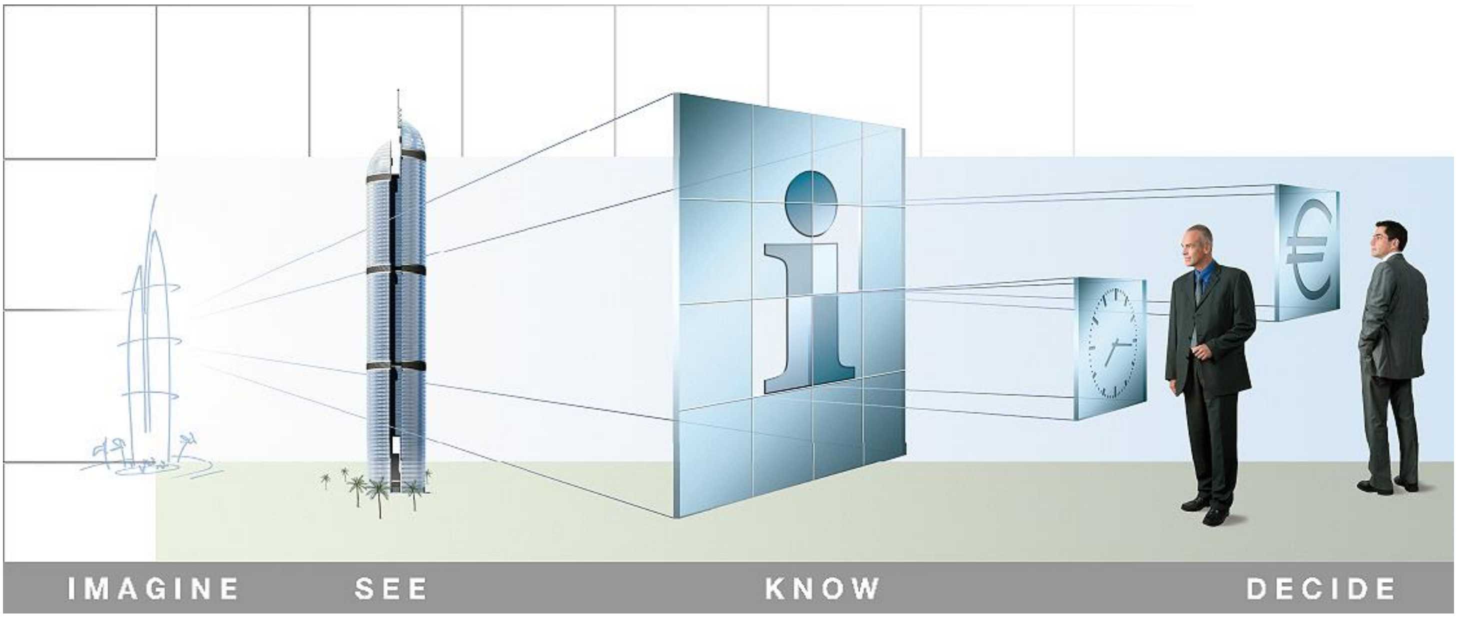

Digital Collaboration and Automized Tracking of information

WP3 Deliverable: Project Data Structure

Report No.: #WP3-01

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1 Executive summary

This report describes the approach of using structured data to establish digital trace links between project requirements and digital assets elements. The report begins with explaining the requirements management approach in infrastructure projects, describing how they are formulated and analyzing which are the main current challenges, as derived from previous work packages of the ongoing DCAT research project. Later, the concept of Project Data Structure (PDS) is presented by illustrating how it can enable BIM use cases in general and the Requirements Management in conjunction with BIM digital assets. Afterwards, it is explained in detail how a Project Data Structure is defined within different common structures and an overall PDS is proposed for further application on test projects data and evaluation within the DCAT scope. The common application of external classification systems within these defined structures is successively described and at the end is demonstrated how the PDS is applied on the digital assets.

2 Abbreviations

BIM	Building Information Modelling
BoQ	Bill of Quantities
PDS	Project Data Structure
RE	Requirements Engineering
WP	Work Package

3 Requirements Management in Infrastructure Projects

The development of an infrastructure project is based on the functional level in the satisfaction of the so-called requirements for this infrastructure measure. Requirements define the capabilities, features or qualities that are necessary (or desired) and are coming from a multitude of stakeholders. Requirements originate from the contract, laws and regulations, operational concepts, site conditions, external interfaces and utilities, industrial codes and standards, operator needs, the public interest and other sources referred to as “Input”. The requirements management process gathers this input from authorized sources to produce managed baselines of validated and traceable requirements. The process shall also gather evidence that requirements were met. Requirements need to be well-written in terms of being:

- Necessary
- Clear
- Achievable
- Traceable
- Verifiable
- Complete
- Implementation free

Meeting these criteria enables the application of a structured requirements management process.

3.1 How are requirements formulated?

The requirements formulation should meet the above-mentioned criteria to be able to implement a targeted requirements management process. In real projects setups and related challenges (please refer also to section 3.2), however, this might not always be the case. Although it may be assumed that usually only "necessary" requirements are formulated for an infrastructure project, the question of "traceability", for example, is not always definitively determined. This is also shown by the example of a requirements excerpt from the Eastlink Railway Project, which also represents the case study in this research project (Figure 1).

id	Name	The Artifact Type	Status	Source Reference
270865	Service roads must be adapted for bridges > 1 km and tunnels > 300 m.	Requirements	Determined	PM Project specific requirements for the Ostlink
263832	Signal points should normally be placed back-in-back (even where signal distances < 850 m).	Requirements	Determined	PM Project specific requirements for the Ostlink

Figure 1: Requirements excerpt from Eastlink Railway Project

One way of addressing this issue of requirements not being formulated according to the above mentioned criteria is the consistent application of Project Data Structures (PDS) in the planning (and thus also during requirements management) and execution of infrastructure projects. The explanation and role of the PDS for the use case of requirements management is the main subject of this document. However, initially, there are provided more-detailed descriptions on current challenges during requirements management and which role the approach of Building Information Modeling (BIM) might play to support it.

3.2 Current challenges

This chapter deals with the challenges in Requirements Communication between the costumer and the supplier especially during the processes of requirements validation, requirements communication, as well as digital asset verification. While investigating these processes, 14 challenges could be identified, which were assigned to four clusters: project management, requirements quality, common requirements engineering (RE), trace links. Theses clusters and the corresponding challenges are explained below.

3.2.1 Project Management

The challenges in this cluster are more related to the project management, communication channels and resources.

Requirements Validation Time

The time is too short for the contractor to validate the requirements properly for a tender project since there are ambiguous and conflicting. The client spends a couple of years coming up with a design, whereas the contractor has a couple of weeks to give a price estimation coupled with a tender model, which is purely price driven. Furthermore, there are requirements that need clarification or revision by the client and this task is very time consuming. Since the contractor submits the bid to the project based on the requirements, it is his responsibility to deliver a proper price, which is also a challenge.

Time to communicate the requirements (changes and questions)

The requirements communication process between the participating parties is considered as a challenge, especially due to change requests to the requirements and questions raised related to the requirements by the contractor or subcontractor.

Requirements' elicitation and validation with non-technical stakeholders

There are many different stakeholders involved and some of them are non-technical ones and are not specialists in the process of elicitation and validation of requirements. Therefore, not everyone speaks the same "language". Consequently, for the non-technical stakeholders to understand the requirements, they need to be adapted, which is quite challenging.

Lack of Experience using tools

There are too many different types of models used in the projects, which require various tools for viewing them making it difficult for the specialist to cope with all them. Consequently, the difficulty in navigating the models results out of the Lack of Experience in using various tools.

3.2.2 Requirements Quality

The challenges listed in this cluster refer to the quality level of the requirements.

Requirements' abstraction

Since there are various abstraction levels, it is challenging to find the right level of granularity for these requirements. Either the requirements are too specific, and you cannot find a solution, or the requirement is very abstract and is easy to be misinterpreted.

Requirements are Impossible to Build

The requirements provided by the client specify an actual solution, which the contractor or subcontractor need to follow. However, there are some requirements which have conflicts and are therefore impossible to build. The challenge hereby is that the contractor or subcontractor has additional work, since it is his own responsibility to come up with a verifiable solution.

Finding the correct information

The documents communicated by the client do not contain all the necessary requirements. There are additional requirement documents (e.g. local rules and regulations), which the client just refers to and the subcontractor or contractor needs to review in order to find the necessary information

Identify Conflicts Early

It is difficult for the client to detect the conflicts in the requirements early.

3.2.3 Common RE

The Challenges in this cluster are related to the requirements engineering process rather than the written requirements quality.

Difficulty Understanding BIM Requirements

For international consultants it is difficult to understand the BIM requirements, due to the language barrier. The requirements can be translated but that does not mean that their translations are accurate enough.

Requirements Management Tool Related

The challenge here is that the usage of new tools (e.g. DOORS) and their limitations hinder the requirements specialists at their work. That results to extra effort and work in order to understand the functionality of the new tool instead of going on with the way it was done until then (old fashioned way for example with spreadsheets).

Prioritizing the Requirements Validation Process

The requirements validation process requires experience and knowledge in the discipline and since there is a lack of resources, the clients do not prioritize the requirements validation process. As a result, the process is overlooked and, in many cases, won't be performed

3.2.4 Trace Links

This cluster refers to Trace Links, which can be between the design documents and system requirements or trace links between different requirements.

Granularity of Traces

Since the trace links are created between requirements and model elements rather than objects, additional time and effort is required to assign and verify them.

Verifying All Requirements

It is challenging for the client to decide whether all requirements should be verified in the delivered models, because there exists no classification of requirements nor a risk analysis based on the requirements severity or importance.

3.3 Using BIM to support requirements management

The aim of DCAT project is to design methods for the exchange of digital information between stakeholders, streamlining their communication throughout the whole life cycle of an infrastructure project. As described in the section 3.2 above, the main challenges faced currently related to the requirements management have been identified. One of the four clusters, namely the *trace links*, proves that the digital asset verification process is impended due to the challenges derived from the traces granularity and the overall requirements verification procedure. Both processes, creating detailed traces from requirements to the digital assets, as well as the verification of all requirements are costly and inefficient if they take place manually. Therefore, structuring the required information could facilitate facing these challenges by bringing automation in the digital verification process.

The Building Information Models (BIM) are structured data carriers and as such can be the vehicle for a systems engineering approach supporting the processes of allocating, tracing, as well as verifying the functions assignment. The information in the structured and classified digital objects of a BIM model can

be the leading component for the forward and backward traceability between the objects and the requirements.
Main precondition for the realization of such an approach is the utilization of a defined Project Data Structure in a way that is described in detail within the paragraphs that follow.

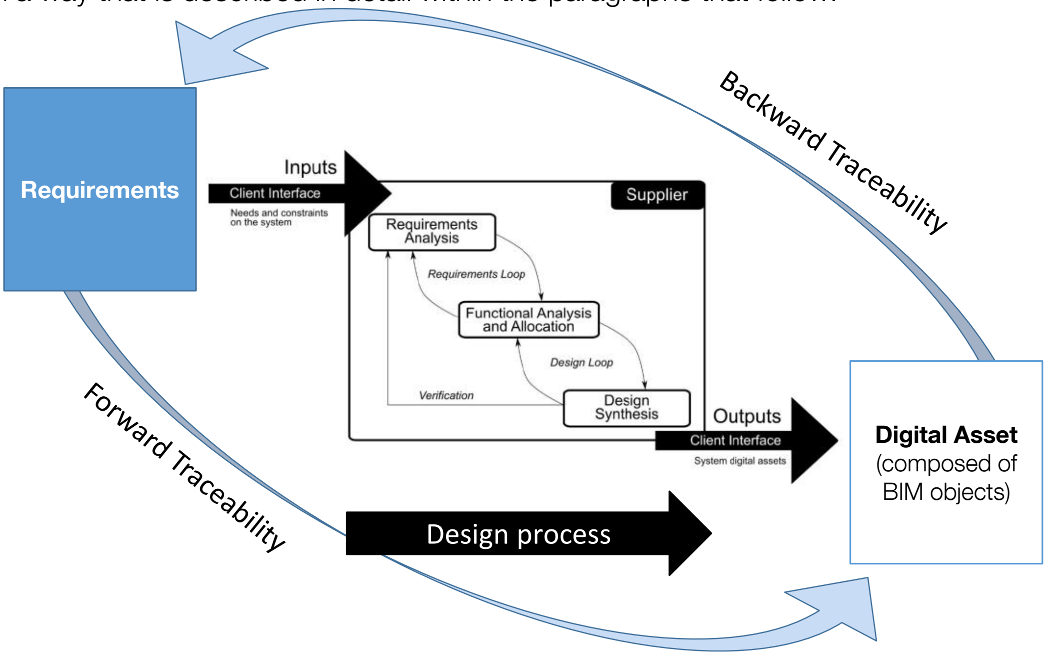

Fig. 1 BIM supported requirements traceability

4 Project Data Structure (PDS)

The DCAT research project pursues the idea of using structured data to establish digital trace links between formulated requirements and the response to them in terms of digital asset elements.
Hence, data structures are the key for bringing multiple project objects in a specific project setup together. In construction projects, a variety of entities can be referred to as project objects. In addition to requirements and digital asset elements that comprise the focus of the DCAT research project, these include, for example, Bill-of-Quantities (BoQ) positions or schedule activities. Also, any kind of other external documentation can be referenced in this way.
Moreover, the data structure forms the basis for attributing project objects and can provide additional information about attributes, such as sources of information (standards and guidelines), calculation rules (for calculating quantities), and responsibilities (who manages the attribute and can provide further information about it).
The PDS is the subset of the consolidated data structures for project objects that is sufficient to simplify the links between the project objects by means of uniform attributes through (partial) automations.
Project objects can be linked to each other, e.g. two project objects contain the same attribute with the same values.
The data structures must be implemented at the project objects at least to such an extent that a transfer or link with other project objects can be made solely based on the attributes. The degree of implementation of the PDS defines the granularity of the link and depends on the selected BIM use case as well as the project phase. The attributes used for this purpose are also referred to as PDS attributes.

4.1 What is a PDS and what can it be used for?

The PDS provides a consistent coding to various teams, elements, or processes of a project, in order to enable team members to correlate data across each element.
Often, there are three common data structures used:

- Location Structure
- Discipline Structure
- Deliverable Structure (The System / Asset Structure).

The PDS serves as the basis for linking relevant project data from different sources in a project for all BIM use cases. It enables a uniform labeling of data even if authors - or even software vendors - usually use different terms and identifiers.

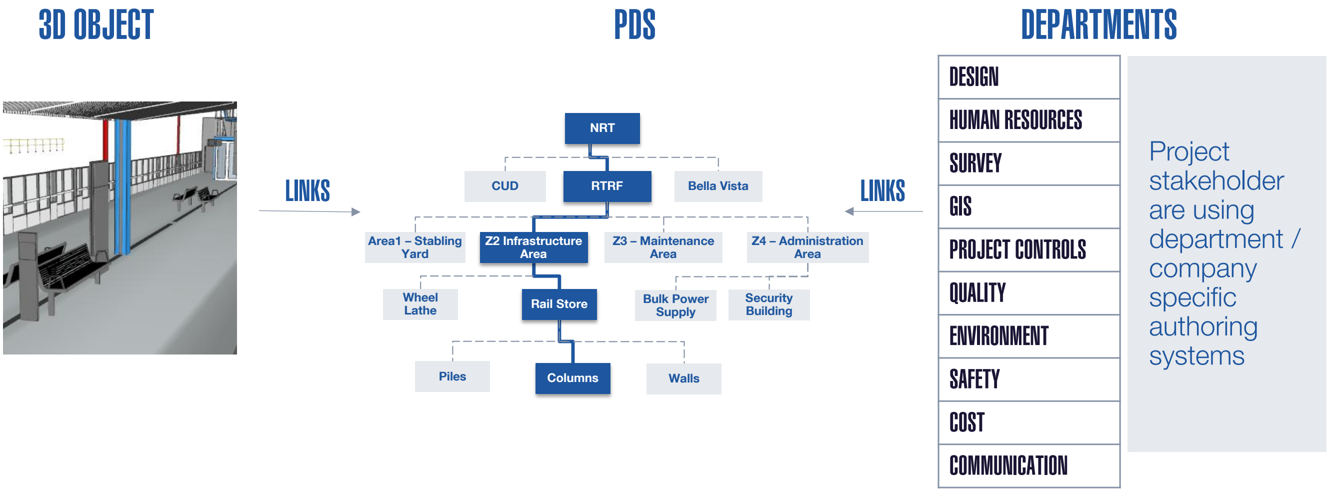

Fig. 2. PDS concept

Key elements of a PDS are the attributes for semantic specification of project objects. Asset objects are often represented as 3D models. They are given a geometry that can be viewed in appropriate software. This is the geometric representation of a building object. This representation sometimes has the advantage that quantities for a building object can be derived from the geometry. Only alone with the geometry it cannot be done yet much, since the meaning for this geometry is missing. Is the geometry a column, a slab, or a wall and if so, what type of wall? Only by describing the geometric object with words does the geometry also acquire a meaning (semantics) with which the user and corresponding algorithms can do something. These descriptive words are also called properties, respectively attributes. In order to be able to distinguish the digital asset objects of a 3D model, they must be described by corresponding attributes.
In addition to asset objects, enriching attributes also leads to a more meaningful description of other project objects, such as the schedule activity or the service items. A service item that is linked to asset objects is more meaningful than one that has no links.

The purpose of a PDS is to gain a project-wide, common framework that aligns information coming from different source and/or being originated in different project stages. Thus, the PDS comprises the “glue” that link information together even when 1:1 relationship between information entities do not exist. As a practical example, one single requirement of an infrastructure project, might be fulfilled by various elements in the digital asset. Selecting this single requirement, would allow for forwards tracing to digital assets provided that both requirements and asset element are associated with respective PDS attribution.

Hence, when all relevant information in a project is originated considering this PDS structure consistently, saying PDS attributes are applied when an information entity is generated, linked information can be found easier, faster and with increased transparency, f.e. by means of a 3D model.

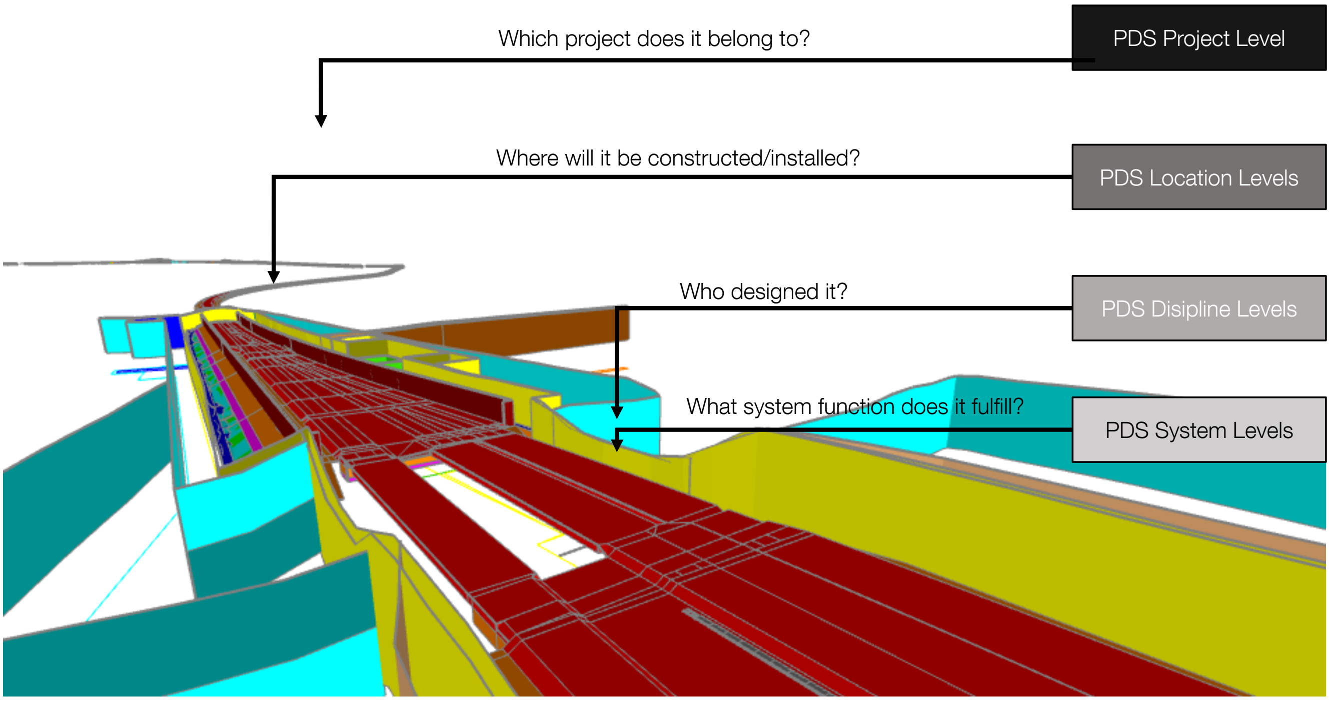

Fig. 3. PDS concept

4.2 Enabling BIM use cases with a PDS

A PDS can be seen as the key to enabling and implementing different BIM use cases. However, it should be noted that although the PDS should always be defined holistically and project-specifically, it is usually the case that only a subset of this PDS is used for certain intended use cases. Furthermore, the implementation of the individual use cases is usually associated with the use of specific software systems. A so-called "use case linking matrix" can help to show in an overall project context which PBS levels and attributes are required for which use cases and how they are related to each other. An example is given in Fig. 4. However, in the DCAT research project, only the use case of “BIM-supported requirements management” will be addressed.

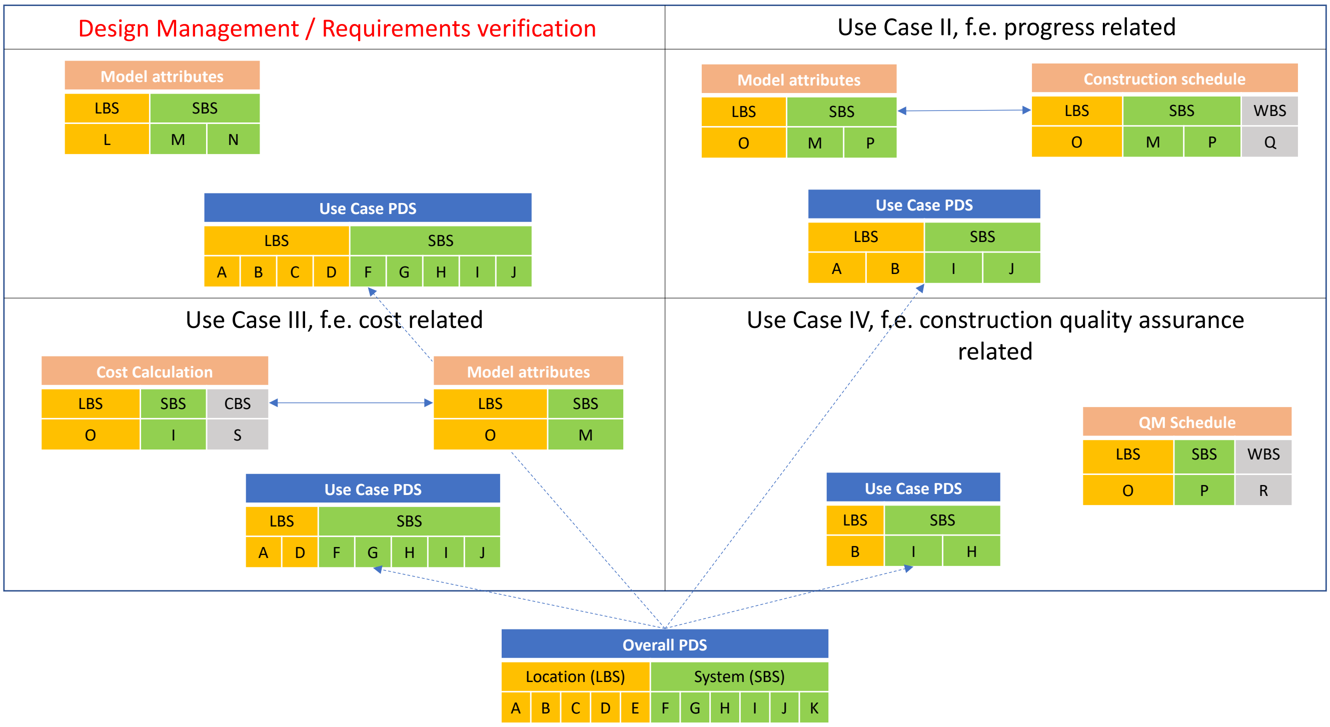

Fig. 4. PDS - Use case linking matrix

4.3 The role of PDS to support the BIM use case of requirements management

During the requirements management process, relevant requirements can be mapped to the digital asset (e.g. the BIM model) via the PDS. To make this possible, both the individual requirements and the elements of the digital assets must be assigned to a defined PDS structure. The digital asset can then be used to retrieve specific information about individual requirements and to initiate a visible or automated verification process. Linking corresponding documents to requirement by the PDS as well enables a traceable and complete documentation of the fulfillment of requirements.

As it is visible in Fig. 4, only a subset of the overall project-specific PDS might be relevant and applicable for the individual BIM use cases. This applies also for the use case of requirements management.

4.4 How to define the PDS

Since there is not yet an established industry standard for PDS, this must be developed and established at the company level.

Project-specific attribute values must be defined and updated.
For attributes that are identified as PDS attributes for the first time in a project, it must be regularly checked whether and how they are included in the company standard:

- PDS attributes are defined in the company standard in terms of scope and detail and are maintained there across the board
- Project-specific attribute values of PDS attributes (e.g. the values for structure name, concreting section, etc.) are to be defined and updated on a project-specific basis

There exist different kinds of relations between the individual PDS levels. Some levels can be independent without any relation to another level, while others require compliance with a hierarchical order to be allocated. Existing classification systems can be used to cover one or more parts of the PDS (e.g. UniClass or SB11 for the System Breakdowns part)

4.4.1 Levels of the PDS

Location Breakdown

- The location structure should be split into three levels:
  - Level 1 – Zone
  - Level 2 – Sub-Zone
  - Level 3 – Space
- The Engineering Manager will consult with other senior managers (including the Design, Procurement, Construction and Commercial Managers) to determine the Location fields content
- When assigning values, the Engineering Manager will consider if the values for each field should be unique (e.g. room numbers) or can they be used for each parent field.
- The values for each field will depend on various factors including the Client, Contractor, contract type or geographical location.

Discipline Breakdown

- The discipline structure should be split into three levels:
  - Level 4 – Project / Sub-Project Type
  - Level 5 – Discipline
  - Level 6 – Sub-Discipline
- The Engineering Manager will consult with other senior managers (including the Design, Construction and Commercial Managers) to select the Discipline fields content relevant to the project from the standard tables.

System Breakdown

- The Engineering Manager will consult with other senior managers (including the Design, Procurement, Construction, Completion and Commercial Managers) to determine the System/Asset fields content.

- The values for these fields will be selected from a Classification System “Systems Tables” (e.g. UniClass or SB11).
- Values will be presented in a single combined field to identify the asset.

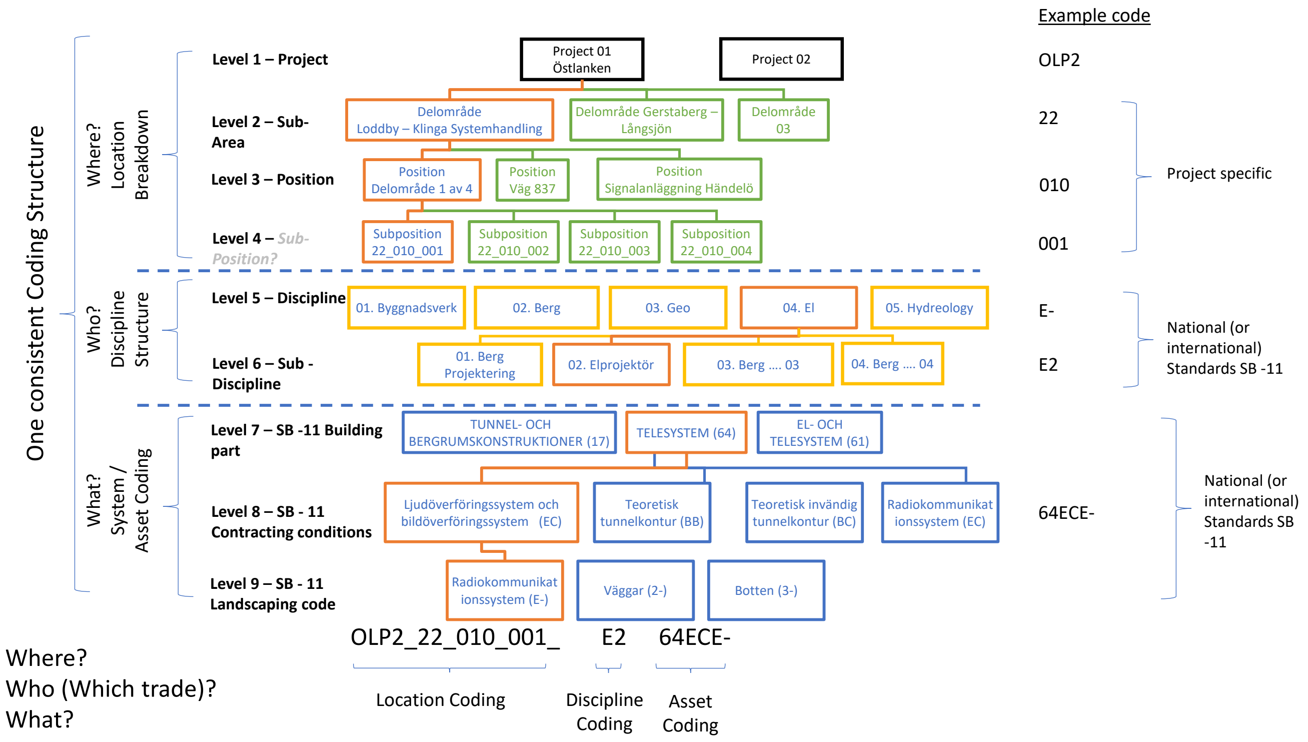

Fig. 5. Exemplary PDS using UniClass classification

4.4.2 Using external classification systems

As described in the section above on PDSs, it is suggested that to describe the "systems" dimension, that is, to answer the question of "What system function does an object fulfill?" (see Fig. 3), existing classification systems in the building industry should be used. The previous investigations in the DCAT research project (WP2) included the evaluation of four classification systems: SB11, CoClass, UniClass and OmniClass. Table 1 shows the results of the evaluation that covered six quality attributes:

1. Comprehensiveness: the ability to classify all known objects.
2. Extensibility: the ability to allow for changes in its structure, i.e. adding, modifying or deleting dimensions, categories or characteristics.
3. Mutual exclusiveness: the ability to identify an object uniquely, i.e. that no object exists in the same dimension under different categories.

4. Explanatory: the ability to enable the user to locate an object in the taxonomy based on its characteristics, or to deduce from the location of an object what characteristics it has.
5. Conciseness: the ability to classify objects of interest with the least possible amount of dimensions, categories and characteristics.
6. Robustness: the ability to differentiate objects of interest.

Attributes 1-4 are characterized by a set of questions that are answered by studying the documentation and the construction process of the classification system. Attributes 5-6 are measured using a quantification of the structure and content of the classification system. The number in parentheses besides the dimension in Table 1 indicates the maximum possible score (e.g. 4 for comprehensiveness) while the numbers in each column indicate the achieved score. More details to the six quality attributes and the methods on how they were assessed are presented in a journal paper[1] that is currently considered for publication.

Table 1 Evaluation of classification systems

	SB11	CoClass	UniClass	OmniClass
Comprehensiveness (4)	0	2	3	3
Extensibility (4)	1	2	1	3
Mutual exclusiveness (1)	0	1	0	0
Explanatory (2)	1	2	1	1
Conciseness (0..1)	0.13	0.14	0.11	0.11
Robustness (0..1)	0.98	0.97	0.63	0.79
Sum (13)	3.11	8.11	5.74	7.9

The last row in Table 1 sums up all scores and provides and indicator how the four classification systems compare to each other. A better way to compare them, however, would be to first select or prioritize the quality attributes and sum the scores using weights that represent the importance for a particular task at hand. Nevertheless, looking at the overall results, even for the individual quality attributes, we would recommend using CoClass or OmniClass, if the quality of the classification systems is of concern. Other practical considerations may however also be of importance:

- Only SB11 and CoClass are available in Swedish. UniClass and OmniClass are only available in English. For international collaborations, CoClass could be preferred as it is also available in English.
- Replacing a classification system in use in an ongoing project is unrealistic. It would however be possible to map between classification systems and use the one more appropriate for the task, when necessary.

Coming back to the PDS and its use of classification systems, the project we studied uses SB11. It would be possible to map SB11 codes to CoClass and benefit from the larger scope (comprehensiveness) of CoClass. Nevertheless, it is possible to use SB11 and Fig. 5 shows therefore the example of a PDS for infrastructure measures using SB11 to describe the system levels.

[1] Michael Unterkalmsteiner and Waleed Abdeen, "A compendium and evaluation of taxonomy quality attributes", Expert Systems: Journal of Knowledge Management, under review (November 2021).

4.4.3 Additional attributes

Examples for additional data structures that could be relevant are:

- Portions – maybe necessary in all applications based on client requirements
- Phases and Sub-Phase / Method – complete list used in Scheduling
- Cost Categories – usually used in Commercial Applications
- Management Categories – maybe needed in planning or for file naming conventions

However, it is yet to be analysed and determined whether and which additional attributes could be relevant for the considered Use Case of BIM-supported requirements management.

5 Applying PDS to requirements and outlook

A single element of a digital asset in terms of a 3D model might be associated relatively easy with PDS attribute values, since it can be for example located very intuitively and precisely. Also, a system allocation of 3D elements is assumed to be feasible without bigger problems for the respective designers. In contrast, requirements may not even refer to any kind of specific spatial location in the project. First of all, it is therefore needed to determine which are the relevant, saying assignable, PDS levels for the use case of requirements with respect to the defined, project-specific PDS (please refer also to use case linking matrix in Fig. 4). Fig. Fig. 6 shows an example for a requirement – PDS matrix that can be used to allocated PDS values to lists of requirements.

id	Name	The Artifact Type	Status	Source Referenc	PDS Location Level 1	PDS Location Level 2	PDS Location Level 3	PDS Discipline Level 1	PDS Discipline Level 2	PDS System Level 1	PDS System Level 2
270865	Service roads must be adapted for bridges > 1 km and tunnels > 300 m.	Requirements	Determined	PM Project specific requirements for the Ostlink							
263832	Signal points should normally be placed back-in-back (even where signal distances < 850 m).	Requirements	Determined	PM Project specific requirements for the Ostlink							

Fig. 6. PDS structure applied to requirements formulization

It is also possible that different types of requirements (e.g. from different documents or relating to different technical areas) could be allocated to different levels of the PDS. Currently, this task can only be performed manually. However, automation of this task is one of the subjects of the DCAT research project and is currently being investigated. The advantages that are hoped to be gained by applying the PDS attributes to the requirements are, as described in section 3.3, the creation of trace links to digital assets and associated documents to foster requirements verification and management processes. The benefits of such trace links will be investigated and evaluated in the next steps of this research project (e.g. via feasibility studies).