A Linked Building Data Approach to Site Planning and Managing Temporary Construction Items

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Abstract. Building Information Modeling (BIM) has brought great benefits to the construction industry by gathering all information in a project and making it available to the involved stakeholders. However, BIM has predominantly generated value in the design phase of a project, while the potential benefits in the construction phase have been disregarded for many years and are now gaining importance. Trending advancements try to utilize existing BIM data, e.g by linking a digital building model with planning efforts of the construction project and create new knowledge to improve construction.

In this paper, we are interested in exploring how semantic models and Linked Building Data (LBD) can support value creation in the construction phase. The presented use case tries to answer the question how the planning of Temporary Construction Items (TCIs) can be improved by semantically describing and classifying TCIs in an ontology that allows to utilize TCI information with BIM data. TCIs only experience little attention in the current planning of construction projects but have a critical impact on the outcome of a project. Thus, the creation of an ontology in this field shall lead to a better and more automated consideration of TCIs in construction planning. Here, we follow the recommendation of the W3C - LBD community group to extend or develop new ontologies and propose the TCI ontology[3] as the main contribution.

We first introduce the TCI ontology and its relation to other ontologies. Then we demonstrate the value of the ontology by answering competency questions and finally provide a proof of concept of planning TCIs by utilizing the new ontology. The proposal of the TCI ontology is accompanied by a second ontology for Location-Based Scheduling (LBS) to consider the time dimension of planning. The main focus, however, lies on the development and presentation of the TCI ontology whereas the LBS ontology will be further developed in future research.

Keywords: Linked Building Data · Temporary Construction Items · Ontology · BIM .

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[3] https://alex-schlachter27.github.io/LBD-for-TCI/TCI

1 Introduction

New technologies and methods in the construction industry are challenging the old traditions of building and are likely to disrupt the industry. Besides newly established methods like Building Information Modeling (BIM) and Lean Construction, Linked Data is found to be an emerging technology in the construction industry that has already gained much attention in other industries and can boost digitalization and knowledge creation in construction [5].

However, most technologies focus on the planning of Permanent Construction Items (PCIs), viz. all items that will become part of the building, as they immediately impact the project in regards to time, cost and quality or existing technologies are not implemented in the process of construction, and Temporary Construction Items (TCIs) are often left out in this consideration [13]. Although improper use of these items can highly impact project performance, including productivity and safety, there is a lack of attention regarding proper planning and management of TCIs [1]. Handling TCIs consists of many, sometimes complex components and activities and in order to integrate TCIs into construction planning, a meta data layer (or ontology) is required to formally put the information into a structure and describe its context. In this paper, we propose a TCI ontology that describes the management of TCIs and allows to use Linked Data (LD) based applications to consider these elements into construction planning.

1.1 State of the art

"Temporary structures in construction are those structures that are erected and used to aid in the construction of permanent projects" [10, p. 292], such as formwork, scaffolding and supporting structures. Facilitating the construction process is the main purpose of TCIs, assigning them a primary impact on the outcome of construction projects while they receive only secondary attention in practice [3]. These items highly impact construction in terms of time, cost, quality, safety, and efficiency due to their quantity, their labour intensive handling and the fact that they are reused many times during a construction project [1]. Nevertheless, TCI planning is still based on basic and manual ad-hoc estimations, which is leading to several problems as inefficient construction processes [4].

In this paper, vertical formwork is chosen as a representative of TCIs and serves as a case example. Specifically for buildings with a high percentage of in-situ-concrete, formwork highly impacts the productivity as those elements are high in number, are frequently moved around, used hundreds of times and directly affect value-adding activities on site [14]. According to Ratay [11], 60% of time in formwork operations can be saved with a better planning, standardization and monitoring. Thus, an improvement of the formwork operation is highly correlated with a successful project outcome.

In order to improve formwork operation and simultaneously the project outcome, TCIs first have to be integrated into current planning processes. PERI CAD and DOKA Tipos are two commercial solutions that attempt to reach this integration with a CAD-based formwork planning tool. Although these solutions allow to plan TCIs even based on 3D-models and calculate their quantities, there are some limitations to a full integration into construction planning. Firstly, most commercial tools are product specific and thus create a strong dependency towards one formwork provider. Secondly, the available tools for TCI planning use CAD-modelling which is labour and time intensive and is often considered too resourceful for these secondary and cheap elements [13]. Furthermore, an external solution with no data-integration is quite limited in flexibility as the building design evolves. Each time there is a change in the design or plan, the formwork provider must reconsider the TCI-plan and little automation is possible.

As TCIs are barely integrated in BIM-based planning and modeling TCIs is labour and time intensive, a new solution is required that allows to plan TCIs in a simple way [6]. Hence, the scope of this work is to integrate information about TCIs with existing BIM-data, comprising of the building model for the spacial dimension and a time schedule for the temporal dimension of planning. This integration shall allow to early and independently consider TCIs as a valuable resource in construction planning.

1.2 Early TCI-planning and BIM-Bots

Early consideration of TCIs is a key for planning a construction site as their spatial and temporal impact can be calculated and evaluated from the beginning of the planning process, minimizing the effort of rework and inefficient ad-hoc planning. To do so, the TCI information must first be specified. In case of formwork, this can either be extracted from a specific product catalogue or by using generic formwork elements. Then this data must be linked to both the geometry of the building and schedule information from BIM planning applications. With this semantic relation, an application could automatically calculate the demand of TCIs with their spatiotemporal properties by analysing the building data and then combining it with the schedule data [3]. This outcome would be a TCI utilization plan that includes information about when and where which type and quantity of formwork elements are needed on the construction site.

In the early project stages, this calculation engine could be maintained by the contractor to automatically calculate an estimation by using a default set of formwork. However, as the project gets more detailed, this calculation can be outsourced towards specialised supplier who will provide more advanced and product-specific algorithms to calculate the TCI information. Netherlands Organisation for Applied Scientific Research (TNO) has previously proposed such a decentralised system where intelligent online tools (BIM Bots[4]) integrate stakeholder expertise into the project delivery and perform various tasks like calculations, simulations or analyses for the project. These tools can retrieve data directly from the BIM environment and automate the communication between the involved stakeholders. This would furthermore allow to early integrate TCI expertise into the project.

[4] https://www.tno.nl/en/tno-insights/articles/bim-bots-boost-construction-sector-productivity/

In order to decentralise the task of calculating the TCI quantities in an integrated approach, a solution must be found that allows to first semantically describe TCIs and provide the raw project data to a service provider (BIM Bot) and integrate the result again in the planning process without compromising data integrity.

2 Linked Data Technologies in Construction

A technology that supports the required data integration is found in Linked Data. Unlike current data generation in commercial software environments, *"Linked Data technologies can provide an open and common environment for sharing, integrating and linking data from different domains and data sources"* [15, p. 1]. According to Pauwels et al. [5], *"across industries, Linked Data is recognized as an important set of fundamental methods and technologies to address interoperability and information exchange challenges"* [5, p. 195]. The benefits of this approach in several industries have also motivated construction related researchers to engage in Linked Data [12].

The W3C - Linked Building Data (LBD) community group and other researchers developed ontologies to describe building information in the context of Linked Data, such as Building Topology Ontology (BOT) which describes basic relationships between components in the scope of buildings [7]. As these ontologies only give a general concept of describing a building, stakeholders in the industry are encouraged to extend or develop new ontologies. According to the LBD community group, the use of Linked Data in the construction industry shall eventually lead to a decentralised and integrated information infrastructure. Integrating data in this industry is increasingly gaining attention and relevance and therefore, Linked data technologies are proposed from several research projects to face this need [15,2,8]. Hence, the use of Linked Data matches the requirements for the proposed approach of planning TCIs as it allows to integrate data from all kinds of domains and data-sources as long as an underlying ontology is used to describe the data. Furthermore, Linked Data allows to enrich a data model with semantic relations and thus, retrieve implicit knowledge. This standardized and enriched data can be processed with an algorithm to derive the required TCI information and finally visualize the results.

3 Ontologies

Following the recommendation of the W3C - LBD community group to extend existing or develop new ontologies, this paper proposes the TCI ontology as its main contribution, extending BOT and aiming to semantically describe and classify temporary construction items in order to integrate them into construction planning. Furthermore, a Location-Based Scheduling (LBS) ontology is developed, allowing to describe the schedule data of a location-based schedule. The ontologies are described in brief below.

3.1 BOT - The Building Topology Ontology

The raw data for planning TCIs includes building data, schedule data and TCI data. The former can be described using BOT[5] [9]. It provides the overall semantics to describe building components in their topological context of the building and can be used for various domains as an underlying frame and extended with domain-specific information. In this work, BOT is used to describe the basic building classes from a BIM model, e.g. walls are exported as *bot:Elements*, levels as *bot:Storeys*. BOT is then extended by the PROPS[6] and PRODUCT[7] ontologies of the W3C LBD Community Group to describe specific properties [8]. A wall, for instance, is defined as a subclass of a building element with *product:Wall rdfs:subClassOf bot:Element*.

3.2 TCI Ontology

This ontology represents the TCI information. As there is no existing ontology, describing TCIs, a new ontology with namespace *https://w3id.org/lbs/tci#* is developed. Although, the ontology was mainly developed to the extend of formwork, it is designed to cover the whole range of TCIs, and is therefore easily extendable with other items as scaffolding or supporting structures.

TCI/PCI: The ontology distinguishes between permanent and temporary construction items, where the former categorises all building elements that comprise the building, e.g. floors and walls. TCIs are grouped in the second category, where several subclasses further detail the TCIs.

```
<Wall_A> a tci:PCI, product:Wall .
<Formwork_Panel_A> a tci:TCI, tci:FormworkVertical, tci:Panel .
```

TCI Classes: Different TCI categories as *tci:Formwork* or *tci:Scaffolding* are described here. All categories can furthermore be declared as either *tci:ConfirmedProduct* or *tci:DefaultProduct*, identifying whether a TCI instance originates from a product catalogue or a default set of standard elements. A default product is a generic TCI set that is derived from existing products and is used to calculate the TCI utilization plan before the specific products are known, to get a first estimation of the TCI demand and the corresponding requirements for space and logistics. Figure 1 shows the information of the default formwork set that is used here.

In more advanced project stages, where detailed information about product-specific solutions and quantities are needed, product catalogues in Resource Description Framework (RDF) format can replace the default product. TCI supplier could, for example, publish their product catalogue as Linked Data in the web or the information could be parsed into RDF with an ontology mapping. A TCI planning tool should always first look for the product information and only if no product is found in the database, the default set shall be used. A

[5] https://w3id.org/bot#
[6] http://lbd.arch.rwth-aachen.de/props#
[7] http://lbd.arch.rwth-aachen.de/product#

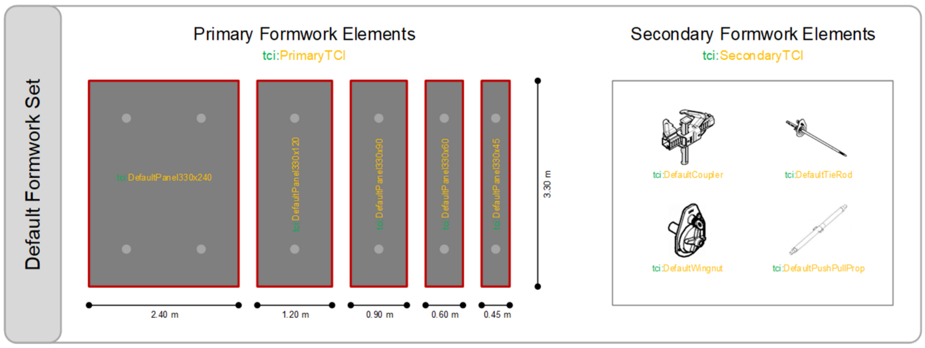

Fig. 1. Default Set of Formwork

further detailing distinguishes between *tci:PrimaryTCI* and *tci:SecondaryTCI*. *tci:PrimaryTCI* includes all elements of which the quantity can be directly derived from data of the building. Vertical formwork panels, for example, can be calculated as a result of analysing the geometry of a wall. *tci:SecondaryTCI* categorises all elements of a TCI system that support the *tci:PrimaryTCI* and are derived by the quantity of primary TCIs.

```
<Formwork_Panel_A> a tci:PrimaryTCI ;
                   tci:isSupportedBy <Supporting_Strut_A> .
<Supporting_Strut_A> a tci:PushPullProp, tci:SecondaryTCI .
```

Figure 2 shows the current extend of the TCI-ontology with all classes and their relationships, with focus on formwork operation.

3.3 LBS Ontology

The third ontology considers the temporal dimension of planning. Here, the data was created by the location-based scheduling software VICO and therefore, the ontology covers the required LBS-information to the extend of time, progress and location. The LBS ontology is only a primitive conception of the necessary schedule data and is subject of future research. The ontology contains several properties to assign schedule information to building element instances, e.g. *lbs:hastaskLoid*, *lbs:hasLocation*, *lbs:taskPlannedStartDate*, *lbs:taskActualStartDate*, *lbs:taskProgressCompletion* and *lbs:taskProgressDate*. By this, individual elements in a building model can be equipped with time and location properties and in case of TCIs, the information can be used to link time information from the elements to the supporting TCIs in order to manage their usage.

4 TCI-management with the proposed ontology

In this section we show how to use the TCI ontology for planning and managing TCIs. Three competency questions demonstrate the functionality.

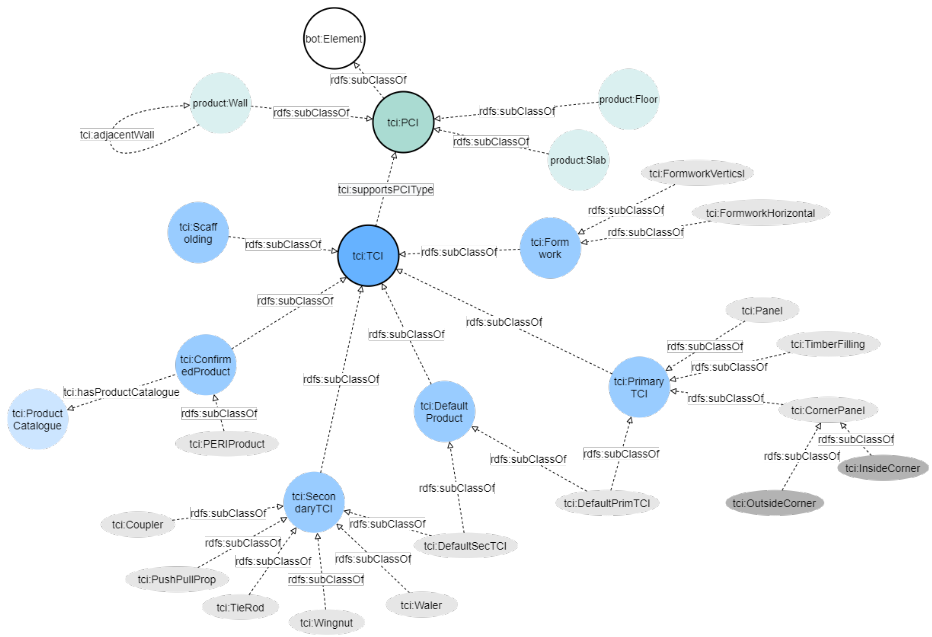

Fig. 2. Class hierarchy of the TCI ontology

CQ1 How to calculate the TCI utlization with building element quantities?
CQ2 How to differentiate, where an automatic calculation is suitable and where a custom calculation is needed by an engineer?
CQ3 How to link TCI quantities to time scheduling?

CQ1 The ontology aims to link permanent building elements as walls to TCIs which support the construction of the PCIs and can be calculated by the geometrical analysis of the PCIs. A simple calculation engine shall first get the required building and TCI data and then calculate the TCI requirement for the given building elements. The building elements can be retrieved as follows.

```
SELECT * WHERE {
    ?s a product:Wall ;
        props:elementID ?ID ;
        props:length ?length ; props:angle ?angle .
    OPTIONAL { ?s bot:adjacentElement ?adjacentElements } }
```

The TCI data (here formwork panel) can be retrieved as follows:

```
SELECT * WHERE {
    ?TCI a ?tciSet, tci:Panel ;
        props:length ?length ; props:height ?height ;
        props:area ?area ; props:width ?width ;
        props:weight ?weight . }
```

A rule-based algorithm can now use the data and calculate the TCI quantities. The example in figure 3 shows a conceptualized visualization for calculating vertical formwork elements on simple wall structures.

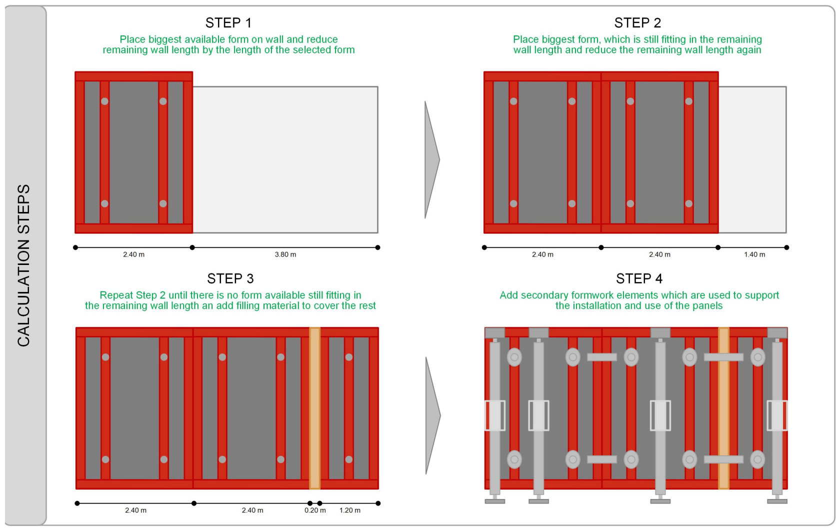

Fig. 3. Consecutive steps of the formwork calculation

CQ2 Data about adjacent wall elements and their angle to each other helps to formulate a logic to calculate formwork quantities for each wall. Here, the developed algorithm can automatically calculate the the amount of formwork components for simple wall structures, if the property *bot:adjacentElement* contains less than or equal to two wall elements. However, if the amount exceeds two elements, a more sophisticated formwork design has to support the process manually. Such an algorithm might reduce the amount of manual work and some rules can be established to mark areas where an automatic planning is not possible and manual assessment is needed. This consideration is important when using an automatic calculation tool for TCI management, as it defines the limitations of the automatic calculation.

CQ3 Extracting schedule information from a time schedule adds the required data to plan the utilization of formwork elements. This data from a location-based schedule, structured by the LBS-ontology, adds time information to each wall, which is then used to retrieve the utilization period for the formwork components. The activity to construct a insitu wall, for example, starts with assembling the formwork and ends with disassembling the formwork. The result is shown in the next section, where the properties with lbs-prefix indicate the added time information.

5 Proof of Concept (Dashboard)

In order to demonstrate the competencies, a case project was used to create a formwork utilization plan with the use of the proposed TCI ontology. The developed files for the case can be found in the GitHub repository LBD-for-TCI[8]. The case includes the process of extracting and parsing data to RDF - building data from Revit via Dynamo, LBS-data via VICO export and Python, TCI-data via translation of a product catalogue -, applying an algorithm to calculate formwork elements to insitu walls and combining the data in one knowledge graph, where it can be used for visualization. This process can be set up as a BIM Bot, that receives the required input information from a building model and provides the results as a dashboard. The developed algorithm in this use case only covers the basic logic of calculating vertical formwork elements for simple walls structures. In order to calculate complex wall structures, a more sophisticated algorithm or manual assessment has to supplement this process, as mentioned in CQ2.

The following data snippet shows the combined data for an exemplary wall.

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix bot: <https://w3id.org/bot#> .
@prefix inst: <http://test/resources/> .
@prefix tci: <https://w3id.org/lbs/tci#> .
@prefix props: <http://lbd.arch.rwth-aachen.de/props#> .
@prefix product: <http://lbd.arch.rwth-aachen.de/product#> .

inst:Wall_A
       a bot:Element, product:Wall ;
       props:elementID "641019" ;
       tci:countDefaultCoupler 8 ;
       tci:countDefaultPanel330x120 2 ;
       tci:countDefaultPanel330x240 6 ;
       tci:countDefaultPushPullProp 10 ;
       tci:countDefaultWingnut 12 ;
       tci:countTimberFilling 2 ;
       tci:hasTimberFillinglength "0.5"^^xsd:decimal ;
       bot:adjacentElement inst:Wall_B , inst:Wall_C ;
       props:angle 90.0 ;
       props:area 24.0 ;
       props:height 3.0 ;
       props:length 8.4 ;
       props:level "Level2" .
       lbs:hasLocation "Lev2_locb(e)" ;
       lbs:taskPlannedEndDate "2019-04-22"^^xsd:dateTime ;
       lbs:taskPlannedStartDate "2019-04-15"^^xsd:dateTime ;
       lbs:taskProgressCompletion "0.55"^^xsd:nonNegativeInteger ;
       lbs:taskProgressDate "2019-04-17"^^xsd:dateTime ;
```

[8] https://github.com/Alex-Schlachter27/LBD-for-TCI

Here, inst: is a generic prefix used to describe instances and all other prefixes relate to ontologies that are either described in this article or discoverable at http://prefix.cc/{prefix}.

The combined data graph is used to create a visualization dashboard (see figure 4). This dashboard addresses the needs of the management level of a site contractor who can review the dashboard to keep track on the TCI utilization over time and by location and properly plan the construction site. The "TCI Allocation" shows the utilization for the whole construction period, based on the scheduled tasks and the included building elements of the task. For the chosen period, we can now determine precisely the amount of TCIs that are required on site. A location and time filter further allows to narrow down the visualized information. The lower left side shows the TCI quantities of each day.

A further consideration that reveals a measurable benefit is the comparison between a static and dynamic stock of formwork elements. The former is aligned to the current practice, where formwork elements are ordered based on estimations for the whole utilization period in order to make sure that the stock covers the peak demand. An oversized stock of formwork elements is the result. Using an automatic planning of formwork with the TCI ontology enables a dynamic stock with just-in-time delivery, saving money, space and time. In the dashboard, this is firstly shown in the chart "TCI Utilization and Remaining Stock" which reveals the daily and proportionate TCI utilization rate, with the static (red) and dynamic (dark blue) stock approach. The charts "Total TCI Cost" show the cost development of both stock approaches over time and as well as the total amount spent and saved, clearly identifying lower total costs of renting formwork elements with the dynamic approach.

By visualizing the TCI utilization plan, the dashboard provides transparency as well as control over the planned TCIs. Thus, this case comprehensively validates the competencies of the proposed TCI ontology as an extension to the BOT ontology in the focus area of temporary construction.

6 Conclusion and Further Research

Enabling automatic Temporary Construction Item (TCI) planning by linking them to permanent building resources with schedule information was achieved with a minimal TCI ontology that extends the existing Linked Building Data (LBD) stack. By semantically describing the TCIs and the relation to their subcomponents as well as the building elements, they support, the TCI ontology allows the integration into construction planning and automatic calculation of TCI quantities and creation of an utilization plan. This was demonstrated by answering three competency questions. By providing default solutions as well as considering specific products, the ontology opens up the process of planning TCIs to the suppliers and invites them to directly publish their product catalogue in Resource Description Framework (RDF) or use a parsing service to do so. The ontology is regarded an attempt to increase the focus on TCIs and demonstrates its value with a simple calculation of vertical formwork elements on

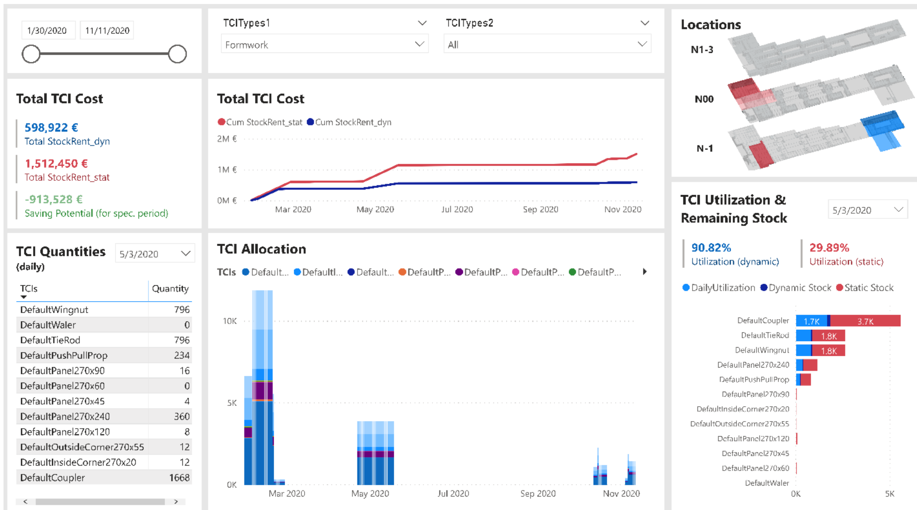

Fig. 4. Dashboard with the projects the TCI utilization

walls. The authors therefore suggest that the ontology shall be subject of further development and extensions to cover a greater variety of TCI types and more complex solutions to be applicable in real construction projects. In the future, the authors aim to further develop the Location-Based Scheduling (LBS) ontology and formalize a sophisticated scheduling ontology that enables an integrated and intelligent process of scheduling construction projects.

The authors furthermore urge other researchers to contribute to the efforts of the Linked Building Data community group. With every new development of an ontology for any disciplines and applications in construction, we come one step closer towards the vision of a decentralised and integrated industry with more data sharing, transparency and higher efficiency.

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