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Smart Commercial Buildings - Use Cases and Digital Twins

Bachelor Colloquium

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Buildings impact resource consumption, safety and well-being

- Our built environment account for one-third of global energy consumption[1]
- A major share is caused by heating, ventilation, and air conditioning (HVAC) systems[2]
- Indoor air pollutant concentrations are higher than outdoor ones[3]

Considerable savings and further benefits can be realized through the **intelligent control** of buildings.

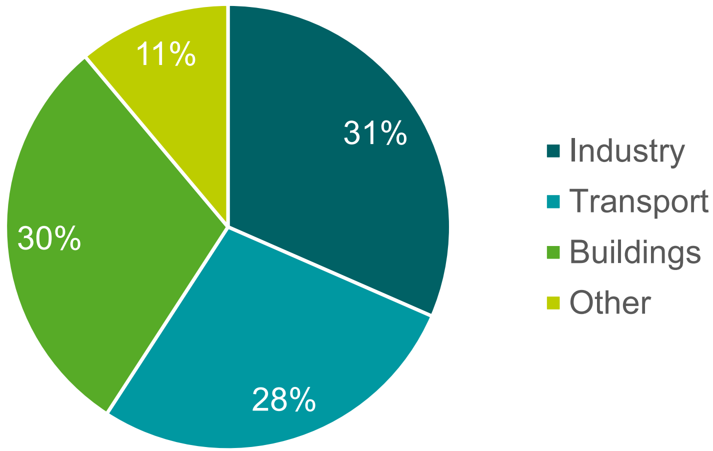

Fig. 1: Final energy consumption by sector, fuel and scenario in 2019 (Mtoe)[1]

[1] IEA 2019
[2] Latifah et al. 2020
[3] Saraga 2020

The Internet of Things (IoT)

- "..the extension of computing power and network connectivity to sensors, devices and other items not typically referred to as individual computers." [4]
- Enabled by different hardware and software technologies [5]
  - things (smart devices) that collect information,
  - technologies that enable devices to process information
  - technologies that improve security and privacy
- IoT for private users is rather human centered (machine-to-user interaction) [6]
- IoT in industrial environments (IIoT) typically interacts machine-to-machine [6]

[4] Rose et al. 2015
[5] Patel et al. 2016
[6] Sisinni et al. 2018

Definition of Smart Commercial Buildings and BIM

Smart Commercial Building (SCB)

- The term is not used consistently in literature
- In this presentation: Commercial or industrial building projects in which IoT technologies are used to improve the comfort, safety and resource consumption of building users

Building Information Modeling (BIM) [7]

- A methodology which is used for the pre-construction design, verification, post-construction, facility management of smartly built environment
- Digital representation of building data

[8] Latifah et al. 2020

Research Questions

RQ1
What is a digital twin / digital shadow of a Smart Commercial Building?

RQ2
What are common Use Cases for a Smart Commercial Building Platform?

Fig. 2: Stylized representation of a Smart Building according to Siemens [9]

[9] Siemens Deutschland 222

What is a Digital Twin / Digital Shadow of a Smart Commercial Building?

Characteristics of a Digital Twin

Individual
DT matches its physical twin exactly

High fidelity
DT can simulate the behavior of the physical twin over its lifecycle

Real-time
New technologies enable the DT to adapt and respond with low latency

Controllable
Changing one twin results in the same change in the other twin, physical and digital twin control each other

[10] Liu et al. 2021

Digital Twin, Digital Shadow and Digital Model

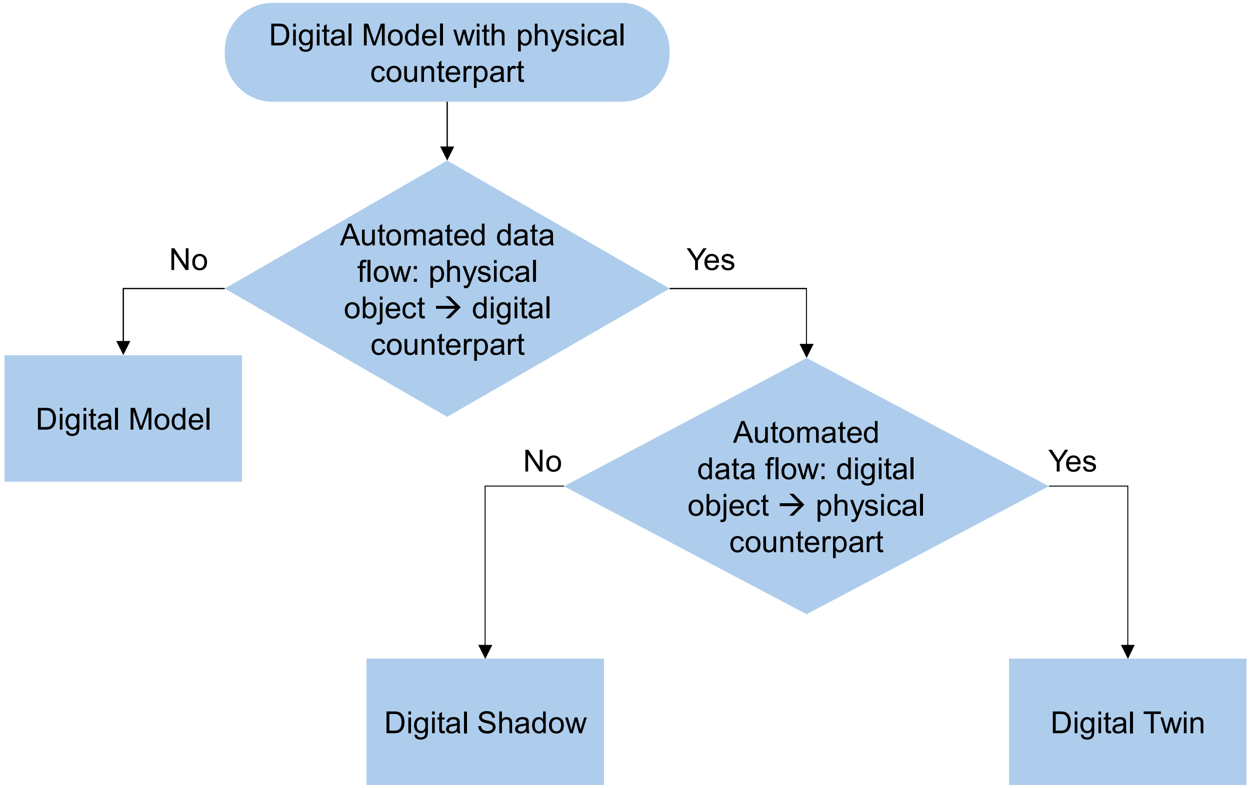

Fig. 3: Decision tree of the digital model subcategories [11]

- A digital model does not necessarily get updated automatically
- A digital shadow serves as an accurate mirror of the physical object and adapts to changes automatically
- A digital twin include bidirectional control mechanisms and extends the virtual representation of a physical asset.

[11] Pronost et al. 2021

What is the Digital Twin of a Smart Commercial Building?

- Virtual representation of building for industrial/ commercial purposes
- Automated continuously bidirectional flow of data and control information between the digital twin and its physical counterpart
- Monitors its individual physical twin precisely and adapts operational changes in real-time
- Integration of Building Information Modeling (BIM) Model
- Contains various services for controlling and services for providing digital shadows, which contain a Use Case specific section of data.
- Maintained and constantly adjusted throughout the entire lifecycle

What is the Digital Shadow of a Smart Commercial Building?

- A digital shadow contains data sets and traces that are accurate enough for a specific task
  - Data from a cyber-physical system
  - Context-describing metadata
- A digital twin consists of a set of digital shadows

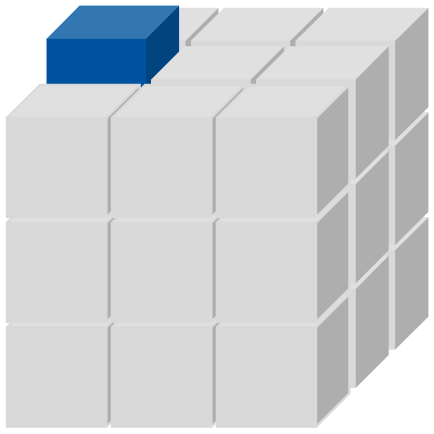

Fig. 4: The digital shadow only contains the data needed for a certain application

[12] Bauernhansl 2018

What are Common Use Cases for a Smart Commercial Building Platform?

Definition of the Term Use Case

- A Use Case is defined as a description of sequences of interactions between a system and its actors, written in natural language [13]
- Expresses the functionality and the functional requirements of a system.
- Use Case descriptions can vary in scope and level of detail

Use Case	**Name:** *Active phrase, that reveals the function (e.g., <verb><object>)*
Description	*Short summary of the system behavior, including the use cases' goal*
Primary actor	*Actor identified in* Grounded Theory (GT) *e.g., the main user*
Preconditions	*Conditions identified in GT, that must be fulfilled before start*
Trigger	*Actuating interaction after all preconditions are fulfilled*
Main success scenario	*Step-by-step specification of all individual actions of the interaction sequence which specifies the most frequent*
Associated use cases	*All associated use cases*

Fig. 5: Use Case Template

[13] Cockburn 201)

Identification of SCM Use Cases

- Identification of SCM Use Cases applying Grounded Requirements Engineering (GRE)
- Source of information: Features of SCB platform providers
- Additional literature research

Common Use Cases

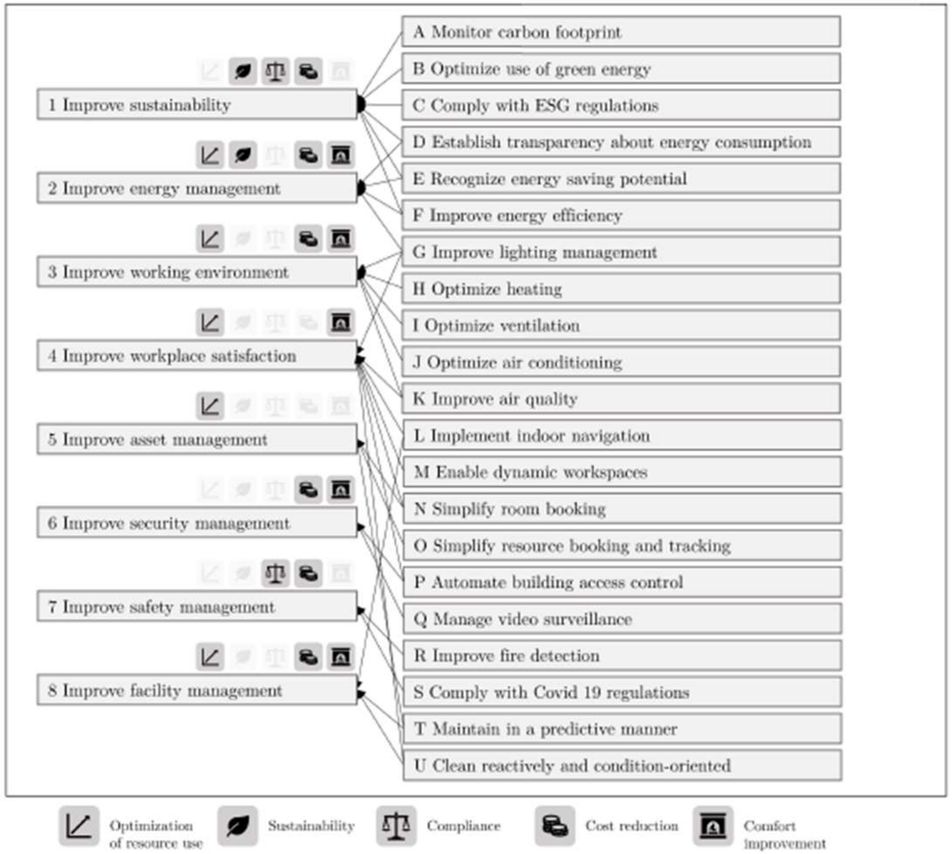

Fig. 6: List of common Use Cases

→Clear assignment to one category is not possible

→Different corporate goals involved, target conflicts

Use Case 1: Recognize energy saving potential

- Energy savings potential can be determined by calculating usage patterns according to Bosch, Johnson Controls, Mapiq, Siemens
- Additional data is often collected (number of attendant employees, time of the year, …)

Use Case: E	Name: Recognize energy saving potential
Description	An intelligent algorithm is used to determine whether more energy is consumed than expected
Primary actor	Either contractor or internal facility management
Preconditions	
Trigger	Detected anomaly in the consumption pattern of energy
Main success scenario	1. Calculate site usage patterns 2. Identify the relationship between energy consumption patterns and operations patterns 3. Receive alerts about energy waste
Associated use cases	Establish transparency about energy consumption, Improve energy efficiency

Use Case 2: Improve lighting management

- Implemented by Siemens, Johnson Controls, Mapiq, Bosch – but little information provided
- Light control mechanism can be triggered when a sensor detects a motion and compares target and actual brightness

Use Case: G	**Name:** Improve lighting management
Description	Improve management of artificial lighting taking into account the change of daylight during the day.
Primary actor	Office employees, facility management
Preconditions	
Trigger	Detection of movement and deviation of actual and target values. This can be caused by the adjustment of the target values by the employees.
Main success scenario	1. Sensors detect occupancy by detecting motion 2. Sensors detect the ambient light in a room 3. The determined values are compared with the target values 4. Lighting is adjusted accordingly and in advance based on pattern recognition using machine learning
Associated use cases	Establish transparency about energy consumption, Recognize energy saving potential, Improve energy efficiency

Roohi et al. 215)

Use Case 3: Recognize energy saving potential

- Mapiq: evaluates data of desk sensors to check if a desk is or was occupied and should be cleaned
- Spacewell: offers the possibility to distribute demand-oriented cleaning schedules in the in-house app using sensors in bathrooms and meetig rooms; manual feedback option

Use Case: U	**Name:** Clean reactive and condition-oriented
Description	User feedback options and traffic tracking can improve the cleanliness of office spaces and restrooms without increasing costs in the long term. Cleaning is no longer done at regular intervals, but depending on the condition.
Primary actor	Employee
Preconditions	Booking tool or manual user feedback
Trigger	User feedback or critical sensor values
Main success scenario	1. Evaluate data of sensors in a room and the dynamic workplace tool to get information about the utilization of the room 2. The user operates a feedback panel to confirm that the room is clean or to report a problem 3. The cleaning schedules are adjusted accordingly 4. The cleaning person actuates a switch or touches buttons to confirm that the cleaning is done
Associated use cases	Enable dynamic workspaces, Simplify room booking, Comply with healthcare regulations

Conclusion

Digital Twin, Digital Shadow and Digital Model

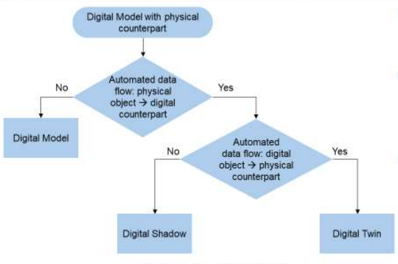

Fig. 3: Decision tree of the digital model subcategories [11]

- A digital model does not necessarily get updated automatically
- A digital shadow serves as an accurate mirror of the physical object and adapts the changes automatically
- A digital twin includes bidirectional control mechanisms and for this reason extends the virtual representation of a physical asset.

[11] Pronost et al. 2021

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What is the Digital Twin of a Smart Commercial Building?

- A virtual representation of a building used for industrial or other commercial purposes
- There is an automated continuously bidirectional flow of data and control information between the digital twin and its physical counterpart
- It monitors its individual physical twin precisely and adapts operational changes in real-time
- It is able to integrate data of a Building Information Modeling (BIM) Model
- It contains various services for controlling and services for providing digital shadows, which contain a use case specific section of data.
- It be maintained and constantly adjusted throughout the entire lifecycle.

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What is the Digital Shadow of a Smart Commercial Building?

- A contains data sets and traces that are accurate enough for a specific task
  - Data from the CPS
  - Context-describing metadata
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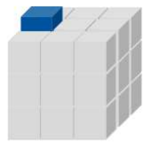

Fig. 4: The digital shadow only contains the data needed for a certain application

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- It expresses the functionality and the functional requirements of a system.
- Use case descriptions can vary in scope and level of detail

Table 5.1: Template for use case description based on [**Wuerfel.2015**]

Use Case	**Name:** *Active phrase, that reveals the function (e.g., <verb><object>)*
Description	*Short summary of the system behavior, including the use cases' goal*
Primary actor	*Actor identified in* Grounded Theory (GT) *e.g., the main user*
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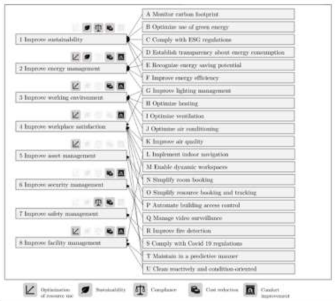
Common Use Cases



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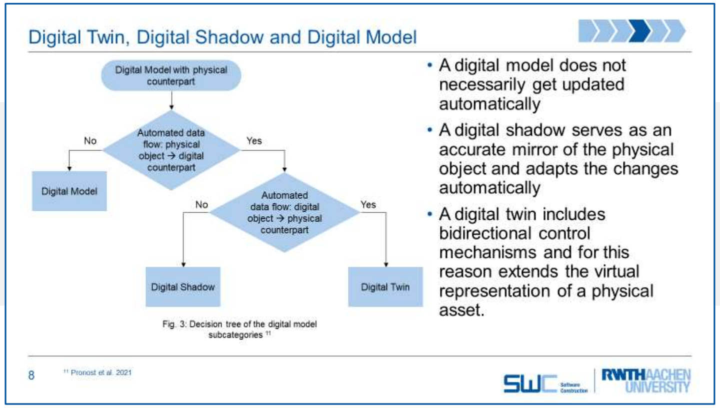
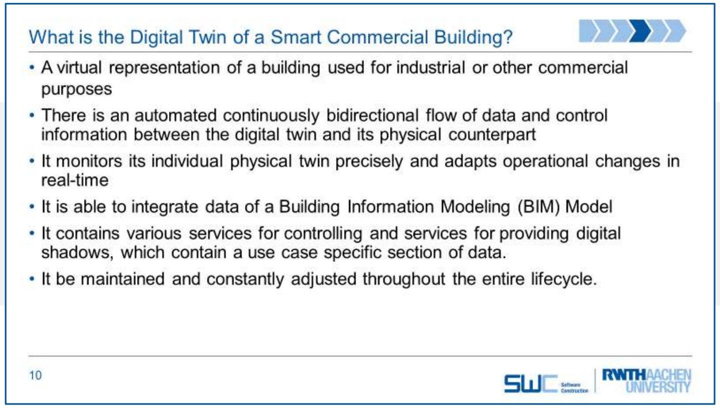
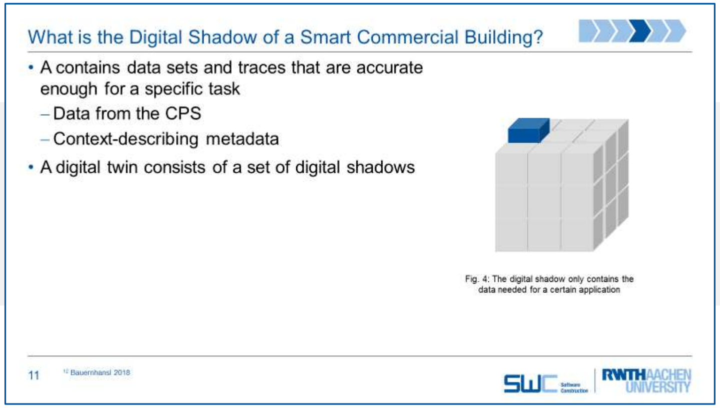
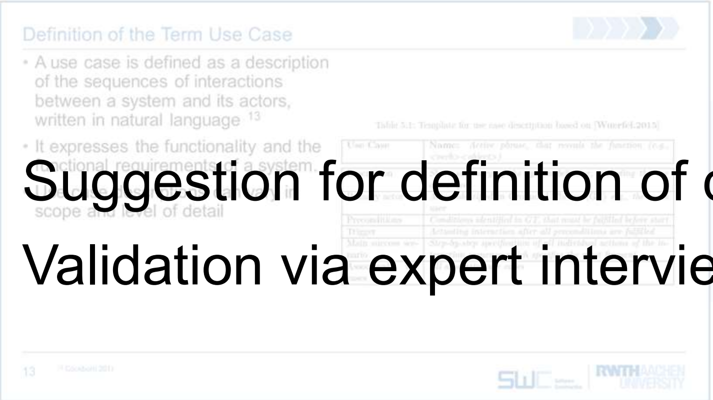
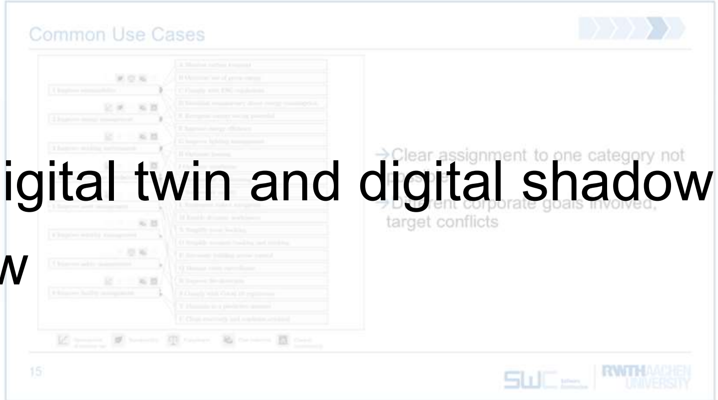
Conclusion

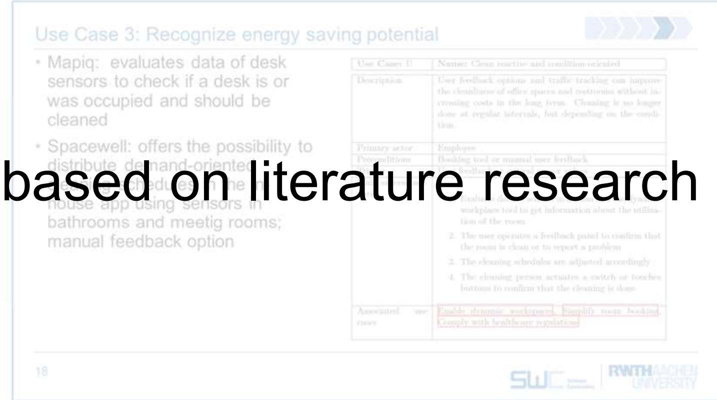








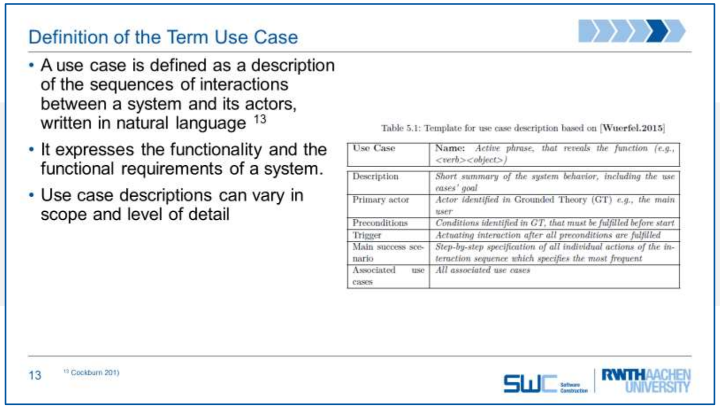


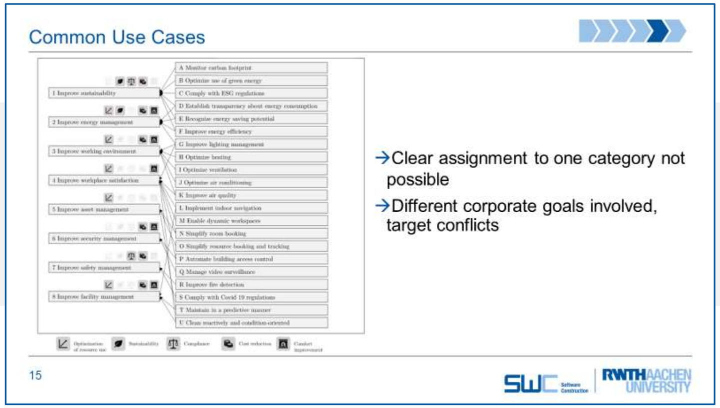


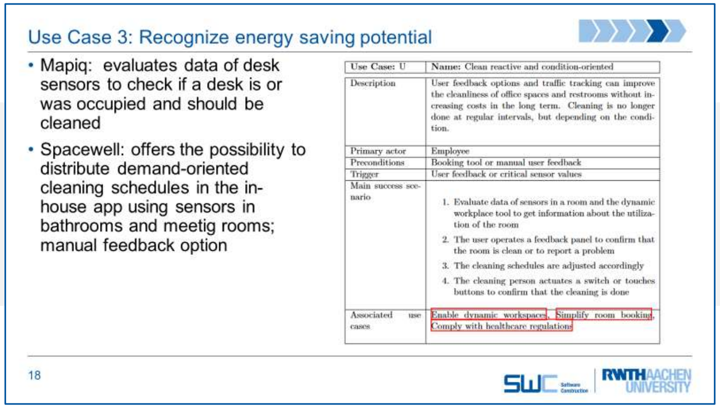
• Suggestion for definition of digital twin and digital shadow based on literature research
• Validation via expert interview

Conclusion

- Appropriate abstraction level for Use Case description defined
- 21 common Use Cases identified
- Use Case description for each Use Case







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