Unlocking the value of Linked Building Data (LBD)

A lean and integrated management process of temporary construction items (TCIs)

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Agenda

I. State of the Art and Research Motivation

II. Research Design

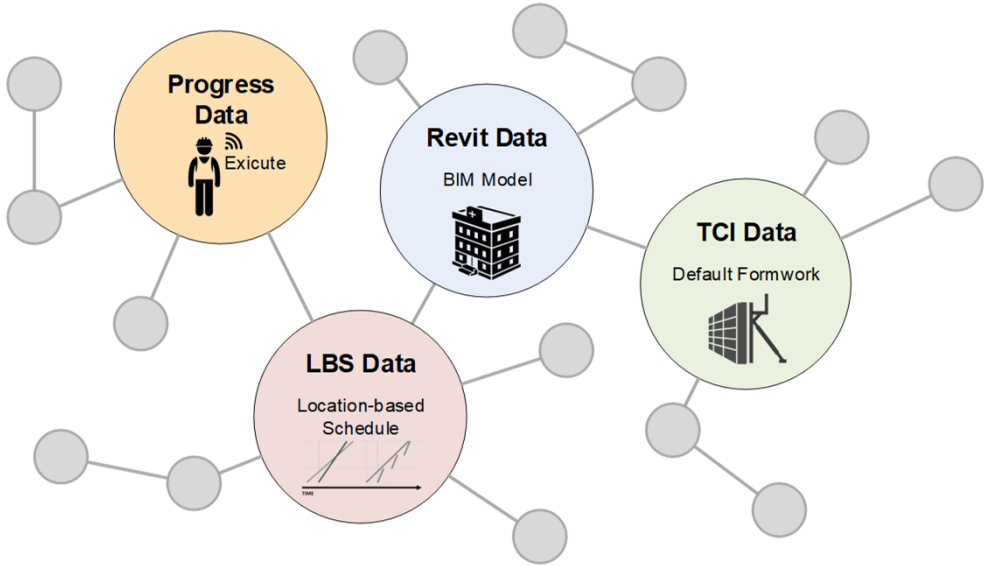
III. Proposed Concept Solution

IV. Prototyping - Demo Project

V. Prototyping - Case Study

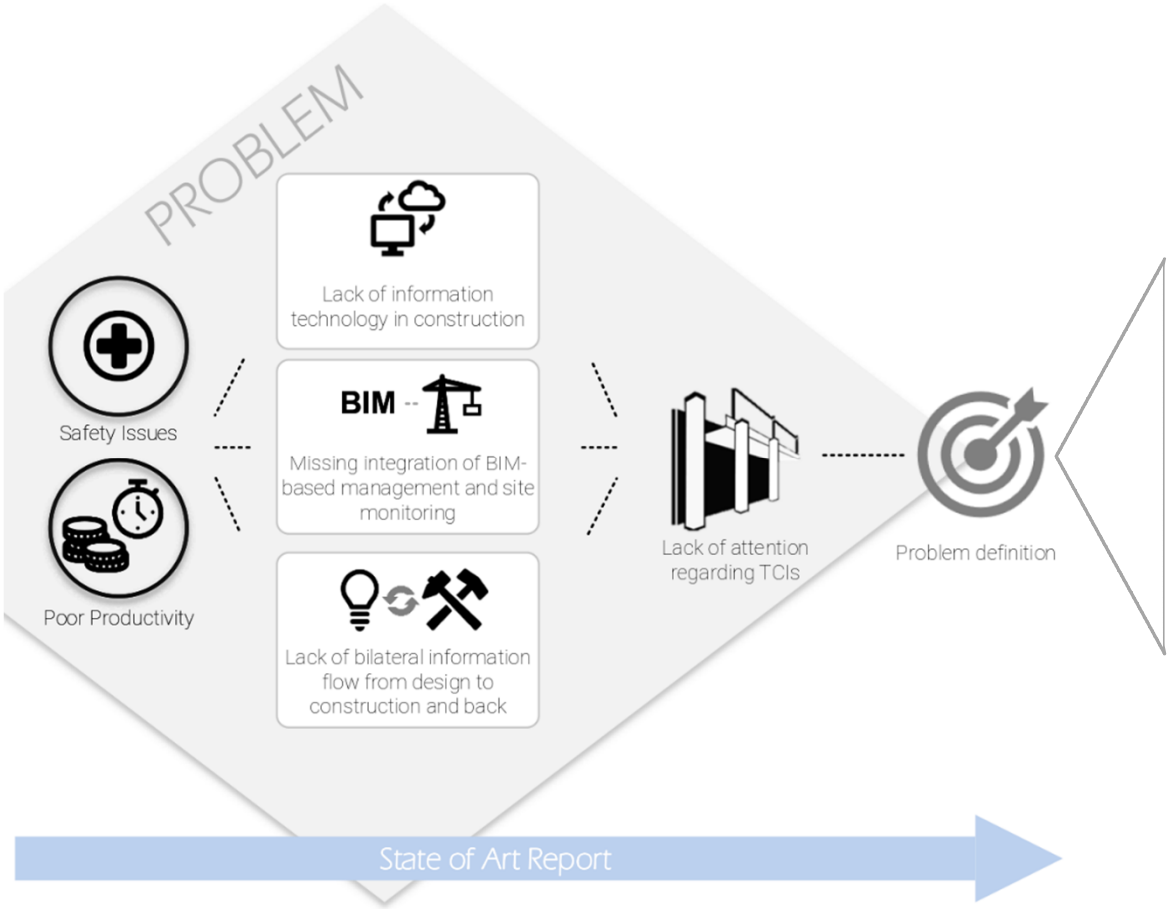
VI. Main Findings from Evaluation Interviews

VII. Reflection



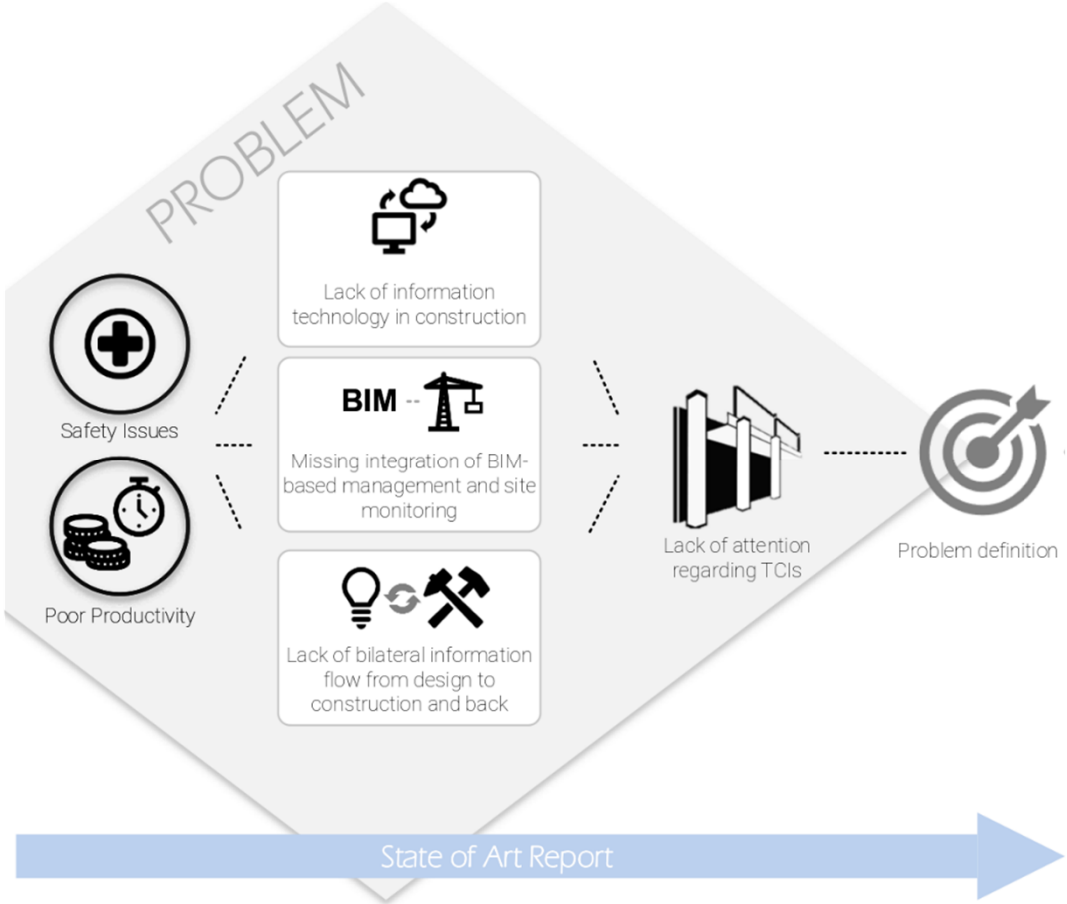
I. State of the Art and Research Motivation

State of Art – Problem Space



Today's construction industry is suffering from productivity and safety issues due to a lack of BIM and IT integration in construction processes, especially regarding temporary construction items (TCIs)

State of Art – Problem Space

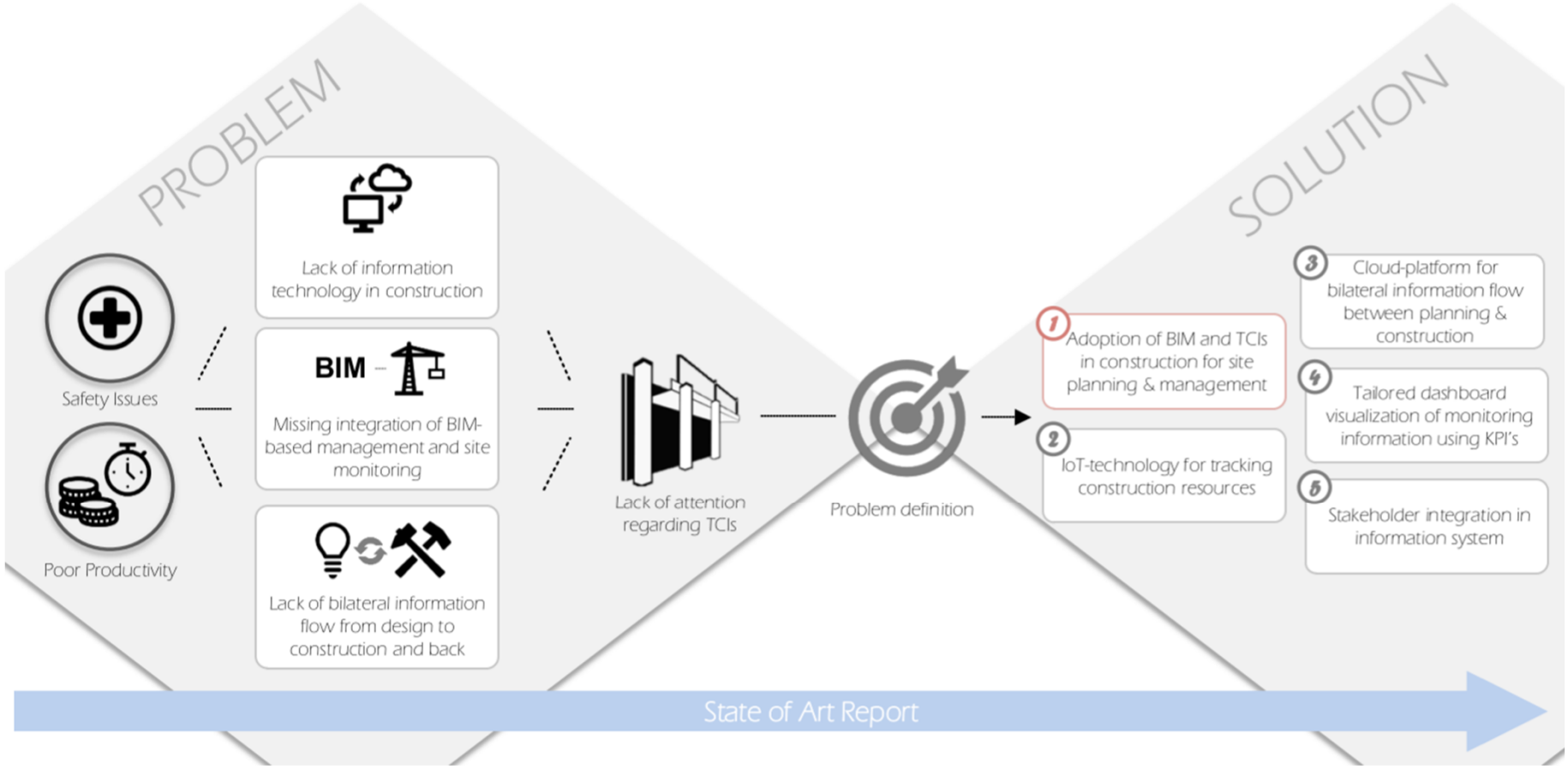


Items are just laying around the construction site, blocking access paths, or causing safety hazards for the construction workers. This was a common issue on site but considered a minor problem by

Temporary construction items are often only considered as an estimation from a very primitive and manual approach, and the site manager is the only person with the knowledge of the TCI utilization

– Contractor 4, Consultant 1, 2, Wu et al. (2018)

State of Art – Solution Space



Research Motivation

Problem Definition

Today's construction industry is suffering from productivity and safety issues due to a lack of BIM and IT integration in construction processes, especially regarding temporary construction items (TCIs)

Research Objective

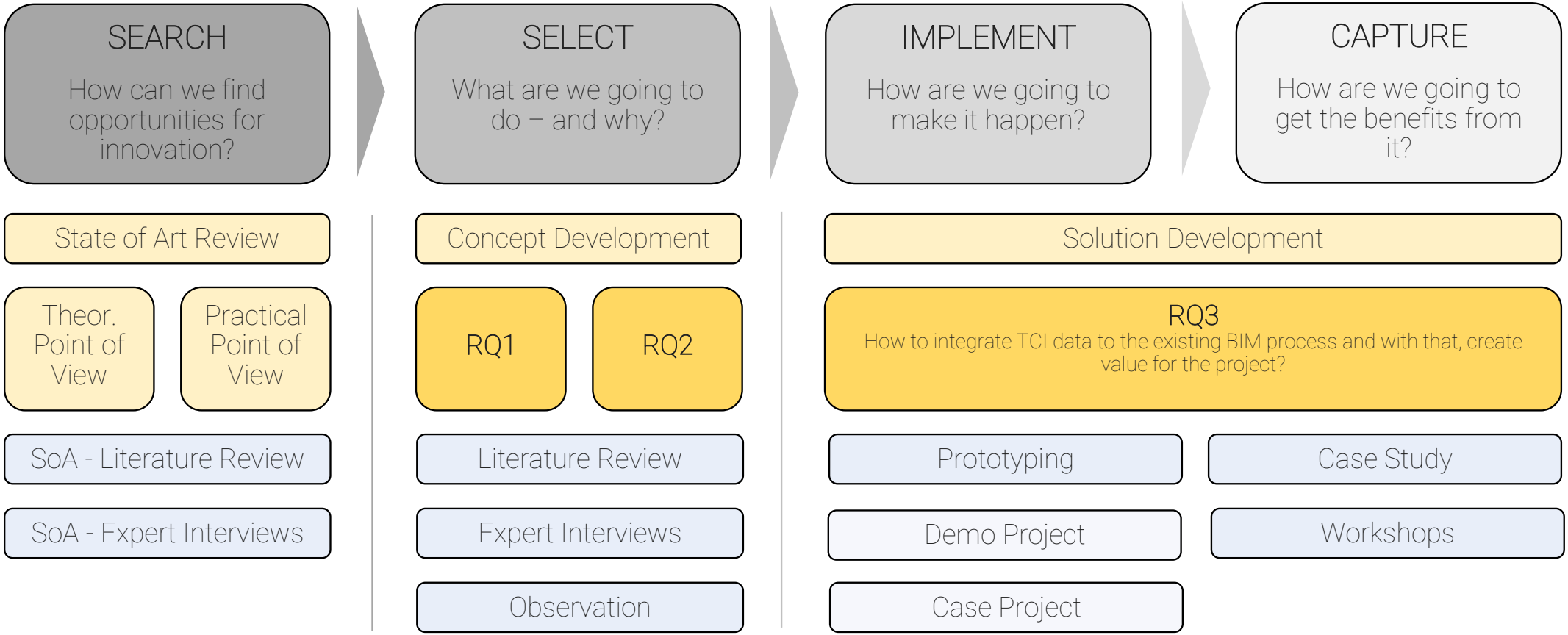
Developing an integrated and lean management process of temporary construction items (TCIs) with a data-driven information flow between planning and construction to improve productivity and safety on site

Main Research Question (RQ0)

How can productivity and safety issues at construction sites be resolved by improving the site and logistics management of temporary construction items?

II. Research Design

Managing Innovation (Tidd and Bessant, 2012)



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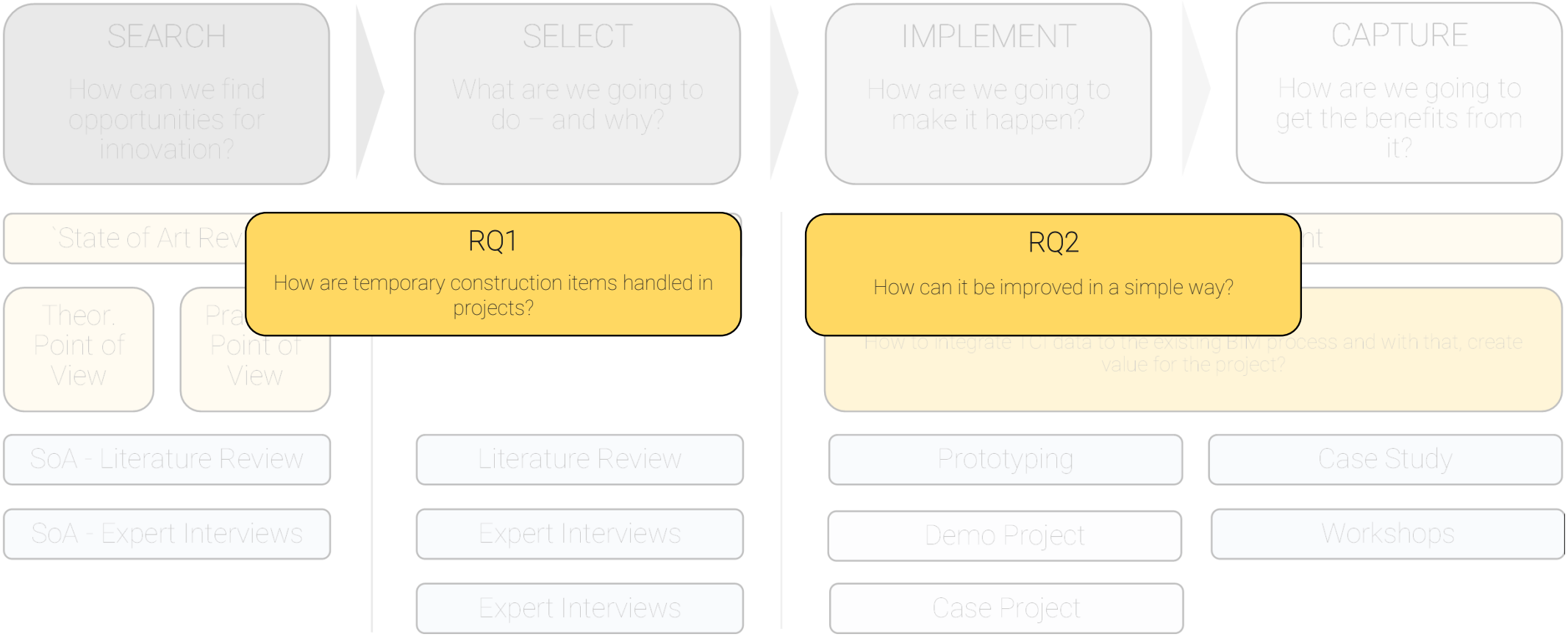

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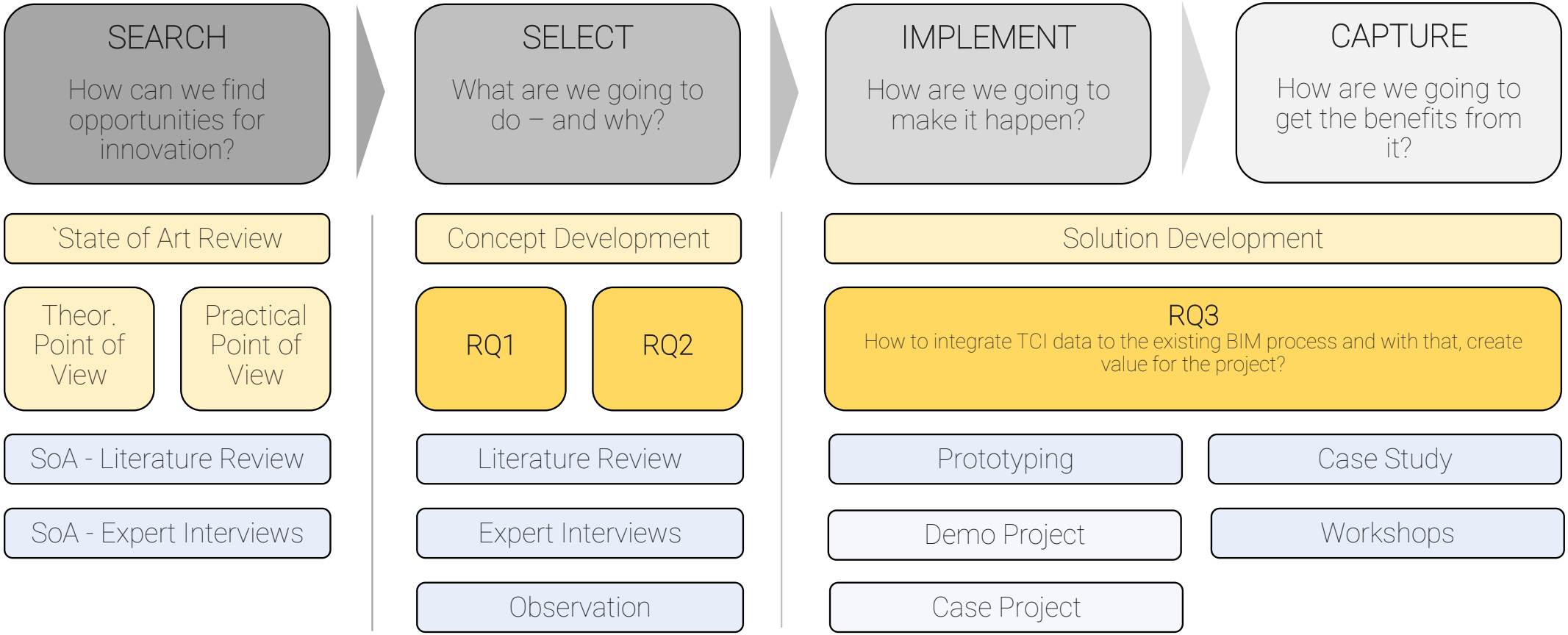
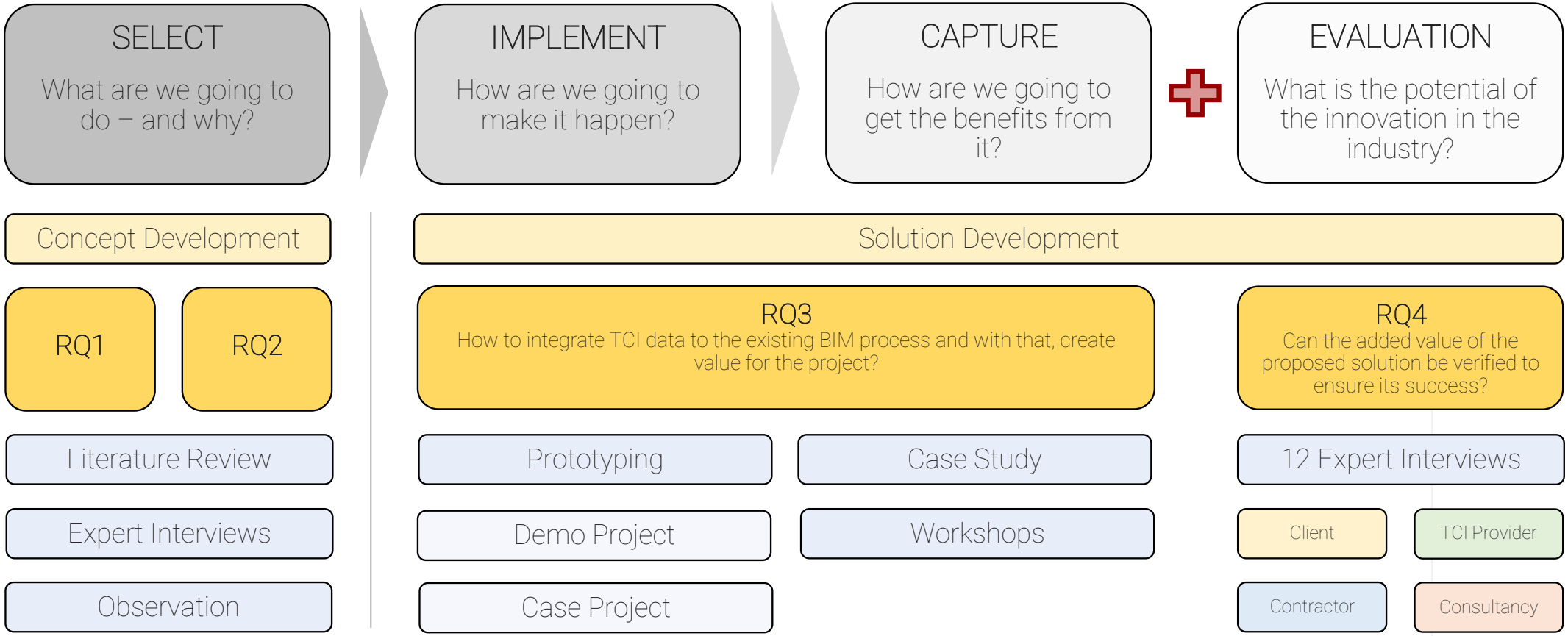
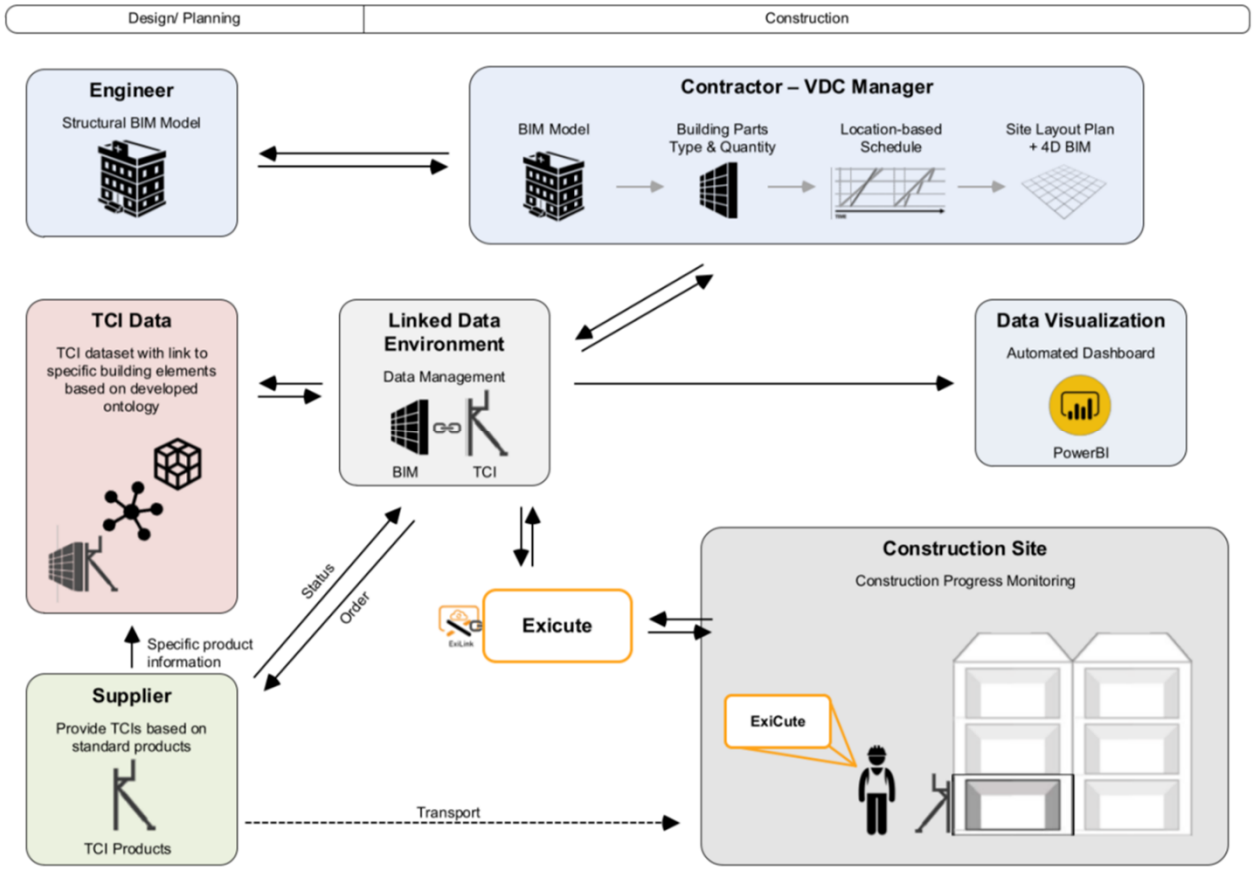


Qualitative Research Interviews (Kvale, 1996)



III. Proposed Concept Solution

Proposed Concept Solution

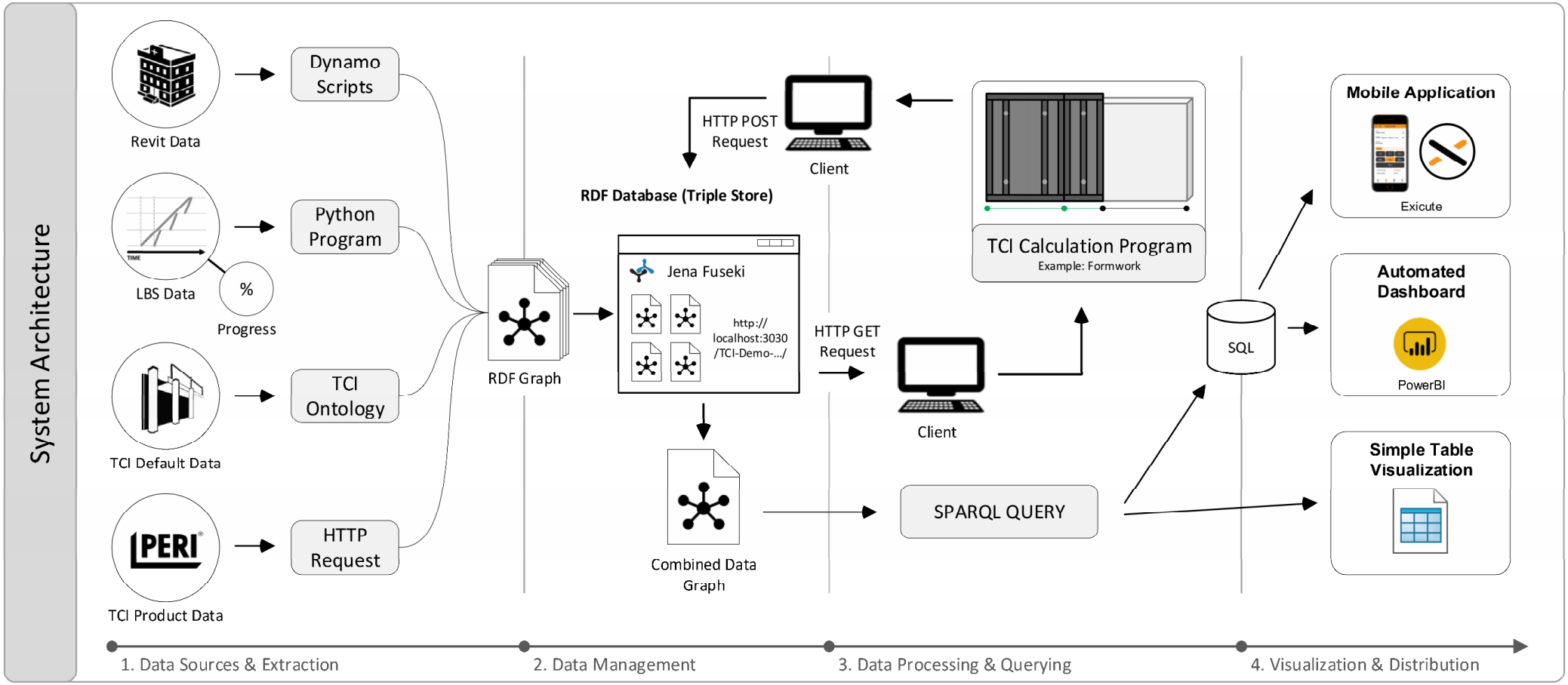


Goals to be accomplished

a) Automation
b) Identification of TCI demand
c) Linking BIM and TCI data
d) Time- and location-based TCI-utilization plan
e) Passive monitoring of TCIs with progress data
f) Data Visualization

IV. Prototyping - Demo Project

System Architecture



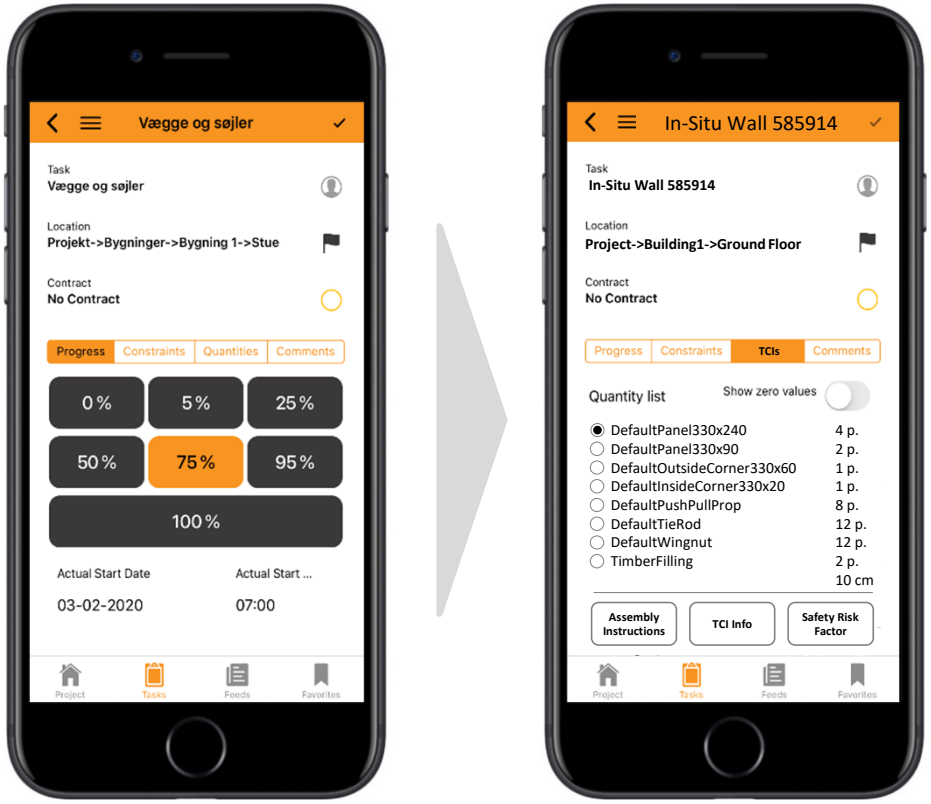
Data Processing & Querying

Desired Data to develop a TCI utilization plan

Revit		TCI					VICO		Exicute			
ElementID	props: length	Primary Formwork	Count	props: length	Secondary Formwork	Count	taskPlanned StartDate	taskPlanned EndDate	taskProgress Date	taskProgress Completion	taskActual StartDate	taskActual EndDate
string	*m*	*string*	*integer*	*m*	*string*	*integer*	*DateTime*	*DateTime*	*DateTime*	*%*	*DateTime*	*DateTime*
585914	6.20	Default Panel 330x240	4	2.40	Default Wingnut	12	2019-04-04 11:00	2019-04-08 07:28	2019-04-06 11:00	70.0	2019-04-04 11:00	NULL
		Default Panel 330x120	2	1.20	Default Tie Rod	12						
		Wooden filling material	2	0.20	Default Coupler	16						
					Default PushPull Prop	6						
					Default Waler	0						
644734	6.20	Default Panel 330x240	4	2.40	Default Wingnut	12	2019-04-08 07:28	2019-04-09 11:57	2019-04-08 16:00	100.0	2019-04-08 11:00	2019-04-08 16:00
		Default Panel 330x120	2	1.20	Default Tie Rod	12						
		Wooden filling material	2	0.20	Default Coupler	16						
					Default PushPull Prop	6						
					Default Waler	0						

Data Visualization & Distribution

Option 1: Exicute Cloud Platform

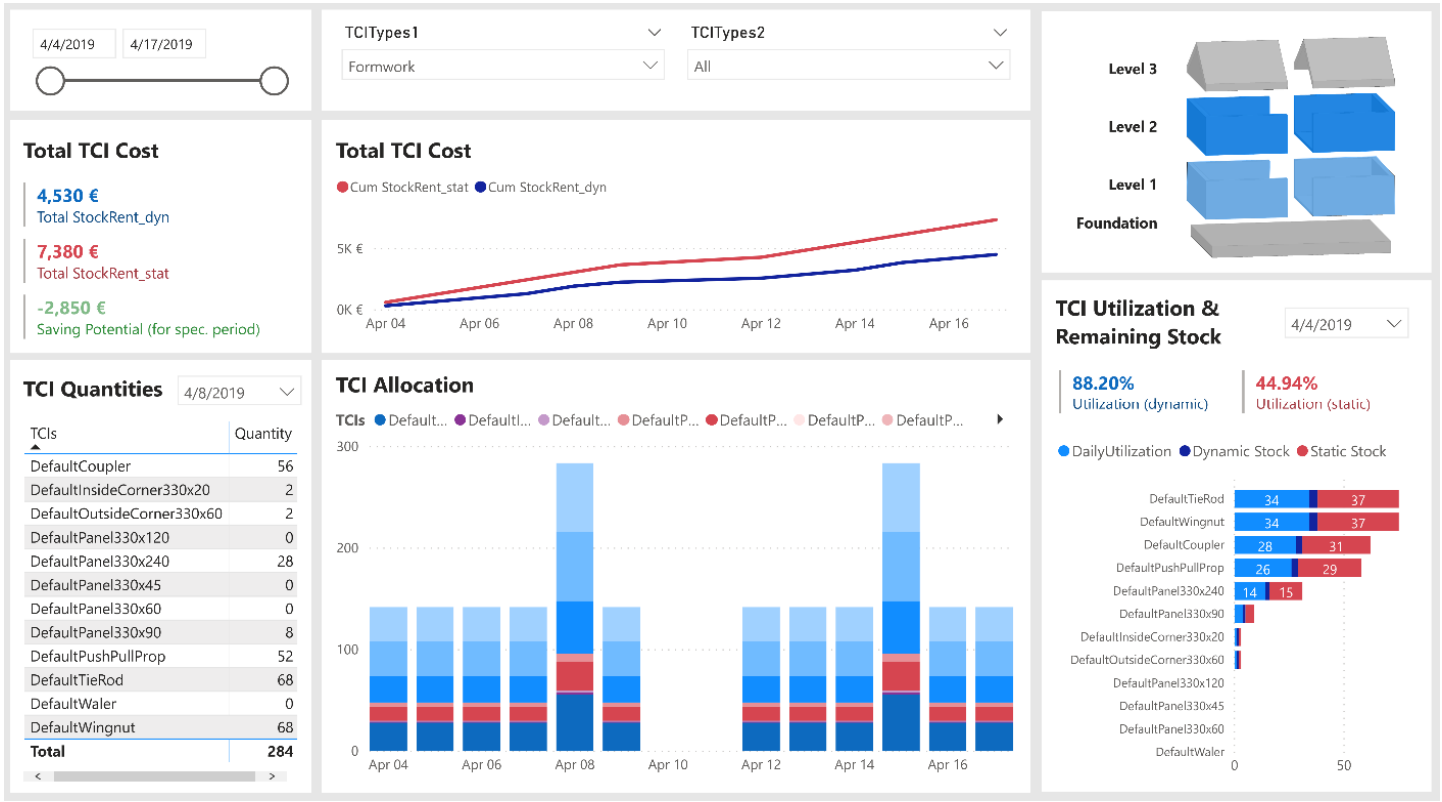


Integration in existing App

- Extension of the existing application "Ëxicute"
- New tab "TCI Quantities"
  - TCI quantities per task
  - Checklist for progress monitoring
  - Assembly instructions
  - Safety Risk Factor
- Conversion of output data into SQL format in order to implement it in Exicute
- Platform solution for bringing BIM data to the construction site and monitor the progress

Data Visualization & Distribution

Option 2: Power BI Dashboard Visualization



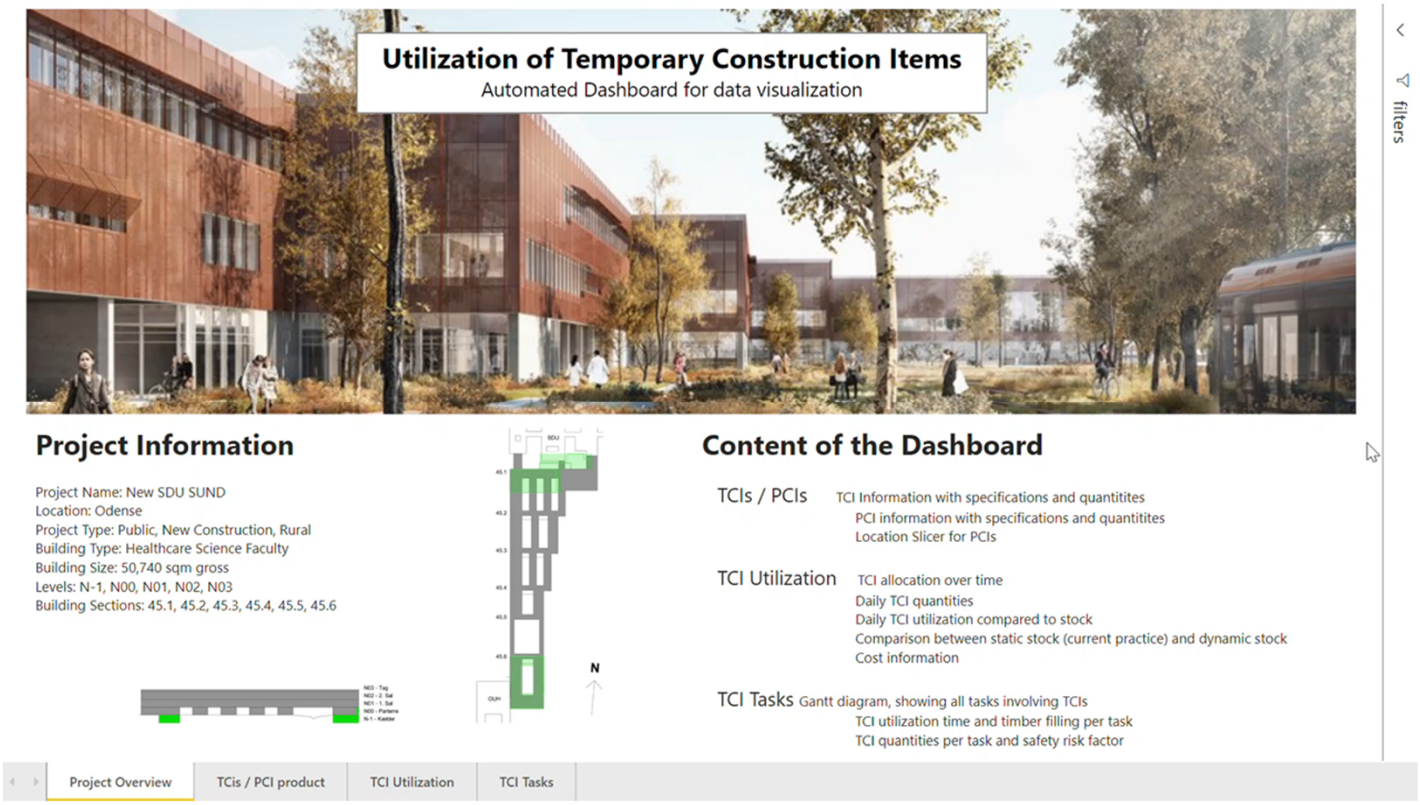
Automated Dashboards

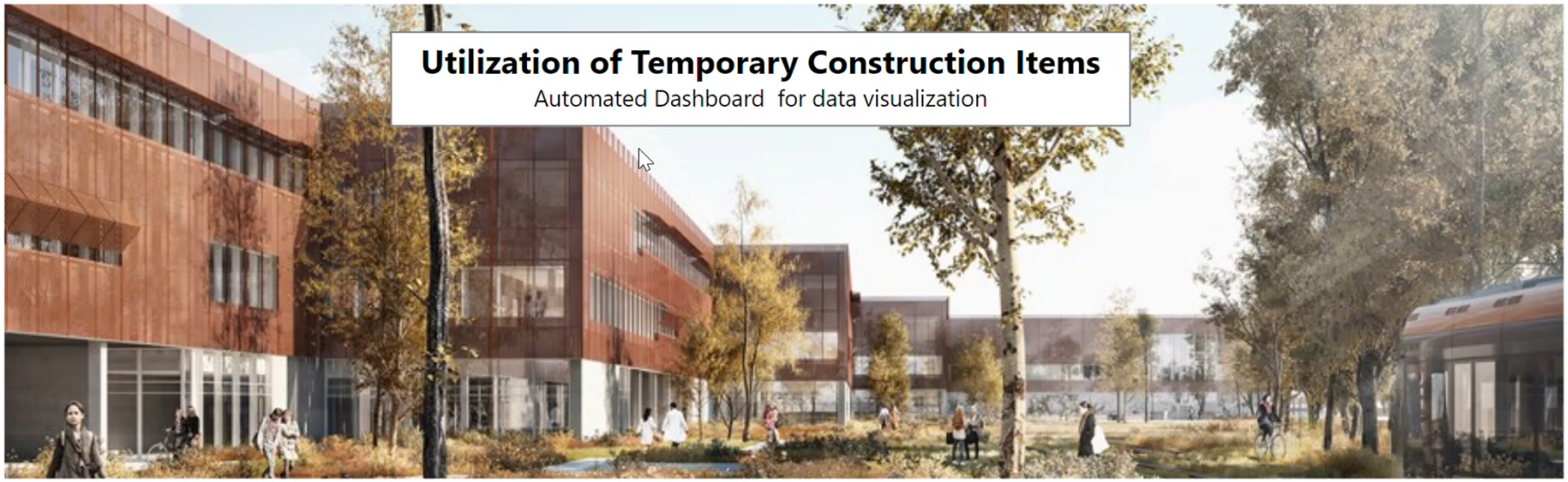
- Direct link between triple store and Power BI over SQL
- TCI utilization plan for the entire time of construction
- Utilization of exploded model view to locate tasks
- Quantities & types of TCIs for each construction task
- Comparison between static and dynamic stock
- Etc.

V. Prototyping - Case Study

Case Study – Results

Power BI Dashboard Visualization – Walkthrough Video





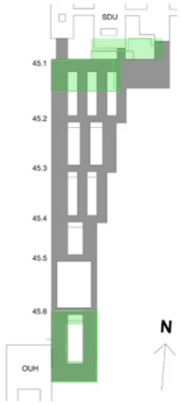
Utilization of Temporary Construction Items

Automated Dashboard for data visualization

Filters

Project Information

Project Name:	Nyt SDU SUND
Location:	Odense
Project Type:	Public, New Construction, Rural
Building Type:	Healthcare Science Faculty
Building Size:	50.740 m² brutto
Levels:	N-1, N00, N01, N02, N03
Building Sections:	45.1, 45.2, 45.3, 45.4, 45.5, 45.6



Content of the Dashboard

TCIs/PCIs

- TCI Information with specifications and quantitites
- PCI information with specifications and quantitites
- Location Slicer for PCIs

TCI Utilization

- TCI allocation over time
- Daily TCI quantities
- Daily TCI utilization compared to stock
- Comparison between static stock (current practice) and dynamic stock
- Cost information

TCI Tasks

- Gantt diagram, showing all tasks which involve TCIs
- TCI utilization time and timber filling per task
- TCI quantities per task and safety-risk-factor

Project Overview | TCIs/PCIs | TCI Utilization | TCI Tasks

VI. Findings from Evaluation Interviews

Main Findings from Evaluation Interviews

Interviewee Count

11

General Validation of the Solution

Solution presents a good way to bridge design and construction with an integrated data environment, where both site planning and management can benefit from the improved control and transparency of the TCI utilization, leading to a more lean and safer management of the construction site

7

Data Integration as Niche Solution

Automatic generation of the TCI utilization plan by using and integrating existing project data is targeting a niche in construction which is not yet fully optimized

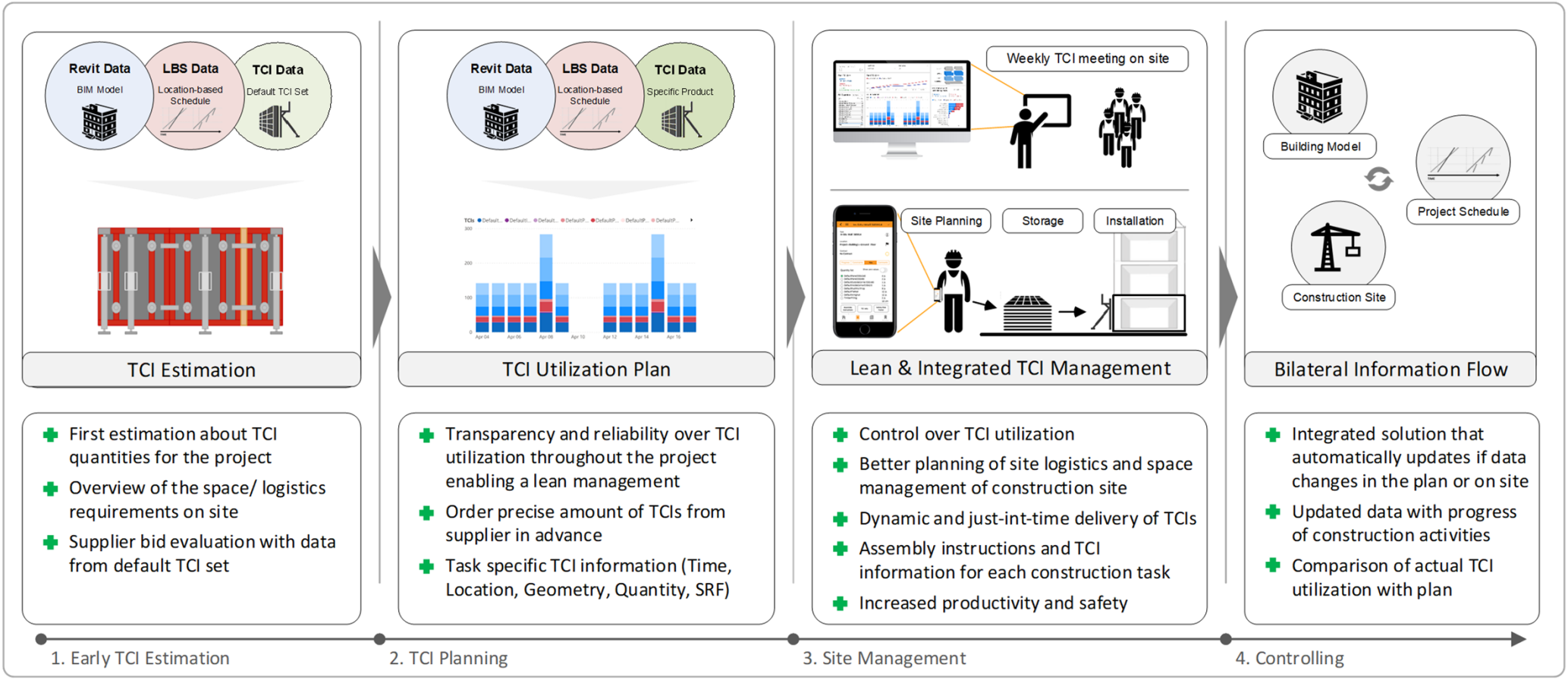
10

Productivity and Safety Increase

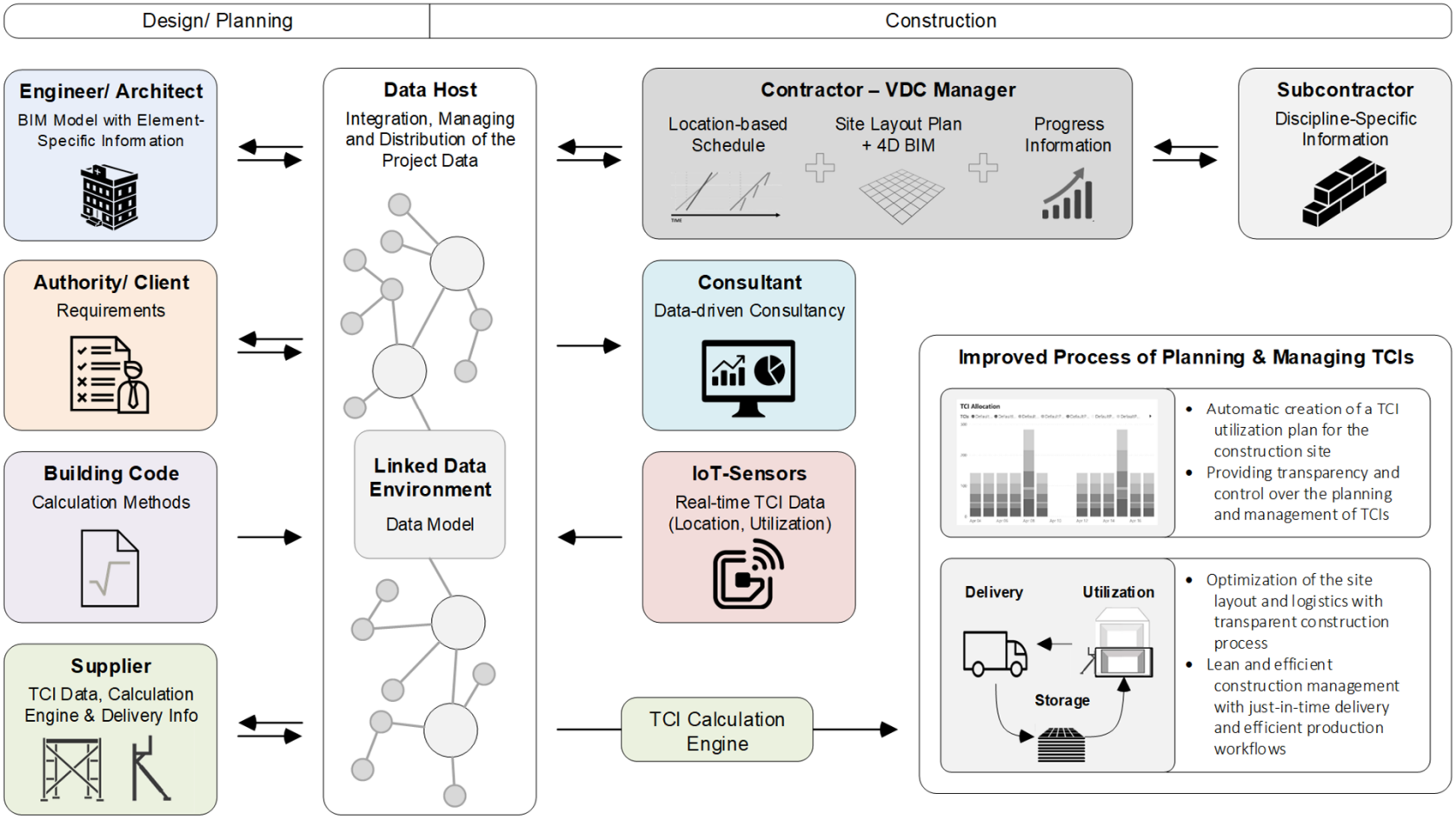
Obvious productivity increase as identified by almost all interviewees and safety improvement as a secondary effect due to more transparency, control and lean management on site

VII. Reflection

Solution Application – Process Flow & Added Value



New Project Delivery System (Linked Data Vision)



Reflection of the Developed Solution

- Limitations

1. Only Revit and VICO are tested for data extraction
2. Building model must be set up correctly to ensure data integrity
3. Solution requires a data-driven project delivery as manual input for the TCI utilization plan is not yet considered
4. Only addressing the use case of formwork elements
5. Formwork algorithm only considers geometry in 2D
6. Linked Data approach requires a lot of change management and further development in the industry

- Further development & research

1. Further prototyping step is needed where the solution is applied as a pilot project to identify areas for further improvements and quantify the added value for all stakeholders
2. Further develop the solution to use active tracking of TCIs using IoT-technology and to integrate other TCIs into the solution as scaffolding and safety barriers.
3. Development of a standardized ontology framework for the construction industry to describe building data in its holistic context
4. Future vision requires the stakeholder to publish their data via RDF and thus, the industry must further develop in terms of the technology level of all stakeholders

Questions/

Feedback?

IX. Appendix

Introduction

1. Little attention regarding the use of advanced technologies to consider TCIs in construction planning and management

2. Inefficient logistics management, construction processes and storage of TCIs on site due to little transparency → Overstock (avoidable rent, storage space, logistics)

3. Poor construction site planning, especially regarding TCIs

4. Discontinued information flow from design to construction

Quotes

Little attention regarding the use of advanced technologies to consider TCIs in construction planning and management

- Site manager is the only guy who can manage the site. If he is sick, everything falls apart. "I'm scared of, if a guy like that leaves or gets sick for a week..." --> The site plan is solely in his head --> Blocking information flow as it is not documented and planned. That's the problem! – **Consultant 1**
- "Either tender list where the designer lists up a lot of different potential things, he thinks that the site might need for temporary works. Or it is just a percentage of the total cost and the designers will never be wiser because the information flow never gets back.“ – **Consultant 1**
- “Planning of TCIs is still done in a very primitive and manual approach based on Excel data which is extracted form the building volume. Based on this rough estimation, TCIs are ordered from supplier”- **Consultant 3**

Quotes

Inefficient logistics management, construction processes and storage of TCIs on site due to little transparency

→ Overstock (avoidable rent, storage space, logistics)

- **Example of Consultant 1: "**If a construction site needs to assemble 50 forms for erecting concrete at peak time, in common practice the site manager would roughly estimate this amount during site employment and order 50 forms. This formwork is then rented for the whole time of construction where it is stored and used alternately. In reality, 50 forms are only needed at the peak time of construction and apart from that only 30 forms are needed to facilitate the normal construction pace. In this situation, it would be nice to tell the logistics centre of the contractor to only provide 30 forms which will constantly stay on site. As soon as the peak time is in reach, 20 more forms are delivered on site but only stay on site for the peak period. After the normal construction pace is set again, the surplus forms can be used on another construction site or returned to the supplier."
- "Due to little transparency of the TCI utilization, the client has to conduct labour-intensive inspections on site in order to validate the quantities of TCIs that the contractor is charging" – **Client 1**
- "Soon I'll be running out of space on the job site to put the formwork. Where shall I put the formwork?" – **TCI Provider 3**
- "No information regarding TCIs on site means inefficient storage of items and an oversized stock of TCIs to prevent shortcomings, resulting as well in a lot of inefficiently used space on site." **– Consultants 1, 2, and TCI Provider 2**
- **The site observation** revealed that several items are just laying around the construction site, blocking access paths, or causing safety hazards for the construction workers. This was a common issue on site but considered a minor problem by the construction workers as this situation is what a construction site normally looks like.
- "Formwork elements which are currently not used are stored in some corner on site and when the item is needed again, the workers might have forgotten where it is and have to look for it or simply order a new form" – **Contractor 4**

Quotes

Poor construction site planning, especially regarding TCIs

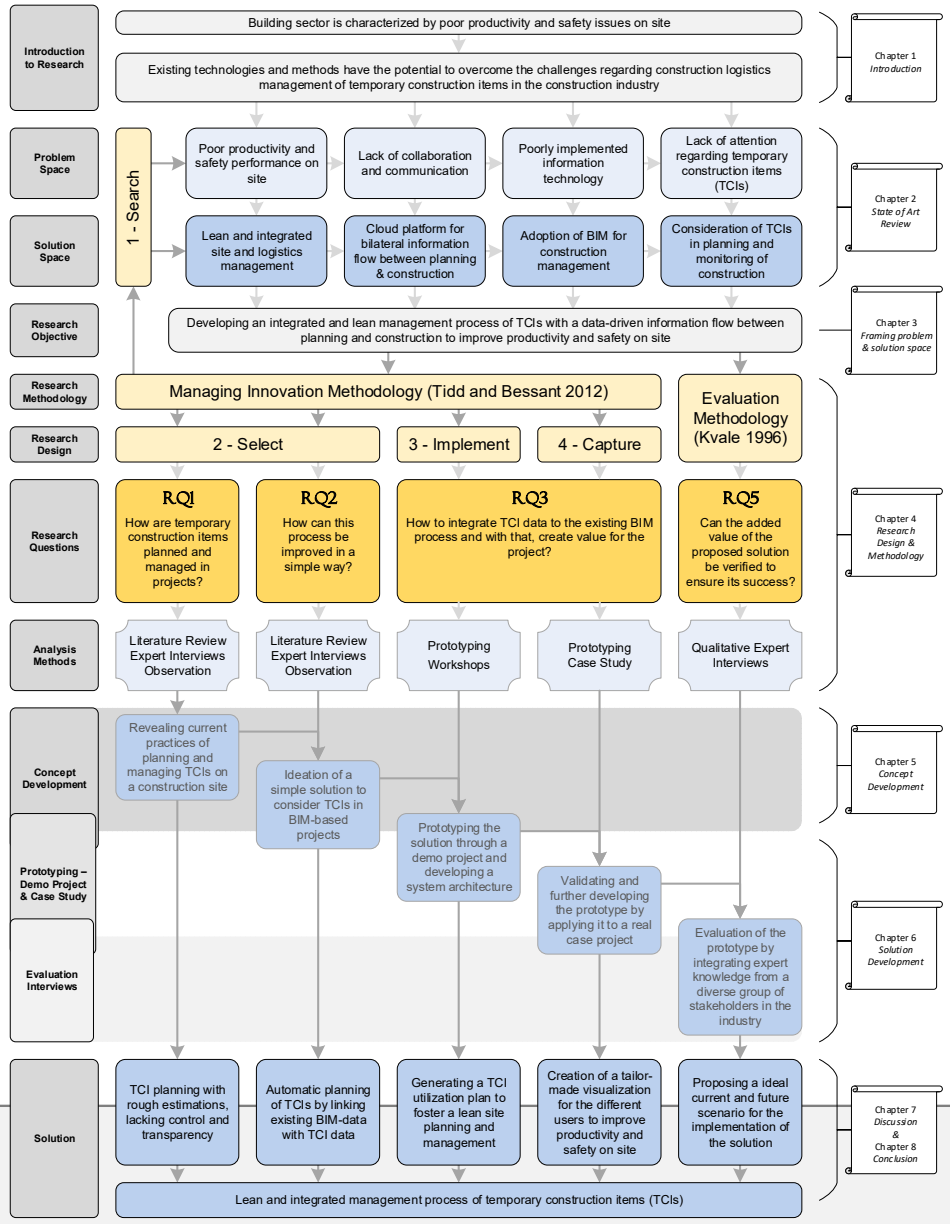
- "As contractors and subcontractors handle the construction site with a day-to-day problem-solving mentality and are not looking far enough ahead to have that degree of planning that we need, poor productivity as well as safety issues are experienced on site" – **Consultant 2**
- **Example of Consultant 2**: "In a previous job, a situation was experienced where an intern was supposed to find a movable scaffolding platform on site but nobody knew where it was and they paid the renting bill for two years --> In the end the construction manager paid much more in rental fees than the material would have cost because nobody knew where it is"
  → This example clearly reveals the indifferent attitude of the construction management towards TCIs
- "Soon I'll be running out of space on the job site to put the formwork. Where shall I put the formwork?" – **TCI Provider 3**
- "a correct choice, good planning, designing and operation of temporary structures are keys for the success of every construction project" - **Beale and André 2017, p. 439**
- "Many construction manager/ foremen order a lot of formwork elements, to be sure that is will be enough for the project!" – **Contractor 1**
- "Temporary construction items are only included as an estimate or percentage of the total cost but is often not planned and monitored properly. It is not sure what is there on site, who is using it, and sometimes they just disappear because they are neither planned nor tracked." - **Consultant 2**

Quotes

Discontinued information flow from design to construction

- "In order to better manage TCIs on site, they first have to be fully integrated in the planning of the construction project to then use the information on site" – **Consultant 1**
- *"Decisions about TCIs already have an impact in the design phase, but the effort of considering TCIs still mainly takes place late during construction"* – **TCI Provider 2**
- "In bigger projects, TCIs are already planned in detail, but what is missing is the process in between from the planning to the site to have a continued information flow from planning to construction"- **Contractor 3**
- "Successful project delivery can be accomplished if continuous knowledge exchange and synchronised planning of TCIs with all relevant stakeholders are established" - **Beale and André 2017, p. 439**

Research Design



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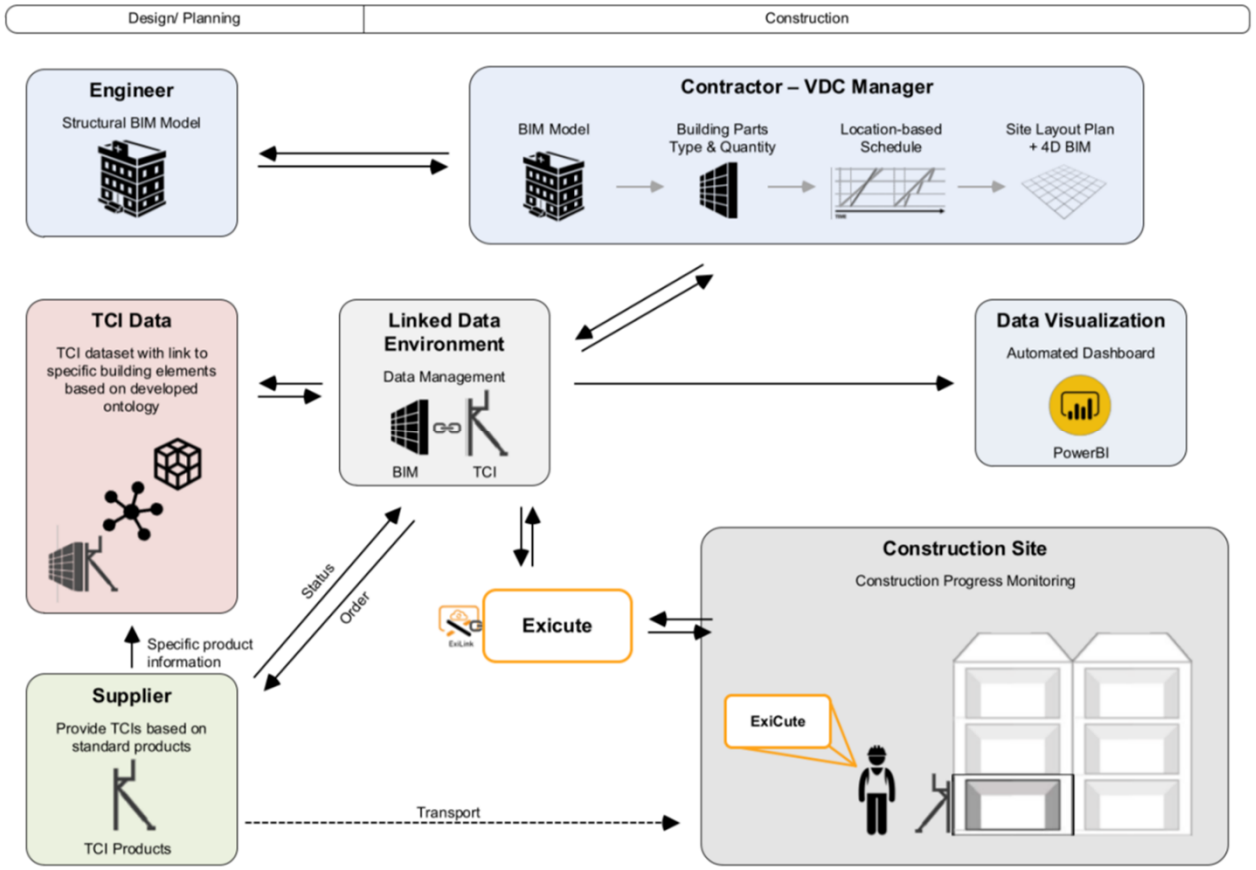


Goals to be accomplished

a) **Automatically** evaluate the building model geometry

b) **Identify required TCIs** to each building element of the building model by applying the rule-based algorithm

c) **Link the building objects** with their respective TCI-information to the building locations and schedule

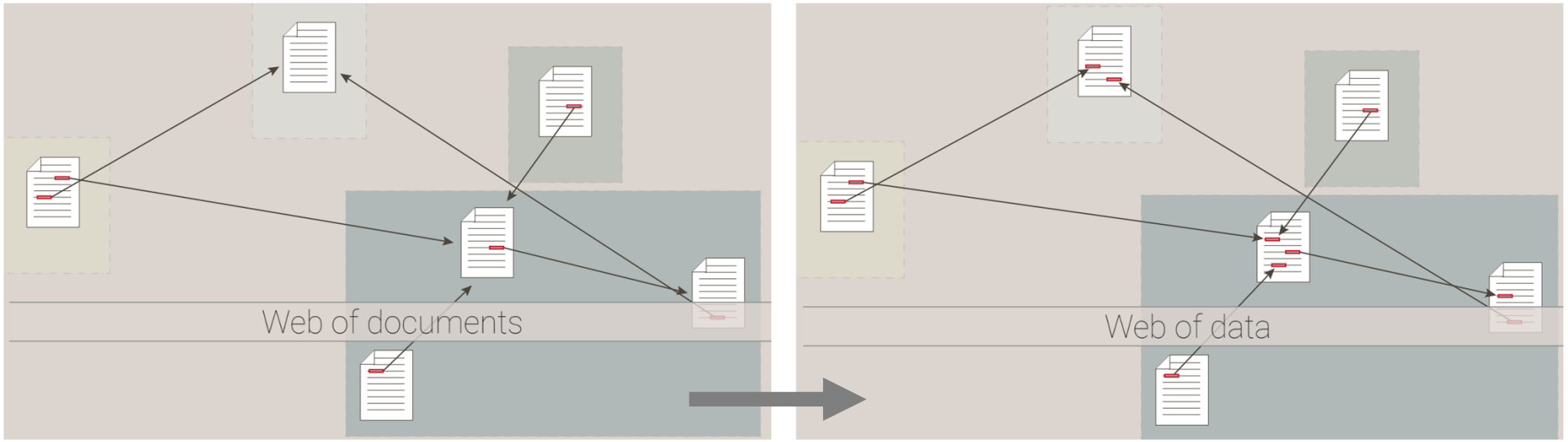
d) Develop a **TCI-utilization plan** based on the building elements, their locations and schedule information

e) Enable **passive monitoring** of the TCI items with progress monitoring data

f) **Visualize data automatically** and interactively for all relevant stakeholders

III. Linked Data Introduction

Linked Data

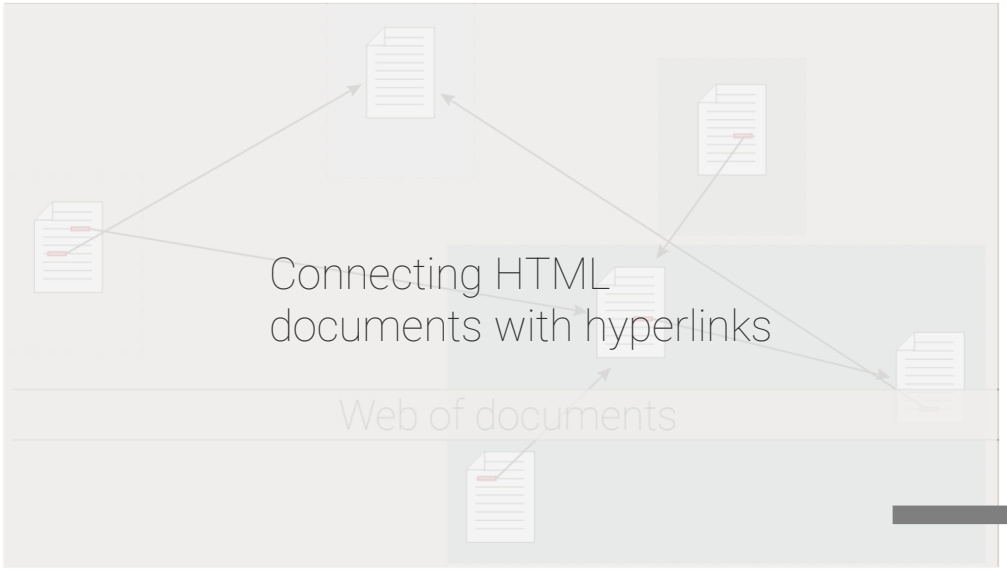


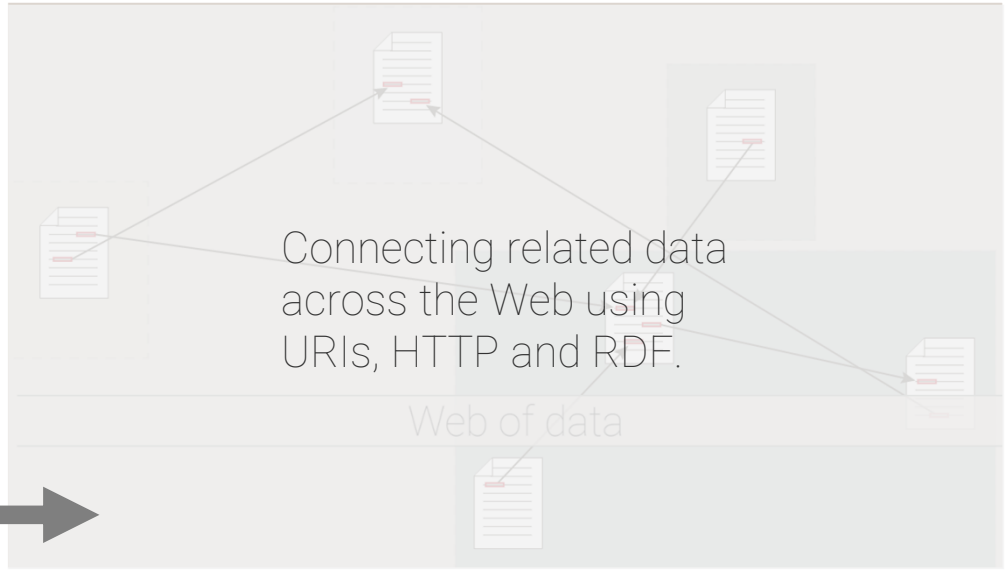
Linked Data principles

1. Use URIs as names for things
2. Use HTTP URIs so that people can look up those names
3. When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL)
4. Include links to other URIs. so that they can discover more things

Source: http://www.student.dtu.dk/~mhoras/presentations/20200305_bSNorway.html#/10/8

Linked Data





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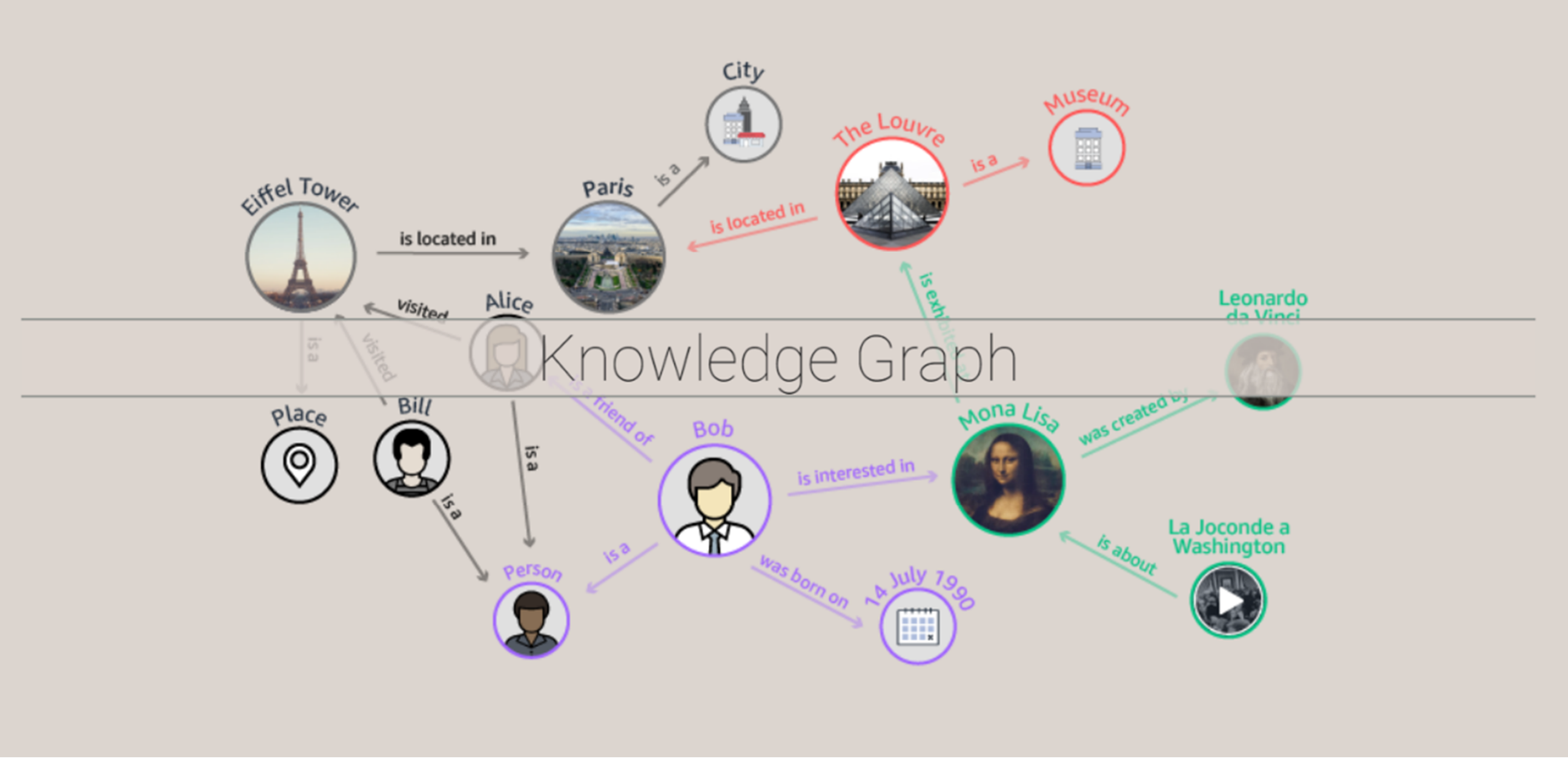


Source: http://www.student.dtu.dk/~mhoras/presentations/20200305_bSNorway.html#/10/8

Linked Data

RDF (Resource Description Framework)

Query Data Graphs with SPARQL Queries
(Similar to SQL Queries)

```
@prefix inst:   <https://my-awesome-knowledge-graph.org/resources/> .
@prefix rdf:    <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix schema: <http://schema.org/> .

inst:Eiffel_Tower   rdf:type    schema:Place .
inst:Paris          rdf:type    schema:City .
inst:Bill           rdf:type    schema:Person .
inst:Alice          rdf:type    schema:Person .
inst:Bob            rdf:type    schema:Person .
inst:The_Louvre     rdf:type    schema:Museum .
```

Assign Subjects to Classes

```
@prefix inst:   <https://my-awesome-knowledge-graph.org/resources/> .
@prefix xx:     <https://my-awesome-knowledge-graph.org/ontology/xx#> .

# RELATIONSHIPS
inst:Eiffel_Tower               xx:is_located_in        inst:Paris .
inst:Alice                      xx:visited              inst:Eiffel_Tower .
inst:Bill                       xx:visited              inst:Eiffel_Tower .
inst:Bob                        xx:is_a_friend_of       inst:Alice .
inst:Bob                        xx:is_interested_in     inst:Person .
inst:Bob                        xx:was_born_on          "14 July 1990" .
inst:Mona_Lisa                  xx:is_exhibited_at      ints:The_Louvre .
ints:Mona_Lisa                  xx:was_created_by       ints:Leonardo_da_Vinci .
ints:La_Joconde_a_Washington    xx:is_about             ints:Mona_Lisa .
```

Define relations between Subjects

Source: http://www.student.dtu.dk/~mhoras/presentations/20200305_bSNorway.html#/10/8

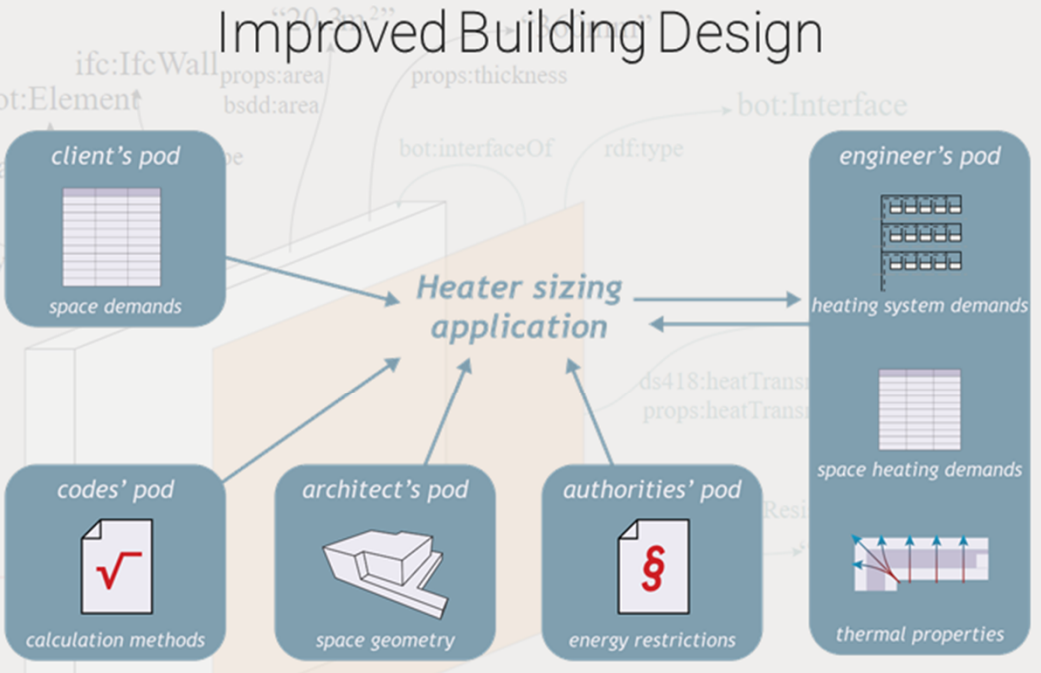
IV. Linked Data in Construction

Linked Building Data (LBD) - Example

Data is stored and hosted by the stakeholder who generated it and is responsible for it

Data can be shared with authenticated people or be made publicly available

The model data can be extended with Linked Open Data (products, material properties, IoT, GIS)



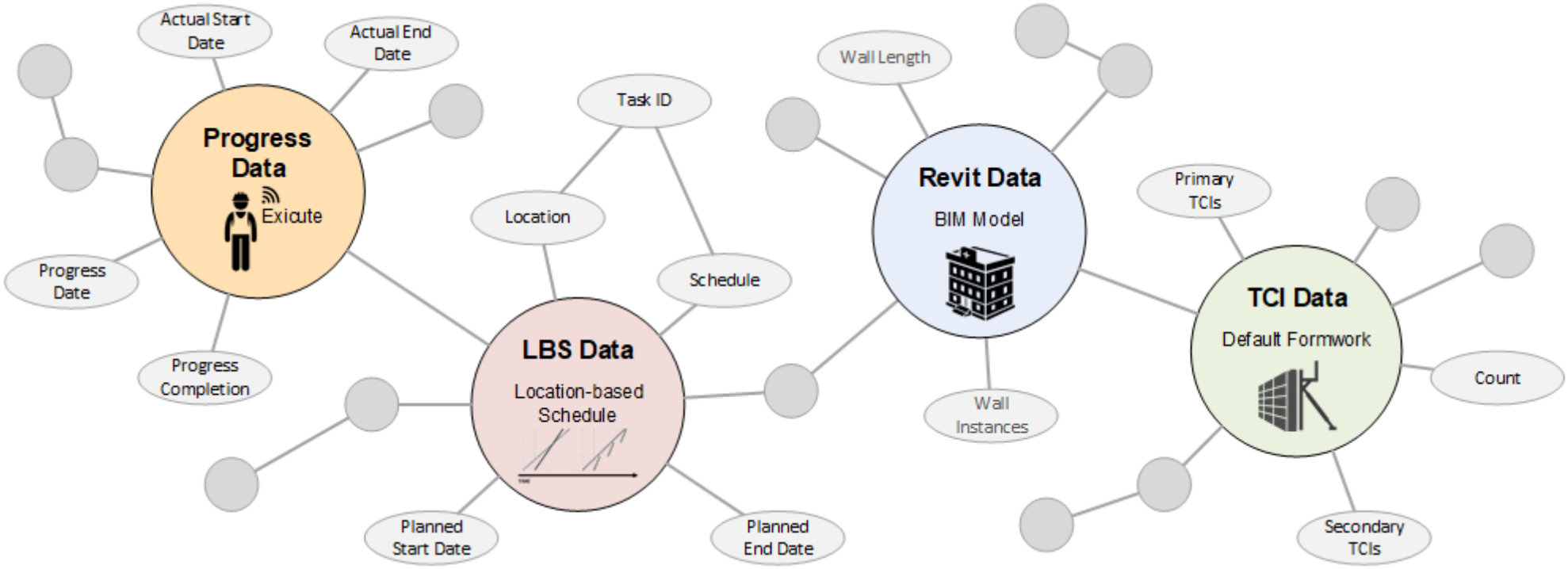
Source: http://www.student.dtu.dk/~mhoras/presentations/20200305_bSNorway.html#/10/8

V. Prototyping - Demo Project

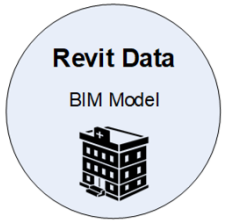
Data Sources

... Important parameter for TCI utilization

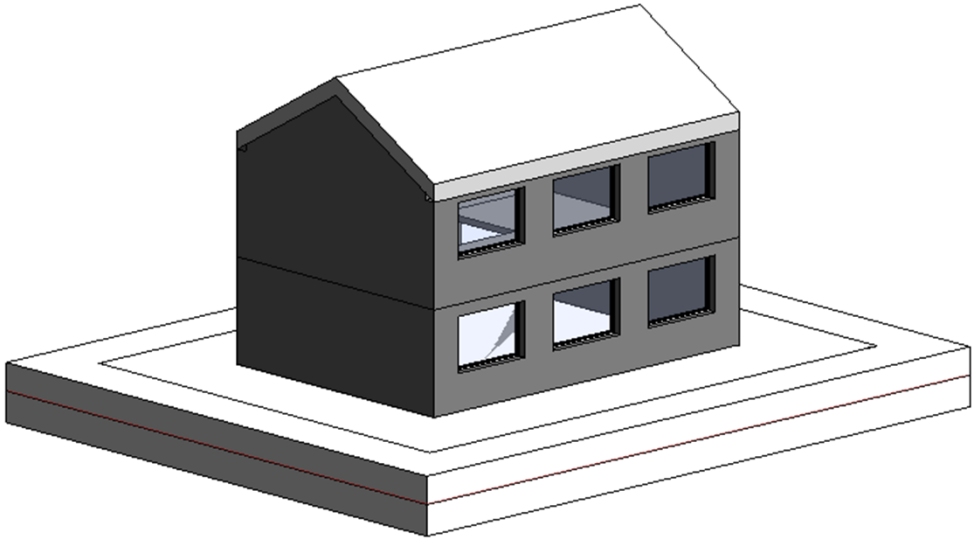
Formwork Example



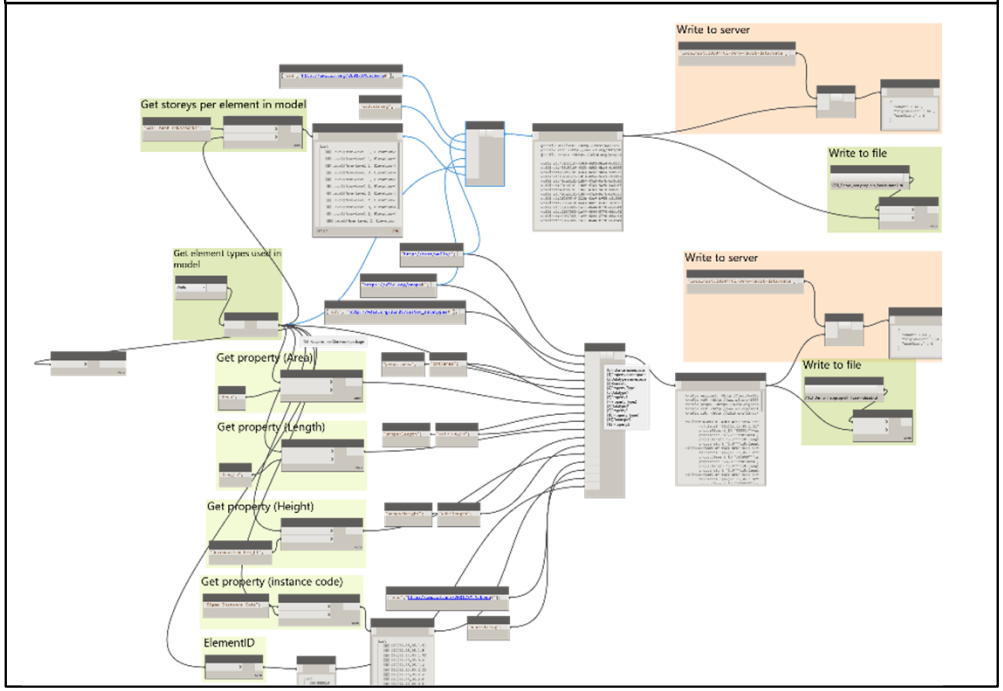
Building Model - Revit



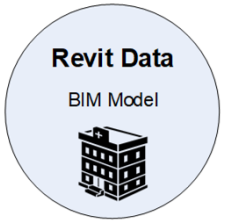
Data Generation in Revit



Data Extraction in Dynamo



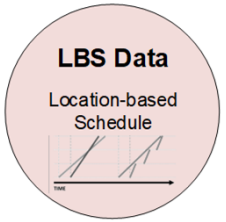
Building Model - Revit



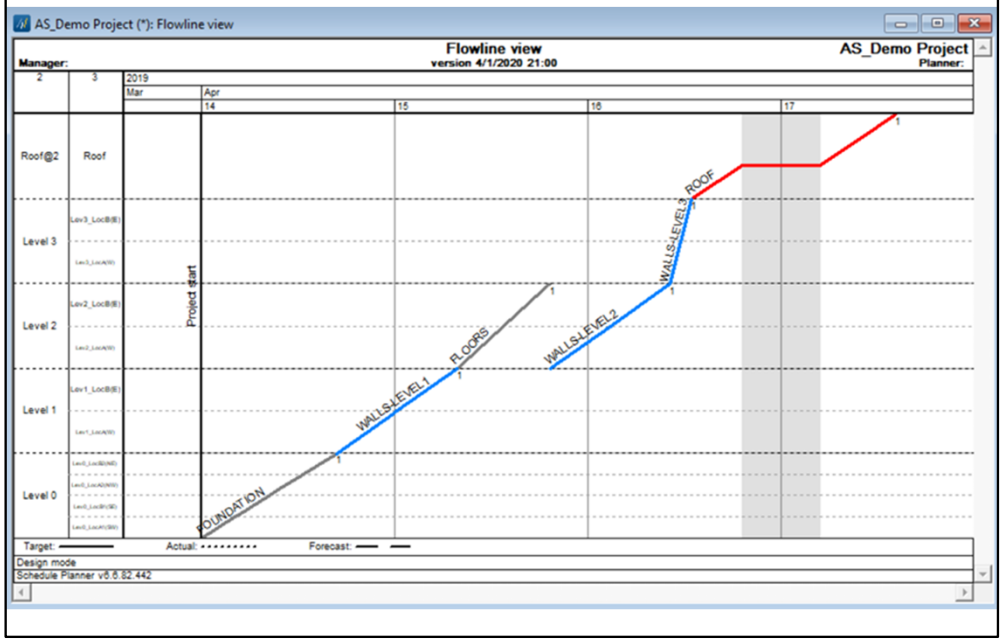
Revit Data Graph

```
wallinst:450d31df-4383-4692-9be4-9c0935e083ef-0008f0ba
        a                   product:Wall , ont:Concrete400MmCastInPlace ;
        rdf:label           "(12)11.15,05.1.S1" ;
        bot:adjacentElement wallinst:40cab1d1-1d6f-47a3-9afb-bd8c6300ff7e-0009c504 , wallinst:c1037085-1aff-4644-8770-66dc41edbf0b-0009d67e ;
        props:Element_ID    "585914" ;
        props:Revit_GUID    "450d31df-4383-4692-9be4-9c0935e083ef-0008f0ba" ;
        props:angle         0.0 ;
        props:area          19.2 ;
        props:height        3.0 ;
        props:length        6.2 ;
        props:level_simple  "Level1" .

wallinst:450d31df-4383-4692-9be4-9c0935e083ef-0008f0f0
        a                   product:Wall , ont:Concrete400MmCastInPlace ;
        rdf:label           "(12)11.15,05.1.E" ;
        bot:adjacentElement wallinst:450d31df-4383-4692-9be4-9c0935e083ef-0008f14f , wallinst:c1037085-1aff-4644-8770-66dc41edbf0b-0009d67e ;
        props:Element_ID    "585968" ;
        props:Revit_GUID    "450d31df-4383-4692-9be4-9c0935e083ef-0008f0f0" ;
        props:angle         90.0 ;
        props:area          24.0 ;
        props:height        3.0 ;
        props:length        8.4 ;
        props:level_simple  "Level1" .
```

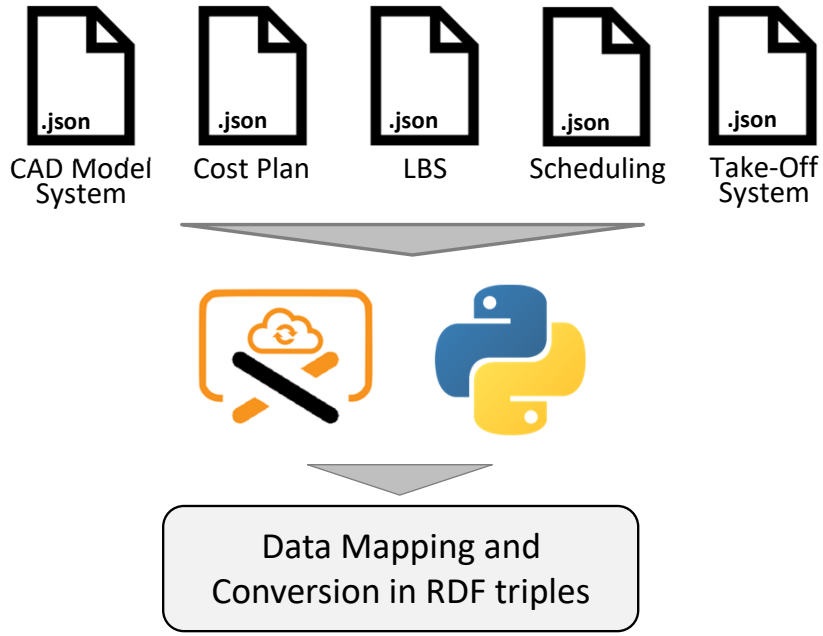
Location-Based Schedule – VICO Office



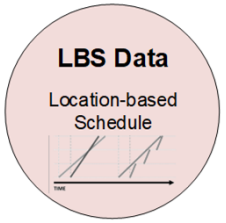
Data Generation in VICO



Data Extraction in ExiLink/ Program



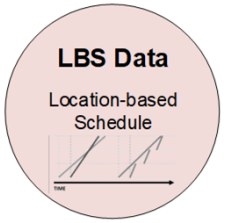
Location-Based Schedule – VICO Office



LBS Data Graph

```
inst:1000.0.145882  a                lbs:CompLoid , product:Wall ;
        lbs:hasCompLoid              "1000.0.145882" ;
        lbs:hasLocation              "Lev1_loca(w)" ;
        lbs:haslocLoid               "1000.0.355001" ;
        lbs:hasschedLoid             "1000.0.321768" ;
        lbs:hastaskLoid              "1000.0.358588" ;
        lbs:taskActualEndDate        "NULL"^^xsd:dateTime ;
        lbs:taskActualStartDate      "NULL"^^xsd:dateTime ;
        lbs:taskPlannedEndDate       "2019-04-08 07:28:48.000"^^xsd:dateTime ;
        lbs:taskPlannedStartDate     "2019-04-04 11:00:00.000"^^xsd:dateTime ;
        lbs:taskProgressCompletion   "0.0"^^xsd:nonNegativeInteger ;
        lbs:taskProgressDate         "NULL"^^xsd:dateTime ;
        props:Element_ID             "585914" ;
        props:Revit_GUID             "450d31df-4383-4692-9be4-9c0935e083ef-0008f0ba" .
```

Location-Based Schedule – VICO Office

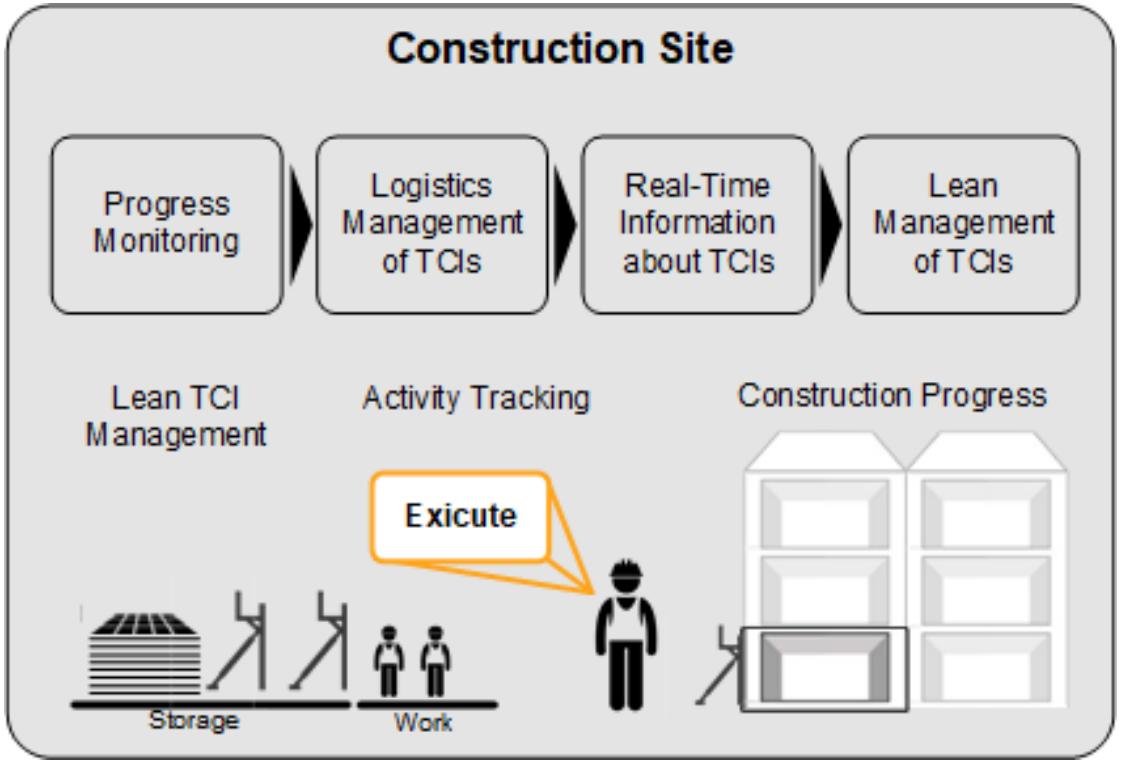


LBS Data Graph

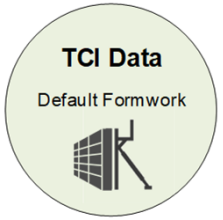
```
inst:1000.0.145882  a                lbs:CompLoid , product:Wall ;
        lbs:hasCompLoid              "1000.0.145882" ;
        lbs:hasLocation              "Lev1_loca(w)" ;
        lbs:haslocLoid               "1000.0.355001" ;
        lbs:hasschedLoid             "1000.0.321768" ;
        lbs:hastaskLoid              "1000.0.358588" ;
        lbs:taskActualEndDate        "NULL"^^xsd:dateTime ;
        lbs:taskActualStartDate      "NULL"^^xsd:dateTime ;
        lbs:taskPlannedEndDate       "2019-04-08 07:28:48.000"^^xsd:dateTime ;
        lbs:taskPlannedStartDate     "2019-04-04 11:00:00.000"^^xsd:dateTime ;
        lbs:taskProgressCompletion   "0.0"^^xsd:nonNegativeInteger ;
        lbs:taskProgressDate         "NULL"^^xsd:dateTime ;
        props:Element_ID             "585914" ;
        props:Revit_GUID             "450d31df-4383-4692-9be4-9c0935e083ef-0008f0ba" .
```

Exicute

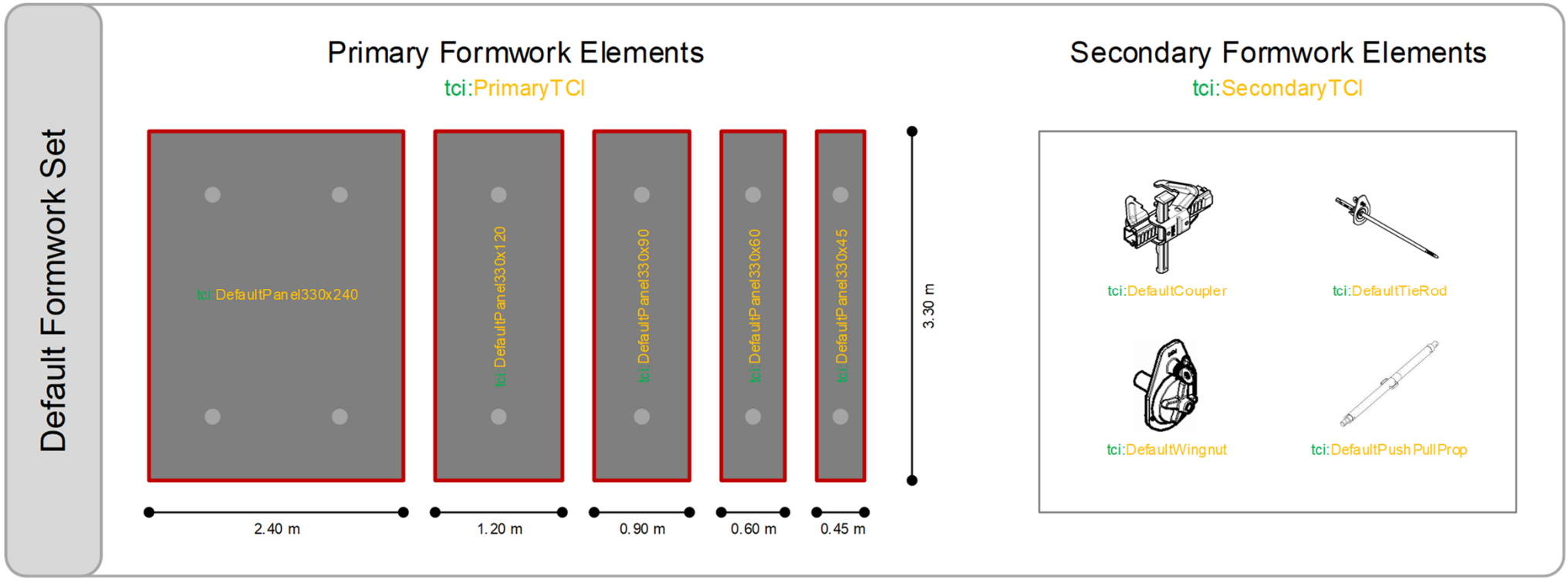
Progress Monitoring – Exicute



Temporary Construction Items – TCI



- TCI Ontology Creation describing the TCI context



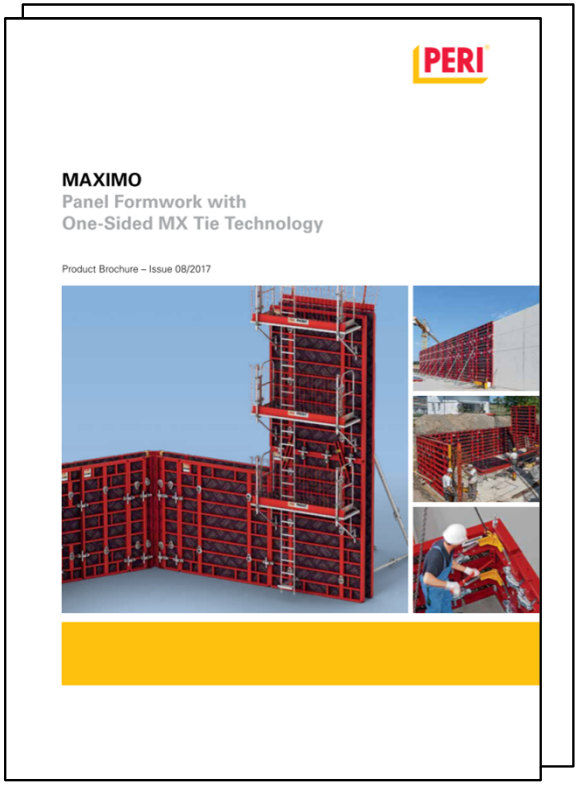
Temporary Construction Items – TCI

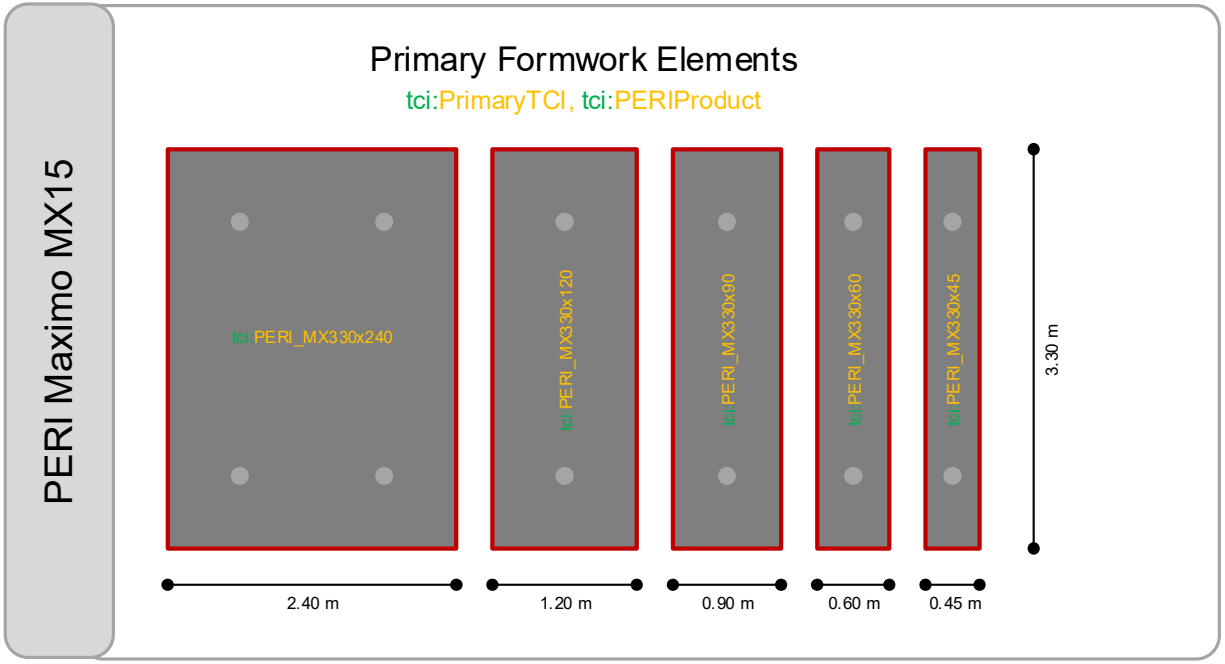
TCI Data Graph

```
tci:PrimaryTCI  a          owl:Class ;
        rdfs:subClassOf    tci:TCI ;
        owl:disjointWith   tci:SecondaryTCI .

tci:SecondaryTCI  a       owl:Class ;
        rdfs:subClassOf   tci:TCI .


tci:DefaultPanel330x240
        a             owl:NamedIndividual , tci:DefaultFormwork , tci:FormworkVertical , tci:Panel ;
        rdf:label     "Default Panel 330x240" ;
        props:area    7.29 ;
        props:height  3.30 ;
        props:length  2.40 ;
        props:weight  408.0 ;
        props:width   0.12 .

tci:DefaultCoupler  a  tci:SecondaryTCI , owl:NamedIndividual , tci:DefaultFormwork , tci:Coupler ;
        rdf:label     "Default Coupler" ;
        props:weight  4.58 .
```

Specific Product – PERI MAXIMO MX15

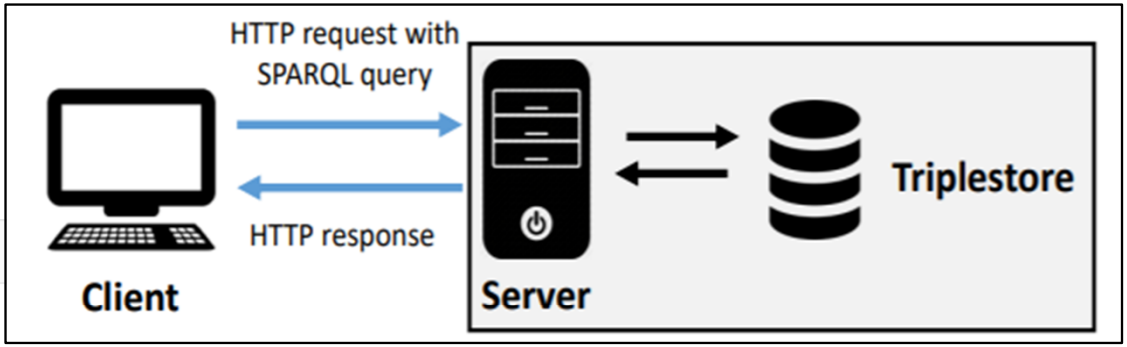
- Product Catalogue

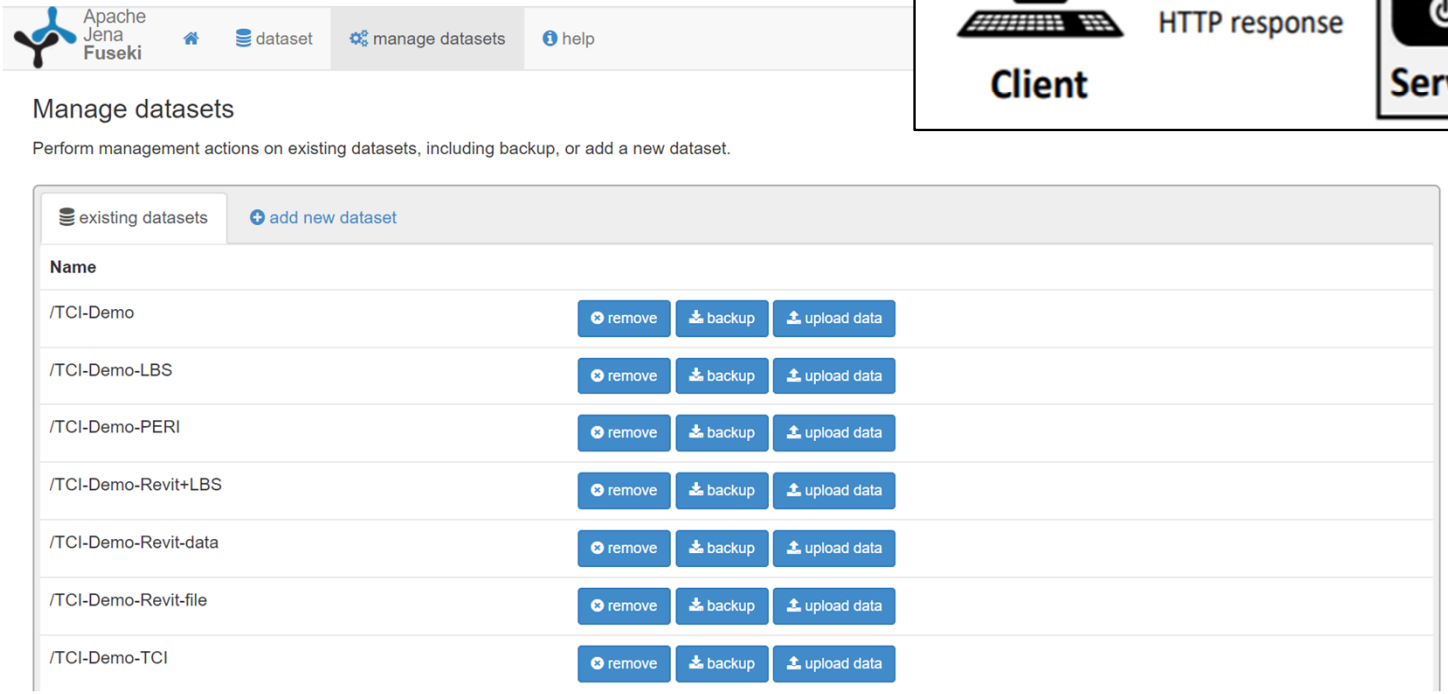




Data Management

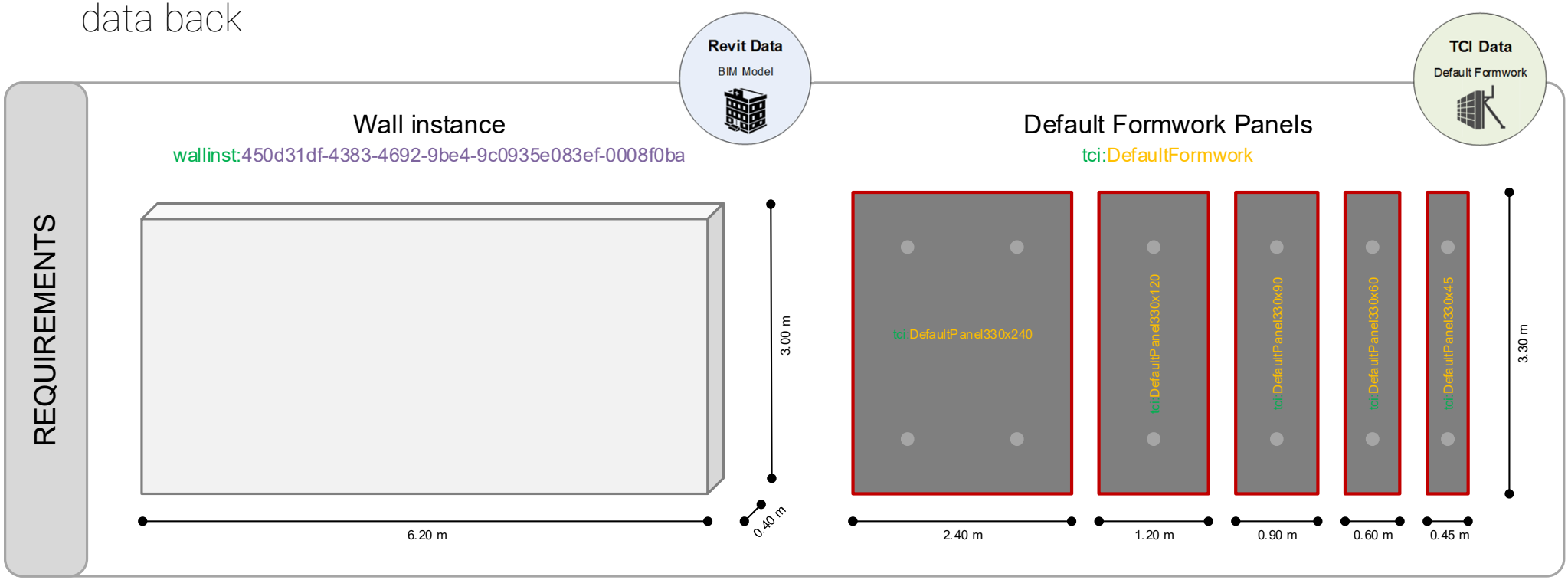
- Storage in triple store Jena Fuseki
- Access through localhost:3030





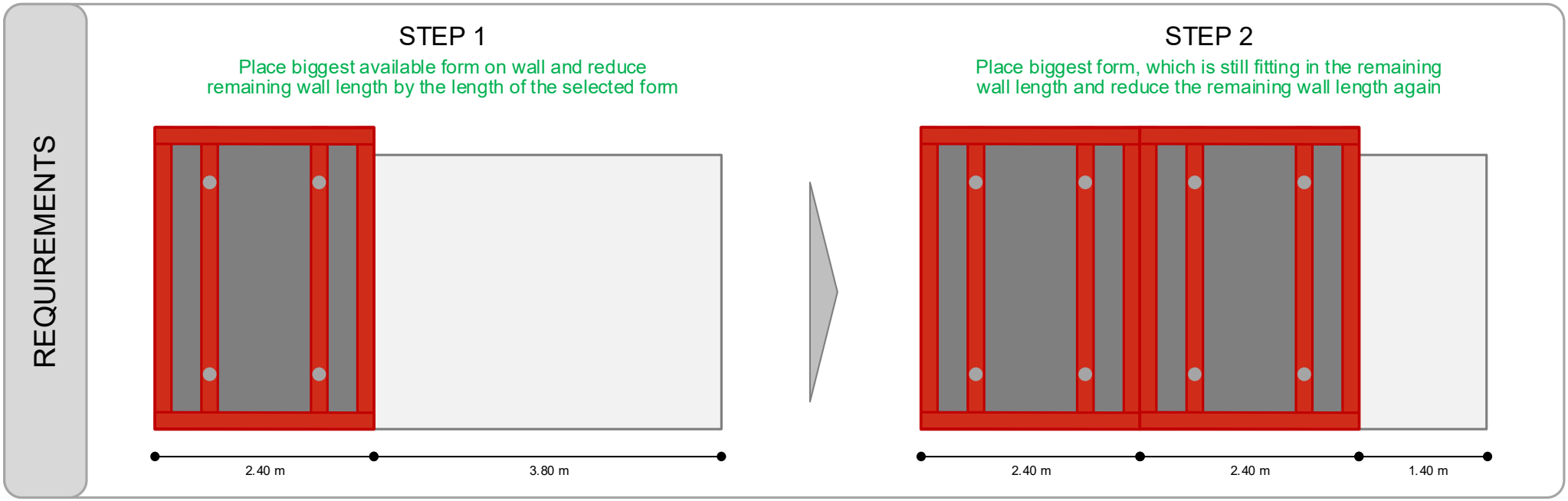
Data Processing & Querying

- Demo project for the calculation of formwork layout on wall elements
- Formwork calculation program that receives data from triple store and write processed data back



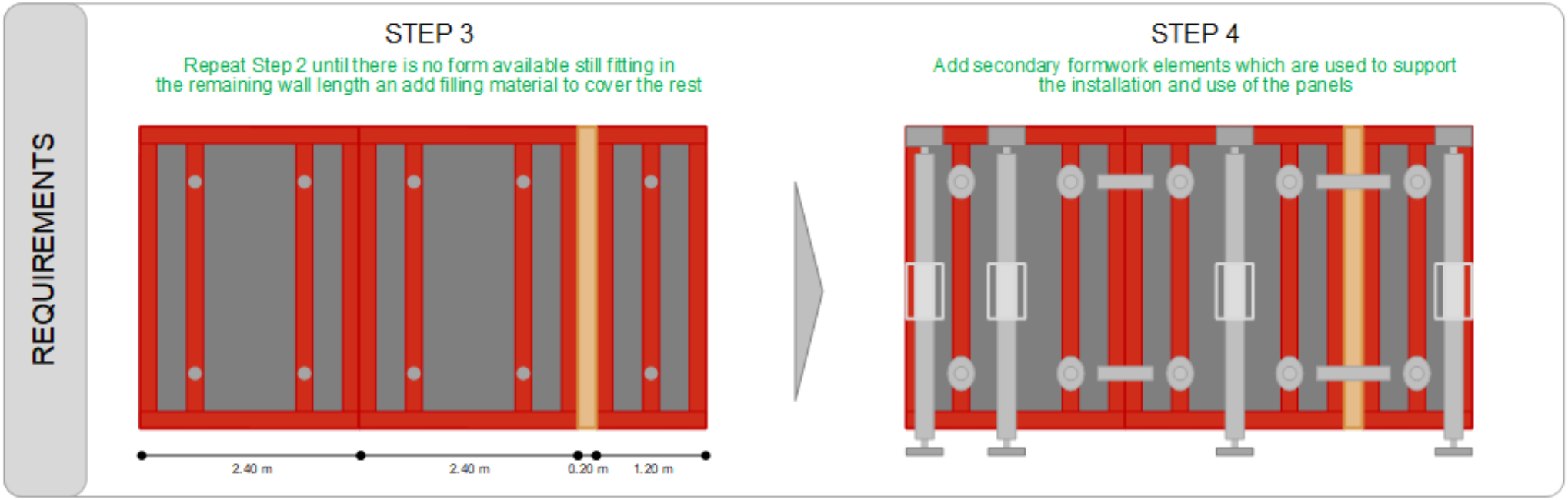
Data Processing & Querying

- Logic of Formwork Calculation Program



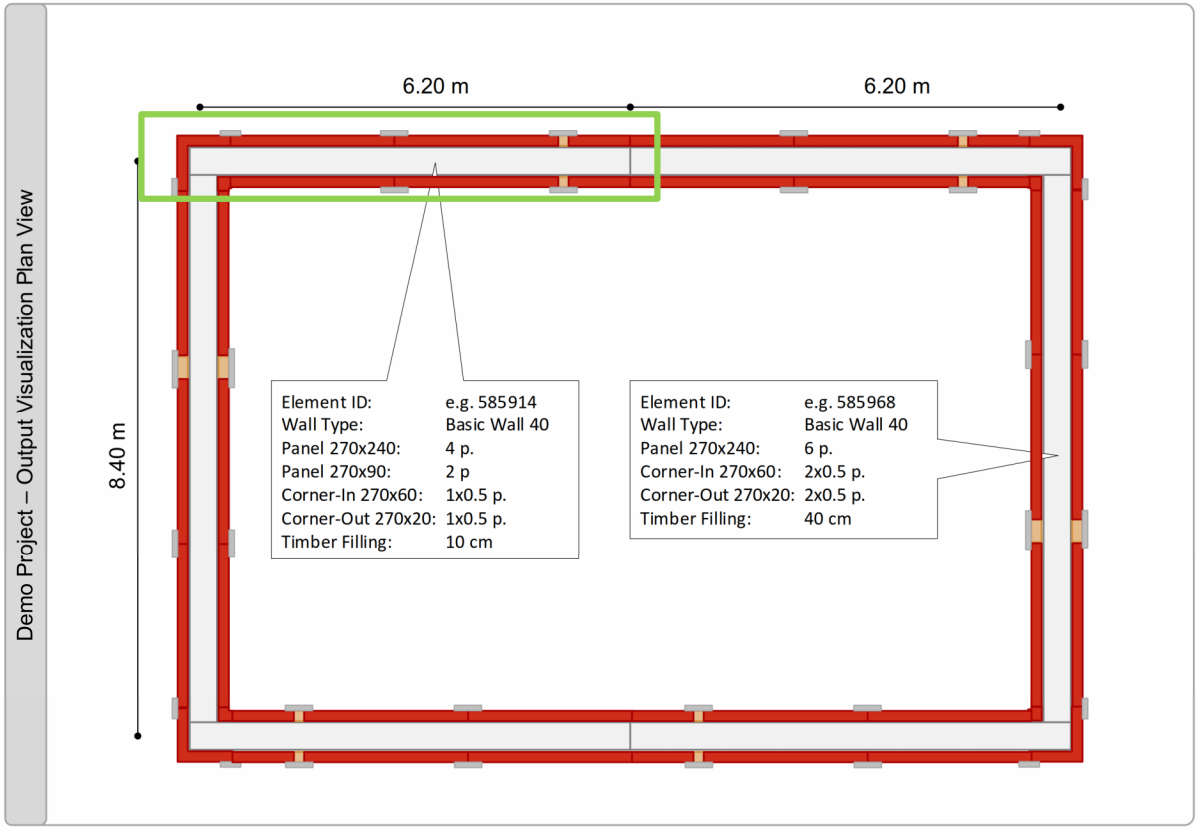
Data Processing & Querying

- Logic of Formwork Calculation Program



Data Processing & Querying

- Demo Project - Output Data

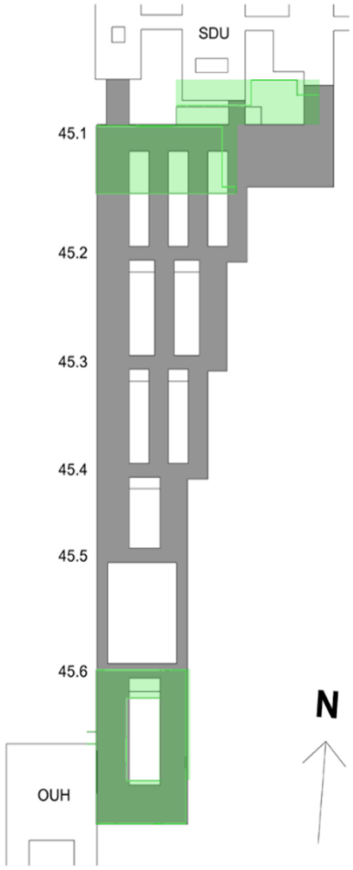


ElementID	VICOinst	TCIs	Quantity
585914	1000.0.351404	DefaultCoupler	8
585914	1000.0.351404	DefaultOutsideCorner330x60	0
585914	1000.0.351404	DefaultPanel330x240	4
585914	1000.0.351404	DefaultPanel330x90	2
585914	1000.0.351404	DefaultPushPullProp	8
585914	1000.0.351404	DefaultTieRod	10
585914	1000.0.351404	DefaultWingnut	10
585914	1000.0.351404	TimberFilling	2
585968	1000.0.351451	DefaultInsideCorner330x20	1
585968	1000.0.351451	DefaultPanel330x120	0
585968	1000.0.351451	DefaultPanel330x45	0
585968	1000.0.351451	DefaultPanel330x60	0
585968	1000.0.351451	DefaultPanel330x90	0
585968	1000.0.351451	DefaultWaler	0
585968	1000.0.351451	DefaultCoupler	12
585968	1000.0.351451	DefaultOutsideCorner330x60	1
585968	1000.0.351451	DefaultPanel330x240	6
585968	1000.0.351451	DefaultPushPullProp	10
585968	1000.0.351451	DefaultTieRod	14
585968	1000.0.351451	DefaultWingnut	14
585968	1000.0.351451	TimberFilling	2

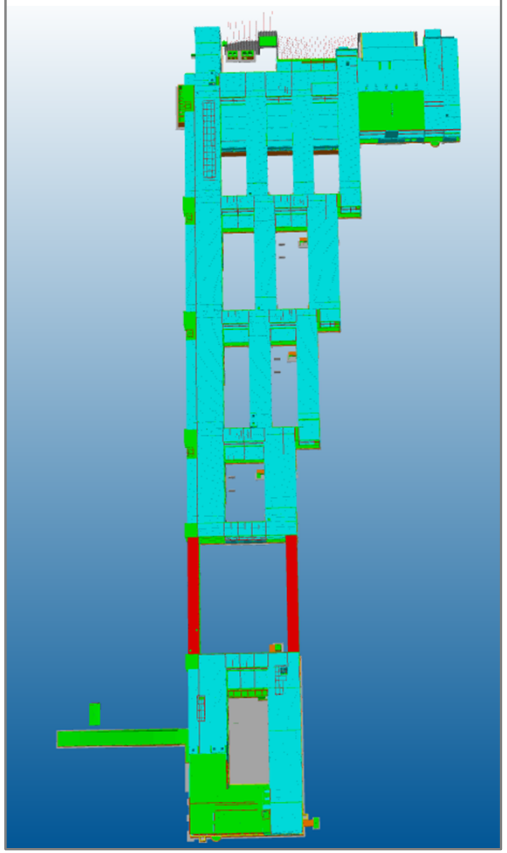
VI. Prototyping - Case Study

Case Study – Project Information

Project Name	SDU SUND
Location	Odense
Project Type	Public, New Construction, Rural
Building Type	Healthcare Science Faculty
Building Size	50.740 m² brutto
Levels	Basement, Level 1-4
Building Sections	45.1 – 45.6
Value for Case Study	In-situ concrete walls are installed in the basement and serve as an application field for the developed prototype solution, creating a utilization plan for the required formwork
Used Data	• 3D-model (rvt-file) • Location-based schedule (vico-file)

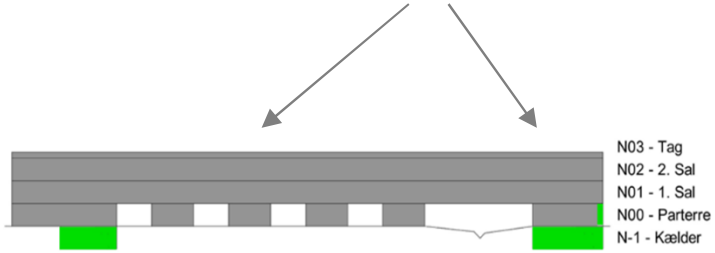


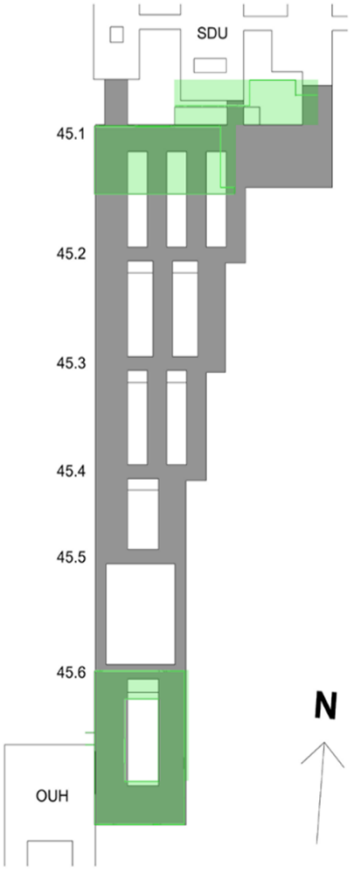
VICO 3D View



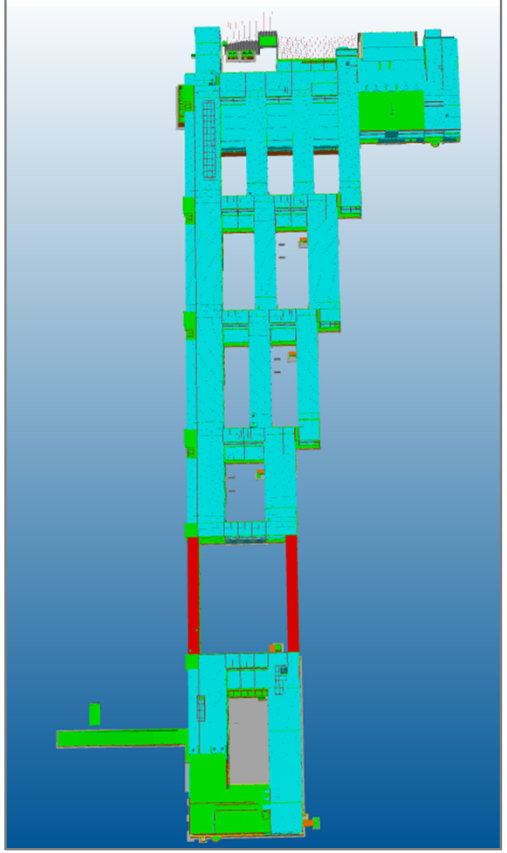
Case Study – Project Information

In-situ walls in the project		
Type	**Location**	**Qty.**
VGY35	45.1 N-1 & N00 45.6 N-1	26
VGY39	45.6 N-1	3
VGY47	45.1 N-1 45.6 N-1	8

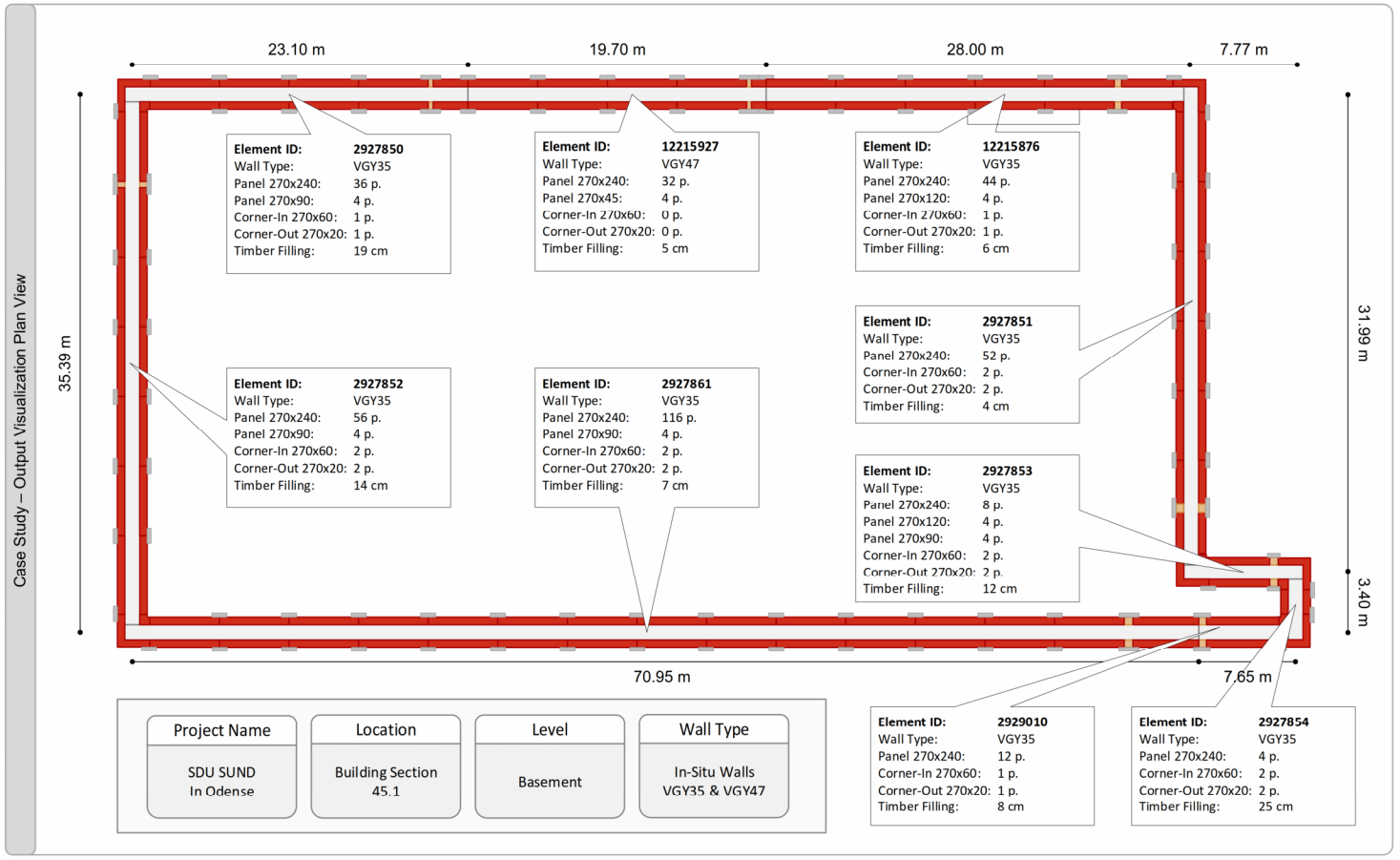




VICO 3D View



Case Study – Results

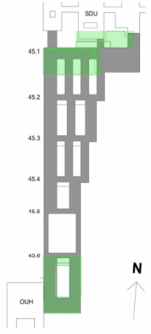


Case Study – Results

Power BI Dashboard Visualization – Page 0: Project Overview

Project Information

Project Name:	Nyt SDU SUND
Location:	Odense
Project Type:	Public, New Construction, Rural
Building Type:	Healthcare Science Faculty
Building Size:	50.740 m² brutto
Levels:	N-1, N00, N01, N02, N03
Building Sections:	45.1, 45.2, 45.3, 45.4, 45.5, 45.6

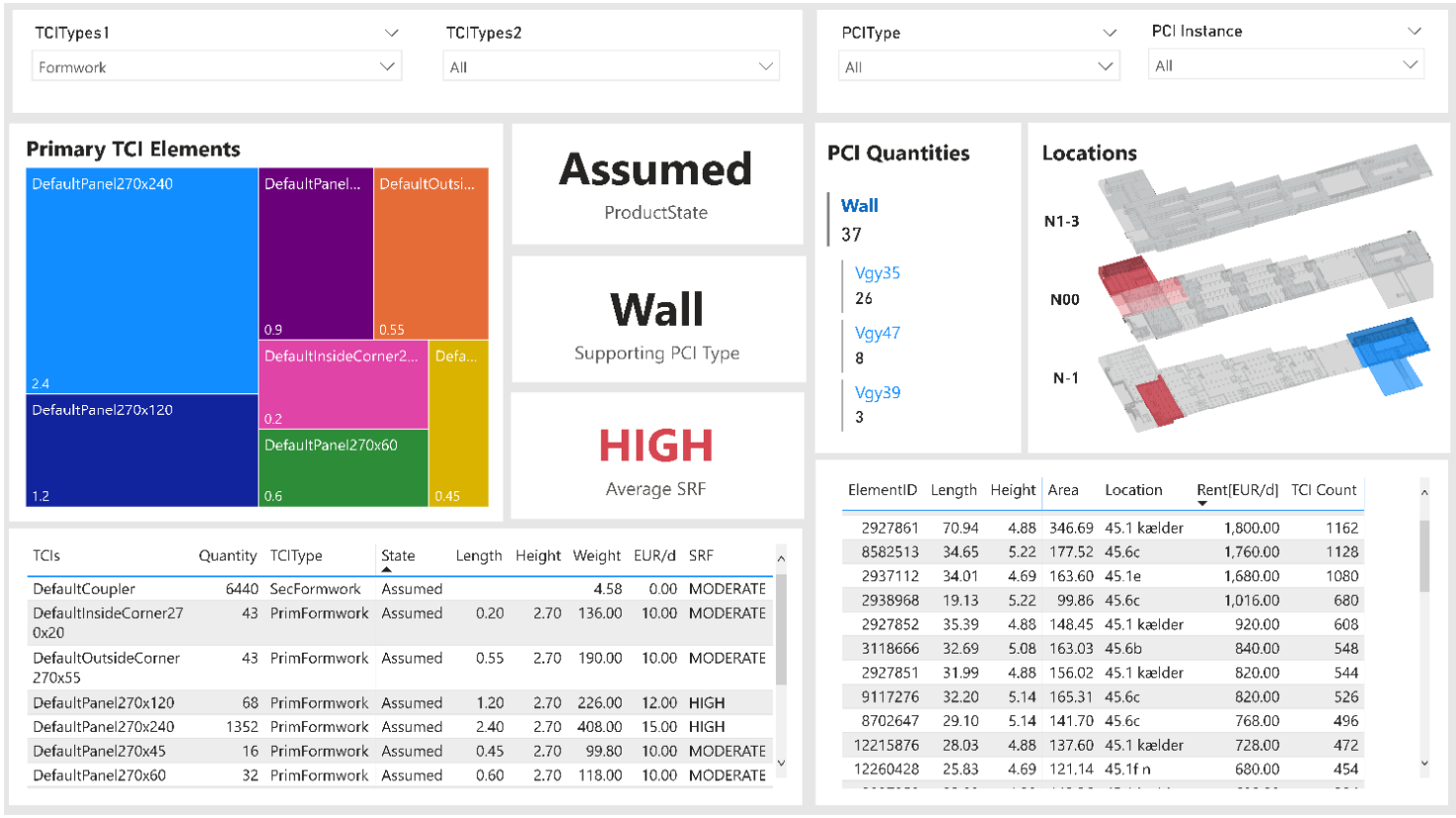


Content of the Dashboard

TCIs/PCIs	TCI Information with specifications and quantitites PCI information with specifications and quantitites Location Slicer for PCIs
TCI Utilization	TCI allocation over time Daily TCI quantities Daily TCI utilization compared to stock Comparison between static stock (current practice) and dynamic stock Cost information
TCI Tasks	Gantt diagram, showing all tasks which involve TCIs TCI utilization time and timber filling per task TCI quantities per task and safety-risk-factor

Case Study – Results

Power BI Dashboard Visualization – Page 1: TCI/PCI Information

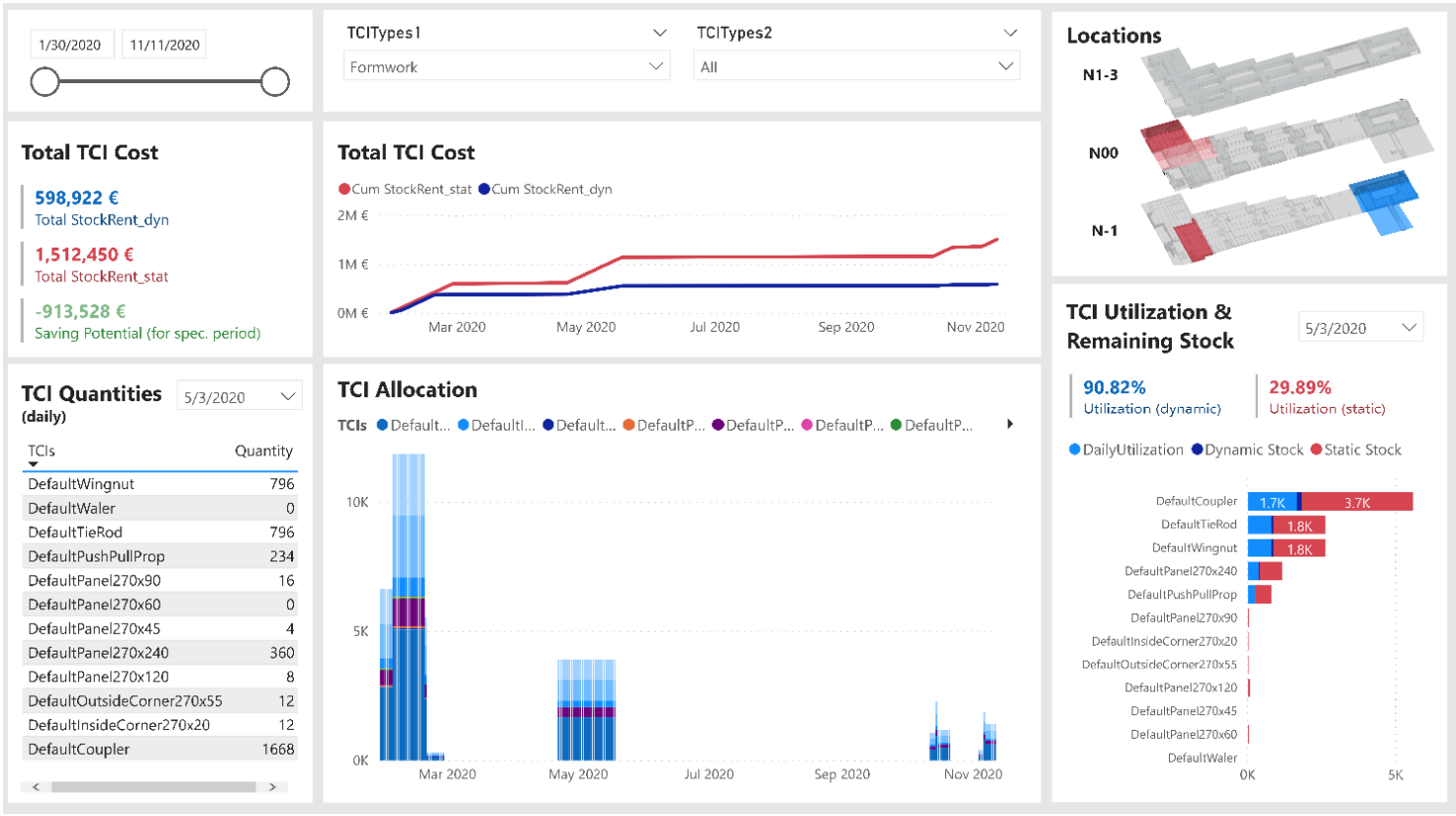


TCIs	Quantity	TCIType	State	Length	Height	Weight	EUR/d	SRF
DefaultCoupler	6440	SecFormwork	Assumed			4.58	0.00	MODERATE
DefaultInsideCorner270x20	43	PrimFormwork	Assumed	0.20	2.70	136.00	10.00	MODERATE
DefaultOutsideCorner270x55	43	PrimFormwork	Assumed	0.55	2.70	190.00	10.00	MODERATE
DefaultPanel270x120	68	PrimFormwork	Assumed	1.20	2.70	226.00	12.00	HIGH
DefaultPanel270x240	1352	PrimFormwork	Assumed	2.40	2.70	408.00	15.00	HIGH
DefaultPanel270x45	16	PrimFormwork	Assumed	0.45	2.70	99.80	10.00	MODERATE
DefaultPanel270x60	32	PrimFormwork	Assumed	0.60	2.70	118.00	10.00	MODERATE

ElementID	Length	Height	Area	Location	Rent[EUR/d]	TCI Count
2927861	70.94	4.88	346.69	45.1 kælder	1,800.00	1162
8582513	34.65	5.22	177.52	45.6c	1,760.00	1128
2937112	34.01	4.69	163.60	45.1e	1,680.00	1080
2938968	19.13	5.22	99.86	45.6c	1,016.00	680
2927852	35.39	4.88	148.45	45.1 kælder	920.00	608
3118666	32.69	5.08	163.03	45.6b	840.00	548
2927851	31.99	4.88	156.02	45.1 kælder	820.00	544
9117276	32.20	5.14	165.31	45.6c	820.00	526
8702647	29.10	5.14	141.70	45.6c	768.00	496
12215876	28.03	4.88	137.60	45.1 kælder	728.00	472
12260428	25.83	4.69	121.14	45.1f n	680.00	454

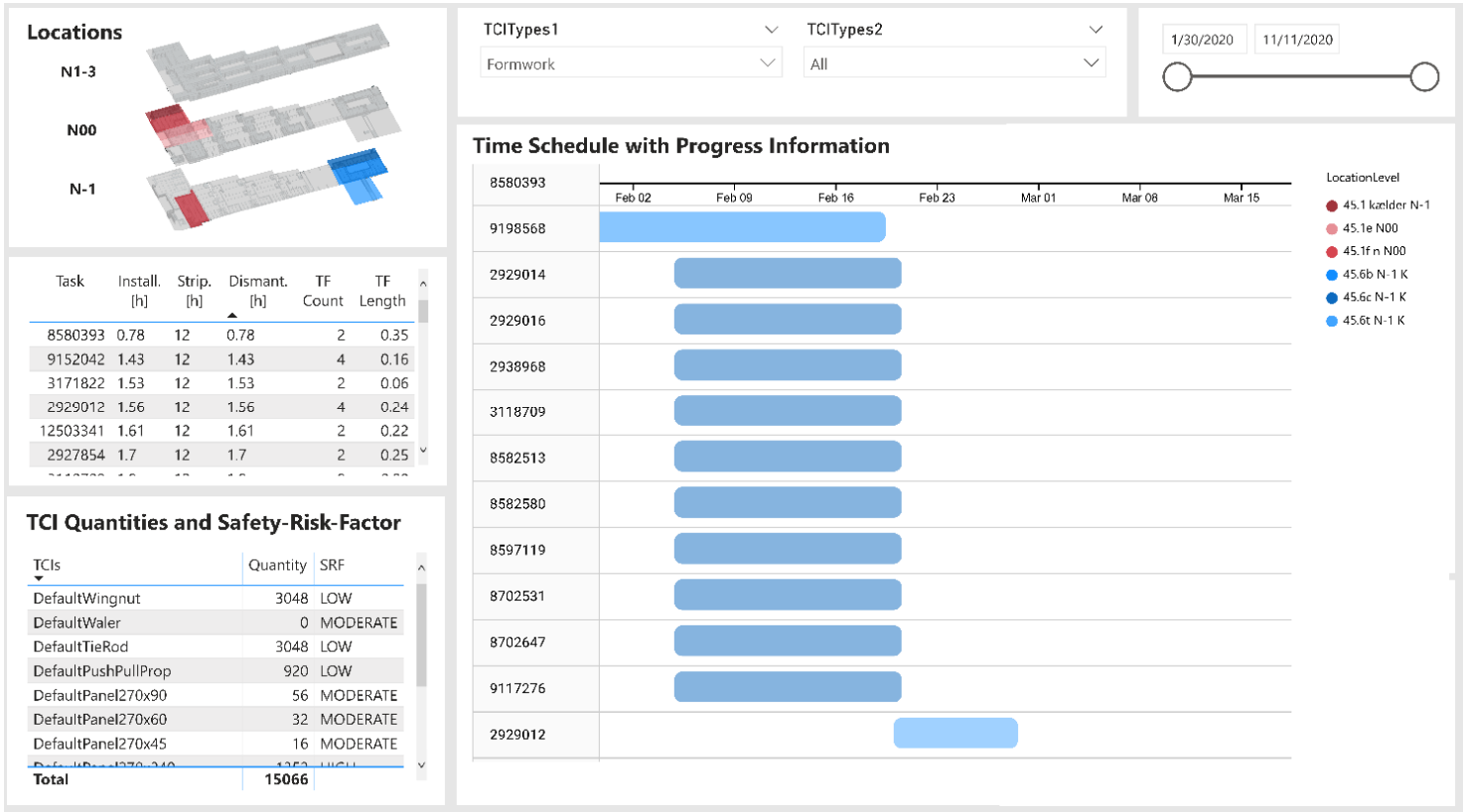
Case Study – Results

Power BI Dashboard Visualization – Page 2: TCI Utilization



Case Study – Results

Power BI Dashboard Visualization – Page 3: TCI Task Information



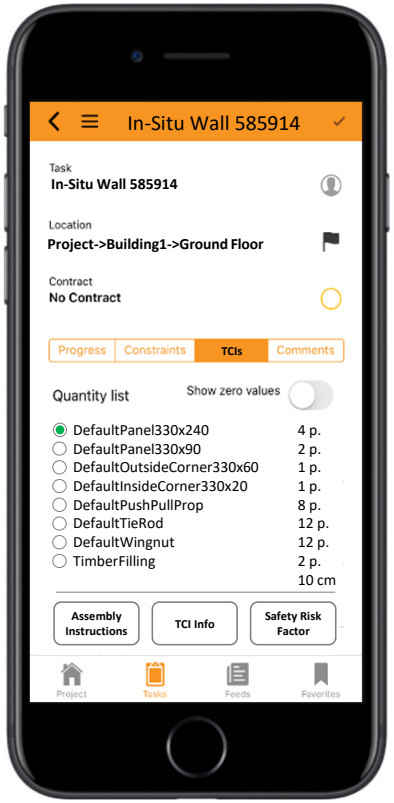
Task	Install. [h]	Strip. [h]	Dismant. [h]	TF Count	TF Length
8580393	0.78	12	0.78	2	0.35
9152042	1.43	12	1.43	4	0.16
3171822	1.53	12	1.53	2	0.06
2929012	1.56	12	1.56	4	0.24
12503341	1.61	12	1.61	2	0.22
2927854	1.7	12	1.7	2	0.25

VIII. Discussion/ Reflection

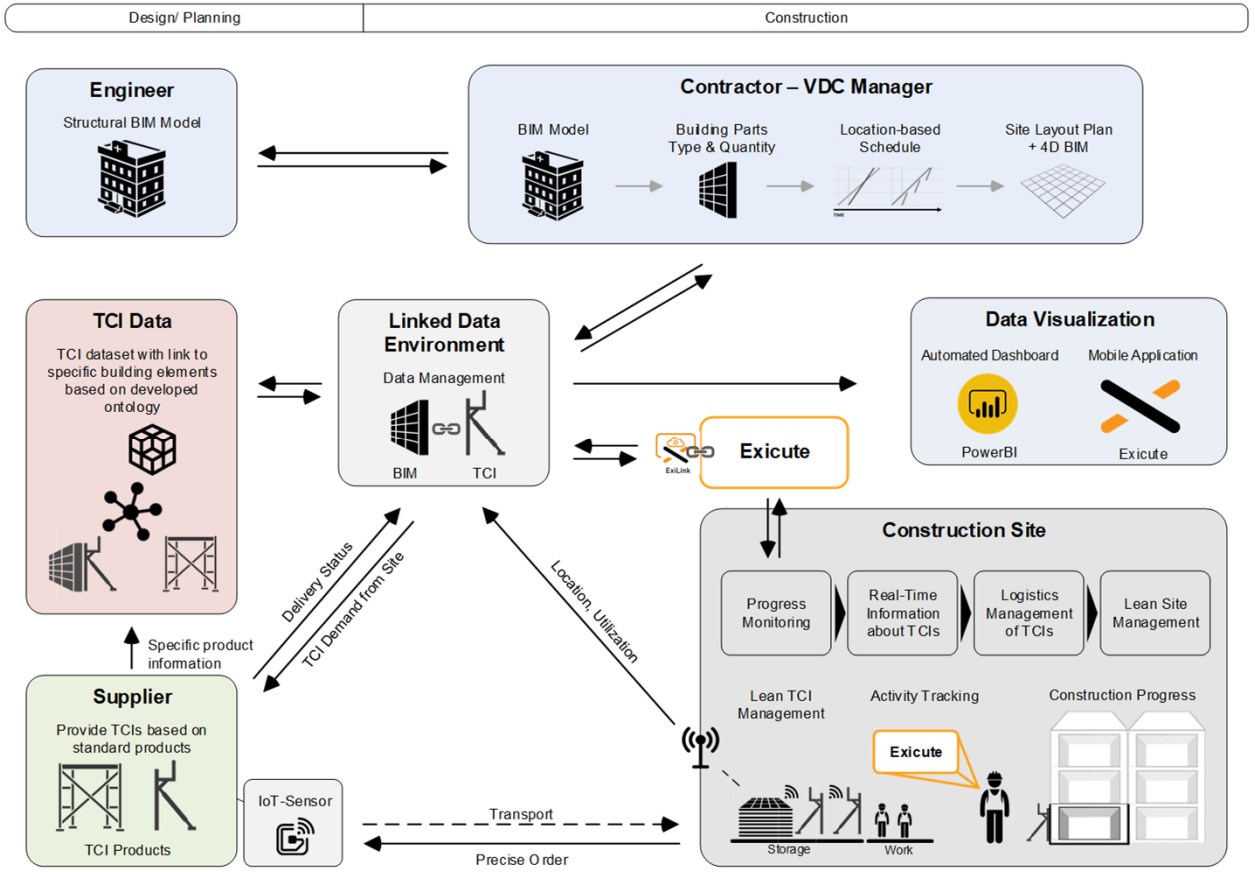
Solution Application – Data Distribution

Information for Project Manager

Information for Construction Worker



Integration in the Existing Project Delivery



- A lean and integrated management process of temporary construction items (TCIs)
- Automatic planning of TCIs with a data-driven and BIM-based approach
- Incorporating all recommendations from the state of art review

1. Adoption of BIM and TCIs consideration in construction for site management
2. IoT-technology for tracking construction resources
3. Cloud-based platform for bilateral information flow between planning & construction
4. Tailored dashboard visualization of monitoring information using KPI's
5. Stakeholder integration in information system

Reflection of the Developed Solution

- Benefits

Client	No direct benefit, but more reliability of the contractor's offer, better overview, less time and cost overruns
Contractor	Transparency and control over TCI utilization to improve the construction site planning & management Proactive planning of TCIs with less reliability on supplier as precise number of items can be ordered
TCI Provider	Precise number of items for each project to better plan the stock, focus on complex structures, where automatic calculations are not applicable, proactive role with consultancy service to address needs and requirements

- Limitations

1. Only Revit and VICO are tested for data extraction
2. Building model must be set up correctly to ensure data integrity
3. Solution requires a data-driven project delivery as manual input for the TCI utilization plan is not yet considered
4. Only addressing the use case of formwork elements
5. Formwork algorithm only considers geometry in 2D
6. Calculation engine is based on Default Formwork Set
7. Linked Data approach requires a lot of change management and further development in the industry
8. Manual approach in triple store to combine the datasets from different sources (e.g. Revit, VICO, TCI)

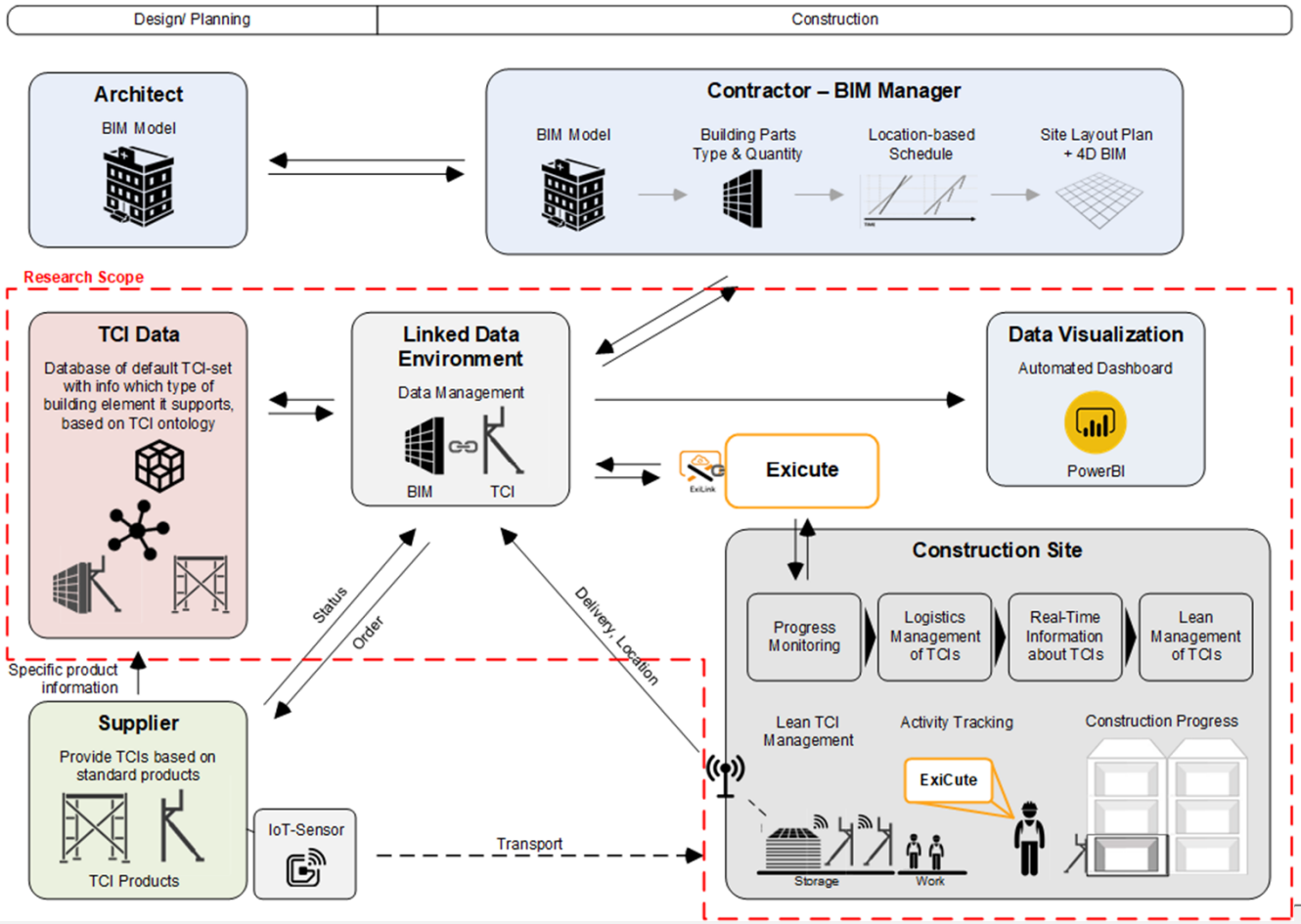
Reflection of the Developed Solution

- Future Research

1. Further prototyping step is needed where the solution is applied as a pilot project to identify areas for further improvements and quantify the added value
2. Active tracking of TCIs using IoT-Technology
3. Integrate other TCIs into the solution as scaffolding and safety barriers
4. Extract data from open standard solutions as IFC
5. Development of a standardized ontology framework for the construction industry to describe building data in its holistic context
6. Development of a QA-process to ensure data integrity from all utilized data sources
7. Develop the concept of the mobile application to bring the data to the construction worker
8. Integration of the TCI utilization plan into site planning & management to enable a lean construction process
9. Integrate AI technology to try out different scenarios of the model or schedule according to the output data of the TCI utilization plan
10. Investigate the solution's impact to the different stakeholder and their specific interests
11. Future vision requires the stakeholder to publish their data via RDF and thus, the industry must further develop in terms of the technology level of all stakeholder
12. To realize the Linked Data vision which may disrupt the industry to be more integrated and efficient, future research is needed to identify and exploit its potential

IX. Ideal Future Scenario

Ideal Future Scenario



Ideal Future Scenario