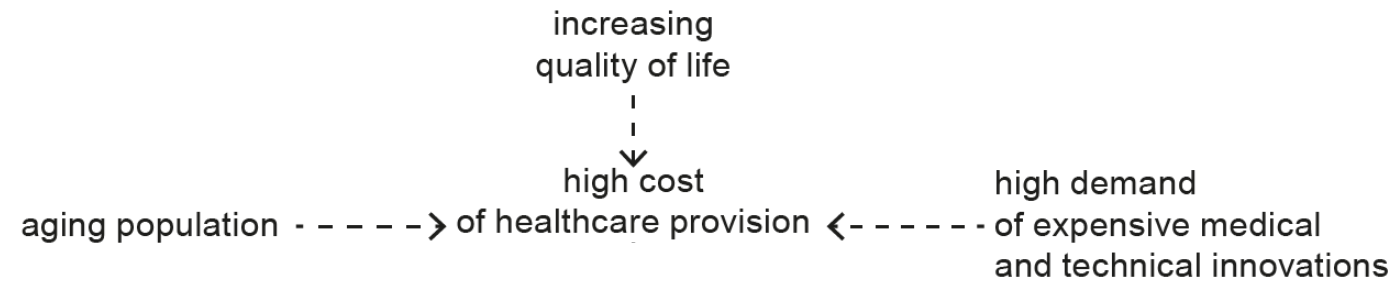
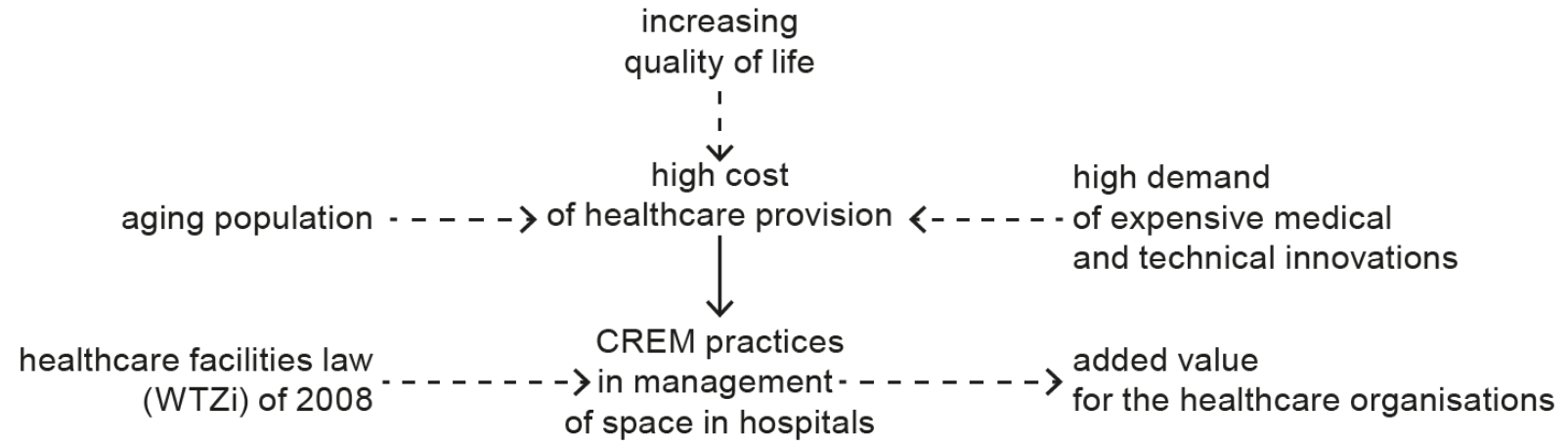
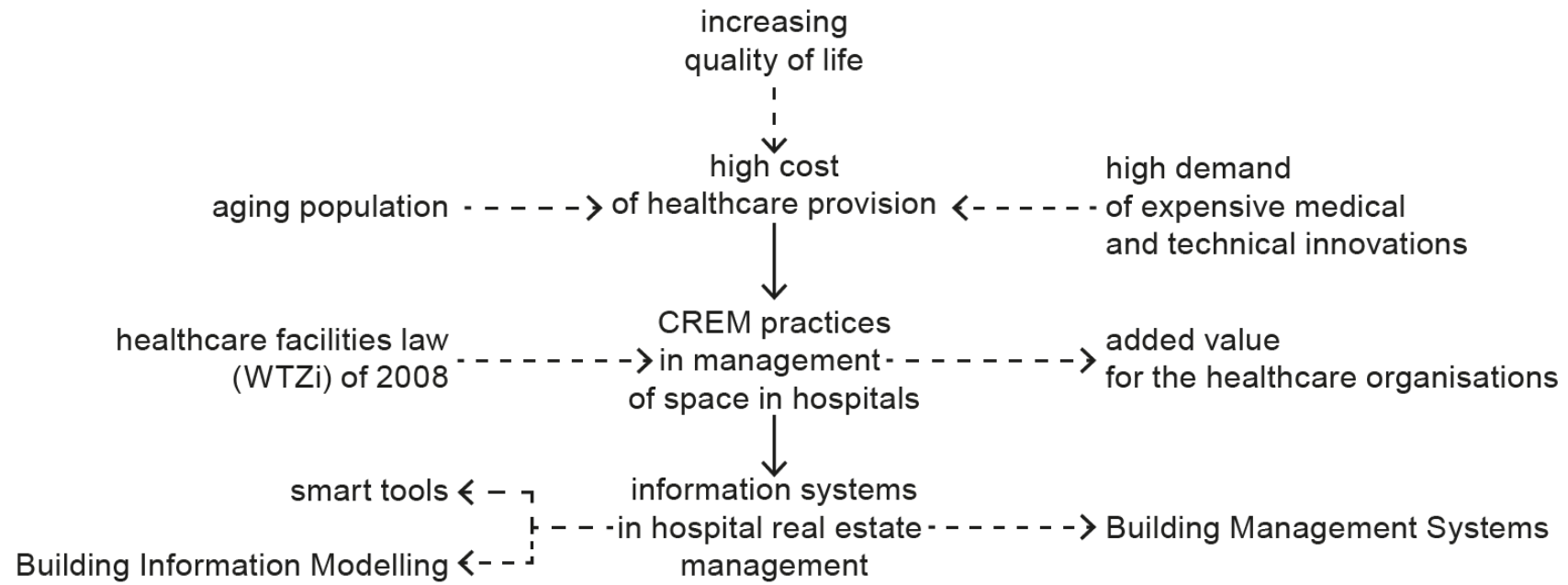


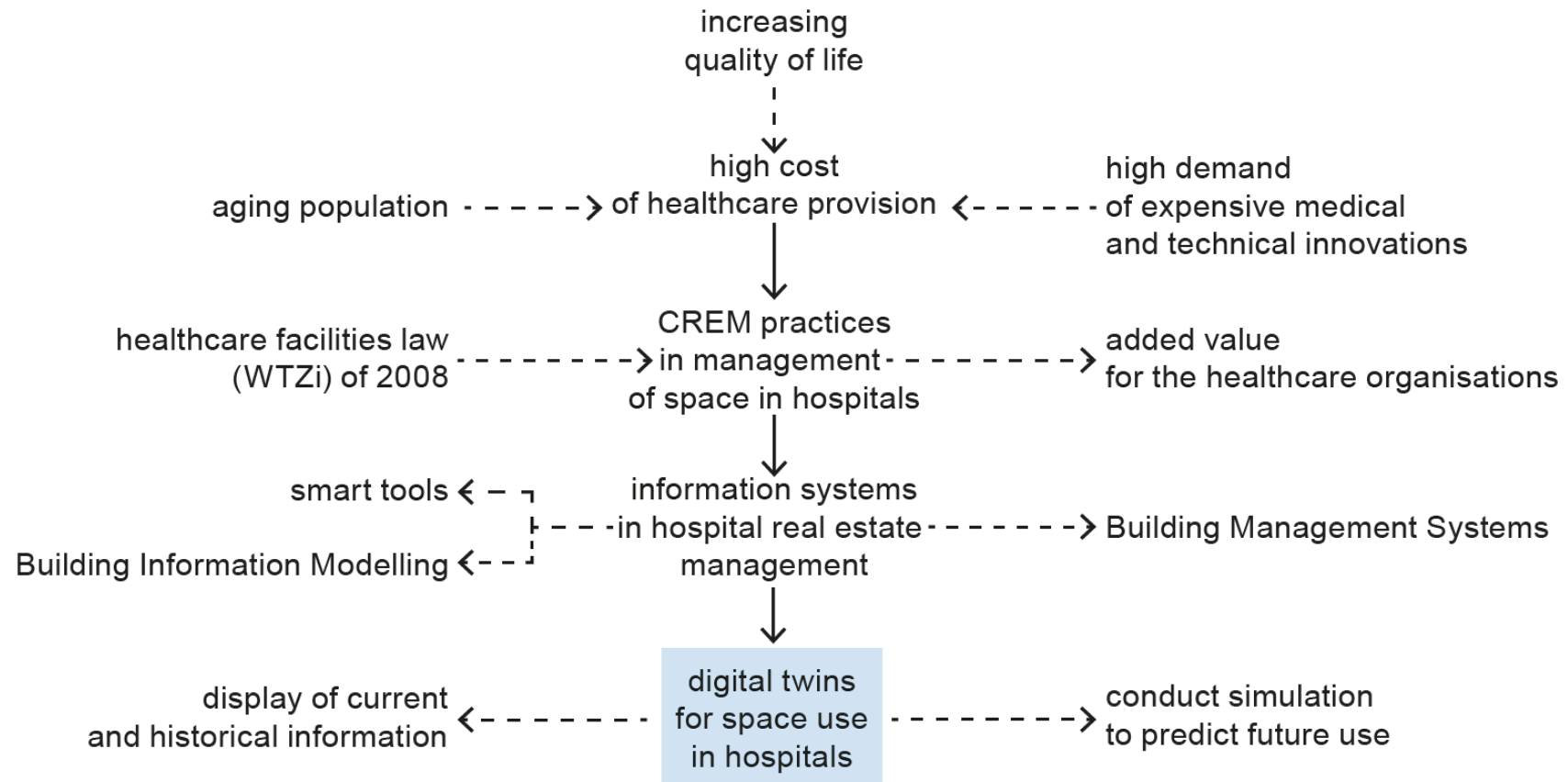
Digital Twin

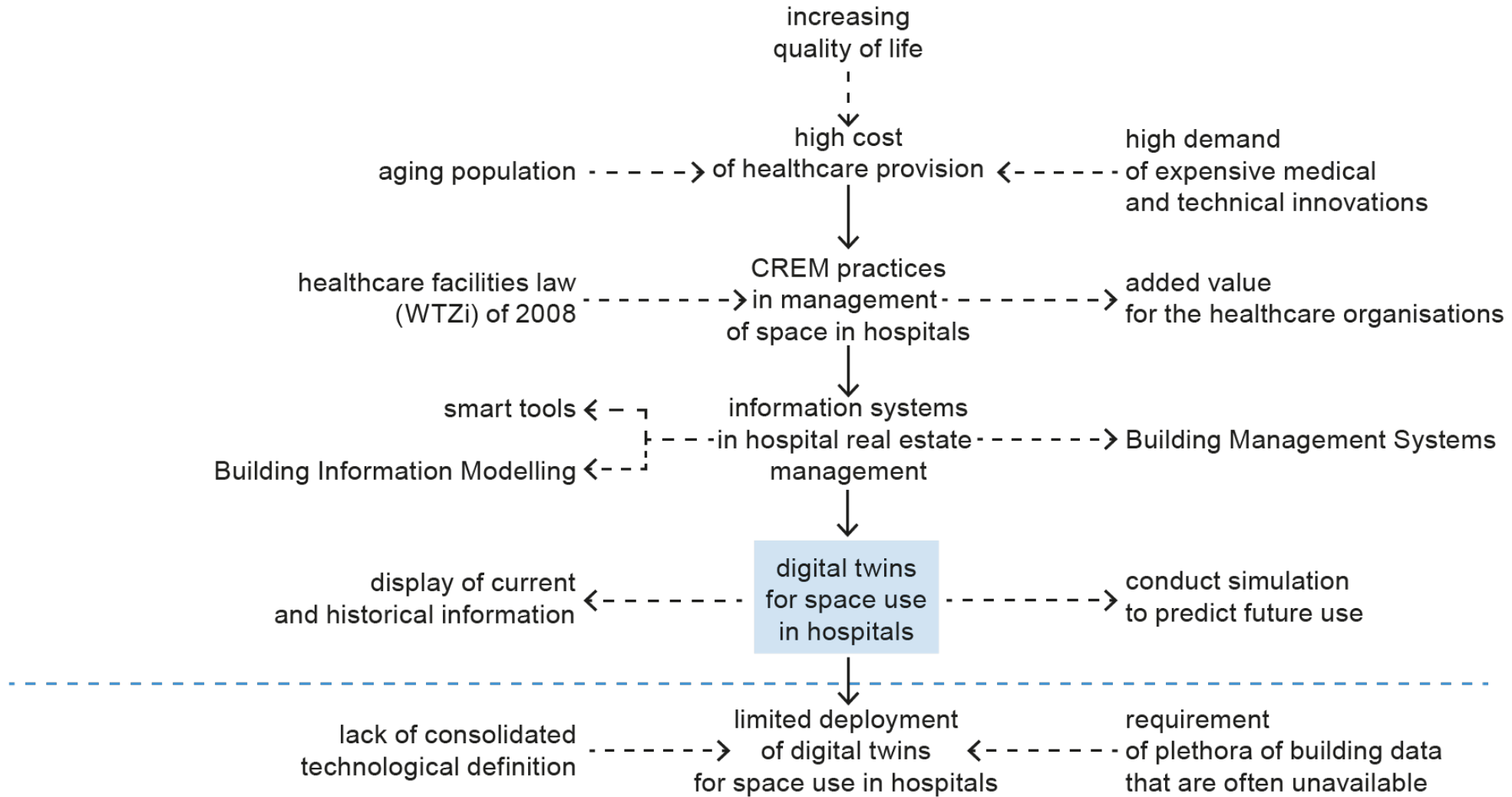
"Physical product in real space, virtual product in virtual space and the connection of data and information that ties the two spaces together" (Grieves & Vickers, 2017)

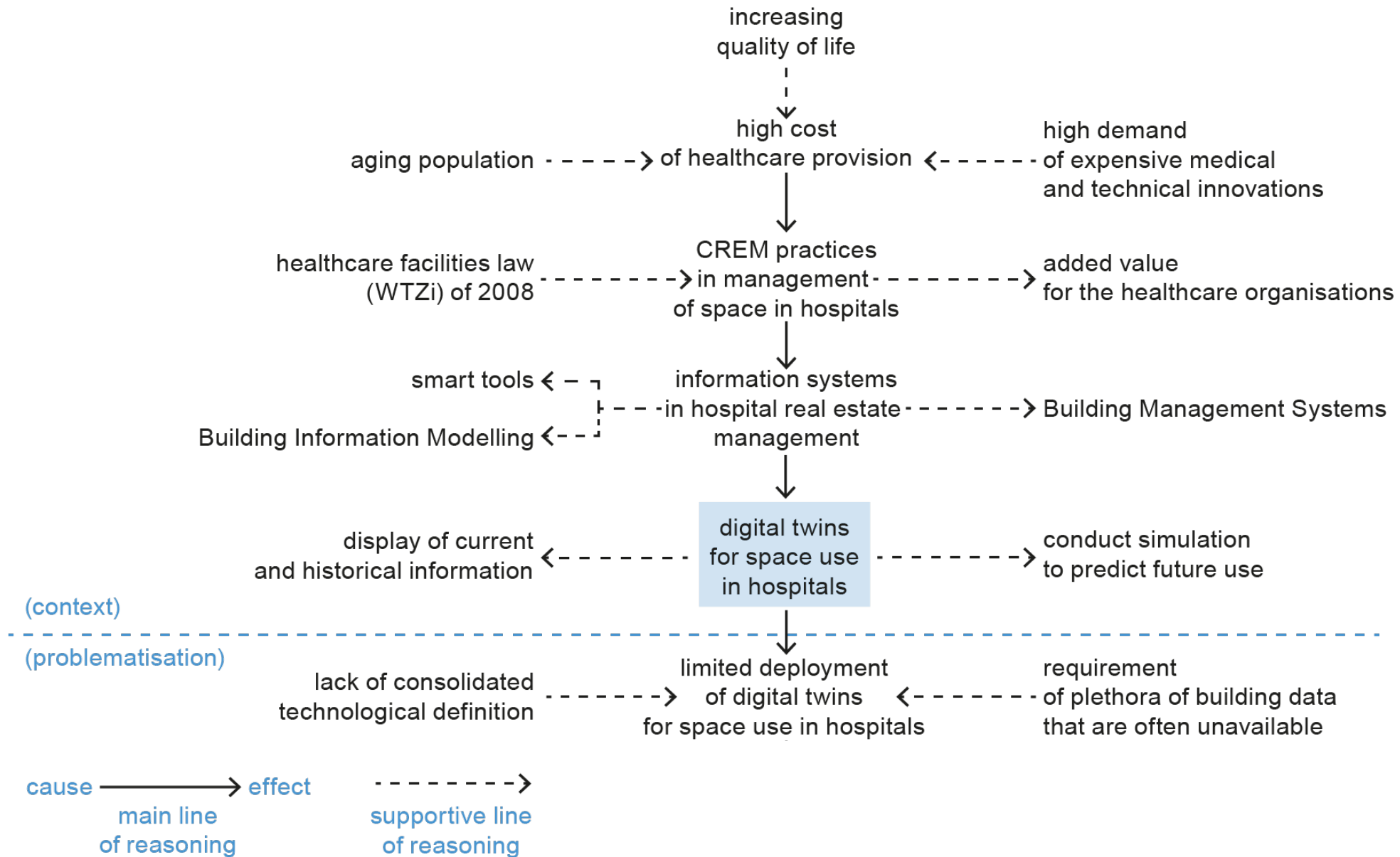


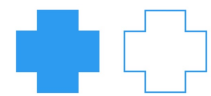






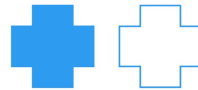






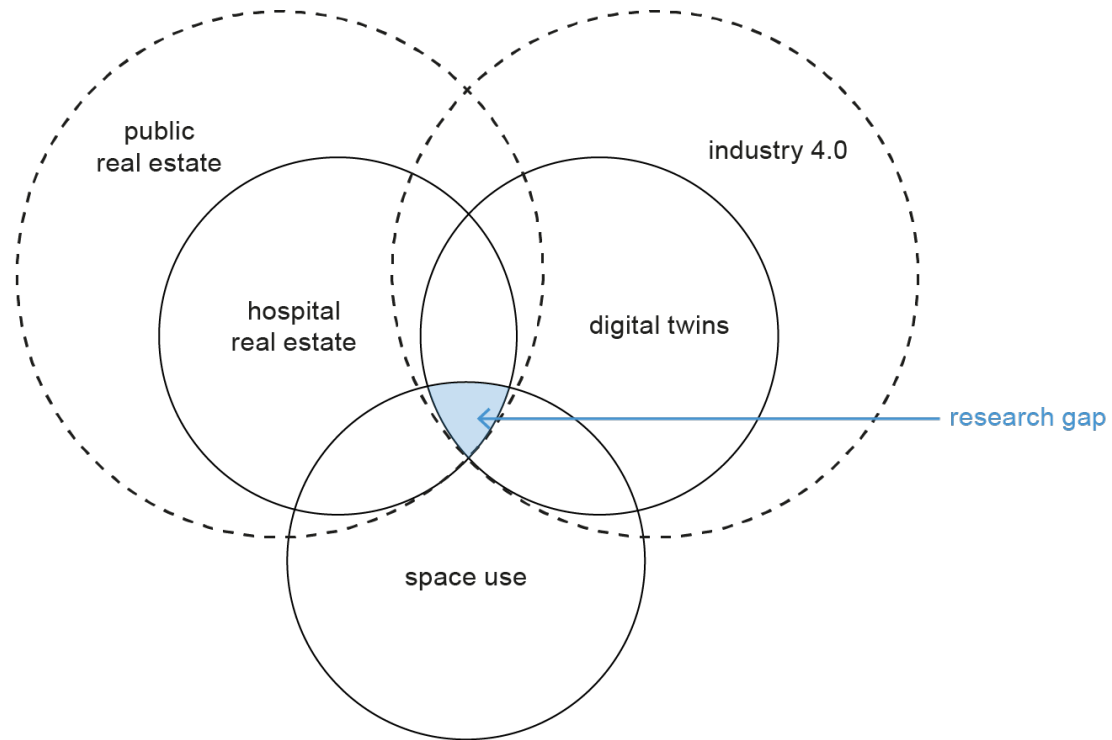
Towards digital twins for space use in hospital real estate

The Erasmus Medical Center as a case study
for the identification of the specifications of a digital twin for space use,
aiming to support decision makers and users of hospital real estate.

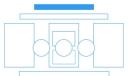
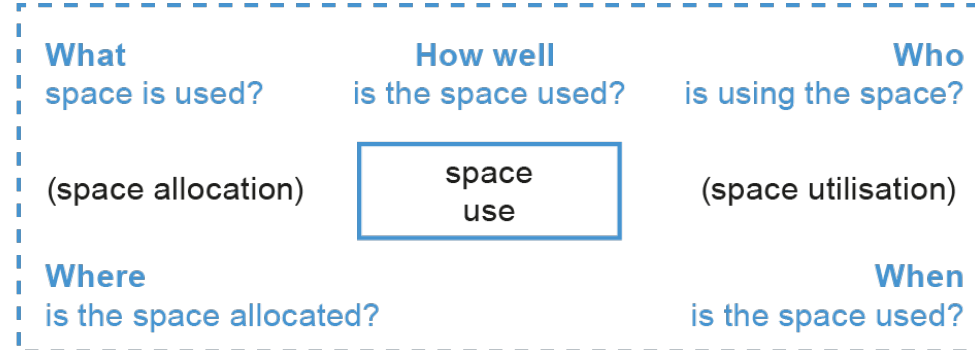


Zisis Vomvas - P5 August 2022

digital twins space use hospital real estate



space use



hospital real estate

hospital + healthcare

real estate management + facility management



Main research question

"How can a digital twin for space use support decision makers and users of hospital real estate"

Research subquestion 1

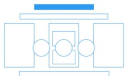
"What design and utilisation principles related to digital twins for space use in hospital real estate management can be extracted from the current academic literature?"

Research subquestion 2

"What design and utilisation principles related to digital twins for space use in hospital real estate management can be extracted from a hospital case study?"

Research subquestion 3

"How can users interact with the information of a digital twin for space use in hospital real estate?"



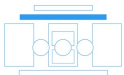
[MRQ]
*"How can a digital twin for space use support
decision makers and users of hospital real estate?"*

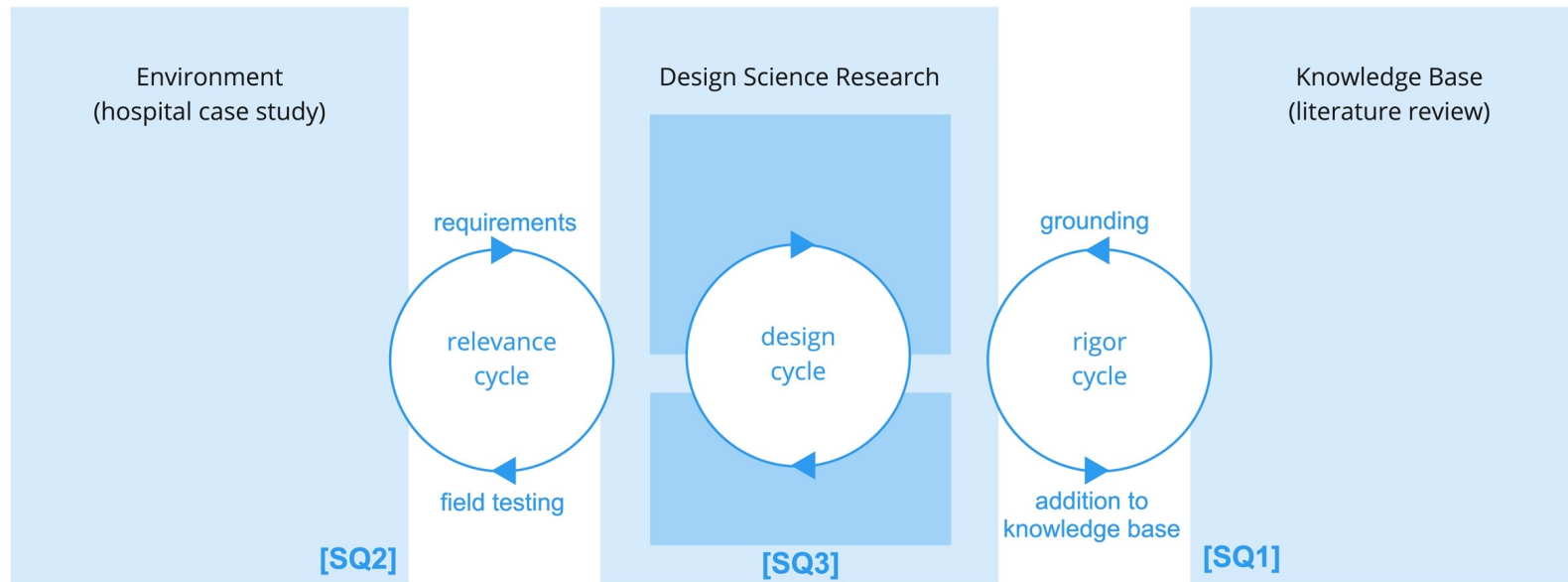
[SQ3]
*"How can users interact with the information
of a digital twin for space use in hospital real estate?"*

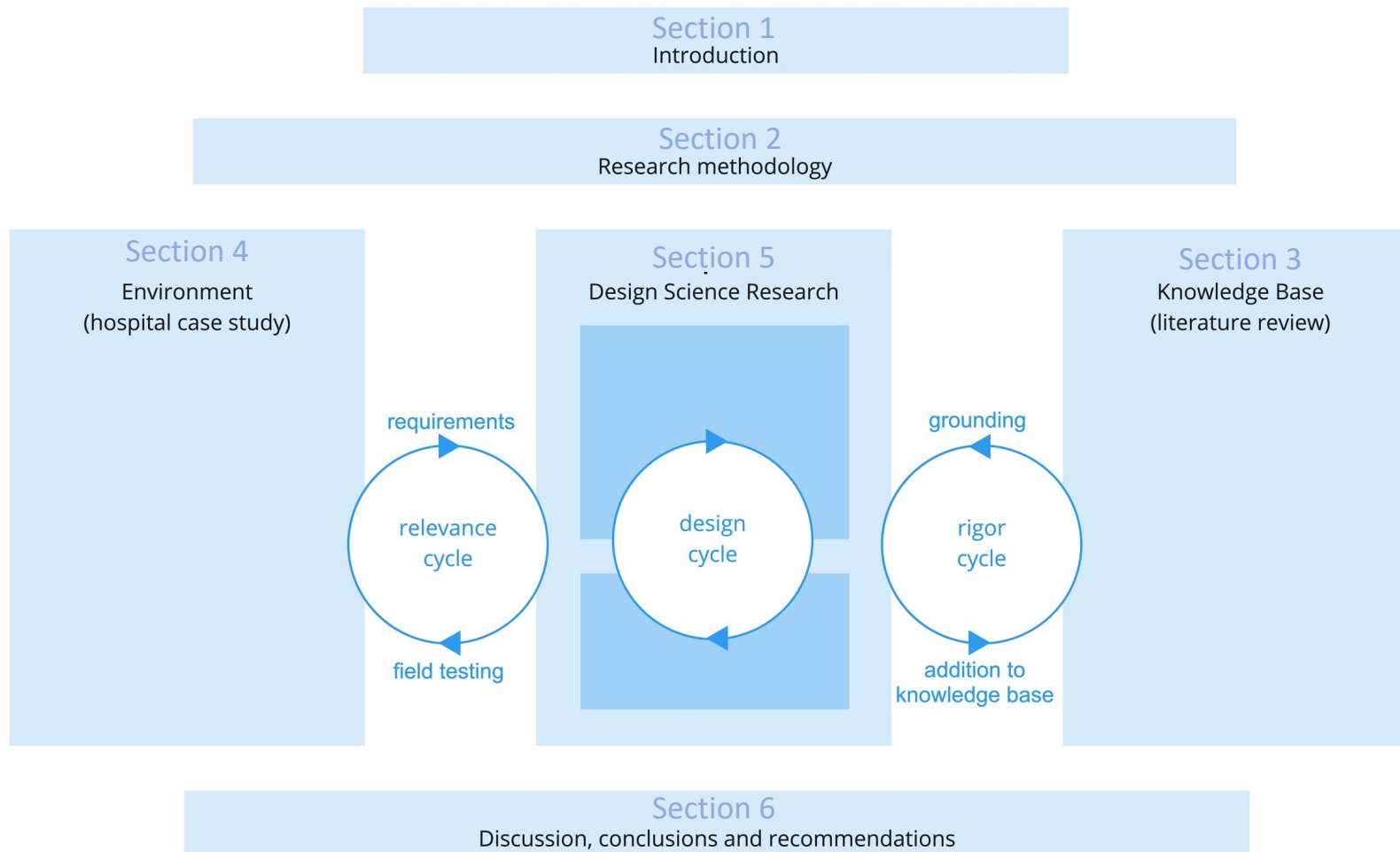
digital twins
for space use
in hospital real estate

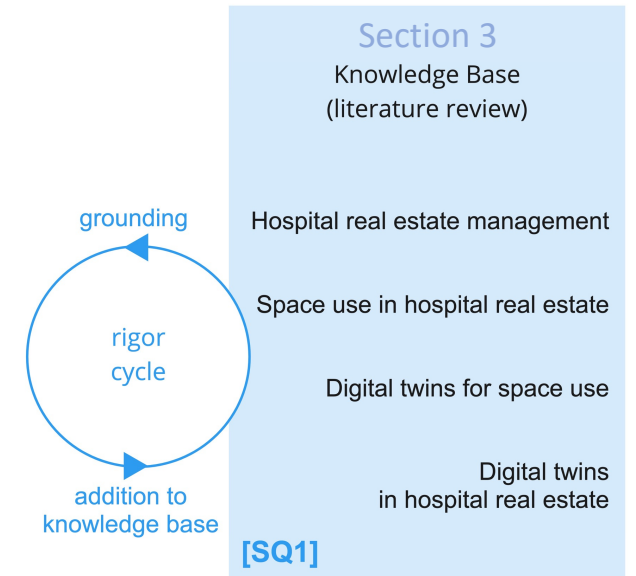
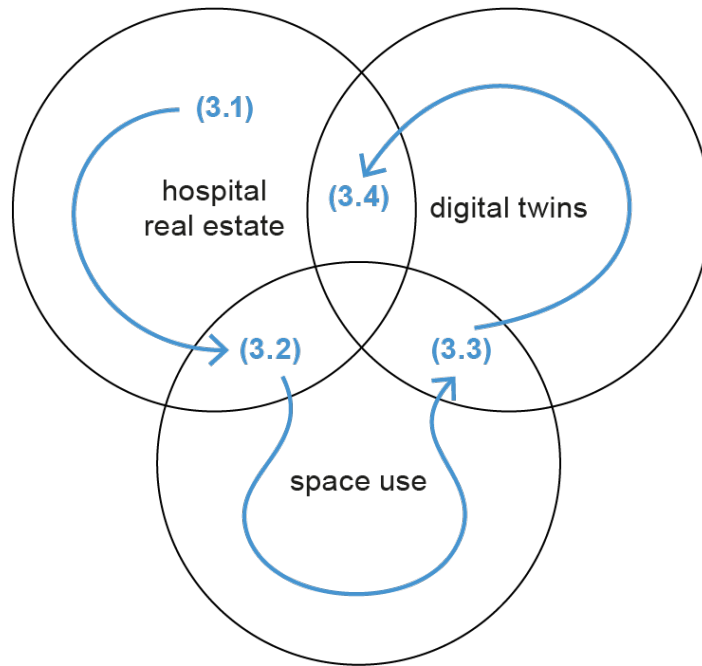
[SQ2]
*"What design and utilisation principles
related to digital twins for space use in hospital real estate management
can be extracted from a hospital case study?"*

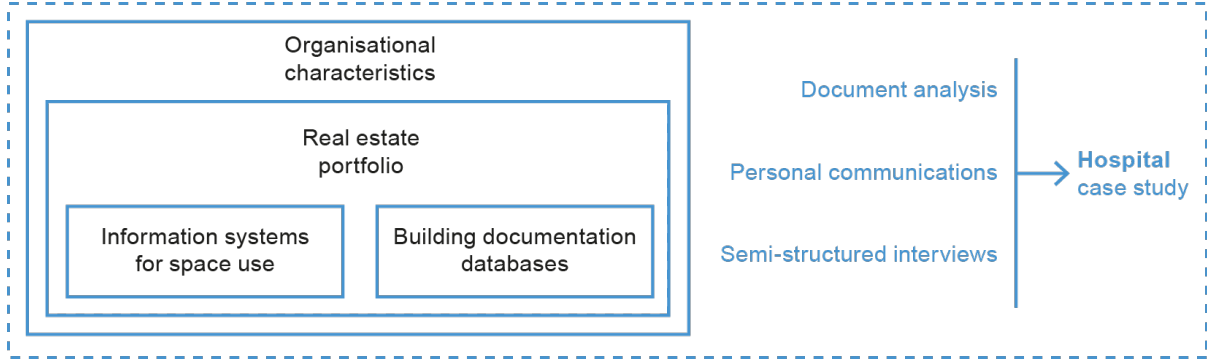
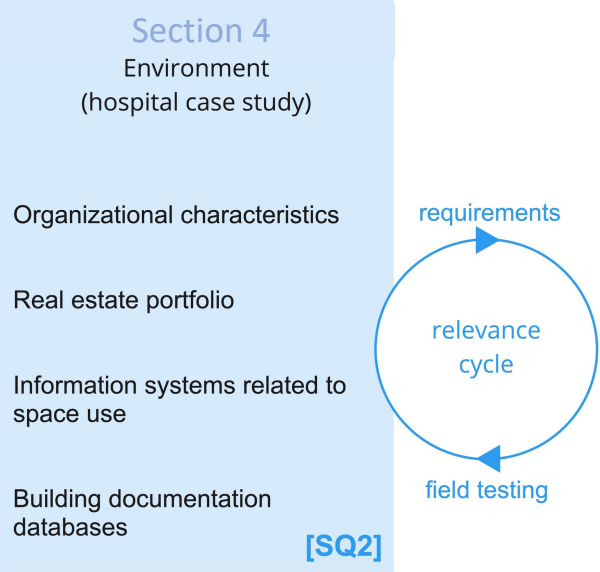
[SQ1]
*"What design and utilisation principles
related to digital twins for space use in hospital real estate management
can be extracted from the current academic literature?"*

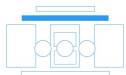
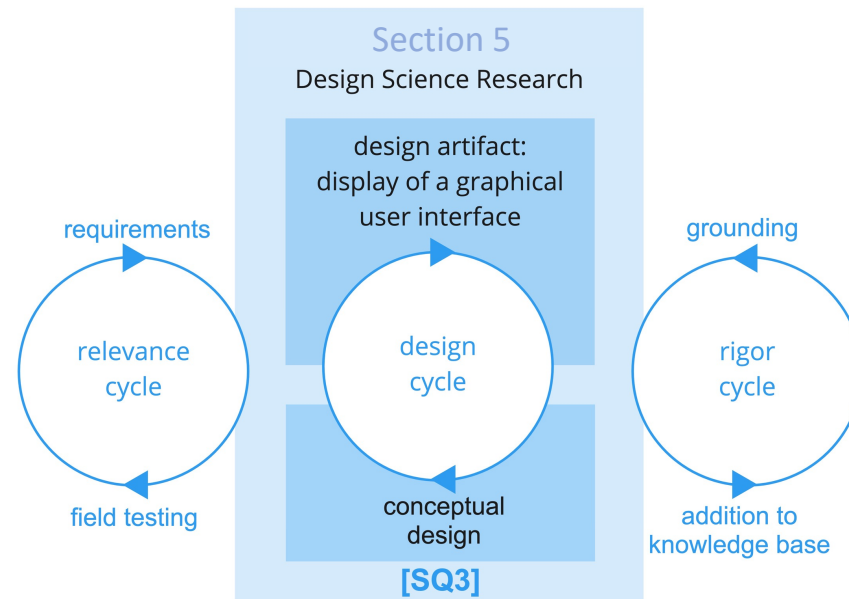
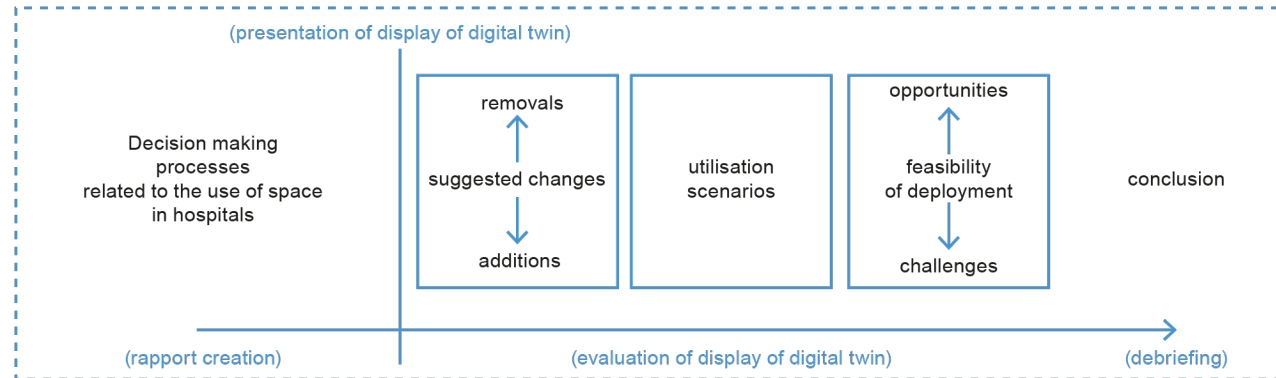












Research subquestion 1

"What design and utilisation principles
related to digital twins
for space use
in hospital real estate management
can be extracted
from the current academic literature?"

digital twins
for space use
in hospital real estate

design and utilisation principles from the current academic literature

Research subquestion 1

"What design and utilisation principles
related to digital twins
for space use
in hospital real estate management
can be extracted
from the current academic literature?"

- 1.1
Data from primary processes
as information about the real estate performance
- 1.2
Information between
adequate (minimum) and controllable (maximum).
- 1.3
Key Performance Indicators
in four real estate perspectives.
- 1.4
Activities
in a strategic, tactical and operational level.
- 1.5
Information about the space norms,
management and utilisation.
- 1.6
Information in temporal, occupant
and spatial resolution.
- 1.7
Combine building visualisation
and performance data.
- 1.8
Use of tabs to manage visual information.



Research subquestion 2

"What design and utilisation principles related to digital twins for space use in hospital real estate management can be extracted from a hospital case study?"

digital twins
for space use
in hospital real estate

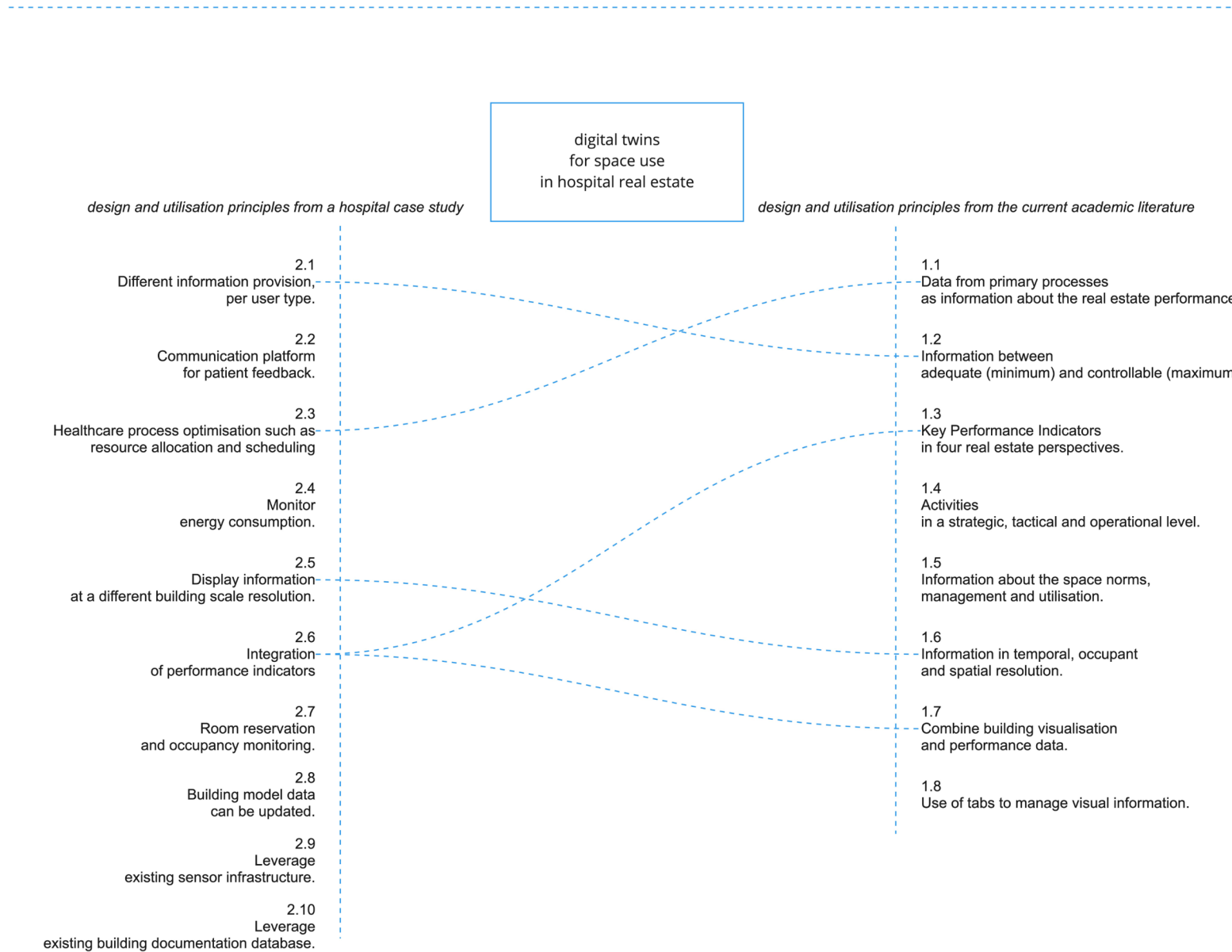
design and utilisation principles from a hospital case study

- 2.1 Different information provision, per user type.
- 2.2 Communication platform for patient feedback.
- 2.3 Healthcare process optimisation such as resource allocation and scheduling
- 2.4 Monitor energy consumption.
- 2.5 Display information at a different building scale resolution.
- 2.6 Integration of performance indicators
- 2.7 Room reservation and occupancy monitoring.
- 2.8 Building model data can be updated.
- 2.9 Leverage existing sensor infrastructure.
- 2.10 Leverage existing building documentation database.

Research subquestion 2

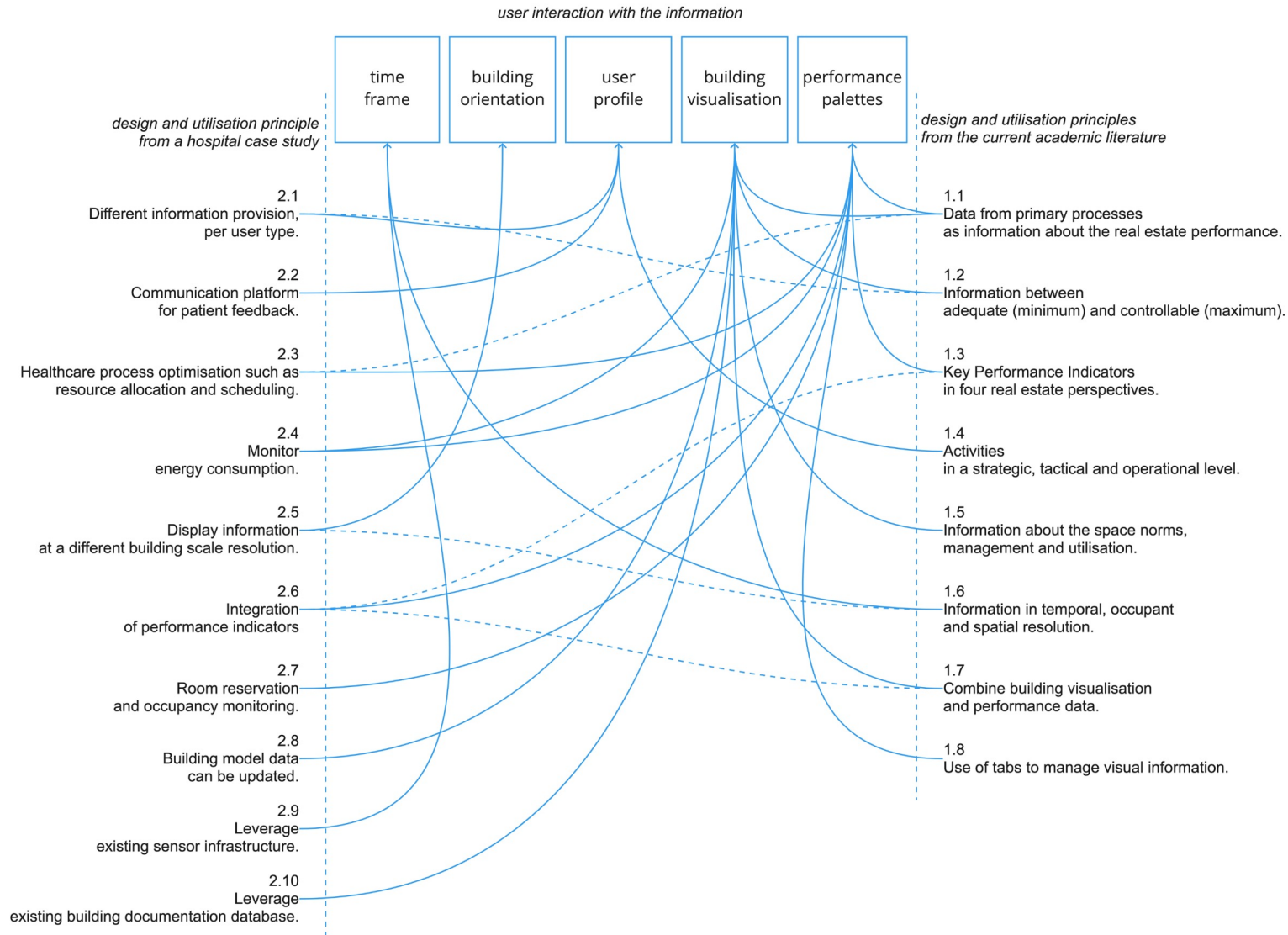
"What design and utilisation principles related to digital twins for space use in hospital real estate management can be extracted from a hospital case study?"

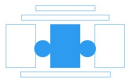


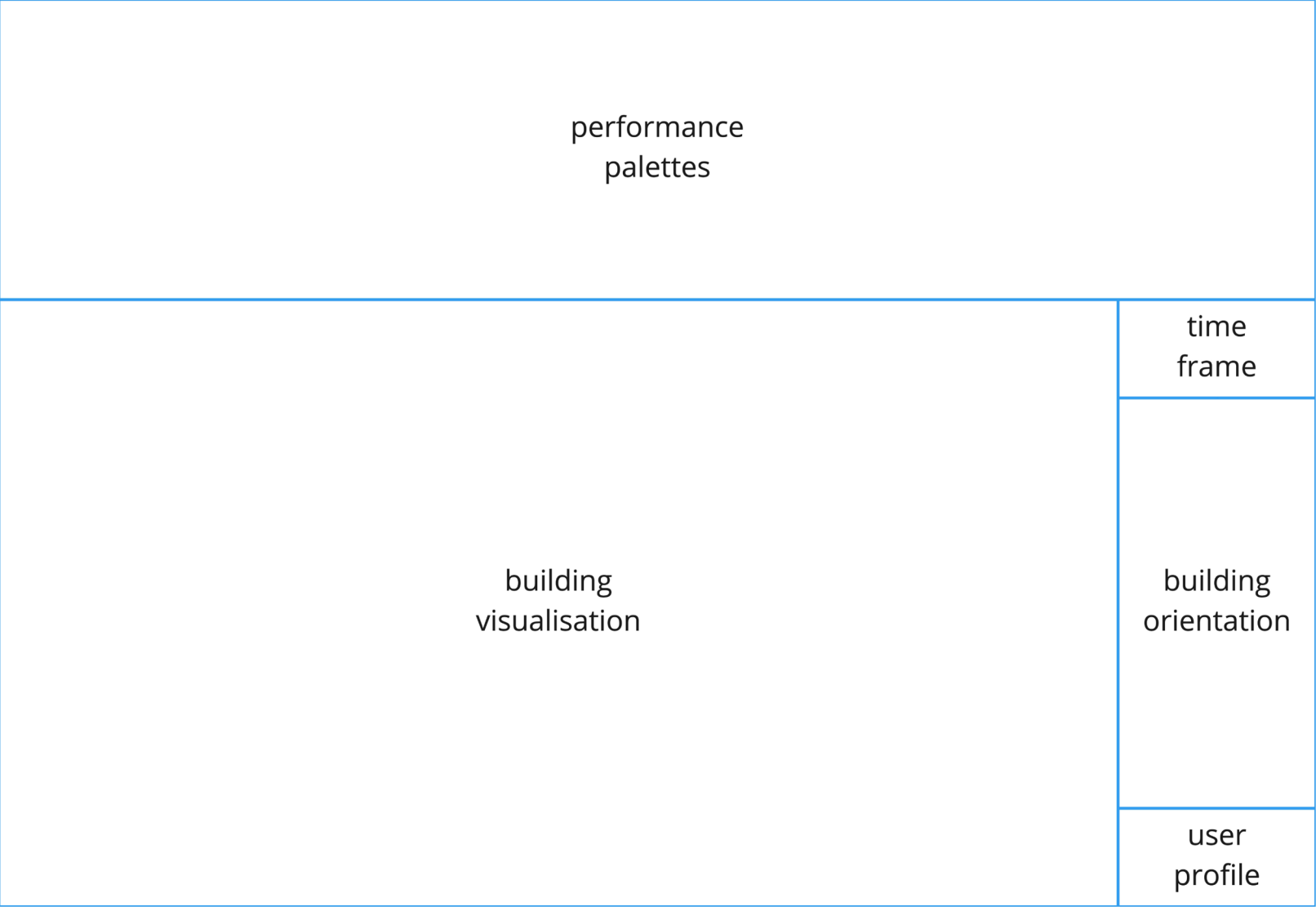


"How can users interact with the information of a digital twin for space use in hospital real estate?"

"How can users interact with the information of a digital twin for space use in hospital real estate?"







time frame window

current

day

month

quarter

year

simulation

time frame:
current



building orientation window

scale

campus

building

floor

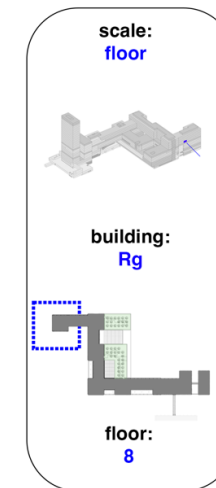
room

building

(building name)

floor

(floor name)



user profile window

name

(user name)

user profile type

decision maker

support staff

medical professional

patient

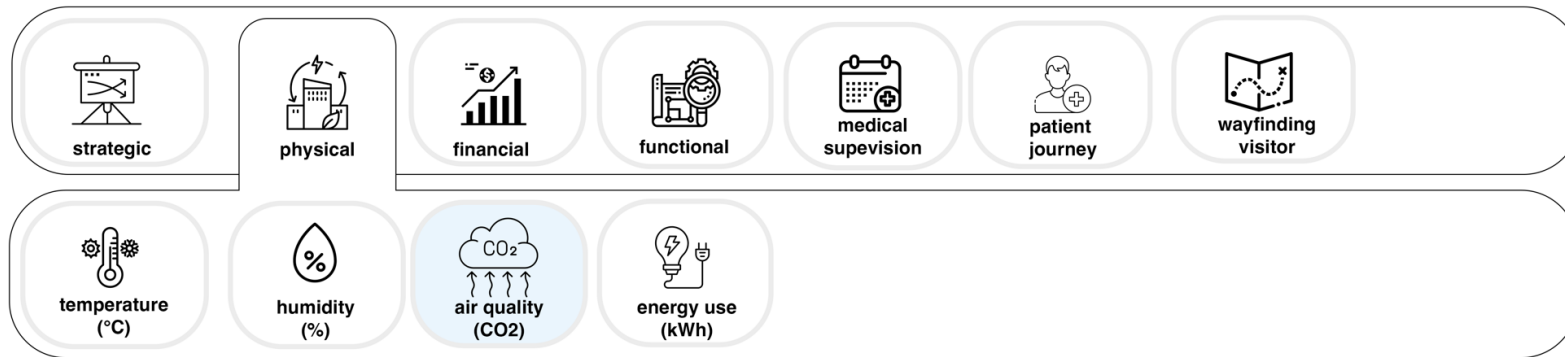
visitor

name:
XX (guest)
user profile:
decision maker



building visualisation window





performance palettes window

strategic

physical

financial

functional

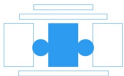
medical supervision

patient journey

wayfinding visitor



"It feels intuitively right"
(A5., 2021)



"It feels intuitively right"
(A5., 2021)

+/-modifications



utilisation scenarios	REM perspective	time frame	building scale resolution	management level focus
Wayfinding (patient, visitor, logistics).	functional	future	floor	operational
Information whether special care is needed for a specific room.	functional	present	floor	operational
Information on current use of a space.	functional	present	campus-floor	operational
Information about the cleanliness of a room.	physical	present	floor	operational
Patient monitoring.	functional	present	floor-room	operational
Environment control (light, heat, ventilation) from inpatient rooms.	physical	present	room	operational
Space allocation (especially in bed capacity).	strategic	past	campus-room	tactical/strategic
Retrieve technical drawings by clicking on a specific room.	physical	past	campus-room	operational
Provide notifications in case a space use is relocated to another place.	strategic/physical	present	campus-floor	tactical
Information about utilisation and occupancy rates.	strategic	past	campus-floor	tactical/strategic
Analysing potential patient journeys.	functional	future	floor-campus	strategic
Medical room scheduling (such as operation rooms).	functional	future	room	operational
Forecast the use of space (capacity management) in relationship to medical data	strategic/functional	future	room	tactical/strategic



"One question one should always ask with tools like this is: is it really worth all the investment? What added value will it create?" (A3, 2021).

opportunities

- An integration of systems could add value to the tool.
- Many improvements in operational level.
- Artificial intelligence operations can predict certain performances
- By using more input from the users of the buildings and the patients, the quality can be improved.

challenges

- Privacy related issues.
- Some types of available data may not be or rarely be used by some professionals, thus overburdening them with information.
- Some information may not be reliable
- Some information systems by some companies are not easy to interconnect.
- Financially related data are difficult to become available to most users.

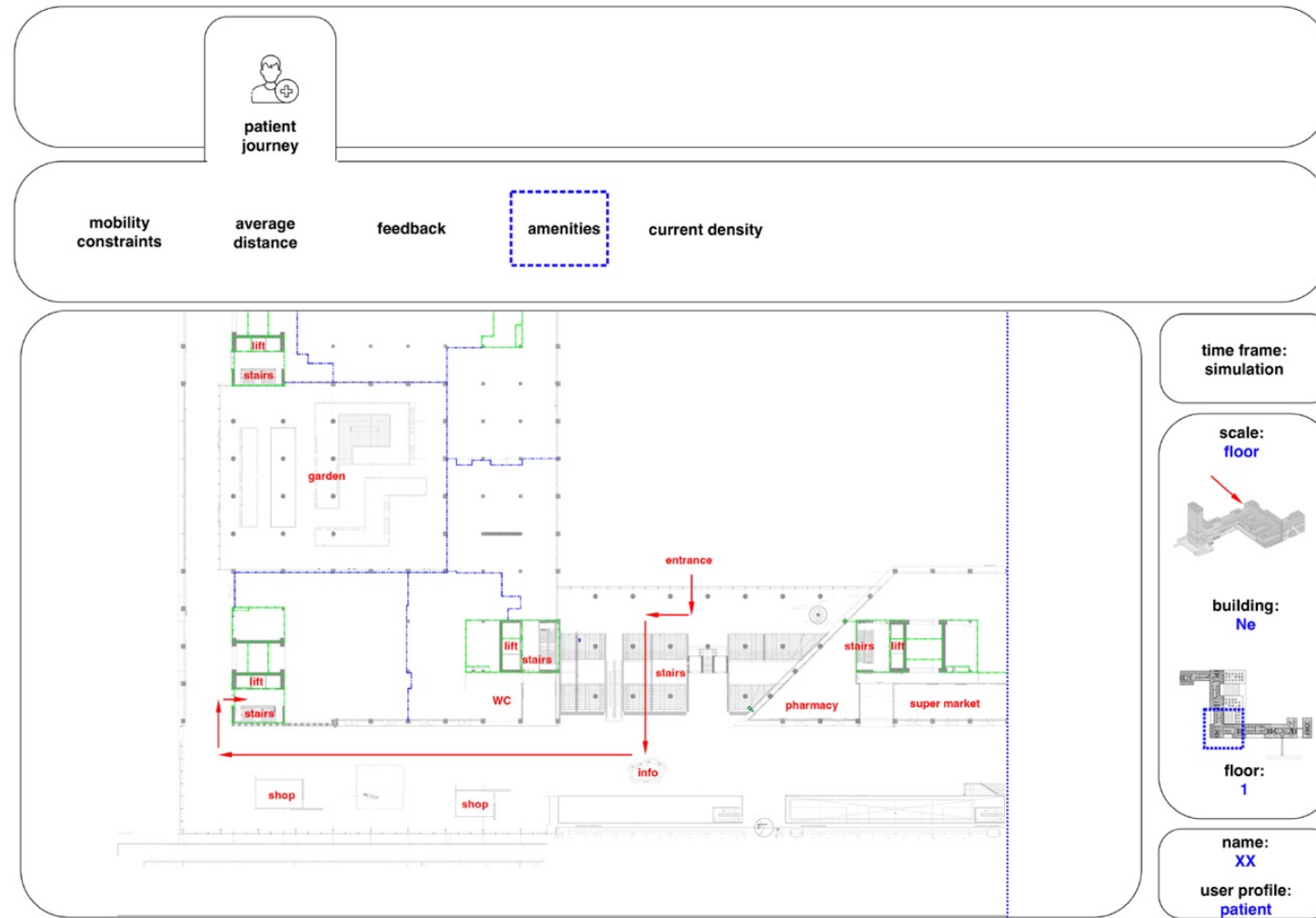


conclusion

A digital twin can be used by different **stakeholder** perspectives, by providing historical, real **time** or simulation information at a room, floor, building or campus **scale resolution** to support operational, tactical and strategic **utilisation processes**.



further design iterations



Recommendations for practice

Facilitate cross-organisation collaboration to reduce the silo effect in data sharing.

Develop information system infrastructure with integration in mind.

Streamline building documentation digitalisation process.

Involve both decision makers and users in tool development.

Acknowledge potential security issues and act upon any privacy concerns.



Recommendations for future research

Comparative research that would involve more hospital case studies.

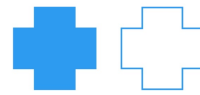
Similar research on other types of real estate.

Analysis of the perspective of the supply side in the development of such a tool.

Assess the impact of such tools in the future.

Focus on the analysis a different layer of the system architecture of a digital twin, for example the data acquisition layer.

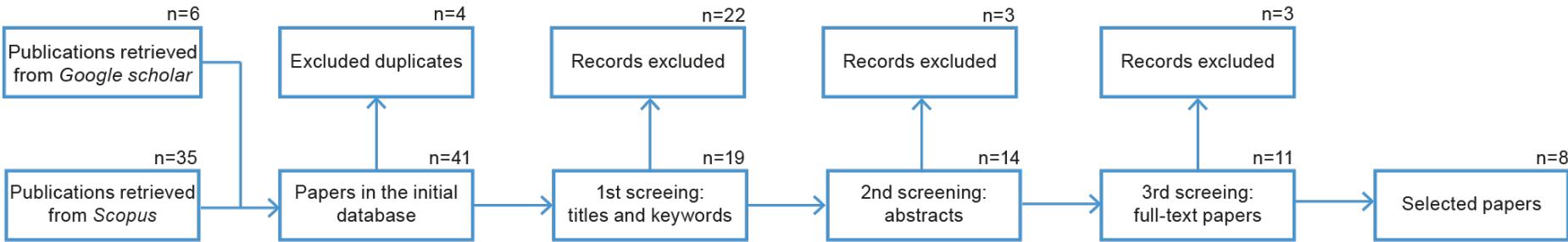




?

Systematic literature approach

Search query (for search on Scopus)	Scopus (09/06/2022)	Google scholar (09/06/2022)
(TITLE-ABS-KEY (hospital OR "healthcare real estate" OR "healthcare building*" OR "healthcare facilit*" OR "healthcare propert*") AND TITLE-ABS-KEY ("space use" OR "space planning" OR "space management" OR "space utilisation" OR "space allocation") AND TITLE-ABS-KEY ("digital twin*"))	1	4
(TITLE-ABS-KEY (hospital OR "healthcare real estate" OR "healthcare building*" OR "healthcare facilit*" OR "healthcare propert*") AND TITLE-ABS-KEY ("digital twin*"))	35	6



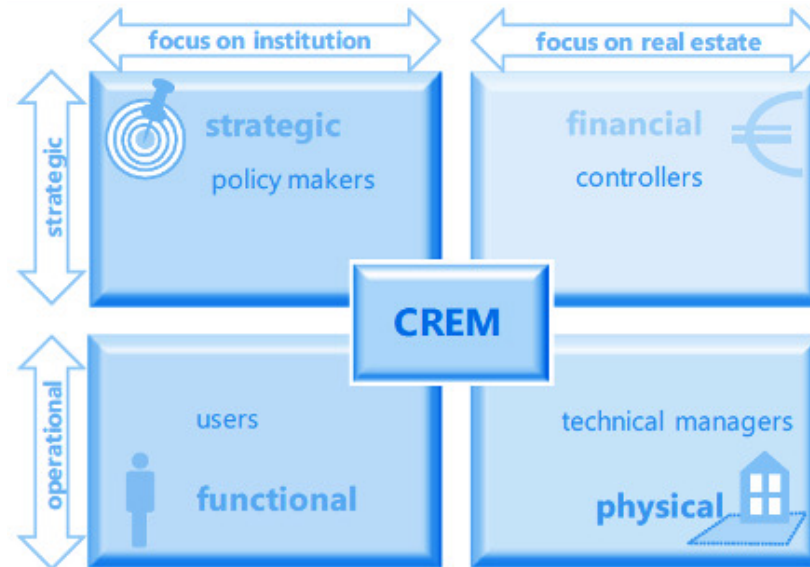
Environment interviews

Id	Interviewee role	EMC Department	Perspective	In-text citation
E.1	Healthcare real estate development consultant	PIB	strategic & physical	(E.1, 2021)
E.2	Technical manager	PIB	physical	(E.2, 2021)
E.3	Healthcare real estate consultant	PIB	strategic & physical	(E.3, 2021)
E.4	Healthcare real estate manager	PIB	physical	(E.4, 2021)
E.5	Technical consultants	PIB	physical	(E.5, 2021)
E.6	Facility management and procurement director	Procurement & Facility management (Service company)	financial & physical	(E.6, 2021)
E.7	Security professional	Procurement & Facility management (Service company)	functional & physical	(E.7, 2021)
E.8	BIM manager	PIB	physical	(E.8, 2021)
E.9	Energy consultant	PIB	physical	(E.9, 2021)
E.10	Healthcare business intelligence consultant	Data & Analytics (Service company)	strategic & functional	(E.10, 2021)

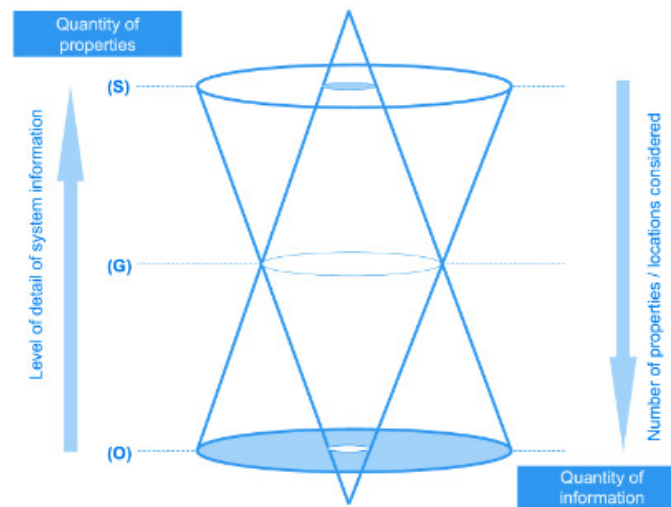
Evaluation interviews

Id	Interviewee role	EMC Department	Perspective	In-text citation
A.1	Healthcare real estate information manager	PIB	physical	(A.1, 2021)
A.2	Medical professional	Thema Daniel	functional	(A.2, 2021)
A.3	Healthcare real estate development consultant	PIB	strategic & physical	(A.3, 2021)
A.4	Technical consultant	PIB	physical	(A.4, 2021)
A.5	Healthcare business intelligence consultant	Data & Analytics (Service company)	strategic & functional	(A.5, 2021)
A.6	Healthcare real estate policy consultant	PIB	strategic & physical	(A.6, 2021)
A.7	Healthcare real estate policy advisor - sector manager	PIB	financial & physical	(A.7, 2021)
A.8	Healthcare facility project manager	Procurement & Facility management (Service company)	physical	(A.8, 2021)
B.1	Medical professional	Thema Daniel	functional	(B.1, 2022)

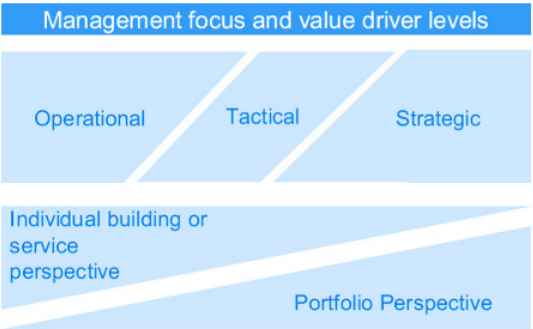
Four stakeholder perspectives



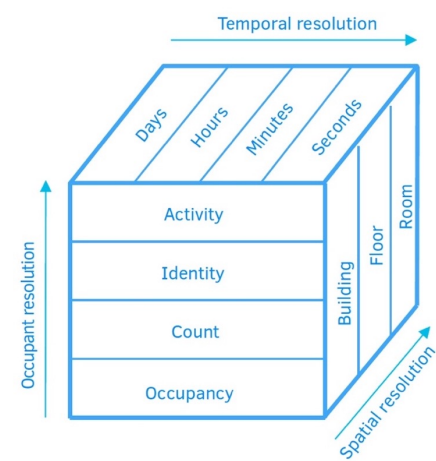
Proposed modifications of the display



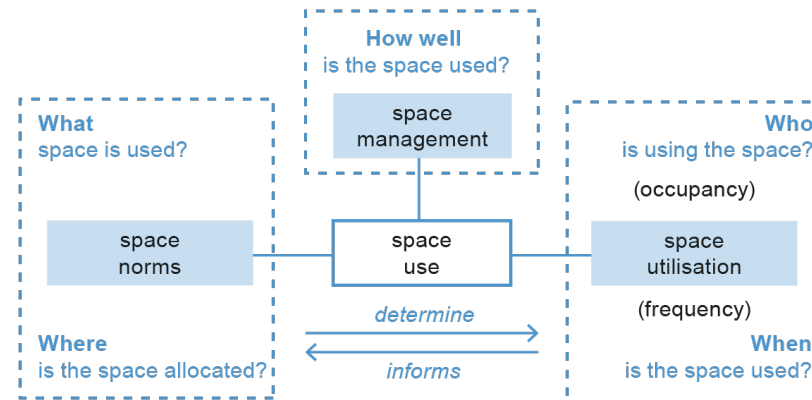
Management focus



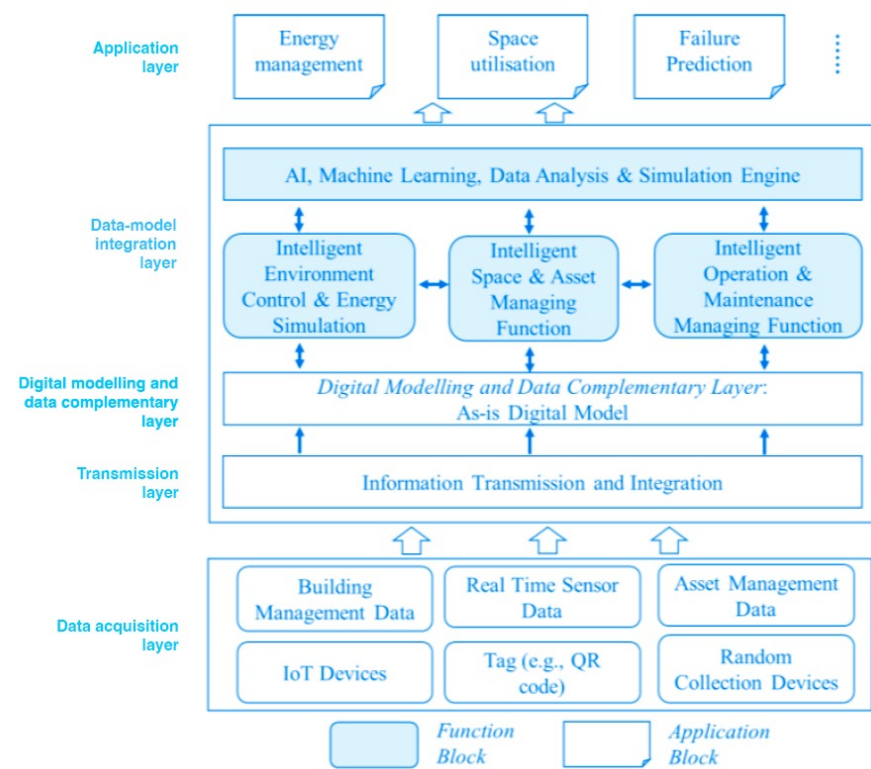
Monitoring resolution



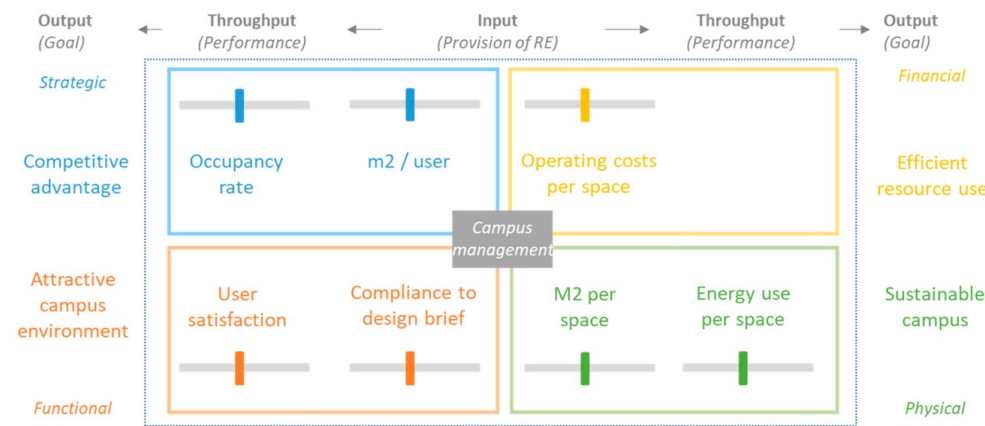
Scope of space use



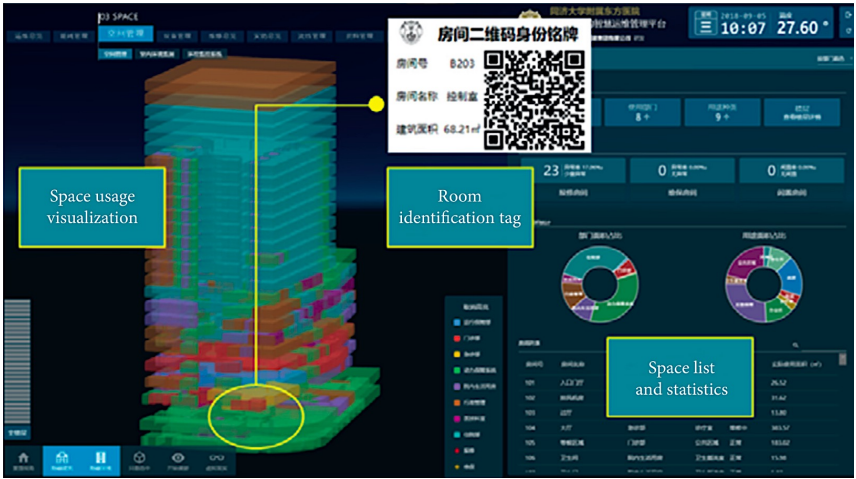
Digital twin system architecture



Conceptual design of a dashboard



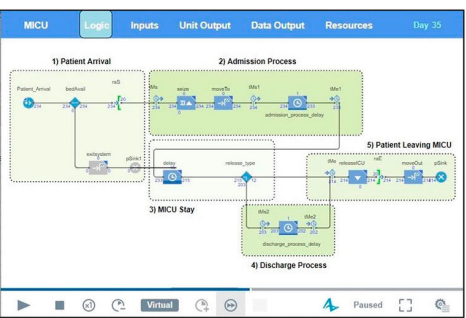
Displays of digital twins



a)



b)



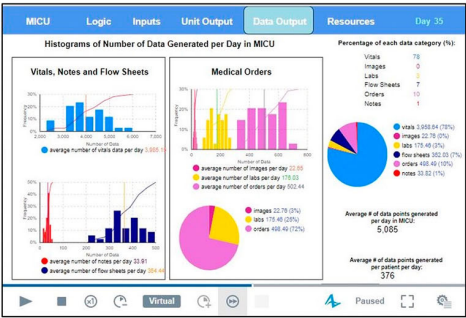
c)



d)



e)



f)



Data catalogue

ID	data	input sensor	type of sensing information	managed by	owned by	related to which building(s)	related to which people	stored at(in)	EMC department	information provided by	data input image	data output image
DC_1	Motion detector	PIR sensors	explicit	EMC/PIB	EMC	Na - Nt, recently renovated buildings or floors and operating theatres.	All users of the spaces	No storage	PIB	(PC.2, 2021)	DC_1_IN_A, DC_1_IN_B, DC_1_IN_C	-
DC_2	Air quality (CO2)	Elsys sensors	implicit	EMC/PIB	EMC	Na - Nt, recently renovated buildings or floors and operating theatres. In the larger rooms of the education center.	All users of the spaces	Cloud	PIB	(PC.2, 2021)	DC_2_IN	-
DC_3	Desk occupancy	PC-login	explicit	EMC/PIB	EMC, supported by Flexwhere	Na, Nc, Nd, Ne, Nf, Ng, Ns, Nt, Rg and Gk	All users of desks	SAAS	PIB	(PC.3, 2021)	-	DC_3_OUT_A, DC_3_OUT_B
DC_4	Lift movements	PC-login	implicit	EMC/PIB	KONE	Na t/m Rg & Ee	Administrator /PIB/ elevator mechanic	PC in Elevator machine room Nc E-Link Liftmanagement system	PIB	(PC.4, 2021)	-	DC_4_OUT_A, DC_4_OUT_B
DC_5	Room reservation sleeping	No sensor	-	Servicedesk	EMC	Ca	EMC employees	service portal	Procurement & Facility Management	(PC.5, 2021)	-	-
DC_6	Room reservation meeting	No sensor	-	Servicedesk	EMC	65 meeting rooms that are located across all EMC buildings	EMC users who have booking rights of rooms.	Outlook Exchange	Procurement & Facility Management	(PC.5, 2021)	-	DC_6_OUT
DC_7	Coffee machine utilisation data	Only coffee supplier has access	implicit	Coffee machine supplier (provision of the data to the EMC in a quarterly update)	Coffee machine supplier	All buildings of EMC	All users of EMC	Only coffee supplier has access	Procurement & Facility Management	(PC.6, 2021)	DC_7_IN	DC_7_OUT_A, DC_7_OUT_B
DC_8	Vending machine utilisation data	Only vending supplier has access	implicit	Vending machine supplier	Vending machine supplier	All buildings of EMC	All users of EMC	Only vending supplier has access	Procurement & Facility Management	(PC.6, 2021)	DC_8_IN	-
DC_9	Badget system for access	Card reader (EAL ATS)	implicit	Access management department	EMC	All buildings of EMC	Cardholders of EMC.	Afas/Oracle EBS	Procurement & Facility Management	(PC.7, 2021)	DC_9_IN	-
DC_10	Security cameras	Video cameras	implicit	Access management department	EMC	All buildings of EMC	All users of EMC	Griffid	Procurement & Facility Management	(PC.7, 2021)	DC_10_IN	-
DC_11	Parking utilisation light detector	PIR sensors	explicit	Access management department	EMC	Parking garages (Wytemaweg and Westzeedijk)	All users of EMC with parking access	No storage	Procurement & Facility Management	(PC.7, 2021)	-	DC_11_OUT
DC_12	Parking utilisation data A	Card reader (EAL ATS)	explicit	Access management department	EMC	Parking garages (Wytemaweg and Westzeedijk)	Cardholders of EMC with parking access.	EAL ATS (for employees) and Skidata (for temporarily parkers: they are transferred daily at spreadsheets) In the future employees will also be at the Skidata.	Procurement & Facility Management	(PC.7, 2021)	-	DC_12_OUT_A, DC_12_OUT_B
DC_13	Parking utilisation data B	Card reader (EAL ATS)	explicit	Municipality of Rotterdam (does not provide data to the EMC). They use their own parking managemnt system.	Municipality of Rotterdam (does not provide data to the EMC, for safety reasons).	Garage Museumpark	Cardholders of EMC with car access.	EAL ATS	Procurement & Facility Management	(PC.7, 2021)	-	-
DC_14	PC login with cards	Card reader	implicit	EMC/Informatie & Technologie (ICT services)	EMC	All buildings of EMC, however not all computers have the [C login card system	Users of the computers who have a card (usually the healthcare stuff).	(no information)	Procurement & Facility Management	(PC.7, 2021)	-	-
DC_15	Textile use data	Card reader (EAL ATS)	implicit	Textile deptament	EMC	Nd and Ca	Cardholders of EMC.	(no information)	Procurement & Facility Management	(PC.7, 2021)	-	-
DC_16	Copy machine use data (multifunctionals)	Card reader	implicit	ICT	EMC	All buildings of EMC	Cardholders of EMC.	(no information)	Procurement & Facility Management	(PC.7, 2021)	DC_16_IN	-
DC_17	Locker access data	Card reader (EAL ATS)	implicit	Servicedesk	EMC	All buildings of EMC	Cardholders of EMC.	Oracle identity management ABS	Procurement & Facility Management	(PC.8, 2021)	DC_17_IN	-
DC_18	Pneumatic Tube System (eg for blood samples)	Card reader (EAL ATS)	implicit	EMC/Delivery Manager	Swisslog	Rg, Nt, Nf, Ns, Ne, Nd, Nc, Nb, Na, Eg, Dp, Ca, Ba, Bd, Ad, Be, S (buildings)	Cardholders of EMC (after following a training about the PTS)	EMC servers	PIB	(PC.9, 2021)	-	-

Building documentation databases

ID	building	software	file type	type of documentation	comments
BD_1	all EMC buildings	Planon	spreadsheet type of database	all building systems (eg architectural and mechanic)	The most up-to-date database regarding building information. Most of the information has been entered manually. It is continuously being revised but they update it immediately, whenever a change is made.
BD_2	all EMC buildings	AutoCAD	2D CAD drawings	all building systems (eg architectural and mechanic)	They are separated per building and not connected so that they can be managed more efficiently.
BD_3	Na-Ng	AutoCAD	3D CAD drawings	only architectural	They were provided by the architect. They don't have a complete BIM model from the new hospital. When the contract was made (mid 2000) the BIM technology was not developed so much yet.
BD_4	Ca	Revit	BIM	all building systems (eg architectural and mechanic)	Every type of system, including architectural and mechanic.
BD_5	Fd, Fe, Ee, Cd, Ce, Ec (medical faculty)	Revit	BIM	only architectural	They were made to be used as input for the renovations. The architect has already started working with them.
BD_6	Sb, Sh, Sp, Sk, Bb, Kp (Sophia hospital for children and children psychiatry)	Revit	BIM	only architectural	They were made to be used as input for the renovations. A small part also has mechanical and structural parts.
BD_7	Ad	Revit	BIM	architectural, electrical, plumbing	-
BD_8	Underground tunnel (runs through all the buildings)	Revit	BIM	all building systems (eg architectural and mechanic)	Was made with a point cloud scanner and is documented with .ifc information
BD_9	Ventilation system at the rooftop of Eg (library)	Revit	BIM	mechanical	Were provided by the manufacturers.
BD_10	Elevators of Ee	Revit	BIM	mechanical	Were provided by the manufacturers.

Knowledge base findings

ID	Knowledge base findings	Design and utilisation principles	System architecture	Section
1.1	"data from the primary processes of an organisation can be transformed to information about the performance of the real estate resources which in turn can be used for further decision making."	A digital twin can use data from primary processes as information about the real estate performance .	Data-model integration layer	3.1.3
1.2	"when the number of properties that are considered increases, the level of detail of the information system has to decrease in order to provide an operational amount of big quantity of information"	The amount of displayed information should be adjusted between adequate (minimum) and controllable (maximum) according to the level of influence of the potential decision that can be assisted.	Data-model integration layer	3.1.3
1.3	"Most of the dominions of the KPIs that were identified can be associated directly with a stakeholder perspective."	A set of KPIs can be introduced and grouped in the four real estate perspectives , determining potential choices of display of information for the users of the tool.	Data-model integration layer	3.1.4
1.4	"corporate real estate management aims for value creation through the administration of real estate resources with activities at a strategic, tactical and operational level."	A digital twin can be used to facilitate activities in a strategic, tactical and operational level .	application layer	3.1.5
1.5	"the interrelationship of space norms, management and utilisation and the feedback loop of determination and information can be transcribed to space use in hospital real estate management".	The design of a tool for space use in hospitals can provide information about the space norms, management and utilisation of the building resources .	Data-model integration layer	3.2.1
1.6	"an information system for space use can be designed to display information in temporal, occupant and spatial resolution."	A digital twin for space use can be designed to display information in temporal, occupant and spatial resolution .	Data-model integration layer	3.2.4
1.7	"when designing a digital twin, data of the performance of the building spaces and a digital model of the building are integrated in a display in order to become operational by the user of the tool"	By combining building visualisation and performance data , the display of the user interface is more comprehensive for the user of the twin	Data-model integration layer	3.3.7 3.4.2
1.8	The displays of the previous three digital twins used tabs to organise the information and make it more perational for the user.	Use tabs to toggle between different information options .	data-model integration layer	3.4.1

Environment findings

ID	Environment findings	Design and utilisation principles	System architecture	Section
2.1	The structure of the organigram for the allocation of staff is an indication of the high organisational complexity of the EMC.	A design that will lead to different information provision, per user type .	Application layer	4.1.2
2.2	The feedback of the patients is deemed crucial and, therefore, implemented for continuous improvement of the healthcare services.	The digital twin can be used as a communication platform whereby the patients can provide feedback on their experience of the use of space	Application layer	4.1.3
2.3	The organisation aspires to enhance the healthcare provision process through the deployment of innovative technologies.	The digital twin can be used as a tool for healthcare process optimisation such as resource allocation and scheduling .	Application layer	4.1.3
2.4	Controlling energy consumption is essential in order to pursue the organisation's sustainability objectives.	A digital twin that can be used to monitor energy consumption .	Application layer	4.1.4
2.5	The several functions of the organization are accommodated in a similarly diverse and complex range of buildings.	A digital twin that can display information at a different building scale resolution .	Data-model integration layer	4.2.1
2.6	In order to manage this real estate portfolio, the real estate decision makers use performance indicators	Integration of performance indicators in the design of the digital twin.	Data-model integration layer	4.2.1
2.7	Information systems such as room reservation and occupancy monitoring are deployed by the organisation.	The digital twin can be used for room reservation and occupancy monitoring .	Application layer	4.2.1
2.8	The real estate portfolio will become even bigger and accommodate even more functionalities.	The utilised building model data can be updated when changes occur in the physical spaces.	Digital modelling and data complementary layer	4.2.2
2.9	Existing infrastructure of sensors.	The existing infrastructure of sensors can be leveraged by the digital twin.	Data acquisition layer	4.3
2.10	Existing building documentation dataset.	The existing building documentation dataset can be leveraged by the digital twin.	Digital modelling and data complementary layer	4.4

Principle association

ID	Design and utilisation principles	time frame window	building orientation window	user profile window	building visualisation window	performance palettes window
1.1	Data from primary processes as information about the real estate performance.	-	-	indirect relationship	direct relationship	direct relationship
1.2	Information between adequate (minimum) and controllable (maximum).	indirect relationship	indirect relationship	-	direct relationship	-
1.3	Key Performance Indicators in four real estate perspectives.	-	-	indirect relationship	indirect relationship	direct relationship
1.4	Activities in a strategic, tactical and operational level.	-	-	direct relationship	indirect relationship	indirect relationship
1.5	Information about the space norms, management and utilisation.	-	-	-	direct relationship	indirect relationship
1.6	Information in temporal, occupant and spatial resolution.	direct relationship	direct relationship	-	indirect relationship	-
1.7	Combine building visualisation and performance data.	-	-	-	direct relationship	-
1.8	Use tabs to toggle between different options.	-	-	-	-	direct relationship
2.1	Different information provision, per user type.	-	-	direct relationship	indirect relationship	indirect relationship
2.2	Communication platform for patient feedback.	-	-	direct relationship	-	indirect relationship
2.3	Healthcare process optimisation such as resource allocation and scheduling.	indirect relationship	-	indirect relationship	-	direct relationship
2.4	Monitor energy consumption.	-	indirect relationship	-	direct relationship	direct relationship
2.5	Display information at a different building scale resolution.	-	direct relationship	-	indirect relationship	-
2.6	Integration of performance indicators	-	-	-	-	direct relationship
2.7	Room reservation and occupancy monitoring.	-	-	indirect relationship	indirect relationship	direct relationship
2.8	Building model data can be updated.	-	indirect relationship	-	direct relationship	-
2.9	Leverage existing sensor infrastructure.	direct relationship	-	-	indirect relationship	indirect relationship
2.10	Leverage existing building documentation database.	-	indirect relationship	-	direct relationship	-

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Proposed modifications of the display

- +More indicators about mechanical systems (heating).
- +Annotation on name and department of the room.
- +Integrate the environment control of the inpatient rooms.
- Removal of the finances. They are not space related in the hospital.
- +Have environmental conditions (weather, outside temperature) in the display.
- +Have a more 3-dimensional view on the building plan.
- +Annotation of technical areas in the plan (elevators, etc).
- +The user can customize the information they can access.
- +The user can customize the display options (font size, contrast, etc).
- +A quality cluster can be added, focusing on qualitative metrics.
- +Instead of "patient journey" integrate additional functionalities for patients (such as make orders or give feedback).
- +Some graph would contribute to the information being more comprehensive.
- +Add performance cluster related to the students and the educational part of the campus.
- +Highlight the name of the room once the cursor hovers over it.
- +Interrelate two or more types of performance information in the building visualisation window

Limitations of the research

It was conducted in a single case study

The primary processes of the hospital had to be strictly respected

Relatively nascent type of technology requires more development

The anticipated timeframe for the research process

A certain degree of researcher's bias