONS AND COMMUNICATION



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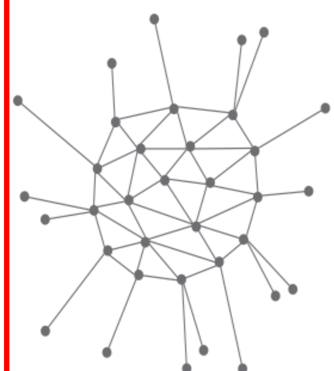
FOUR PRIMARY NETWORK STRUCTURES

DECENTRALIZED NETWORKS often contain numerous subgroups that are connected through central individuals. Similar to centralized, decentralized networks funnel information through central nodes. While designers may view this as an efficient structure for IP because it reduces the people with whom they directly communicate, this network structure has two weaknesses. It is effective at pushing information from the center out, but is not effective at bringing information into the central team. It also does not foster collaboration or shared learning between clusters of stakeholders.



CORE-PERIPHERY NETWORKS are generally two-tiered networks with a densely connected and distributed core and a sparsely connected periphery structure [9]. These networks are well suited to solving complex problems such as building design [13]. The dense core facilitates knowledge transfer and diversity in the periphery facilitates bringing new ideas into the network. When the dense core and diverse periphery work together, they foster innovation and informed decision making, making this the ideal network for integrative process.

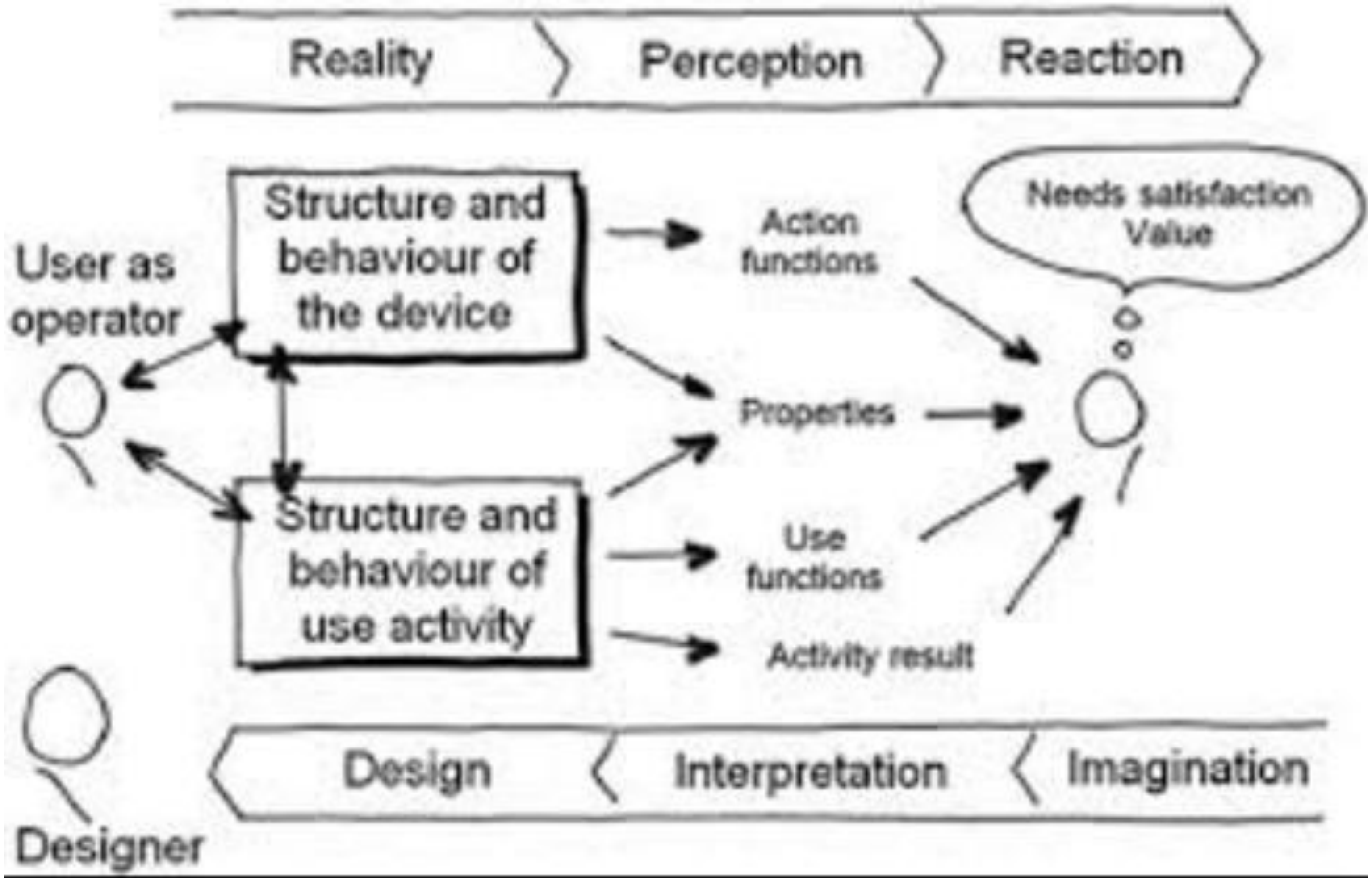
A CASE STUDY OF THE DOMAIN THEORY

DOMAIN THEORY

- Domain Theory an engineering design framework, consisting of several models and concepts for understanding and researching design practices
- The basic domains in Domain Theory include:
  - **The Activity Domain:** user's application of the product (use functions) for fulfilling the unsatisfied need
  - **Organ domain:** a set of functions, the means of a product, displaying a mode of action (realization of function) and its behavior (properties)
  - **Part (structure) domain:** consists of components as an elementary material system, making-up an organ, realizing the organ's mode of action by the part's physical states and interactions
- An artefact is defined by its structure, describing the anatomy of components, properties and relationships

(Andreasen et al. 2015)

DOMAIN THEORY



CONCEPTUALIZATION OF AN ENGINEERING DESIGN FRAMEWORK FOR CONSTRUCTION

- In this work we consider the domains of DT as a common denominator for design processes and disciplines:
  - **Activity domain:** focused on decomposing client processes (personal or business) into user activities/sub-activities and their properties that realize the client's goals and thus are value-adding (typically poor in construction industry)
  - **Organ domain:** Findings in the activity domain become the basis for defining the environment and its facility centric functional organs to be decomposed into sub-functions. Typically articulated in the project brief (room program and typology together with requirements)
  - **Part domain:** It is an embodiment of functions and expected behaviors, and its configurations and connections (Ullman, 2009).
- Buildings as a container of functional units, environmentally and dimensionally conditioned spaces, facilitates the satisfaction of users' personal or business needs

CASE STUDY AND RESULTS

- In the case study the focus was on how the design ontology informs the design process in the early stages of design.

CASE STUDY AND RESULTS

- Observation of Existing Solutions and User Needs – Activity Domain
  - Complex nature of the client
  - Typical spatial layout
  - Limitations of building form, layout and solutions
  - Technical solutions

CASE STUDY AND RESULTS

- Design Conceptualization

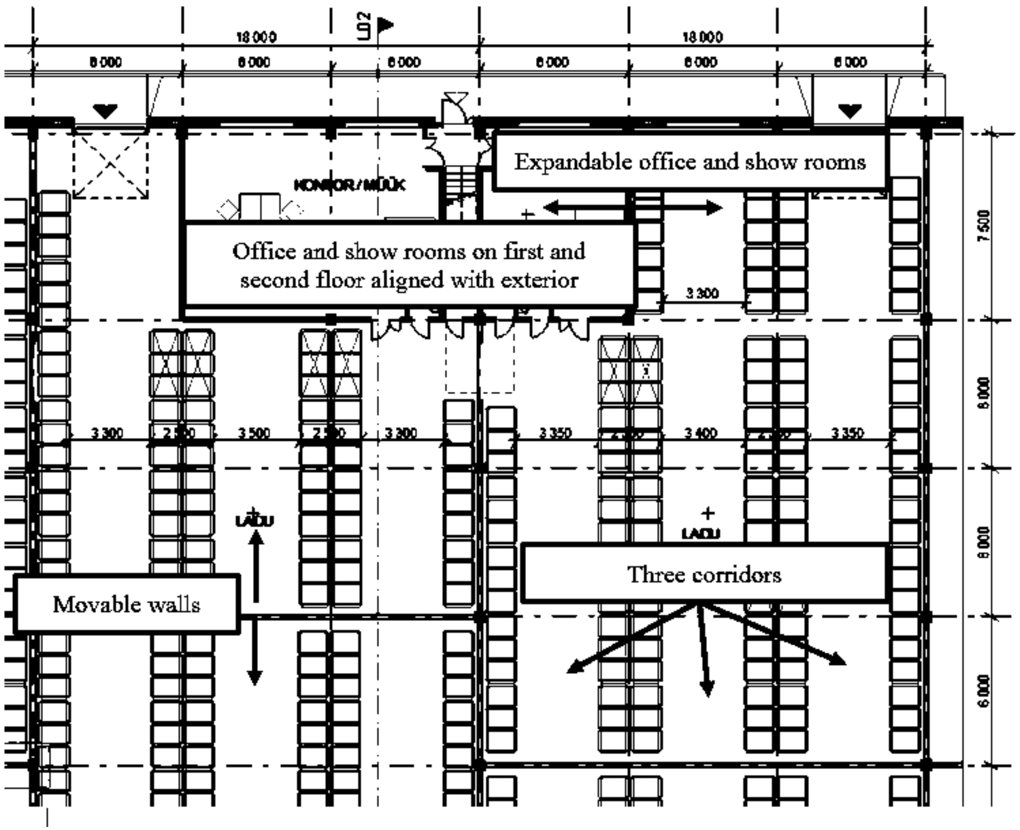
– Organ Domain

  – Office spaces
  – Show rooms
  – Service areas
  – Storage spaces

Nr	Category	Expected Performance
		Suitability
1	Modular spaces	Space range per module: 200-600 m^2
2	Flexible storage and show room spaces for expansion	Movable internal walls and flexible building services
3	Effective form, spatial layout and stowing of goods	• Office spaces shall be along the front exterior wall of building • Storage spaces shall have optimal paths for the movement of equipment and transportation of goods • Office spaces must have small kitchenette and toilet on first and second floors • The width of the corridor shall be designed based on maneuvering radius of forklifts with lifting capacity of $\leq$ 1.5 tons. Expected width between shelves $\geq$ 3.2 m • For the maximization of storage spaces the optimal spacing of shelves shall have two or three corridors • Office space $\cong$ 10 m^2 per person • Size of the transportation doors: $\geq$ 2.8m height and $\geq$3 m width • Clean height of storage space under trusses: 6m (clean height for stowing is 4.5 m)
		Aesthetics
5	Comfortable working conditions	Well-lit working spaces and aesthetical materials
		Sustainability
6	Energy efficient	Cost effective energy efficient solution: minimum requirement is B-class (consider renewable energy)
7	Indoor climate control	Users have possibility to control indoor climate, heating, cooling, ventilation and lighting
		Durability
8	Optimized structures and details	Cost optimized solutions of structures and details
9	Optimal maintenance costs	Highly enduring materials and maximum lifespan (50 years for structures)
		Construction Cost
10	Construction cost	$\leq$ 400 €/m^2 (target cost)

CASE STUDY AND RESULTS

- Product Concept Development – Part Domain



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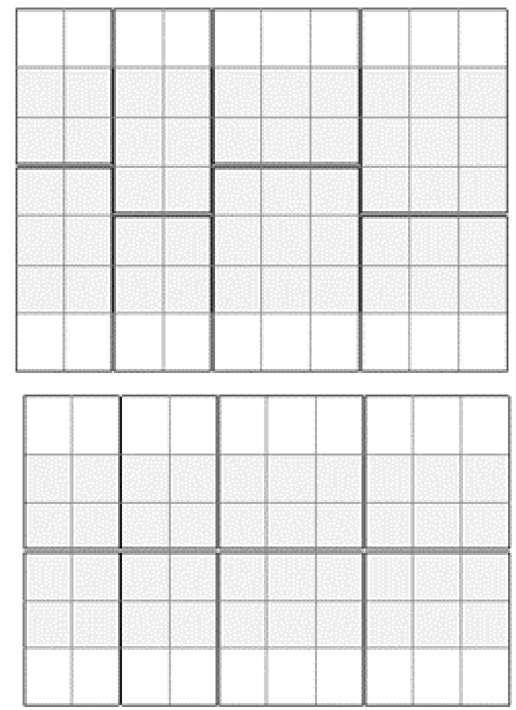


b)

DISCUSSION

- Case study indicated the different content of design development stages:

  I stage: as a part of activity domain was focused on observing existing solutions and user needs;

  II stage: as a part of organ domain was the design conceptualization; and

  III stage: as a part domain focused on the materialization of product concept

- All involved parties agreed about the usefulness of common domains, entities and relationships

- The team also noticed that systematic approaches tend to be resource intensive, which currently is not a typical practice for the early stages of design

DESIGN COLLABORATION

DIFFERENT VIEWS OF COLLABORATION

Two competing views of collaborative design: constructivist approach (Bucciarelli 2003) and communication theory (Carlile 2004, Kvan 2000):

1. **Constructivist approach**: Acknowledges design collaboration a as a social process, where design is a dynamic intersection of social and cultural views for developing a common meaning and interests

2. **Communication theory**: A field of information theory and mathematics, focused on the efficiency of exchanging information and meaning between two points (dispersed locations, individuals or groups of individuals)

DIFFERENT VIEWS OF ENGINEERING DESIGN

1. Engineering design is a social process requiring the participation of different individuals having different competencies, responsibilities and technical interests. Each participant sees the object of design differently, in accord with the paradigmatic core of their discipline, their position of responsibility.

2. Engineering is an instrumental process requiring the application of established, rational scientific theory in the development of new products and systems for the benefit of humankind. Different engineering disciplines rest upon different paradigmatic sciences.

Bucciarelli, L. L. (2003). Designing and learning: a disjunction in contexts. *Design Studies*, *24*(3), 295-311.

DEFINITION: COLLABORATIVE DESIGN

- **Collaborative design** is the process through which actors from different disciplines share their knowledge about the design process and the design itself. This creates shared understanding related to both process and artefact, helps integrate their knowledge, and helps them focus on bigger common objectives—the final product to be designed **(Andreasen et al. 2015).**

- Three building blocks of collaboration:
  - **Knowledge creation and integration** between disciplines;
  - **Communication;**
  - The creation of a **shared understanding.**

(Kleinsmann 2006)

WHY COLLABORATION – DEPENDENCIES

- The need to collaborate has been caused by the division of master builder into distinct functional disciplines **(Pikas et al. 2015),** operating within their own object world **(Bucciarelli 2003).**

- In design and engineering, disciplines must work together for following three reasons (Koskela 2016):
  - Needs arising from demanding requirements (purpose/goal of the artefact, when prior solutions do not suffice);
  - Needs arising from the design process (timely delivery of each task outputs); and
  - Needs arising from the product being designed (parts must fit mutually, artefact behavioral performance has to be achieved through network of connected parts).

COLLABORATION REQUIRES BOUNDARY CROSSING AND BRIDGING

- Two types of boundaries
  - **Material:** caused by the arrangement of individuals into organizations, disciplines, tasks and physical locations;
  - **Knowledge boundaries:** syntactic (common vocabulary), semantic (common meaning) and paradigmatic (common goals and interests) differences in sociocultural worlds.

- These two do not exist separately but are entangled into the interaction of individuals working together:
  - An example from design could be an architect and engineer from two separate organizations working together on a common project, with shared interests, aiming to achieve common goals.

MATERIAL BOUNDARY BRIDGING CONCEPTS

Boundaries		Syntactic	Semantic	Pragmatic	
Collective	Organizations Disciplines Tasks	**Goal:** Common vocabulary to reduce uncertainty **Temporal:** Formally structured processes for information sharing **Fit:** Information interoperability	**Goal:** Common meaning **Temporal:** Processes for developing a shared meaning **Fit:** 'Sharedness' of meaning	**Goal:** Common interests and goals to work towards **Temporal:** Processes for defining goals and common interests **Fit:** Aligned interests and goals	**Managing material boundaries:** Boundary Crossing Roles and Standardized methods
Individual	Personal				

Managing knowledge boundaries: Learning Mechanisms (questioning, analysis, modelling, examining and implementing) and Boundary Objects

VEIDEKKE'S MAIN DESIGN ELEMENTS

MAIN ELEMENTS

Common interests/Goals
- Common vocabulary
- Common meaning
- Common Interests/Goals
- Boundary bridging roles
- Organizational structure
- Commercial terms

The start-up process

Start-up meeting/assembly
- Go through description
- Make a phase schedule for design
- Draw up a group agreement (joint goals)
- Clarify roles and expectations
- Set up the project team

The obstacle analysis

6 conditions for sound designing
- Design basis
- Expectations and requirements
- Dialogue
- Decisions
- Team
- Methods and tools

Design Management
- Boundary objects
- Collective learning
- Standardized methods

Design Management
- Standardized processes
- Standardized methods

The scheduling system

Progress plans/schedules
- Overall progress plan (entire project)
- Phase schedule, design
- Lookahead schedule (weeks 10-15)
- Weekly schedule (weeks 5-9)

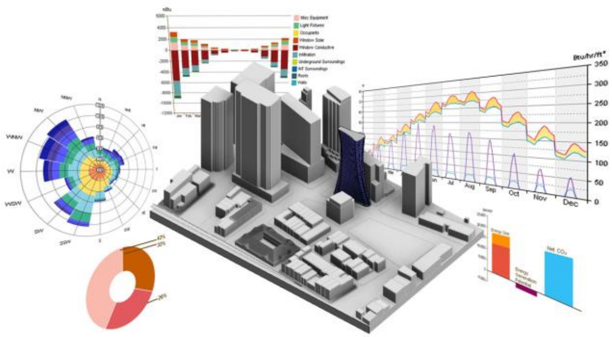
Other schedules
- Purchasing schedule
- Decision schedule

Meetings structure

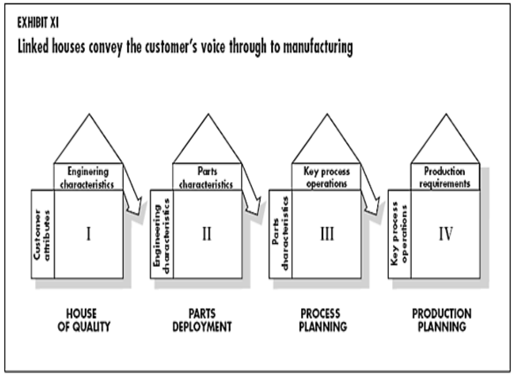
General meetings
- Start-up assembly
- The design meeting

Special meetings
- Section meetings/thematic meetings
- Meetings between the architect and the consultant engineer from construction
- Meetings between the production section and the architect

DIFFERENT MEANS FOR COLLABORATION

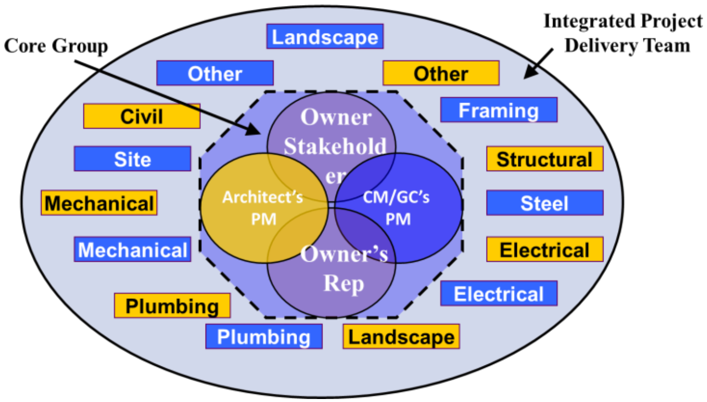


Technology (simulations and communication)



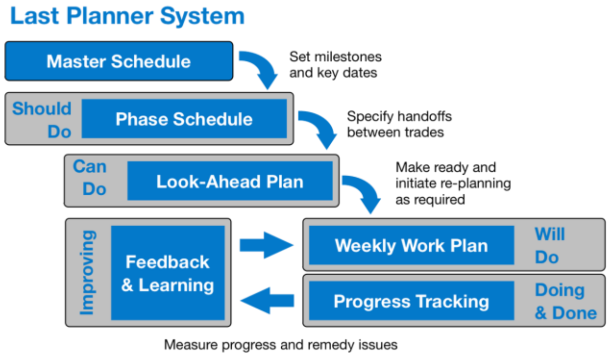
Source: Modified from a figure supplied by the American Supplier Institute, Inc., Dearborn, Michigan.

Methodologies

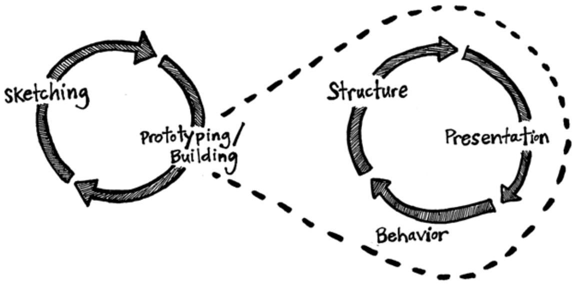


Contractual and organizational

Joint-design sessions



Collaborative planning

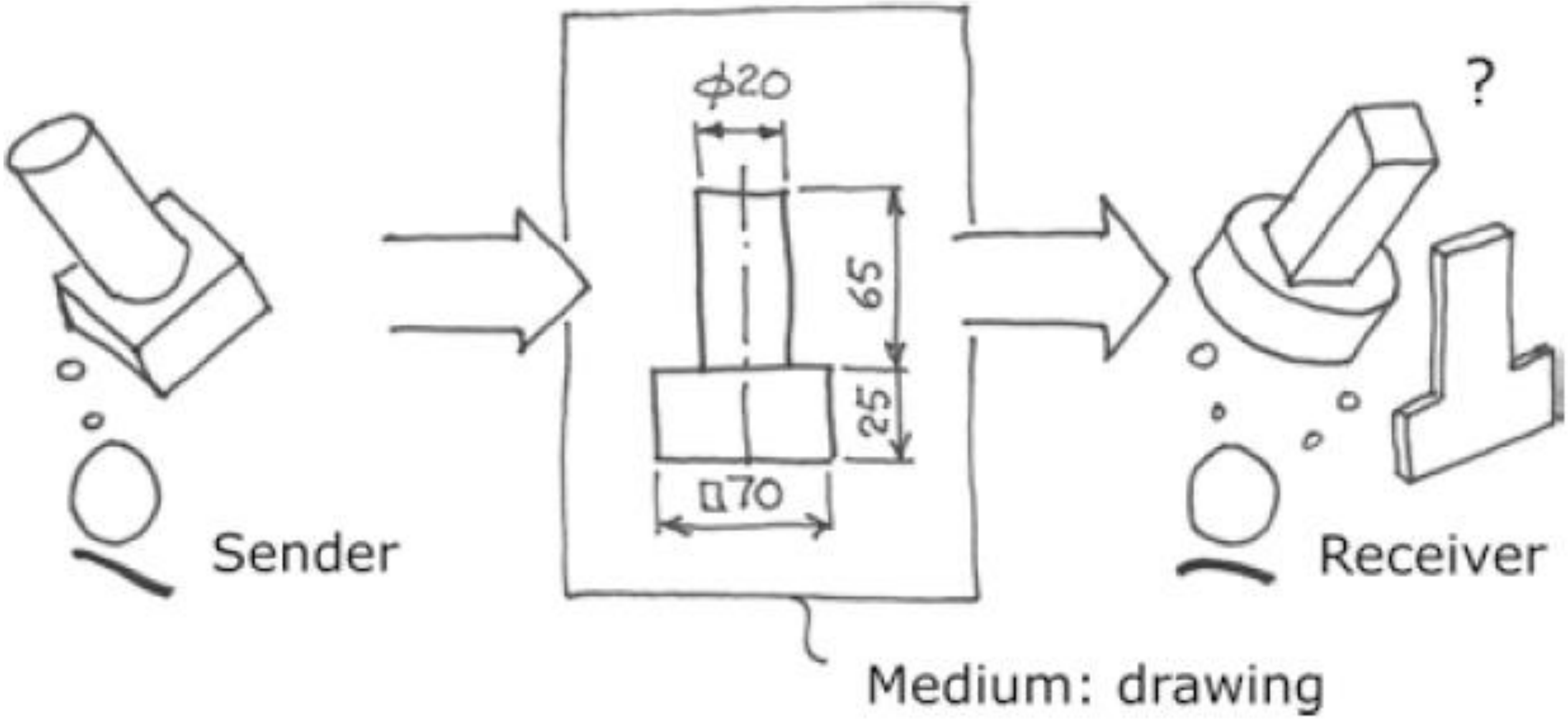


Prototyping

FACTORS HINDERING COLLABORATION

- **Poor integration of design disciplines leading to partial designs** - one discipline at the time (Clausing 1994)
- **Unaligned project contract terms** (Sacks and Harel 2006)
- **Poor design management practices** (Pikas et al. 2015)
- **Limitations of boundary objects** (Andreasen 2015)
- **Misunderstanding between disciplines** – different languages and paradigms (Bucciarelli 2002)

EXAMPLE OF HINDERING ASPECTS – LIMITATIONS OF BOUNDARY OBJECTS



Andreasen 2015

IN SUMMARY – COLLABORATIVE DESIGN

Common Goals/ Interests and Processes

Functions and Expected Behavior

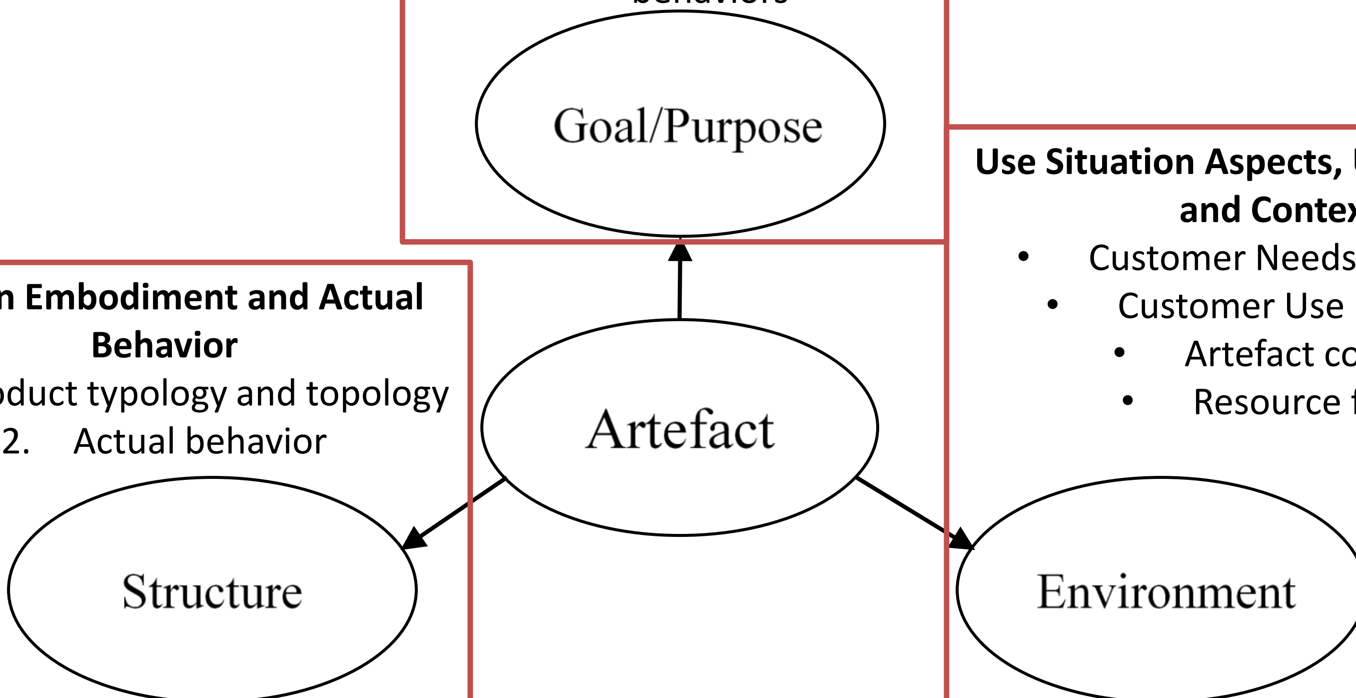
- Artefact functions
- Artefact expected behaviors

Use Situation Aspects, Use Functions and Context

- Customer Needs and Values
- Customer Use Functions
- Artefact context
- Resource flows

Design Embodiment and Actual Behavior

1. Product typology and topology
2. Actual behavior



Simon 1969

CONCLUSION

- **Change in the mind-set from piece-optimization to the optimization of the whole**
  - Value before the transformation view, or in other words the time needed for value generation should drive the design scheduling, but not the opposite
  - Early involvement of all related stakeholders, especially in a demanding projects: end-users, client, designers, engineers, contractors, operators and maintainers
  - In design every person involved is a supplier and client of the information at the same time

- **Change the behavior of participants involved**
  - From individual interests to collective interests
  - Participation in design requires empathy

CONCLUSION

- **Change operating/production systems by continuous negotiation and debating among all involved within the whole life-cycle**
  - Development of the communication, cooperation and common goals/interests within the project
  - Use processes, methods and boundary/mediating artefacts/objects that can help to do boundary bridging and crossing
  - Reduction of batches for shorter iterations
  - Concurrent engineering, align the goals of users/client(s), designers/engineers and contractors
  - Organize design process by functional building modules – design clusters
  - Use standardization as much needed and reasonable
  - More explicit management of information flows.

CONCLUSION

- Collaboration requires the management of material and knowledge boundaries, in order to develop common goals, processes and product.
  - Bridging the material boundaries: Boundary bridging roles, standardized methods, organizational structures and commercial terms.
  - Crossing the knowledge boundaries: collective learning by means of debating, negotiating and combining of different perspectives and conceptualizations and boundary objects.
- Boundary objects and standardized methods, such as building information modelling/models, Target Value Design etc. will aid the collaborative practice in design and construction process.

CONCLUSIONS

- **Domain Theory implications**
  - Provides common language and a mental model for the design team and design concept development
  - Reinforced focusing on key parameters, issues and design requirements
  - Supported the design team to understand the difference and purpose of verification and validation
    - An example of verification was the involvement of structural and building services' engineers in the early stages of design, doing design review
- **Limitations**
  - The concept development took several months longer than was initially planned
  - Operations management methods must be implemented to avoid the situation, where the architect would have to work based on assumptions, especially by using a pull mechanism

Q&A

A "composite mind" is necessary when a wealth of knowledge needs to be assembled for a single goal.

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