Welcome!

Please mute yourself during the presentation and Q&A ;)

Digital Twins as Enabler in Circular Construction Management

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P5 presentation
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Table of Content

Why


Circularity?

Circularity Constrcution（CC）？

50%

Construction industry consumes 50% of all **materials** used in Europe

36%

Construction industry generates 36% of the total **waste** in Europe

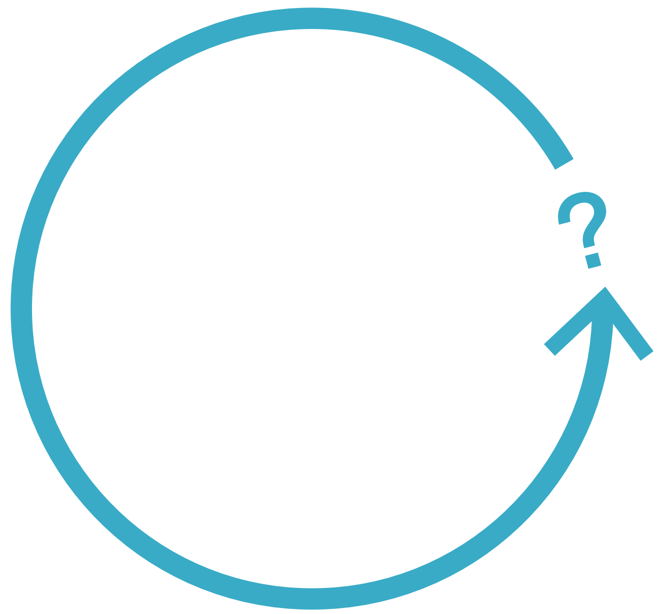
85%

Around 85% of the C&DW are **downcycled** (e.g. landfill) in the Netherlands

< 3%

Less than 3% of C&DW are **upcycled** and returned to building construction in the Netherlands

Schut & Mesman (2016); Herczeg et al. (2014); Eurostat (2021)




Digitalization?

Intelligent construction process

Smart life cycle management

Reduced waste

Reduced carbon impact

Energy efficiency

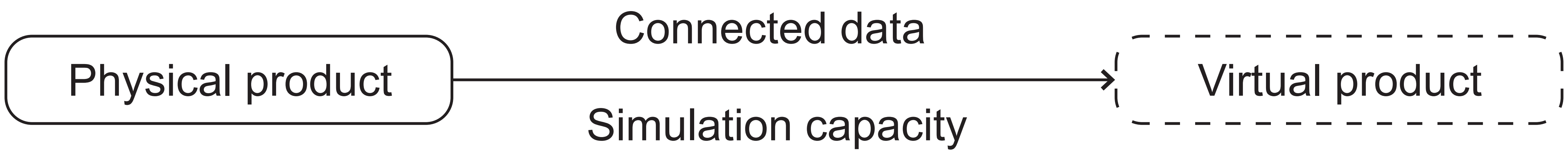
Improved life cycle cost

ARUP (2019); Boje et al., (2020); Kehily & Underwood (2017)

Introduction

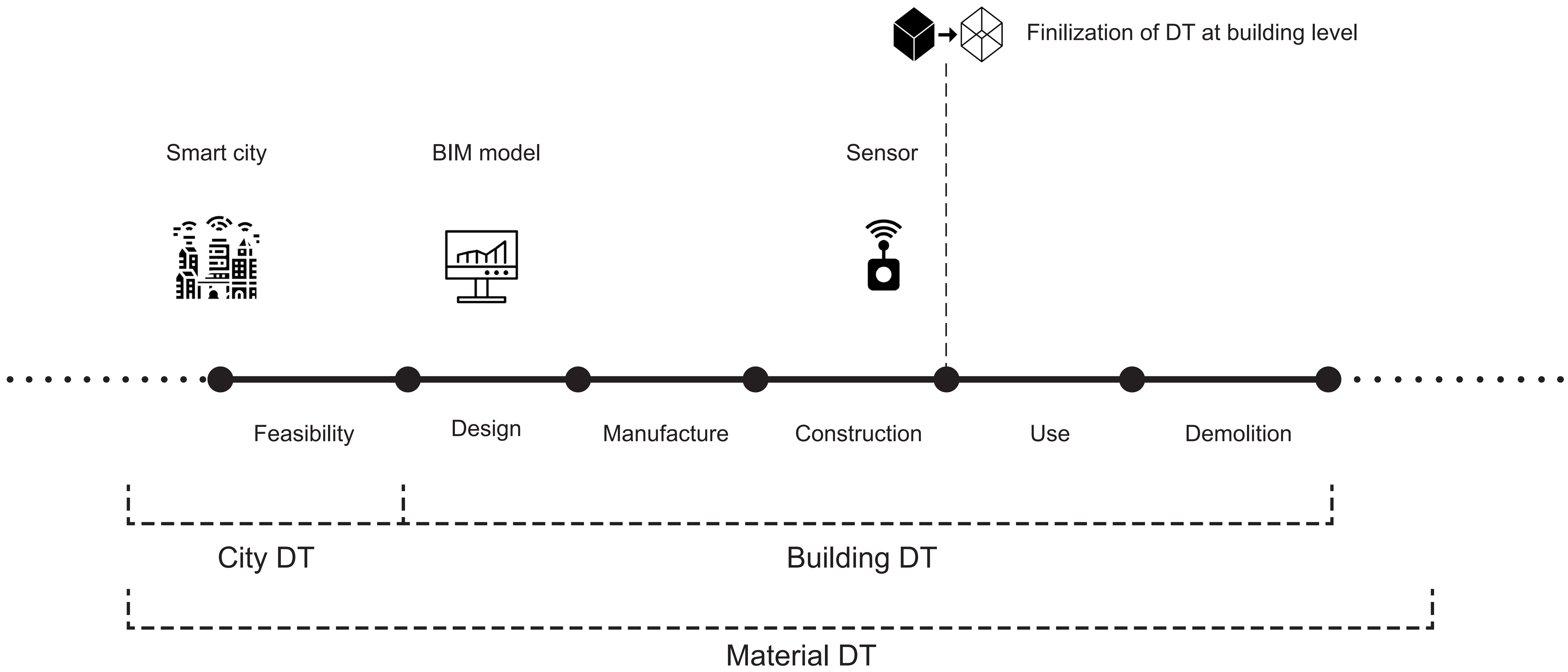

What are Digital Twins?

Digital Twins



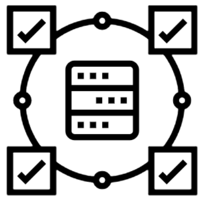
ARUP (2019); Tao et al., (2017)

Digital Twins

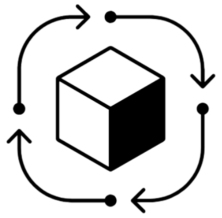


Problem statement

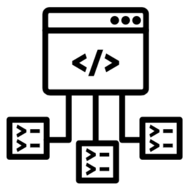
Little research has been done so far concerning the value of DT in circularity.



Only the final product of building DT is discussed, instead of the embedded technologies.



Fragmented application of the DT concept across the project life cycle.



In order to maximize DT's benefits in CC, an implementation framework is required.

Research objective

This research aims to analyze the role of DT and CC in the project life cycle, and to develop a framework of implementing DT technologies in realizing CC.

Research design

Research question

“How can digital twins be used to improve circular construction management?”

Research question

“How can digital twins be used to improve circular construction management?”

SQ1: What is the role of circularity in the built environment?

Research question

“How can digital twins be used to improve circular construction management?”

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SQ2: Why are DT technologies able to assist CC?

Research question

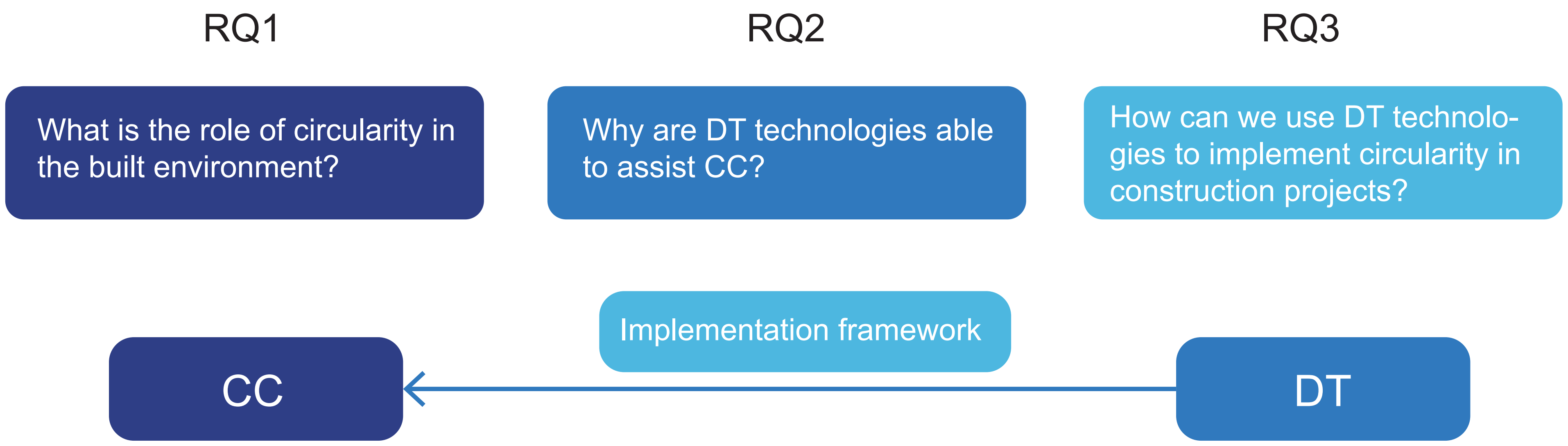
“How can digital twins be used to improve circular construction management?”

SQ1: What is the role of circularity in the built environment?

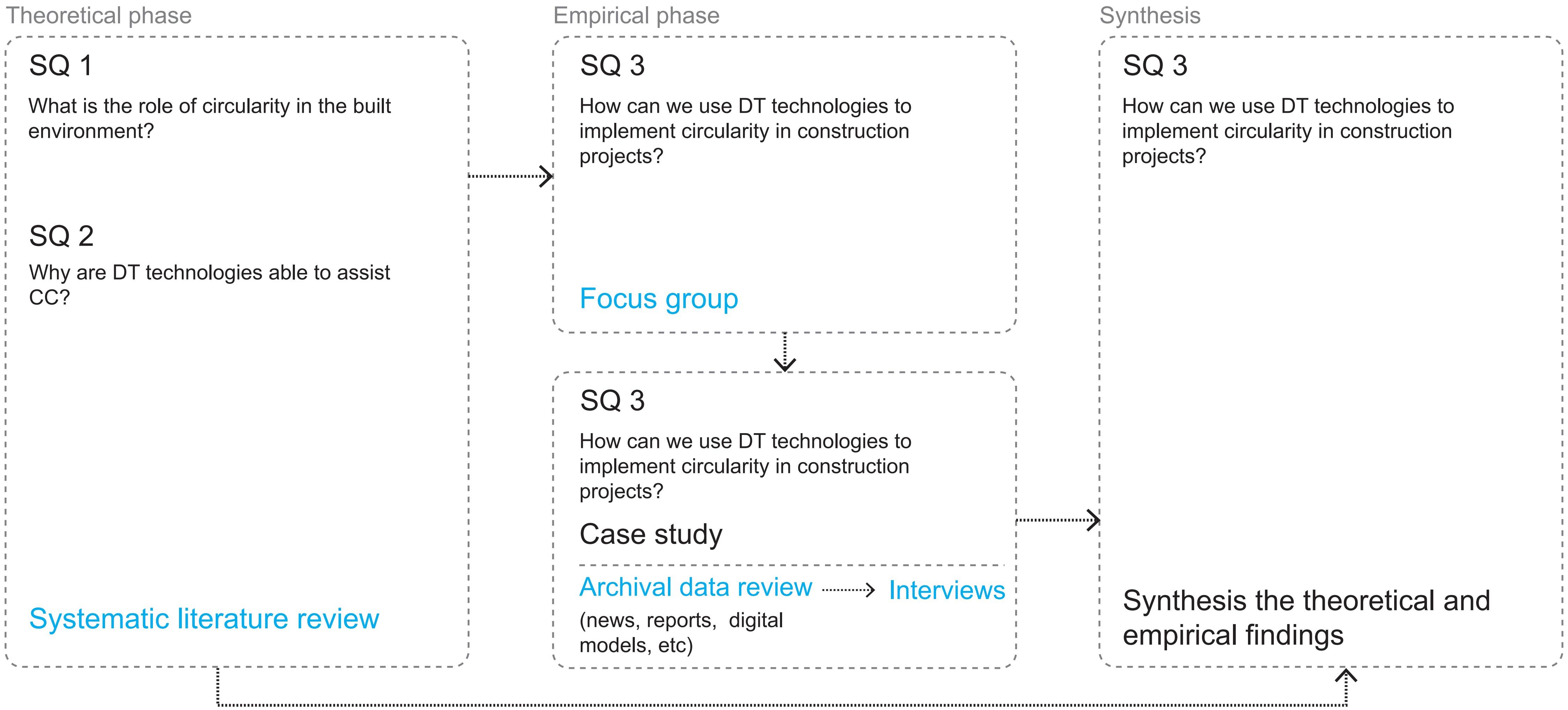
SQ2: Why are DT technologies able to assist CC?

SQ3: How can we use DT technologies to implement circularity in construction projects?

Conceptual framework



Methodology



Methodology

Theoretical phase

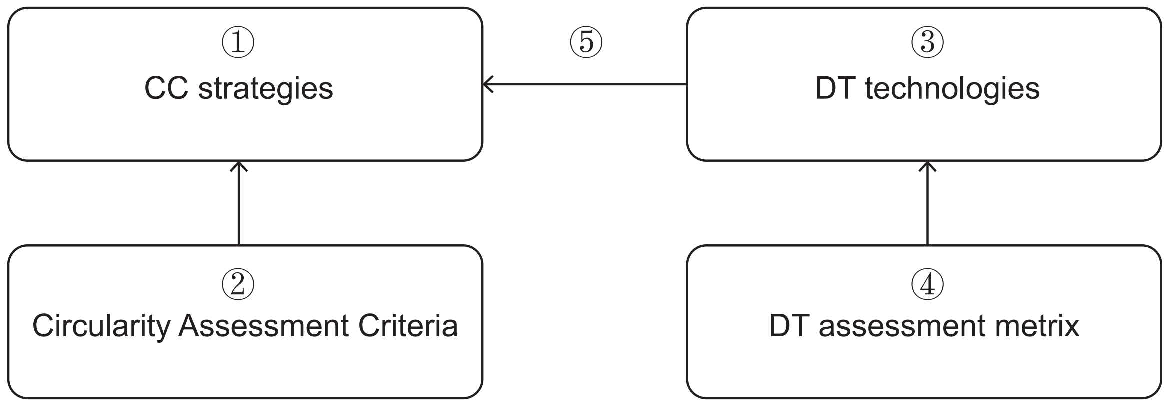
SQ 1

What is the role of circularity in the built environment?

SQ 2

Why are DT technologies able to assist CC?

Systematic literature review



Methodology

Theoretical phase

SQ 1

What is the role of circularity in the built environment?

SQ 2

Why are DT technologies able to assist CC?

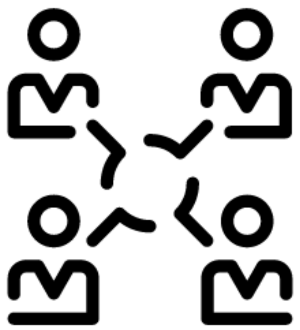
Systematic literature review

Empirical phase

SQ 3

How can we use DT technologies to implement circularity in construction projects?

Focus group



Methodology

Theoretical phase

SQ 1
What is the role of circularity in the built environment?

SQ 2
Why are DT technologies able to assist CC?

Systematic literature review

Empirical phase

SQ 3
How can we use DT technologies to implement circularity in construction projects?

Focus group

SQ 3
How can we use DT technologies to implement circularity in construction projects?

Case study

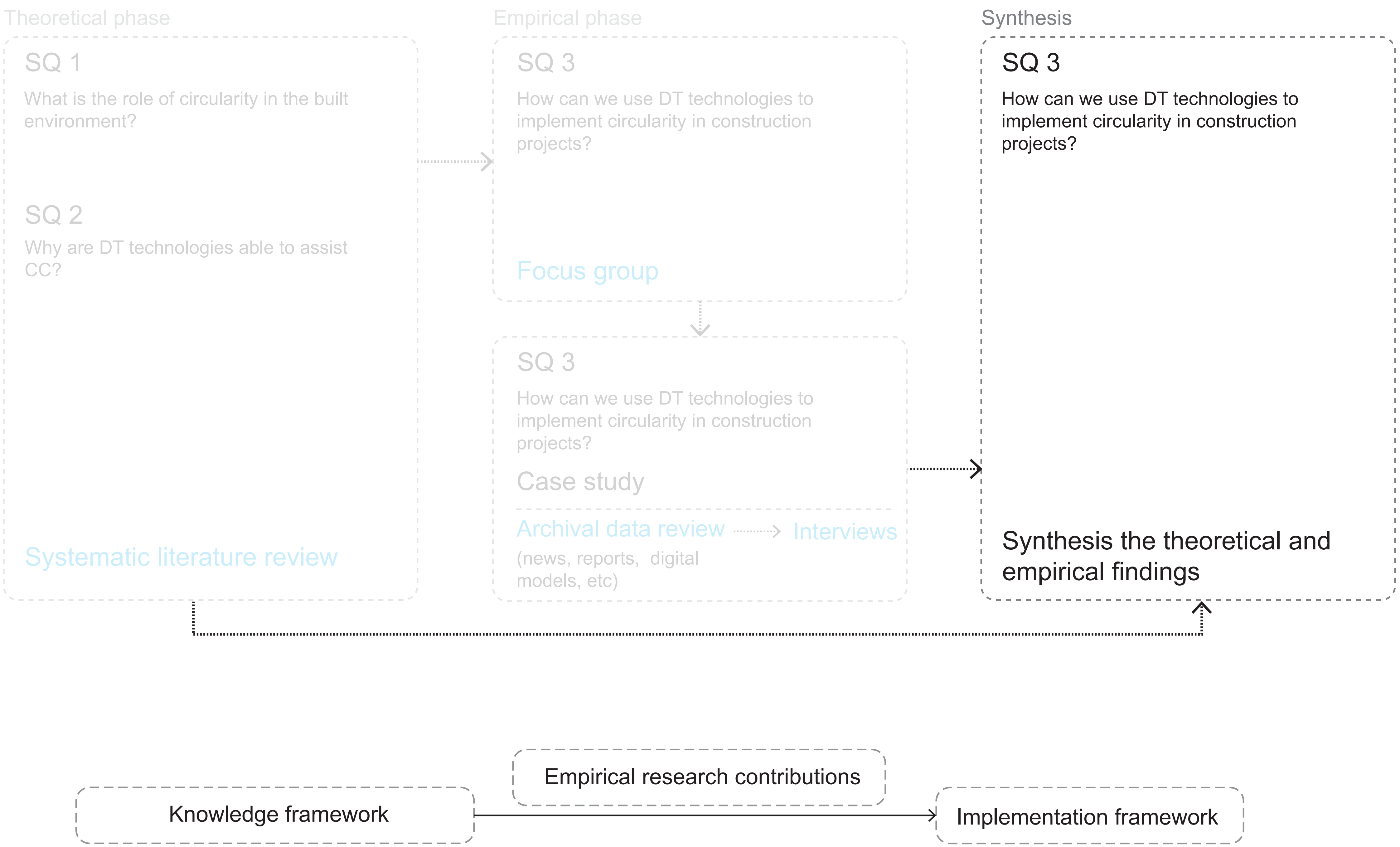
Archival data review → Interviews
(news, reports, digital models, etc)

Covered as much as CC principles

Applied most of the DT technologies

Data accessibility

Methodology



Theoretical research findings

1.
The role of CC across project life cycle

2.
Available DT technologies across project life cycle

3.
DT technologies' benefits to CC

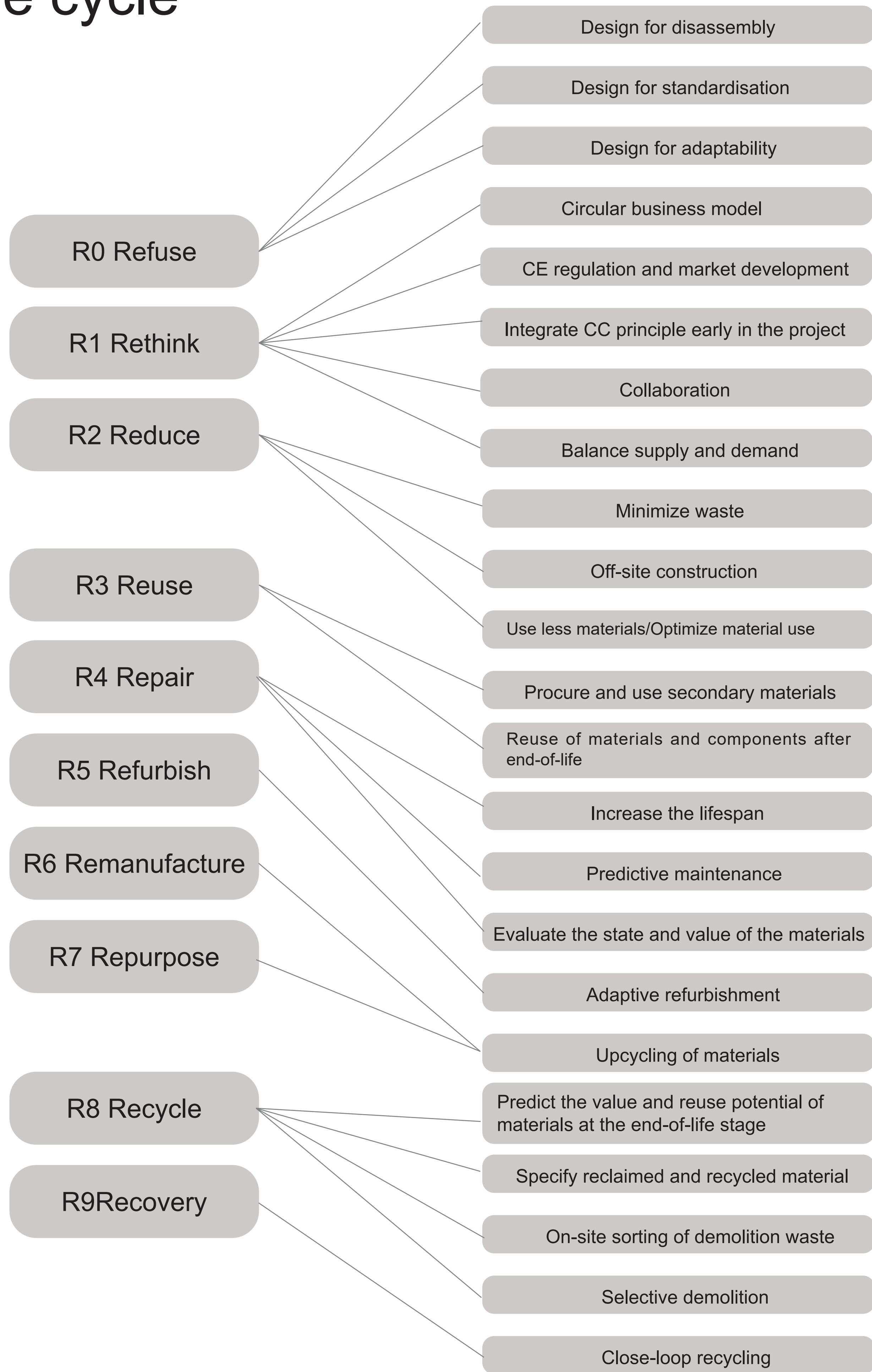
1. The role of CC in the built environment

The role of CC across project life cycle

Smart use and manufacture of materials

Extend lifespan and prodicivity of material and its parts

Useful application of materials

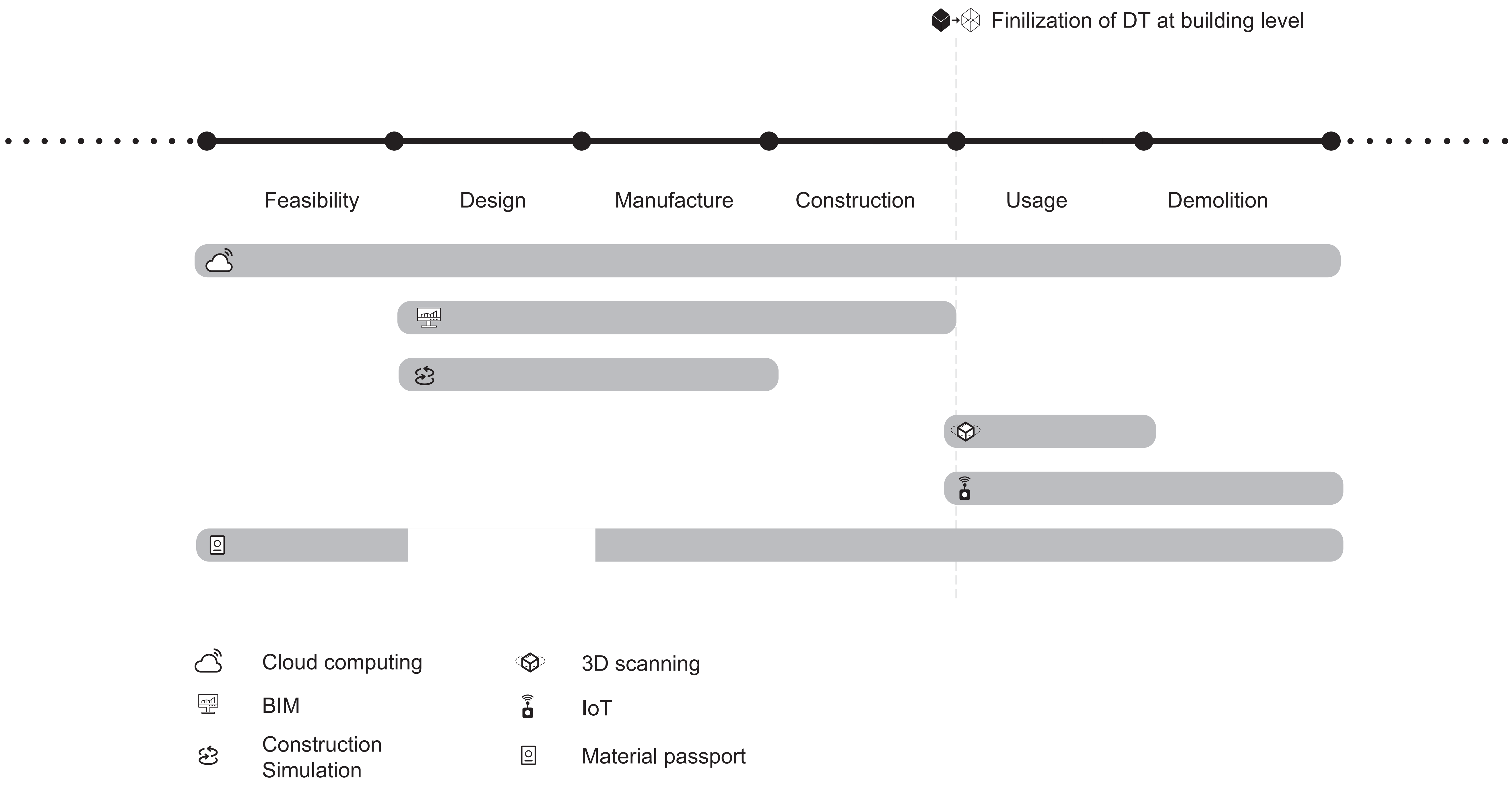


Potting et al. (2017)

1.
The role of
CC in the built
environment

2.
Available DT technologies across project life cycle

Available DT technologies across project life cycle



1.
The role of
CC in the built
environment

2.
Available DT
technologies
across project
life cycle

3.
DT technologies'
benefits to CC

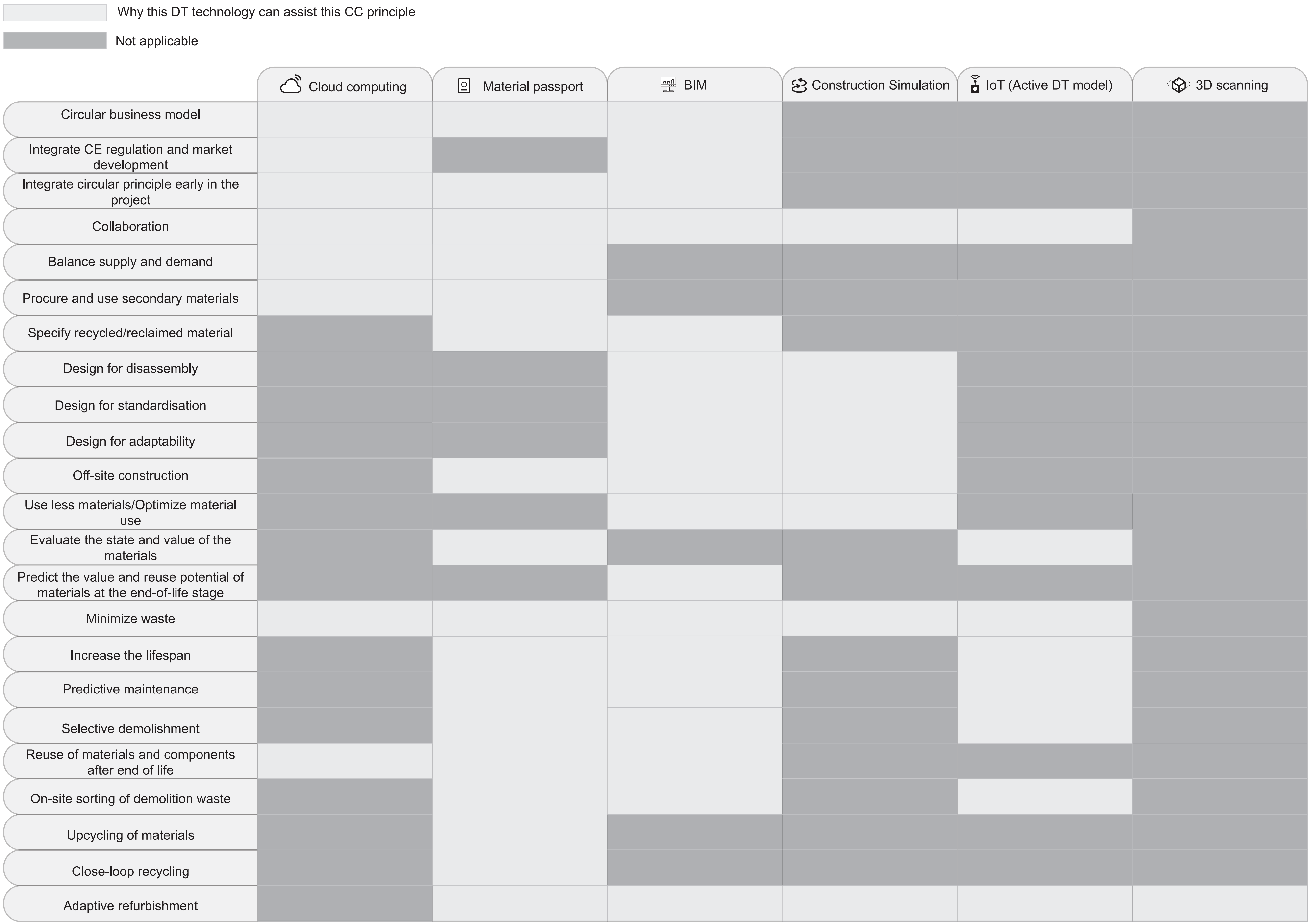
DT technologies’ benefits to CC: Knowledge framework

Why this DT technology can assist this CC principle

Not applicable

	Cloud computing	Material passport	BIM	Construction Simulation	IoT (Active DT model)	3D scanning
Circular business model	Integrating circular intention across the project life cycle	Supporting circular business model across sectors and projects	Integrating diverse circular requirements in design			
Integrate CE regulation and market development	Optimizing decision-making by increasing awareness of circularity					
Integrate circular principle early in the project	Increasing awareness of circularity by providing revevant reference projects	Integrating circular intention from the beginning of the projects				
Collaboration	Enabling effective and efficient communication within the project organization	Enabling effective and efficient communication cross sectors and projects	Enabling effective and efficient communication within the project organization	Enabling effective and efficient communi-cation between certain stakeholders (contractor, suppliers,engineer)	Enabling effective and efficient communi-cation betweem certain stakeholders (operators and users)	
Balance supply and demand	Supporting the redistribution of the resources	Matching the resources between different sectors and projects				
Procure and use secondary materials	Recording and providing materials' information	Recording and providing materials' information				
Specify recycled/reclaimed material			Working as supporting platform for storing materials'information			
Design for disassembly			Providing technical support for circular design and its realization	Supporting the realization of the design		
Design for standardisation						
Design for adaptability						
Off-site construction		Providing materials' information of assembly and suppliers				
Use less materials/Optimize material use			Optimizing design	Simulating the construction process to minimize mistakes and reworks		
Evaluate the state and value of the materials		Recording and providing materials' information for evaluation			Providing active information of materials	
Predict the value and reuse potential of materials at the end-of-life stage			D-DAS predicts the value of the materials			
Minimize waste	Minimizing rework by scheduling management	Recording materials' information for design optimization	Optimizing design	Simulating the construction process to minimize mistakes and reworks	Facilitating energy efficiency by moniroting the interior environment	
Increase the lifespan		Recording and providing materials' information	D-DAS predicts the value of the materials		Providing active information of materials	
Predictive maintenance						
Selective demolishment			Working as supporting platform for storing materials'information			
Reuse of materials and components after end of life	Supporting the redistribution of the resources					
On-site sorting of demolition waste					Providing active information of materials	
Upcycling of materials						
Close-loop recycling						
Adaptive refurbishment		Benefiting reusing material from existing builidngs	Supporting design and reuse of materials	Supporting the realization of the design	Providing active information of the building's condition	Duplicating the building's condition precisely

DT technologies’ benefits to CC: Knowledge framework



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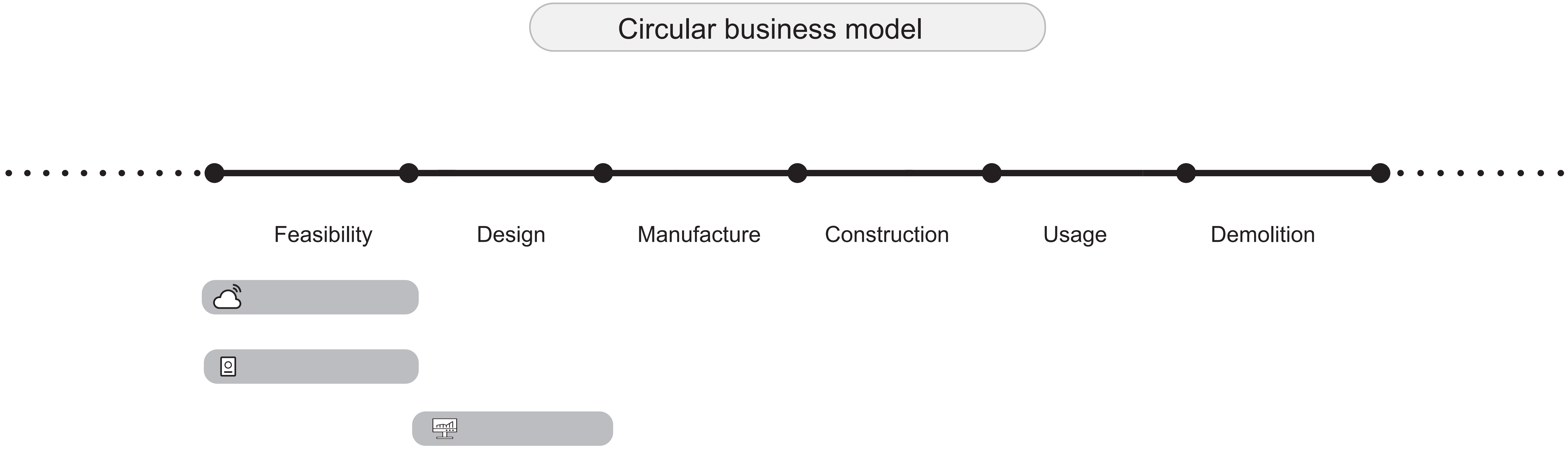
DT technologies’ benefits to CC: Knowledge framework

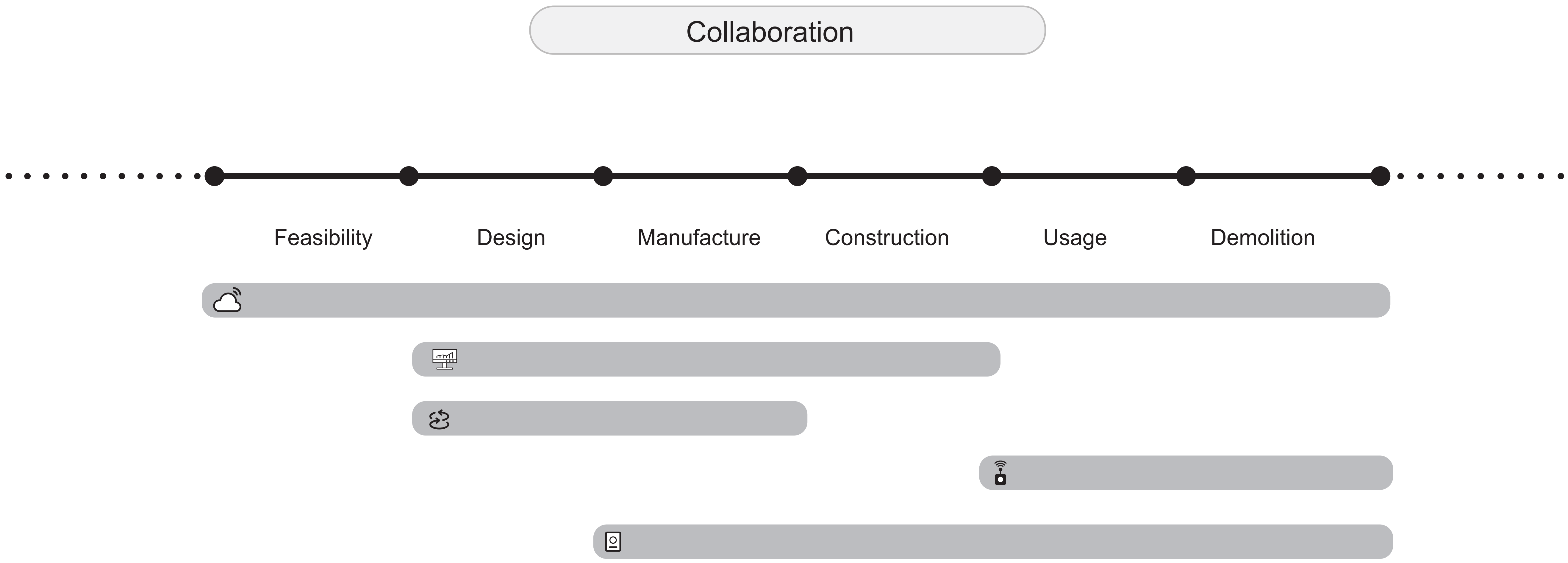


The cloud platform increases the decision-makers’ awareness of circularity by providing references, so as to encourage applying circular business model.

Adapting the building as a material bank is one of the circular business models.

Integrating circular regulations, codes, and requirements for design reference.

DT technologies’ benefits to CC: Knowledge framework



Enabling effective and efficient collaboration within and across the project organizations by scheduling management, information exchange, etc.

Benefiting collaboration during design and construction by updating modeling information.

Benefiting collaboration between certain stakeholders (architects, contractor, suppliers,engineer)

Benefiting collaboration between certain stakeholders (operators and users)

Enabling effective and efficient communication in single project and cross sectors and projects by providing materials information for supplyment, assembly, maintenance, and demolition.

DT technologies’ benefits to CC: Knowledge framework

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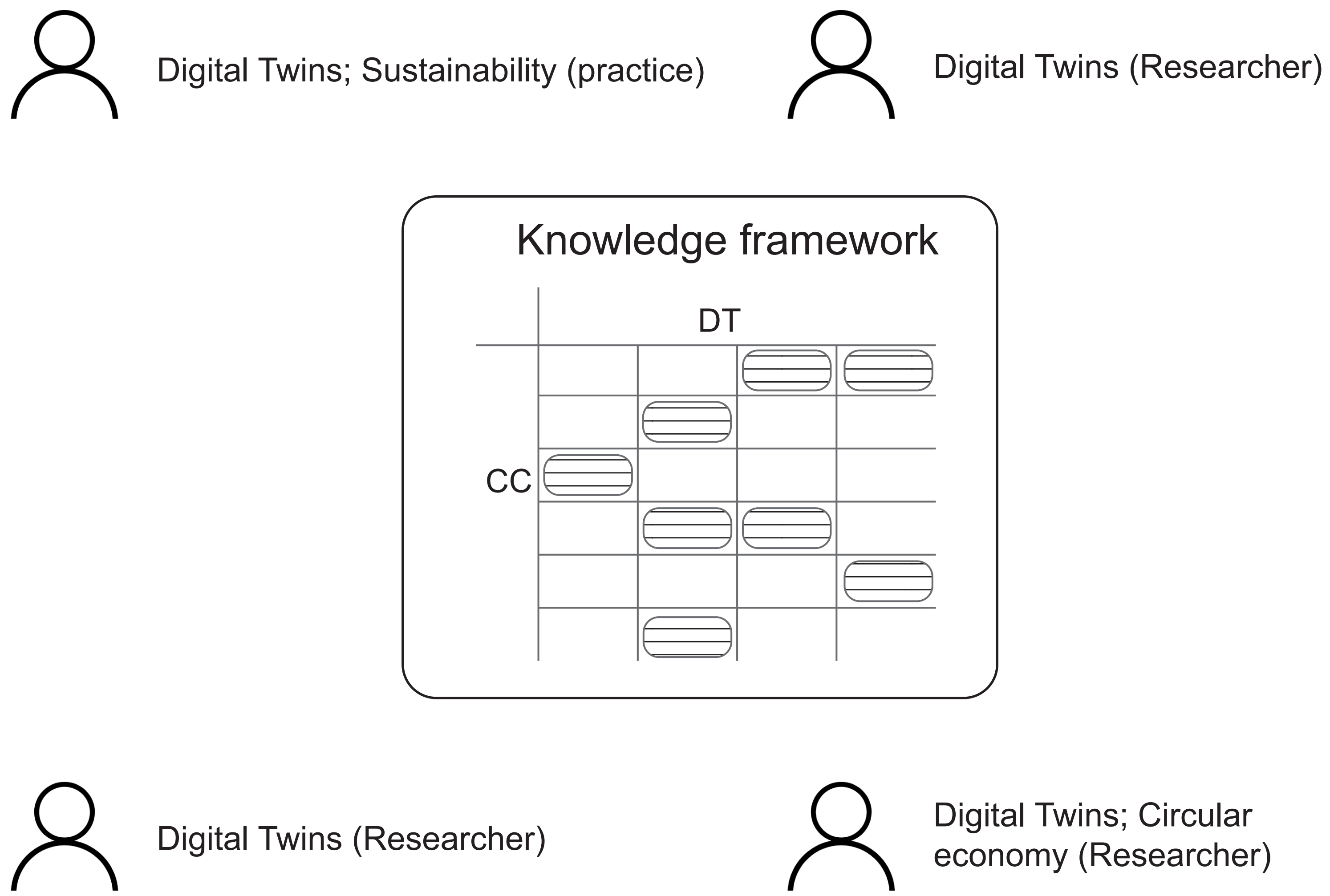
Empirical research findings

1.
Focus group

2.
Case study

1.
Focus group

Focus group


Digital Twins; Sustainability (practice)
Digital Twins (Researcher)
Knowledge framework
DT
CC
Digital Twins (Researcher)
Digital Twins; Circular economy (Researcher)

Focus group

WHAT

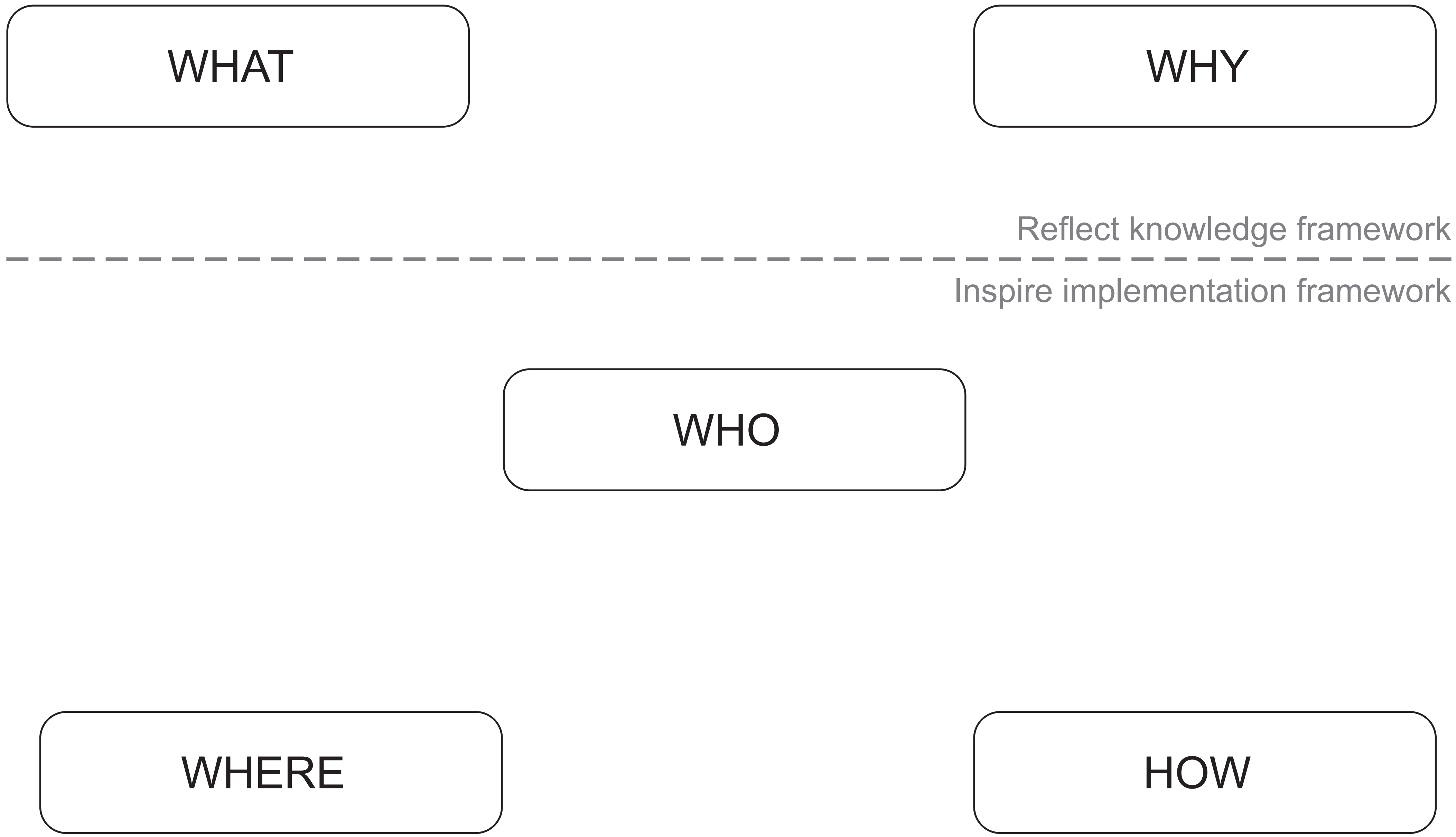
WHY

WHO

WHERE

HOW

Focus group


WHAT
WHY
Reflect knowledge framework
Inspire implementation framework
WHO
WHERE
HOW

Focus group

WHAT

WHY

Reflect knowledge framework

Inspire implementation framework

WHO

WHERE

HOW

Focus group

WHO

"The first question comes in implementing such new technologies (DT) is who will pay for it. "

-- Participants in the focus group

Focus group (DT-based CC implementation framework canvas)

XX Stakeholder perspective

Why this DT technology can assist this CC principle

Not applicable

	Cloud computing	Material passport	BIM	Construction Simulation	IoT (Active DT model)	3D scanning
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Integrate CE regulation and market development						
Integrate circular principle early in the project						
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Adaptive refurbishment						

1.
Focus group

2.
Case study


Leishenshan hospital

Case study

Case description

Leishenshan Hospital

Location: Wuhan, China
Client: Housing and Urban-Rural Development department of Wuhan municipality
Procurement strategy: Design & Build
Architect: Central South Architectural Design Institute (CSADI)
Contractor: China Construction Third Engineering Bureau Co. Ltd
Year of construction: 2020
Area: 75000 m²
Development type: New built
Main function: Hospital
Number of beds: 1500

Case study

Project organization

Client	CL	Engineer	EG	Project manager	PM	Architect	AR
Technical Consultant	TC	Contractor	CT	Cost specialist	CS	Operator	OP
Supplier	SP	User	US				

Case study

Project organization

Client	CL	Engineer	EG	Project manager	PM	Architect	AR
Technical Consultant	TC	Contractor	CT	Cost specialist	CS	Operator	OP
Supplier	SP	User	US				

Project life cycle	Stakeholder involved
Feasibility	CL PM AR
Design	PM EG AR TC CS
Manufacture	PM EG AR CT SP
Construction	PM EG AR CT SP
Usage	OP US CT TC

Case study

Development restrictions and requirements

Time Limitation

Date	Progress
25-01-2020	Initiate
26-01-2020	Design and construction started
30-01-2020	61% done
03-02-2020	79% done
06-02-2020	Delivery phase 1
14-02-2020	Delivery phase 2

Supply problem

Material shortage

- Closed local factory
- Stopped logistics

Stakeholders

20.000 participants involved

- Difficulties in management

Case study

Development restrictions and requirements

Time Limitation

Supply problem

Stakeholders

Modularity

Reuse materials

Collaboration

Case study

Development restrictions and requirements

Time Limitation

Supply problem

Stakeholders

Modularity

Reuse materials

Collaboration

Case analysis

Legend

- Applied CC principles assisted by DT technologies
- Applied CC principles without DT's support
- Potentially applicable CC principles in the future

- Not applicable
- Theoretical applicable DT technology
- Actual applied DT technology
- Potentially applicable DT technologies

Stakeholder perspective

Client	CL	Project manager	PM	Supplier	SP	Contractor	CT
Technical Consultant	TC	Architect	AR	Operator	OP		
Cost specialist	CS	Engineer	EG	User	US		

AA DT technologies users

AA Predicted DT technologies users

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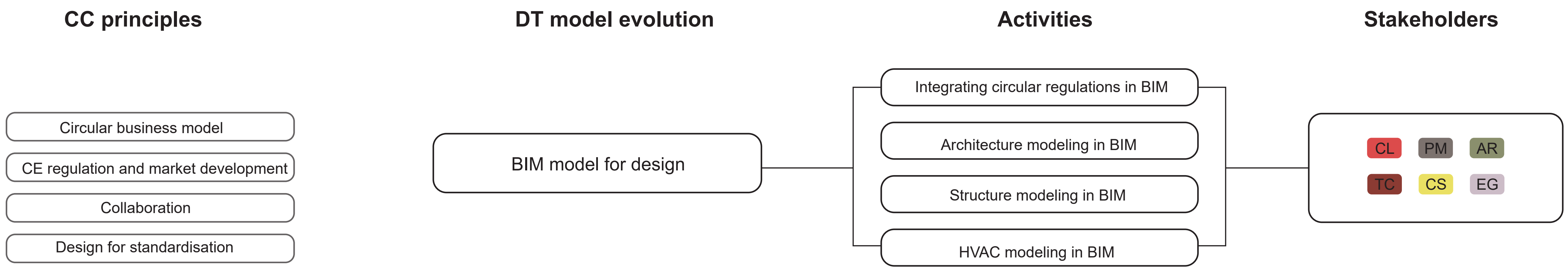
Circular business model	CL PM		PM AR			
Integrate CE regulation and market development	PM AR		PM AR			
Integrate circular principle early in the project						
Collaboration	CL PM TC AR	AR EG CT OP	TC AR EG CS	AR EG CT SP	CT OP TC US	
Balance supply and demand	SP	SP TC				
Procure and use secondary materials						
Specify recycled/reclaimed material						
Design for disassembly						
Design for standardisation			AR EG	AR EG		
Design for adaptability						
Off-site construction		AR EG CT	AR EG CT	AR EG CT SP		
Use less materials/Optimize material use			AR EG	EG CT		
Evaluate the state and value of the materials					OP TC	
Predict the value and reuse potential of materials at the end-of-life stage						
Minimize waste	PM AR	AR EG	AR EG CT	EG CT	OP TC	
Increase the lifespan		CT			OP CT	
Predictive maintenance		OP	OP AR TC		OP TC	
Selective demolishment		SP OP			OP TC	
Reuse of materials and components after end of life	SP OP	SP OP				
On-site sorting of demolition waste		SP OP			SP TC	
Upcycling of materials						
Close-loop recycling						
Adaptive refurbishment						

Finding

Applied CC principles assisted by DT technologies



Client	CL	Engineer	EG	Project manager	PM	Supplier	SP	Cost specialist	CS
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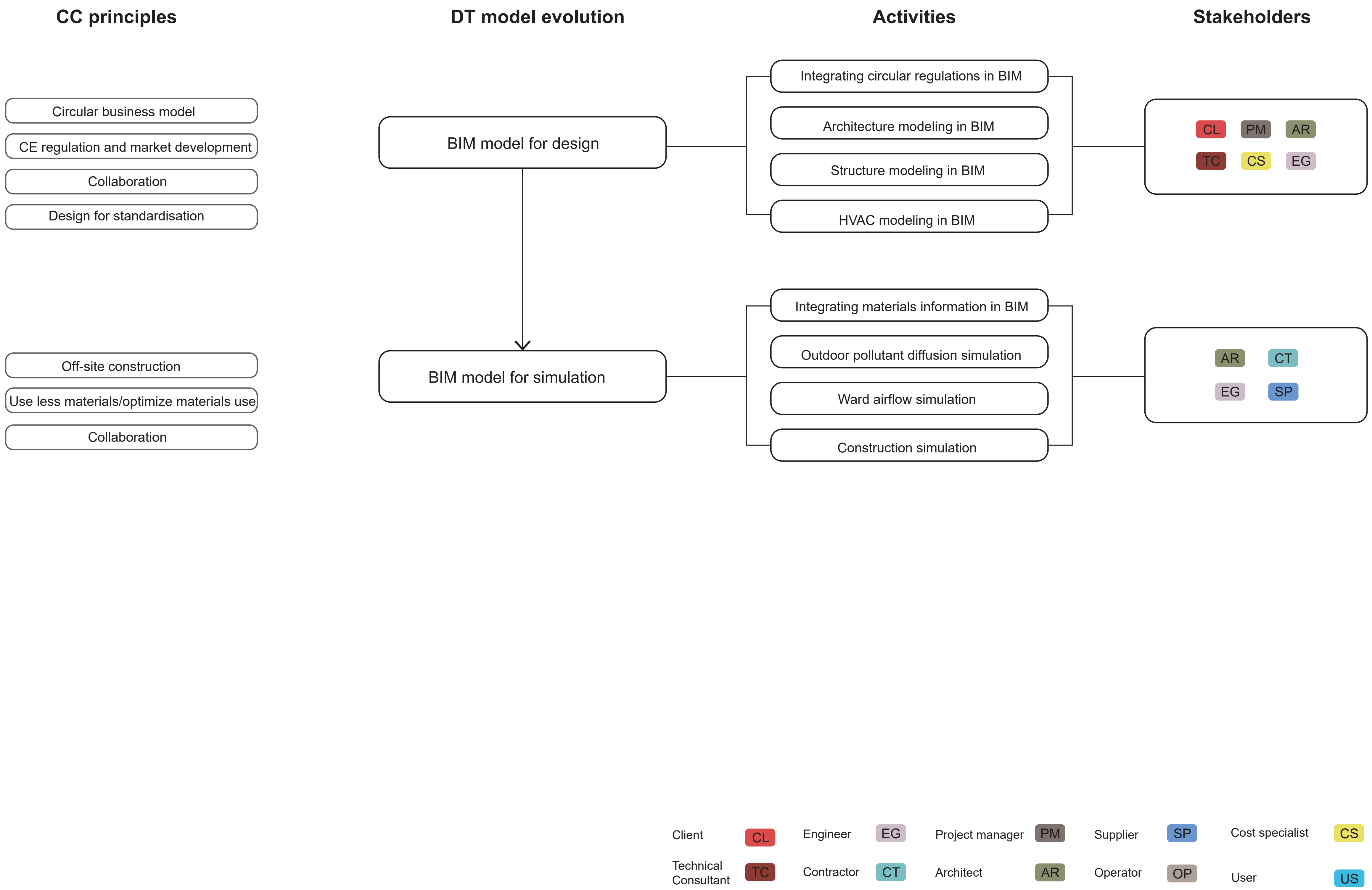
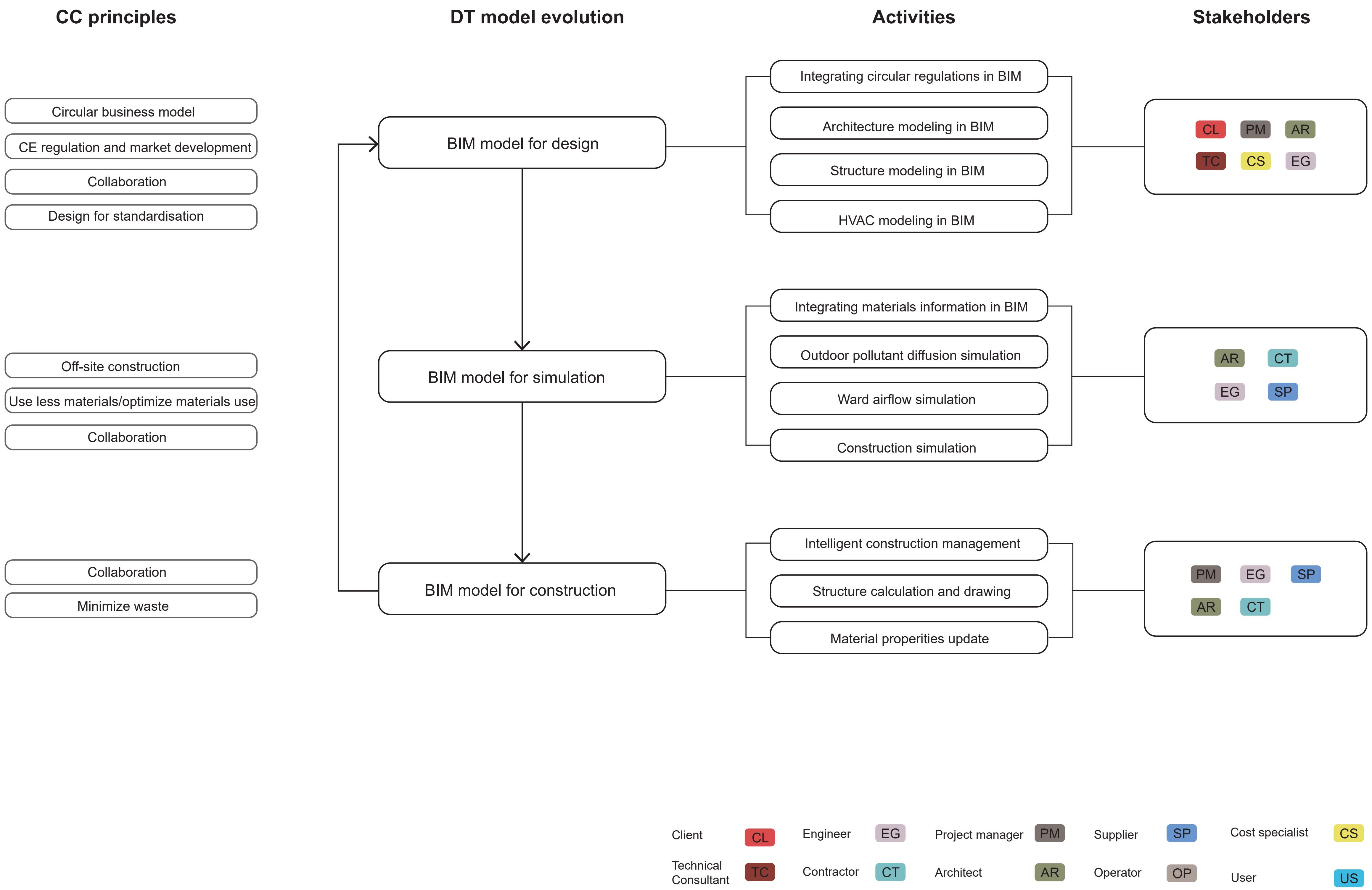
Finding

Applied CC principles assisted by DT technologies



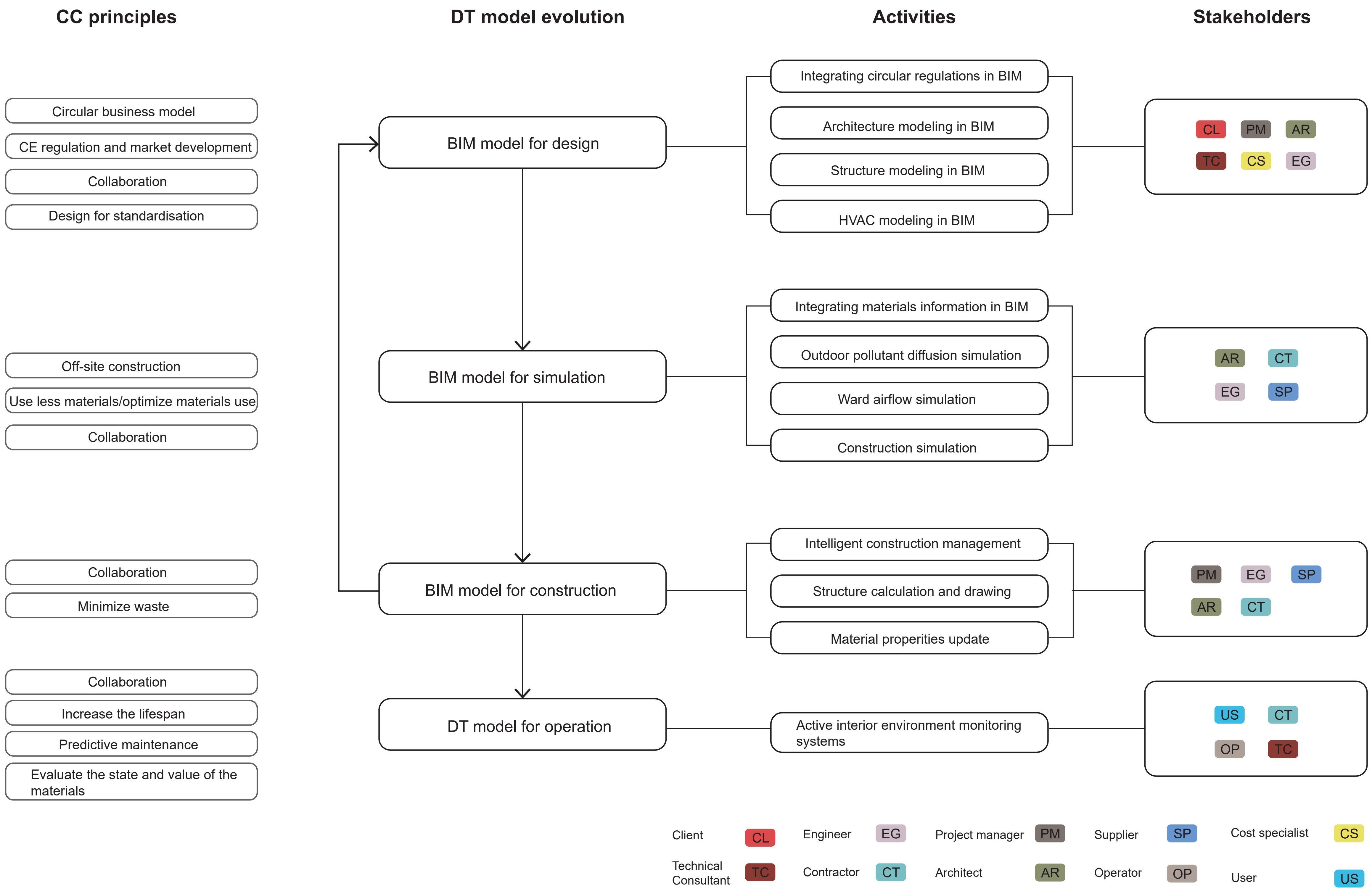
Finding

Applied CC principles assisted by DT technologies



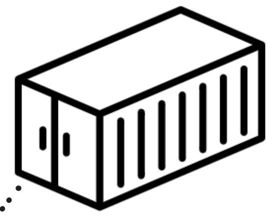
Finding

Applied CC principles assisted by DT technologies

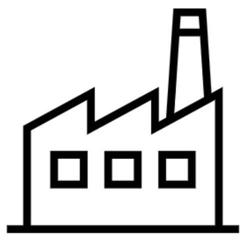


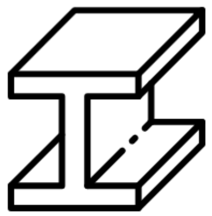
Finding

Applied CC principles without DT’s support



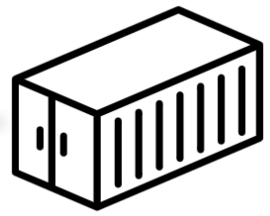
New material



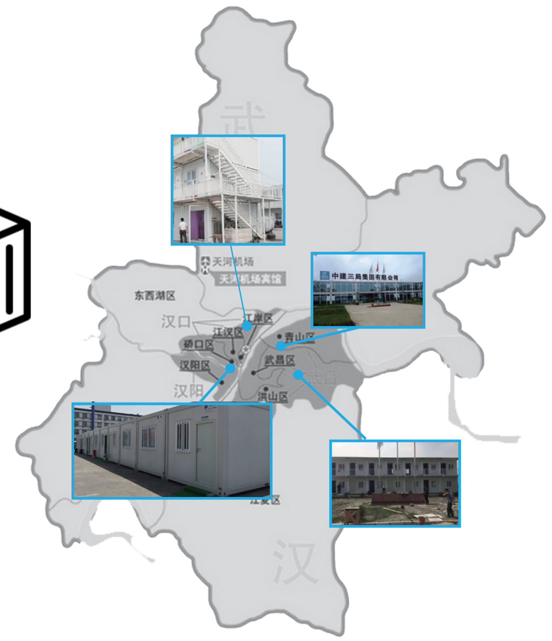


New material

Modular components of ward zone



Reused material



Modular components of technical zone

Source: Zhou & Tian (2020); Interview A

Finding

Potentially applicable CC principles

50 years
Lifespan period

1,700 tons steels
3,300 container-type units
Amount of reusable materials

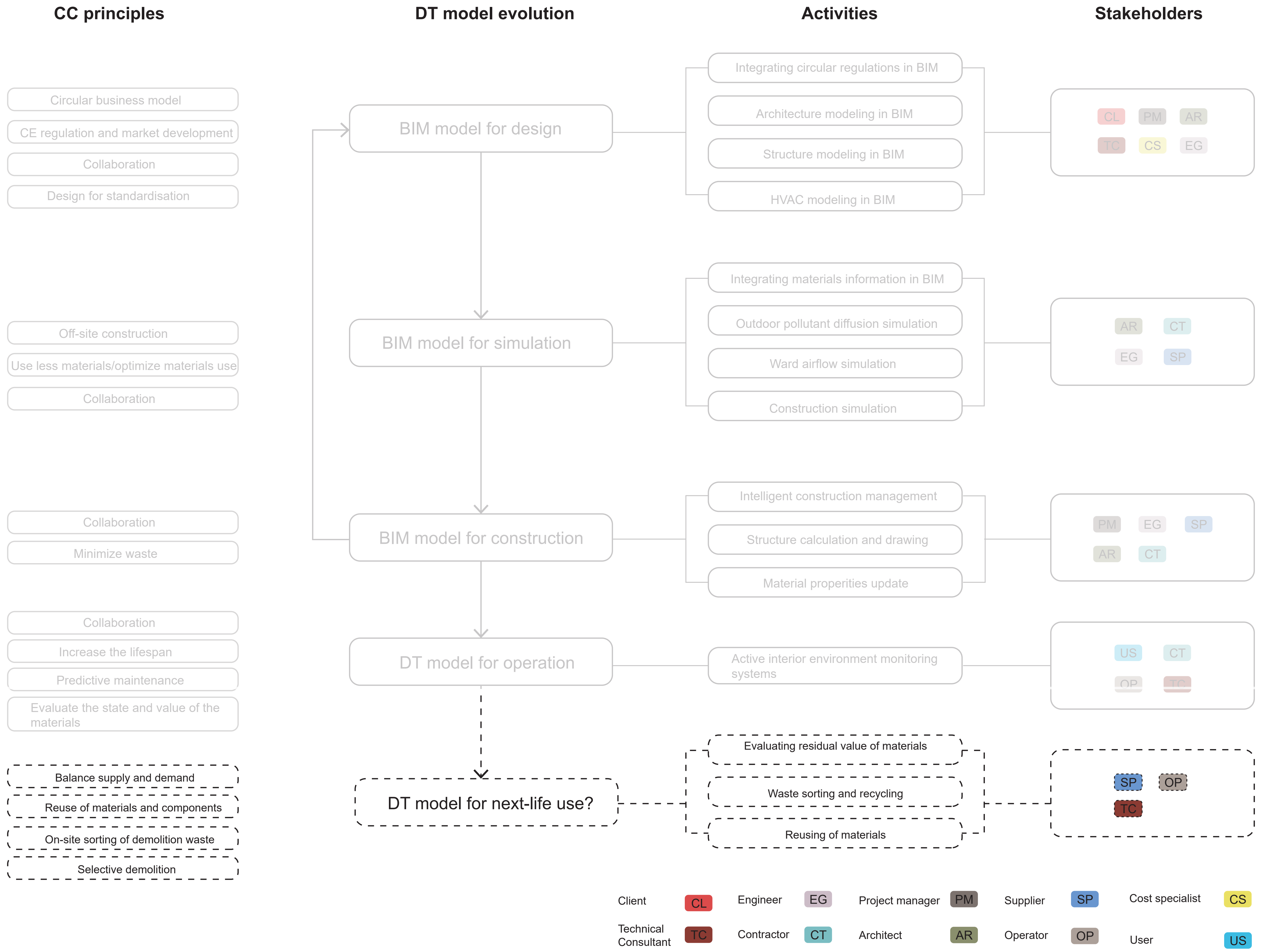
Steel: 60% of new ones
Container-type units: 16% of new ones
Estimated residual value of secondary materials

The building is temporary closed but ready for reopen anytime during the pandemic.

Zhou & Tian (2020); Interview A

Finding

Potentially applicable CC principles



Conclusion: DT-based CC management framework (primary version)

Legend

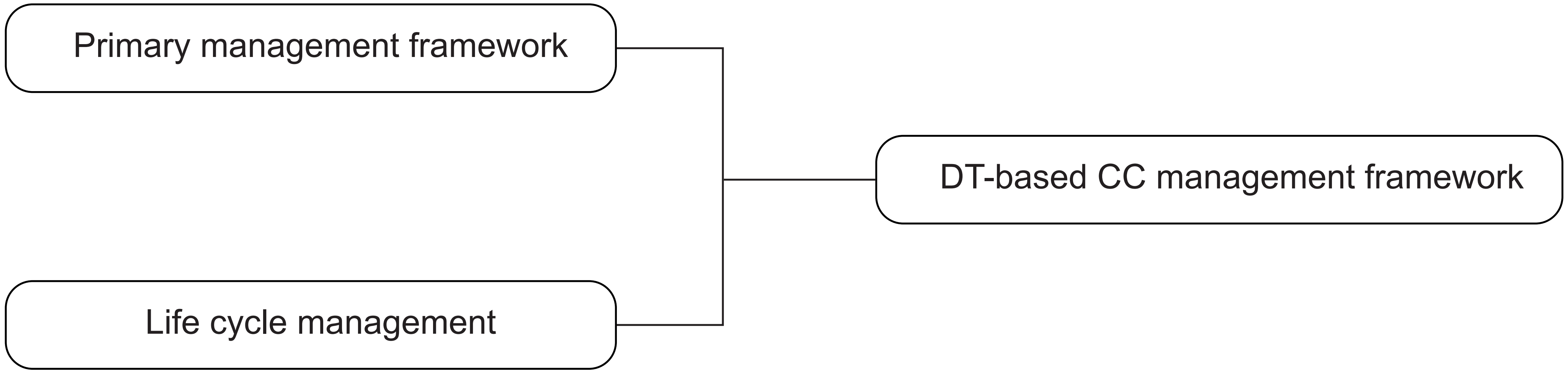
- Why this DT technology can assist this CC principle (light cell)
- Not applicable (dark grey cell)

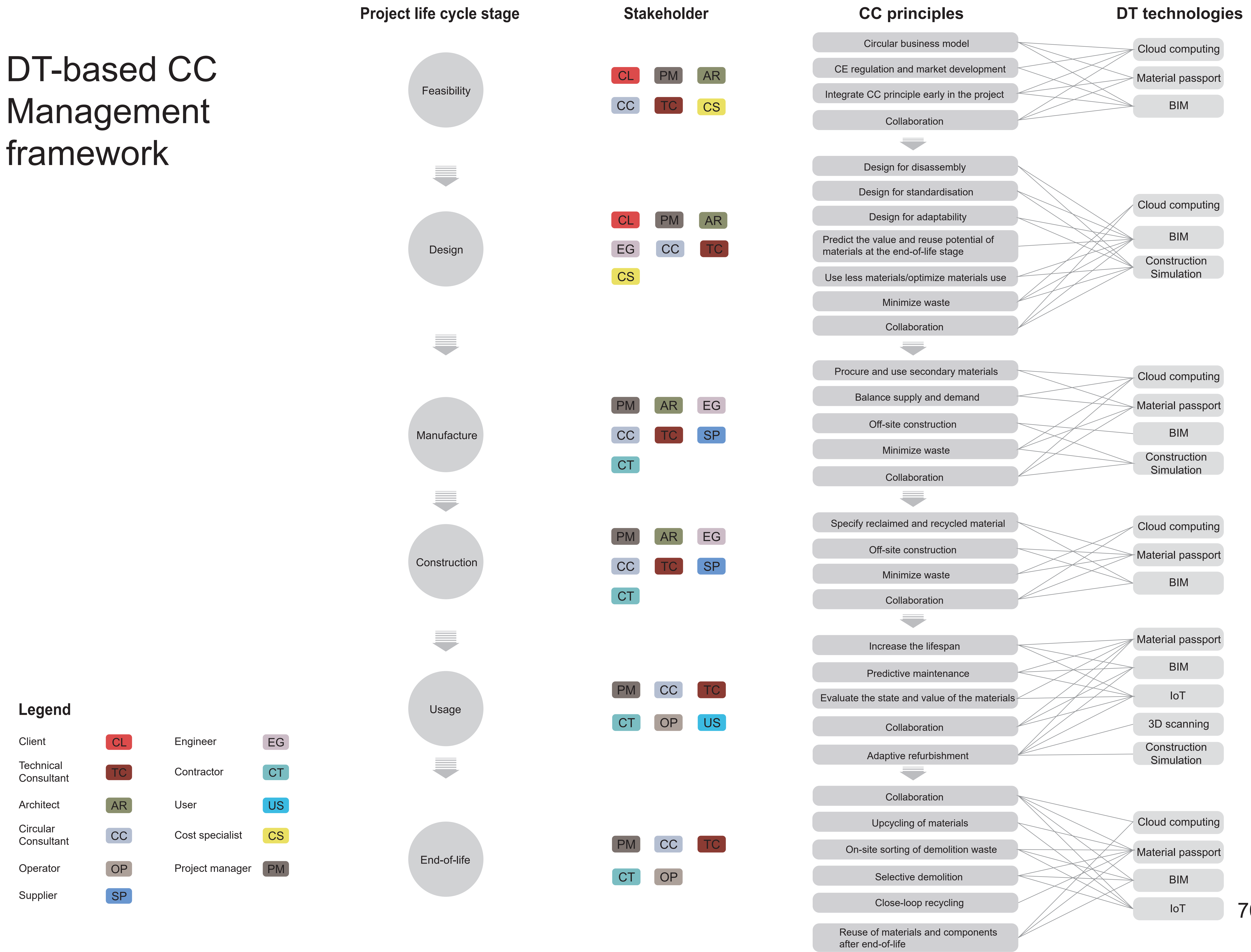
Stakeholder perspective

Client	CL	Engineer	EG	Architect	AR	User	US	Supplier	SP	Project manager	PM
Technical Consultant	TC	Contractor	CT	Circular Consultant	CC	Cost specialist	CS	Operator	OP		

<table>
<tr><th></th><th>Cloud computing</th><th>Material passport</th><th>BIM</th><th>Construction Simulation</th><th>IoT (Active DT model)</th><th>3D scanning</th></tr>
<tr><td>Circular business model</td><td>CL PM CC</td><td>CC PM</td><td rowspan="3">CL PM CC AR CS</td><td></td><td></td><td></td></tr>
<tr><td>Integrate CE regulation and market development</td><td>CL PM CC</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Integrate circular principle early in the project</td><td>CL PM CC AR</td><td>CC PM</td><td></td><td></td><td></td></tr>
<tr><td>Collaboration</td><td>CL PM CC AR</td><td>CC SP AR CT</td><td>AR EG TC</td><td>CT TC SP EG</td><td>OP TC US</td><td></td></tr>
<tr><td>Balance supply and demand</td><td rowspan="2">PM SP</td><td>CC SP</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Procure and use secondary materials</td><td>CC CT</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Specify recycled/reclaimed material</td><td></td><td>AR</td><td>AR</td><td></td><td></td><td></td></tr>
<tr><td>Design for disassembly</td><td></td><td></td><td rowspan="3">AR EG TC CS</td><td rowspan="4">AR EG CT SP</td><td></td><td></td></tr>
<tr><td>Design for standardisation</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Design for adaptability</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Off-site construction</td><td></td><td>CT SP</td><td>EG CT</td><td></td><td></td></tr>
<tr><td>Use less materials/Optimize material use</td><td></td><td></td><td>AR EG</td><td>EG CT</td><td></td><td></td></tr>
<tr><td>Evaluate the state and value of the materials</td><td></td><td>CC OP</td><td></td><td></td><td>OP TC</td><td></td></tr>
<tr><td>Predict the value and reuse potential of materials at the end-of-life stage</td><td></td><td></td><td>AR</td><td></td><td></td><td></td></tr>
<tr><td>Minimize waste</td><td>PM</td><td>AR</td><td>AR EG</td><td>EG CT</td><td></td><td></td></tr>
<tr><td>Increase the lifespan</td><td></td><td>CC AR</td><td rowspan="2">OP CT</td><td></td><td rowspan="3">OP CC TC</td><td></td></tr>
<tr><td>Predictive maintenance</td><td></td><td>CC OP</td><td></td><td></td></tr>
<tr><td>Selective demolition</td><td></td><td rowspan="5">CC OP SP</td><td rowspan="3">OP SP</td><td></td><td></td></tr>
<tr><td>Reuse of materials and components after end of life</td><td>CC OP</td><td></td><td></td><td></td></tr>
<tr><td>On-site sorting of demolition waste</td><td></td><td></td><td>TC SP</td><td></td></tr>
<tr><td>Upcycling of materials</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Close-loop recycling</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Adaptive refurbishment</td><td></td><td>CC OP SP</td><td>AR EG TC</td><td>AR EG CT</td><td>TC OP</td><td>AR OP CC TC</td></tr>
</table>

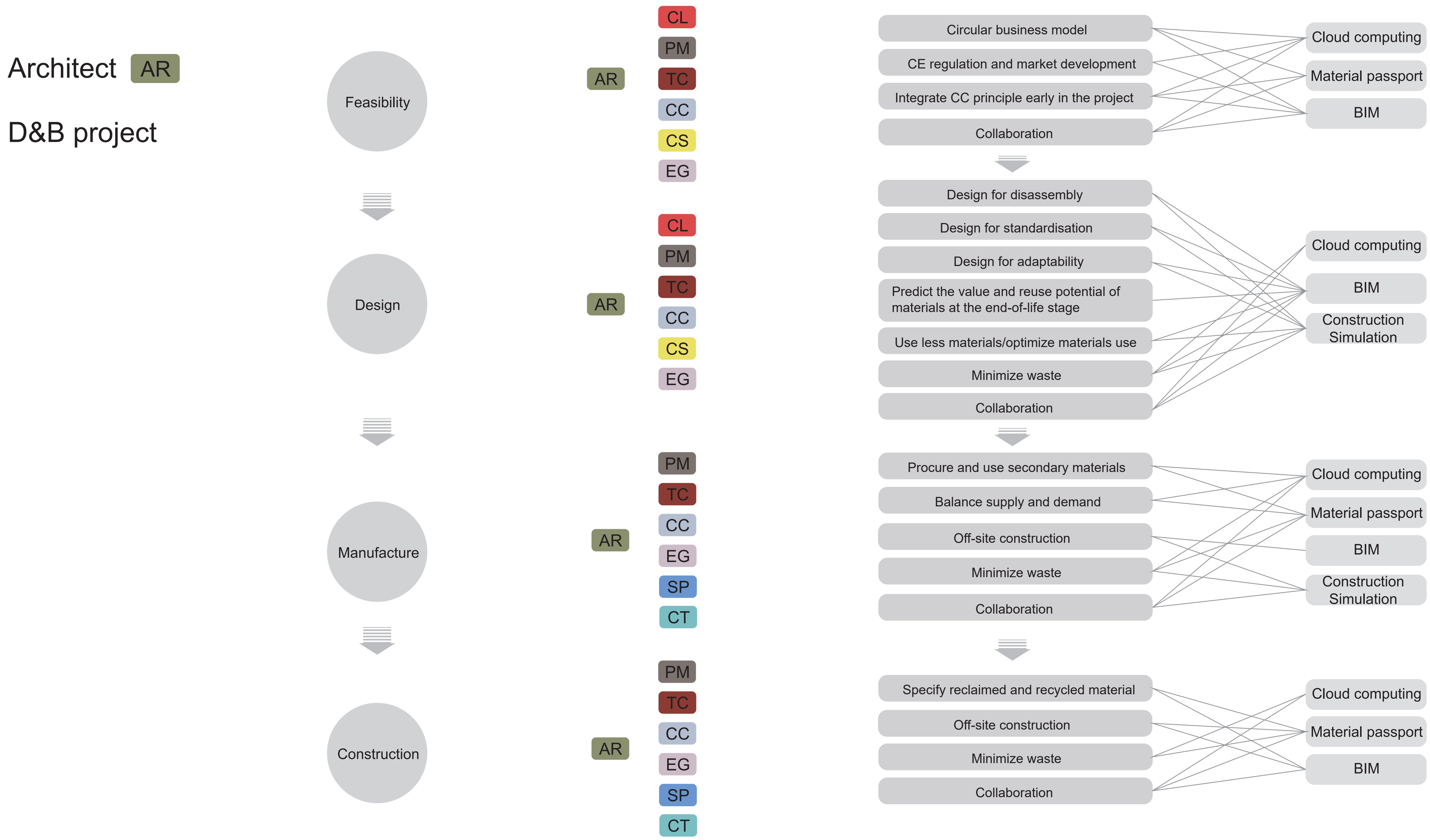
Synthesis


Primary management framework
Life cycle management
DT-based CC management framework



DT-based CC Management framework
Project life cycle stage
Stakeholder
CC principles
DT technologies
Feasibility
CL PM AR CC TC CS
Circular business model
CE regulation and market development
Integrate CC principle early in the project
Collaboration
Cloud computing
Material passport
BIM
Design
CL PM AR EG CC TC CS
Design for disassembly
Design for standardisation
Design for adaptability
Predict the value and reuse potential of materials at the end-of-life stage
Use less materials/optimize materials use
Minimize waste
Collaboration
Cloud computing
BIM
Construction Simulation
Manufacture
PM AR EG CC TC SP CT
Procure and use secondary materials
Balance supply and demand
Off-site construction
Minimize waste
Collaboration
Cloud computing
Material passport
BIM
Construction Simulation
Construction
PM AR EG CC TC SP CT
Specify reclaimed and recycled material
Off-site construction
Minimize waste
Collaboration
Cloud computing
Material passport
BIM
Usage
PM CC TC CT OP US
Increase the lifespan
Predictive maintenance
Evaluate the state and value of the materials
Collaboration
Adaptive refurbishment
Material passport
BIM
IoT
3D scanning
Construction Simulation
End-of-life
PM CC TC CT OP
Collaboration
Upcycling of materials
On-site sorting of demolition waste
Selective demolition
Close-loop recycling
Reuse of materials and components after end-of-life
Cloud computing
Material passport
BIM
IoT
Legend
Client CL
Technical Consultant TC
Architect AR
Circular Consultant CC
Operator OP
Supplier SP
Engineer EG
Contractor CT
User US
Cost specialist CS
Project manager PM

DT-based CC Management framework



Conclusion

Conclusion

“How can digital twins be used to improve circular construction management?”

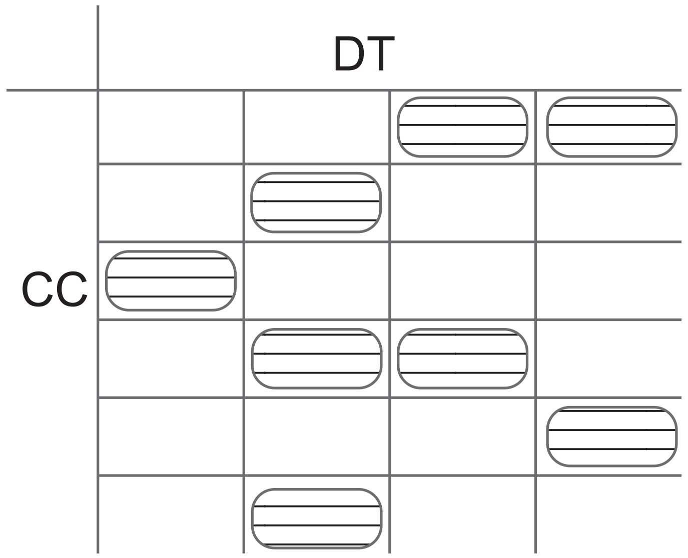
SQ1: What is the role of circularity in the built environment?

10 Rs CC strategies — CC principles

Conclusion

“How can digital twins be used to improve circular construction management?”

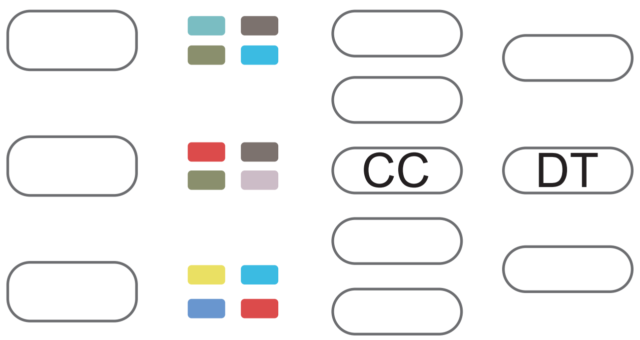
SQ2: Why are DT technologies able to assist CC?



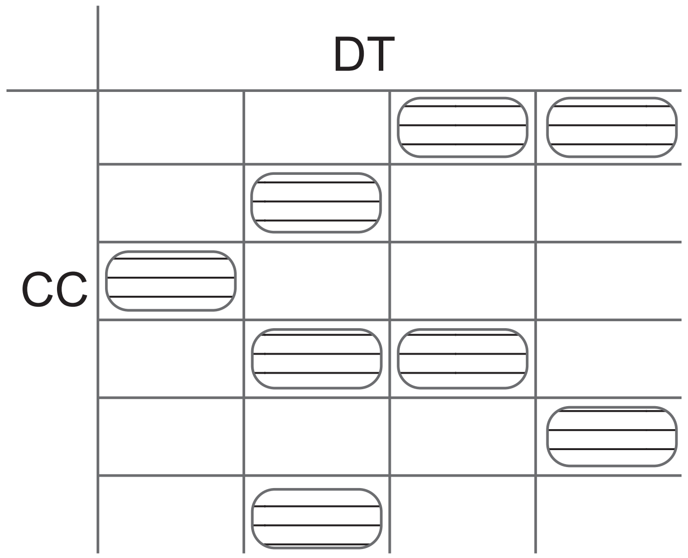
Conclusion

“How can digital twins be used to improve circular construction management?”

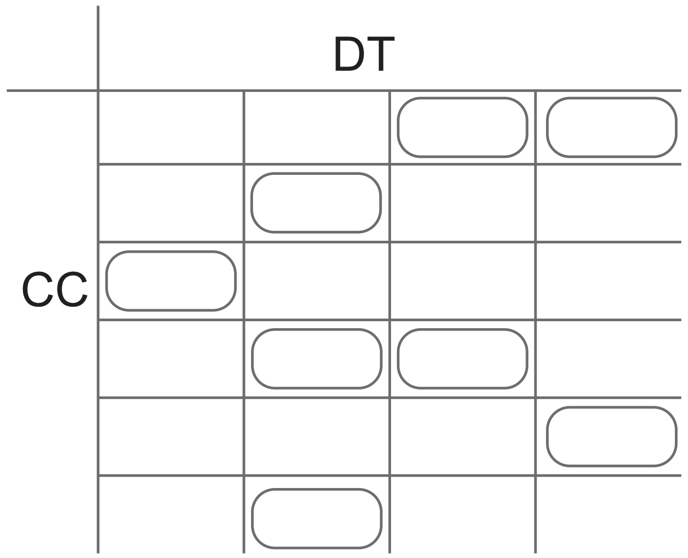
SQ3: How can we use DT technologies to implement circularity in construction projects?



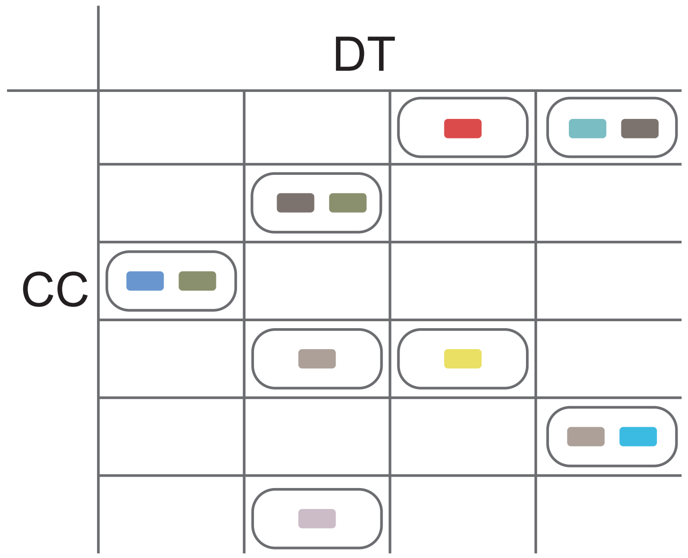
Wrap up



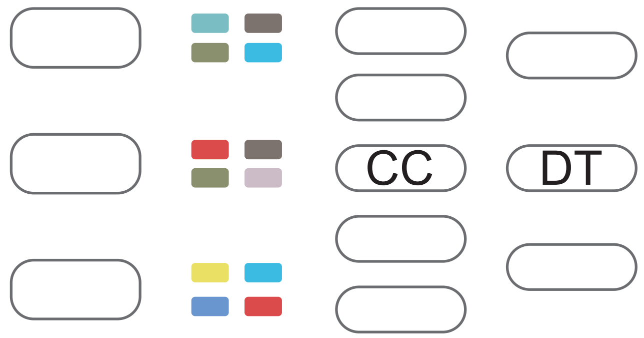
1.
Knowledge
framework



2.
Implementation
framework
canvas



3.
Management
framework
(primary)

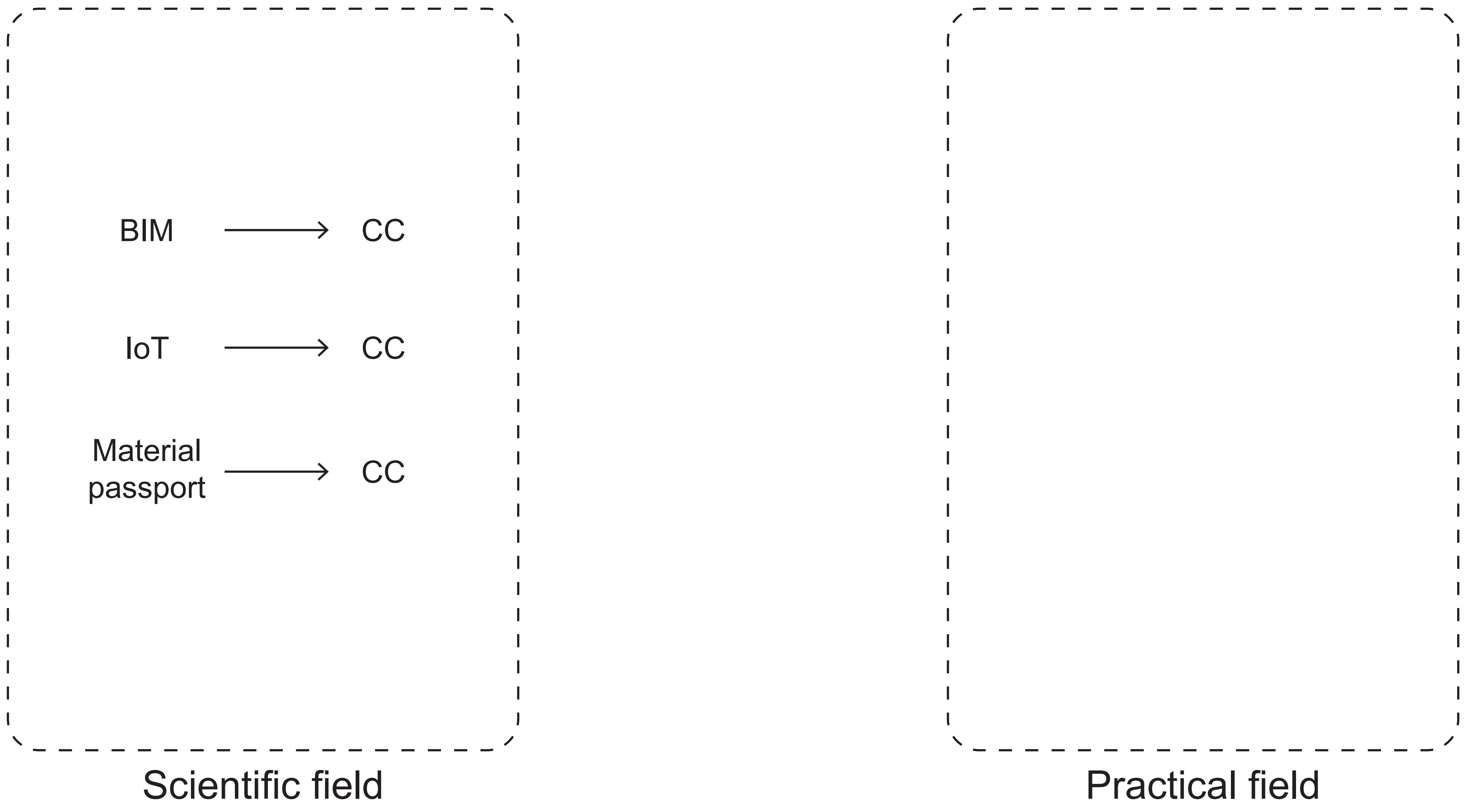


4.
Management
framework

Discussion

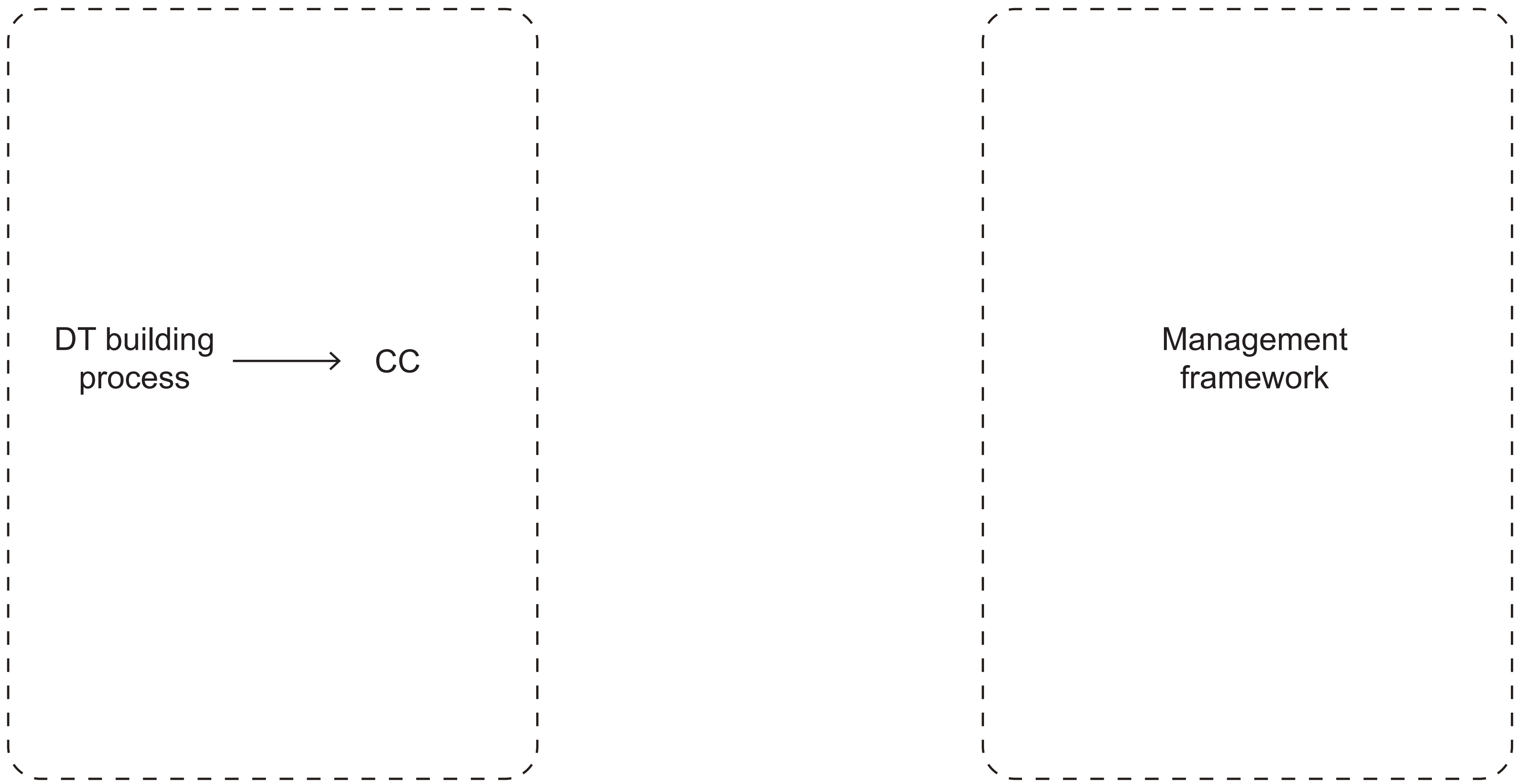
Discussion

Reflect on existing knowledge



Discussion

Reflect on existing knowledge

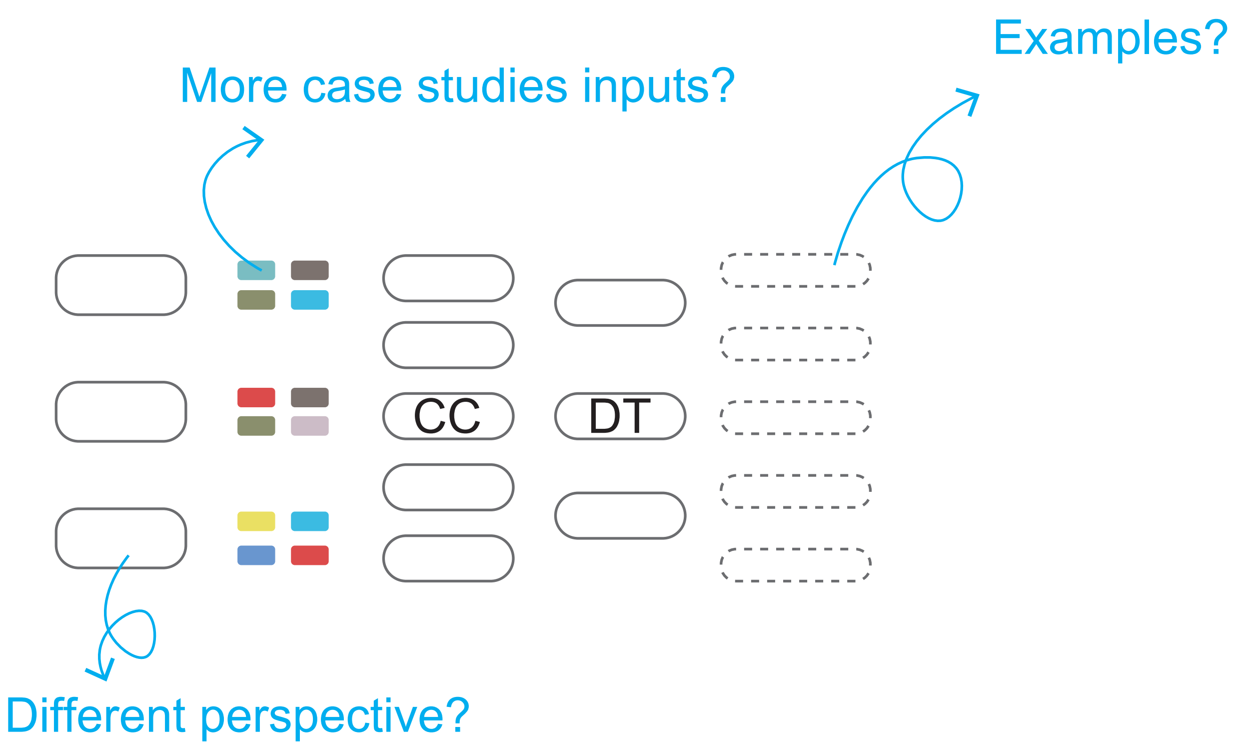


Scientific field

Practical field

Discussion

Furture approach



1.
Conduct more case studies, to make the results more concrete.

2.
Add practical activities in the management framework as examples.

3.
Add new perspectives in the management framework.

4.
Develop the management framework be more flexible in different projects.

Thanks for listening!

Questions?