MASTER THESIS

Designing a Level of Development information modelling framework for subsurface utility design and construction

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siers

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Summary

Information modelling is becoming more commonplace in construction. In this context, the Building Information Modelling (BIM) paradigm combines information modelling features by modelling object-based, storing object geometries and their relations in 3D, and attaching semantic/attributes to them. This approach has been adopted in this industry, and to this end, guidelines have been developed that express how models incrementally (e.g. along the project lifecycle) gain detail and semantic richness.

The subsurface utility (SU) sector follows this trend gradually. It has started exploring the potential of, for example, 3D visualization, semantic modelling in geographic information systems (GIS), and geo-databases. Information models, with properties similar to BIM models, are also used in an increasing number of SU-projects. However, what is less known to date for this sector, is when and how lifecycle information of assets (that are modelled as Model Elements) should be captured in those models, and how this information changes when an assets moves between project life cycle stages. Siers Infraconsult B.V. is one of the (utility) contractors facing this problem, and consequently struggles to implement this BIM-paradigm inspired work practice.

The literature proposes that the Level of Development (LOD) framework could be used to revolve this issue. Here, the development of a Model Elements' geometry and associated numeric and/or textual attribute data are defined within six general and distinctive levels. In other words, it defines different levels of how to specify Model Elements and how to interpret these. The LOD framework functions as a reference when stakeholders exchange Model Element data. To date, LOD frameworks have been developed for the building subsector. However, such a specification does not exist to support practice in SU. To address this gap, and resolve the problems faced at Siers, *the goal of this study was to design a Level of Development framework for information modelling of utility network elements in subsurface utility projects.*

To reach this goal, this research followed three-phases of a design science methodology, which iterated over the activities of designing and investigating. In the first phase of *Problem Investigation*, a stakeholder analysis was performed, documents and literature regarding existing specifications and information model applications were reviewed and an empirical case study was executed. Next, in the *Treatment Design*-phase, requirements for the LOD framework are specified. Besides, available specification frameworks were studied and Model Elements in existing 2D and 3D project deliverables of Siers were analysed. Moreover, seven actors were consulted via workshops and interviews to gain more data about how they would want to specify Model Elements in a possible future information modelling practice at Siers. The LOD framework was validated during the *Treatment Validation*-phase, via an end-user session. Here, four (future) end-users evaluated the design of the LOD framework on its specified requirements and five criteria: understandability, usability, completeness, structure, and utility. In addition, the interaction between them and the designed LOD framework was assessed.

The validated outcome of this design project entails a LOD framework and accompanying specification documentation for information modelling in the SU sector. The deliverable focuses on one type of project in which Siers considers to gain most value from 3D modelling, namely complex projects. The designed LOD framework consists of six distinctive levels (LODs) which capture the development of the specification of assets in the SU sector. In short, this evolves from schematic (LOD 100), to conceptual (LOD 200), to exact exterior geometry (LOD 250), to exact geometry (LOD 300), exact geometry with connections (LOD 350), to fabrication (LOD 400). These LODs each contain a custom definition for the SU sector of a Model Element's geometry, attribute data and reliability. Besides, the LOD framework includes hierarchy as it assumes Model Elements pass through these level and therefore become more enriched with details. In addition, the framework is of cumulative nature as lower LODs are prerequisites for following LODs.

Validation showed that the designed LOD framework is complete: end-users claimed that the LOD framework is applicable to the total collection of utility network elements among the SU sector and it properly reflects the evolvement of the geometry and attribute data within a correct number of distinctive levels. Besides, both crucial terms and concepts as well as the separate LOD definitions within the LOD framework are (very) clear and understandable to end-users. In addition, it required low effort to understand the LOD framework. Moreover,

the validation showed that end-users correctly implemented the LOD framework, both from the narrative LOD definitions into the correct graphical extent and vice versa. In the end, this resulted in all requirements were met.

The limitations of this study entail three topics: it only considered practice from the host organization and district heating projects, not all stakeholders were involved in the design process by representatives, and the design was validated by only four actors. To address these, information models of other organizations (than Siers) and other disciplines than district heating could have been included. In addition, involving representatives of different organisations and roles could have resulted in different insights, needs and hence outcomes. Moreover, having more stakeholders involved during this validation would have significantly increased the value of the design and hence its representativeness.

Future research could look into five aspects. First, the designed LOD framework could be implemented in a real-world context to test if its use indeed yields the believed advantages such as improved communication and efficient information exchange. Second, the scope of this thesis study was limited to the design and construction of subsurface utilities. The LOD framework of the construction industry however also includes post construction via field-verified representation (i.e. LOD 500). It could be researched whether such an extension of the designed LOD framework is of added value for the SU sector and how it would be defined. Third, practitioners argued that an information model for SU projects is much more than only utility network elements and requires the modelling of the project environment. Hence, future research could look into the functioning of the designed LOD framework in combination with the specification of these surrounding components within an information model for SU projects. Fourth, the spatial extent (and its accuracy) of assets is a fundamental issue within the SU sector (Olde Scholtenhuis & Zlatanova, 2018) and the main incentive of information modelling. Practitioners indicated a practical request of the definition of this spatial data and a potential integration of a spatial data statement with the LOD framework. This thesis study proposed several options to practitioners but they indicated it needed more time, attention and research. Future research could dive into this topic and propose a solution for the integration with the designed LOD framework. Fifth, in supporting practice, future research could study the relation between the LODs and project stages by identifying which LODs apply for certain Model Elements along project stages. In this way, a practical translation of the LOD framework will be made which support integration in current working practices.

The main scientific contribution of this study is the creation of a shared understanding of the evolving specification of utility network elements during the design and construction of subsurface utility projects. In so, the LOD framework is uniquely designed as it uses utility attribute categories to specifically address the evolvement of assets' semantical richness. In addition, a new LOD was defined and added to the framework: LOD 250. This level fits between LOD 200 and LOD 300 to allow the modelling of subsurface utilities' exact exterior geometry that have low semantical richness. These are needed to represent the existing infrastructure in a project space (that is commonly represented on statutory records, such as KLIC-drawings). Moreover, the thesis outcome incorporates accompanying specification documentation of the identified evolving geometry in LODs of multiple (types of) utility network elements by visually exposing implementation examples to minimize misinterpretation of the narrative descriptions.

The project has delivered an outcome that contributes to practice as it produces a reference description of how the specification of utility network elements evolves over time. This helps overcome the practical ambiguities during the development information models in SU projects and improves communication and information exchange between end-users. Once applied in a structural manner, this thesis outcome furthermore supports the implementation and adoption of information models of Siers, and if endorsed and used by a larger group of stakeholders in the industry, within the SU sector.

Samenvatting

Informatiemodellering wordt steeds gebruikelijker in de bouw. In deze context combineert het Bouw Informatie Model (BIM)-paradigma functies voor informatiemodellering door object gebaseerd te modelleren, objectgeometrieën en hun relaties in 3D op te slaan en semantiek/attributen eraan te koppelen. De huidige industrie heeft deze werkwijze geadopteerd en met het oog hierop zijn richtlijnen ontwikkeld die vastleggen hoe modellen stapsgewijs (bijv. langs de projectlevenscyclus) aan detail en semantische rijkdom winnen.

De sector van de ondergrondse nutsvoorzieningen (SU) volgt deze trend geleidelijk. Eerst stappen zijn gezet in de verkenning van de mogelijkheden van bijvoorbeeld 3D-visualisatie, semantische modellering in geografische informatiesystemen (GIS) en geodatabases. Ook in steeds meer SU-projecten worden informatiemodellen gebruikt, met eigenschappen die vergelijkbaar zijn met BIM-modellen. Wat tot op heden echter minder bekend is voor deze sector, is wanneer en hoe levenscyclusinformatie van activa (die zijn gemodelleerd als modelelementen) in die modellen moet worden vastgelegd, en hoe deze informatie verandert wanneer activa tussen projectlevenscyclusfasen worden verplaatst. Siers Infraconsult B.V. is een van de (nuts)aannemers die met dit probleem te maken hebben en heeft daarom moeite om deze werkpraktijk te implementeren.

Literatuur stelt voor dat het Level of Development (LOD)-raamwerk kan worden gebruikt om deze kwestie om te buigen. Dit raamwerk definieert de ontwikkeling van de geometrie van een modelelement en bijbehorende numerieke en/of tekstuele attribuutgegevens in zes algemene maar onderscheidende niveaus. Met andere woorden, het definieert verschillende niveaus voor het specificeren van modelelementen en hoe deze te interpreteren. Het LOD-raamwerk fungeert als een referentie hulpmiddel voor de (digitale) gegevensuitwisseling tussen stakeholders. Tot op heden zijn er LOD-raamwerken ontwikkeld voor de deelsector bouw. Een dergelijke specificatie bestaat echter niet om de praktijk in de SU sector te ondersteunen. Om deze kloof te dichten en de problemen bij Siers op te lossen, was het doel van deze studie het ontwerpen van een Level of Development raamwerk voor informatiemodellering van nutsnetwerkelementen in ondergrondse nutsprojecten.

Om dit doel te bereiken volgde dit onderzoek een wetenschappelijke ontwerpmethodologie van drie fasen waarin de activiteiten ontwerpen en onderzoeken iteratief werd uitgevoerd. In de eerste fase is een stakeholderanalyse uitgevoerd, zijn documenten en literatuur met betrekking tot bestaande specificaties en informatiemodeltoepassingen beoordeeld en is een empirische case study gedaan. Vervolgens zijn in de tweede fase de eisen voor het LOD-raamwerk gespecificeerd. Daarnaast werden bestaande, beschikbare specificatie raamwerken bestudeerd en werden modelelementen in bestaande 2D- en 3D-projectresultaten van Siers geanalyseerd. Bovendien werden zeven actoren geraadpleegd via workshops en interviews om meer gegevens te verkrijgen over hun (toekomstige) kijk op de specificatie van modelelementen. Het LOD-raamwerk werd gevalideerd tijdens de derde fase via een eindgebruikerssessie. Vier (toekomstige) eindgebruikers evalueerden het ontwerp van het LOD-raamwerk op de geïdentificeerde eisen en vijf criteria: begrijpelijkheid, bruikbaarheid, volledigheid, structuur en toepasbaarheid. Daarnaast werd de interactie tussen hen en het ontworpen LOD-raamwerk beoordeeld.

Het gevalideerde resultaat omvat een LOD-raamwerk en bijbehorende specificatiedocumentatie voor informatiemodellering van nutsnetwerkelementen in de SU-sector. Het onderzoek richtte zich op één type project waarin Siers meent het meeste voordeel te halen uit 3D-modellering, namelijk complexe projecten. Het ontworpen LOD-raamwerk bestaat uit zes onderscheidende niveaus (LOD's) die de ontwikkeling van de specificatie van activa in de SU-sector vastleggen. In het kort evolueert dit van schematisch (LOD 100), naar conceptueel (LOD 200), naar exacte buitengeometrie (LOD 250), naar exacte geometrie (LOD 300), exacte geometrie met verbindingen (LOD 350), naar fabricage (LOD 400). Deze LOD's bevatten elk een toegespitste definitie van de geometrie, attribuutgegevens en betrouwbaarheid van een modelelement op de SU-sector. Daarnaast bevat het LOD-raamwerk hiërarchie, omdat het ervan uitgaat dat modelelementen door elke LOD gaan en daarom meer worden verrijkt met details. Bovendien is het raamwerk van cumulatieve aard aangezien lagere LOD's een voorwaarde zijn voor opvolgende LOD's.

Validatie toonde aan dat het ontworpen LOD-raamwerk compleet is: eindgebruikers beweerden dat het LOD-raamwerk van toepassing is op de totale verzameling van nutsnetwerkelementen in de SU-sector en dat het de

evolutie van de geometrie en attribuutgegevens binnen een correct aantal onderscheidende niveaus is vastgelegd. Bovendien zijn zowel cruciale termen en concepten als de afzonderlijke LOD-definities binnen het LOD-raamwerk (zeer) duidelijk en begrijpelijk voor eindgebruikers. Bovendien vergde het weinig inspanning om het LOD-raamwerk te begrijpen. Bovendien toonde de validatie aan dat eindgebruikers het LOD-raamwerk correct implementeerden, zowel van de verhalende LOD-definities naar de juiste grafische weergave en vice versa. Dit heeft er uiteindelijk toe geleid dat aan alle eisen is voldaan.

De beperkingen van deze studie omvatten drie onderwerpen: er werd alleen gekeken naar de praktijk van de gastorganisatie en stadsverwarmingsprojecten, niet alle belanghebbenden werden door vertegenwoordigers bij het ontwerpproces betrokken en het ontwerp werd door slechts vier actoren gevalideerd. Het onderzoek had versterkt kunnen worden door informatiemodellen van andere organisaties (dan Siers) en andere disciplines dan stadsverwarming op te nemen. Daarnaast had het betrekken van vertegenwoordigers van verschillende organisaties en rollen tot andere inzichten, behoeften en dus uitkomsten kunnen leiden. Bovendien zou het hebben van meer belanghebbenden bij deze validatie de waarde van het ontwerp en daarmee de representativiteit ervan aanzienlijk hebben verhoogd.

Toekomstig onderzoek zou naar vijf aspecten kunnen kijken. Ten eerste zou het ontworpen LOD-raamwerk in een reële context kunnen worden geïmplementeerd om te testen of het gebruik ervan inderdaad de verwachte voordelen oplevert zoals verbeterde communicatie en efficiënte informatie-uitwisseling. Ten tweede was de scope van dit onderzoek beperkt tot het ontwerp en de constructie van ondergrondse voorzieningen. Het LOD-raamwerk van de bouwsector omvat echter ook operatie en onderhoud via in het veld geverifieerde weergaves (LOD 500). Daarom kan onderzocht worden of een dergelijke uitbreiding van het ontworpen LOD-raamwerk van toegevoegde waarde is voor de SU-sector en hoe deze vervolgens gedefinieerd moet worden. Ten derde gaven actoren aan dat een informatiemodel voor SU-projecten veel meer is dan alleen de nutsnetwerkelementen en dat het modellering van de projectomgeving vereist. Daarom zou toekomstig onderzoek kunnen kijken naar het functioneren van het ontworpen LOD-raamwerk in combinatie met de specificatie van deze omringende componenten binnen een informatiemodel voor SU-projecten. Ten vierde is de locatie (en de nauwkeurigheid ervan) van activa een fundamentele kwestie binnen de SU-sector (Olde Scholtenhuis & Zlatanova, 2018) en de belangrijkste drijfveer van informatiemodellering. Vanuit de praktijk bestaat er een verzoek om de definitie van deze gegevens vast te leggen en een mogelijke te integreren in het LOD-raamwerk. Deze studie stelde verschillende opties voor aan actoren, maar deze gaven aan dat hier meer tijd, aandacht en onderzoek voor nodig was. Toekomstig onderzoek zou daarom dit kunnen onderzoeken en een oplossing kunnen voorstellen voor de integratie met het ontworpen LOD-raamwerk. Ten vijfde zou toekomstig onderzoek, ter ondersteuning van de praktijk, de relatie tussen de LOD's en projectfasen kunnen bestuderen door te identificeren welke LOD's van toepassing zijn voor bepaalde modelelementen in de projectfasen. Op deze manier wordt een praktische vertaalslag gemaakt van het LOD-raamwerk dat integratie in de huidige werkpraktijk ondersteunt.

Al met al heeft dit onderzoek een wetenschappelijke bijdrage aangezien het ontworpen LOD-raamwerk een door de sector gedeeld en representatief begrip is over hoe nutsnetwerkelementen stapsgewijs geometrische details en semantische rijkdom verkrijgen tijdens SU-projecten. Het ontwerp van het LOD-raamwerk is uniek omdat het gebruikmaakt van attribuut categorieën om specifiek de ontwikkeling van de semantische rijkdom van activa vast te leggen. Daarnaast bevat het LOD-raamwerk een nieuw gedefinieerde LOD: LOD 250. Dit niveau past tussen LOD 200 en LOD 300 om het modelleren van de exacte buitengeometrie van ondergrondse nutsvoorzieningen met een lage semantische rijkdom mogelijk te maken. Deze zijn nodig om de bestaande infrastructuur weer te geven in een projectruimte (die vaak wordt weergegeven op wettelijke documenten, zoals KLIC-tekeningen). Bovendien bevat het resultaat van het proefschrift bijbehorende specificatiedocumentatie van de geïdentificeerde evoluerende geometrie in LOD's van meerdere (types van) nutsnetwerkelementen door implementatievoorbeelden visueel bloot te leggen. Dit minimaliseert verkeerde interpretatie door eindgebruikers van de verhalende beschrijvingen.

Dit draagt op zijn beurt bij aan de praktijk aangezien het de praktische dubbelzinnigheden helpt te overwinnen tijdens de specificatie van nutsnetwerkelementen binnen informatiemodellen, aangezien het een referentiebeschrijving oplevert van hoe deze zich in de loop van de tijd ontwikkelen. Daarom zal het gebruik van dit raamwerk de communicatie verbeteren en inadequate en inefficiënte informatie-uitwisseling tussen eindgebruikers minimaliseren. Wanneer het LOD raamwerk op een structurele manier wordt toegepast, ondersteunt dit onderzoek bovendien de implementatie en adoptie van informatiemodellen van Siers en, indien onderschreven en gebruikt door een grotere groep stakeholders in de industrie, binnen de SU-sector.

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2D	Two-dimensional
3D	Three-dimensional
ADE	Application Domain Extension
AEC	Architecture, Engineering and Construction
ASCE	American Society of Civil Engineers
BIM	Building Information Modelling
CAD	Computer Aided Design
GML	Geography Markup Language
IFC	Industry Foundation Classes
IMKL	Informatie Model Kabels en Leidingen (Dutch)
INSPIRE	Infrastructure for Spatial Information in Europe
KLIC	Kabels en Leidingen Informatie Centrum (Dutch)
LOD(s)	Level(s) of Development
LODetail(s)	Level(s) of Detail
OGC	Open Geospatial Consortium
PAS	Publicly Available Specification
PMKL	Presentatie Model Kabels en Leidingen (Dutch)
SU	Subsurface Utility/Utilities

Glossary

[1]	Artifact	Something created by people for some practical purpose (Wieringa, 2014).
[2]	Attribute (data)	A quality or characteristic that a Model Element has (Cambridge Dictionary, n.d.)
[3]	Framework	A system of rules, ideas, or beliefs that is used to plan or decide something (Cambridge Dictionary, n.d.).
[4]	Geometry	The area of mathematics relating to the study of space and the relationships between points, lines, curves, and surfaces (Cambridge Dictionary, n.d.).
[5]	Information model	An information model is a representation of concepts, relationships, constraints, rules, and operations to specify data semantics for a chosen domain of discourse (Y. T. Lee, 1999).
[6]	(Model) Element	A portion of a (3D) model representing a component, system or assembly within a utility network or construction site (based on (American Institute of Architects, 2008)).
[7]	Modelling	To make or construct a descriptive or representational model (The Free Dictionary, n.d.).
[8]	Reliability	The extent of which the (downstream) users can rely on the content (Bedrick et al., 2020).
[9]	Semantic(s)	The study of meanings in a language (Cambridge Dictionary, n.d.).
[10]	Specification	The definition of a Model Element’s [6] geometry [4] and associated numeric and/or textual attributes [2] (based on (Bedrick et al., 2020)).
[11]	Stakeholder	A person, group of persons, or institution affected by treating the problem (Wieringa, 2014).
[12]	Subsurface utility	Any public utility infrastructure [16] which is underground (The Free Dictionary, n.d.).
[13]	Taxonomy	A system for naming and organizing things into groups that share similar qualities (Cambridge Dictionary, n.d.).
[14]	Topology	The way the parts of something are organized or connected (Cambridge Dictionary, n.d.).
[15]	Treatment	The interaction between an artifact [1] and the problem context (Wieringa, 2014).
[16]	Utility infrastructure	Infrastructure with the purpose of transporting commodities (R. B. A. ter Huurne, 2019).

1. Introduction

An increasing number of stakeholders need physical underground 'space' to place their assets. This is partly due to population growth, urbanisation and industrialisation, and has increased the pressure on land-use planning and development. As a result, space above and below ground level is increasingly used (Aien, 2013). In the face of these growth predictions and climate change, interdependencies between urban planning objectives and the subsurface become ever more important (von der Tann et al., 2018). Especially, considering the fact that the underground in urban area comes now to a phase in which it is saturated with all these facilities, resulting in the margins in the underground space are quickly running out (Municipality of Best, 2014; Niesing & Hekkenberg, 2019).

In dealing this issue, the subsurface utility (SU) sector is progressing toward the adoption of three dimensional (3D) information models capable of representing each design element together while providing a better dynamic visualization (Pilia & Anspach, 2014). According to literature, such information models are supportive within several domains (Cheng et al., 2016; Hartmann et al., 2008; J. Lee & Zlatanova, 2018; Olde Scholtenhuis & Zlatanova, 2018; van Manen et al., 2021).

Within an object-oriented information model, construction data is captured through the concept of Model Elements. Each element represents a component, system or assembly within a project (American Institute of Architects, 2008). Such a Model Element contains two types of information: 1) the element's (2D or 3D) geometry and 2) associated numeric and/or textual attributes (Bedrick et al., 2020), together referred to as its specification.

The way in which stakeholders specify Model Elements depends when this model is used during the project life cycle. Generally, the model gradually shifts from a rough sketch towards a detailed representation of reality within a project. It progresses through project time due to different information needs for decision-making at different project stages (Ewenstein & Whyte, 2009). Although multiple initiatives from the last decade(s) in the SU sector emphasized on the implementation of information models by the development of data standards, guidelines and more, there exists no sector wide uniform specification of utility information models (Bradley et al., 2016; R. B. ter Huurne & Olde Scholtenhuis, 2018). With regards to the use of information models, this has a consequence that there is also no shared understanding between end-users of information models about how Model Elements' geometry and attribute data need to be specified to meaningfully support construction and planning stages.

As a result, multiple organizations are currently having different perceptions and interpretations of reality and define different model specifications (R. ter Huurne, 2018). These organisational information modelling approaches often conflict leading to confusion and miscommunication between end-users. This fragmented practice enlarges the variety in data standardization which consequently leads to an ineffective, dispersed adoption in the sector. In addition, it causes information being missed or even redundant in produced models (inadequate information) since different definitions of model specification are perceived, resulting in a loss of process efficiency and less profit of the investment in 3D development. This, on its turn, results in a perpetual circle of poor adoption of information modelling in the SU sector as indicated in Figure 1. Thus, due to a lack of a uniform specification, the adoption of information modelling is lagging behind causing two dimensional (2D) utility mapping still to be the standard (Pilia & Anspach, 2014; R. ter Huurne, 2018).

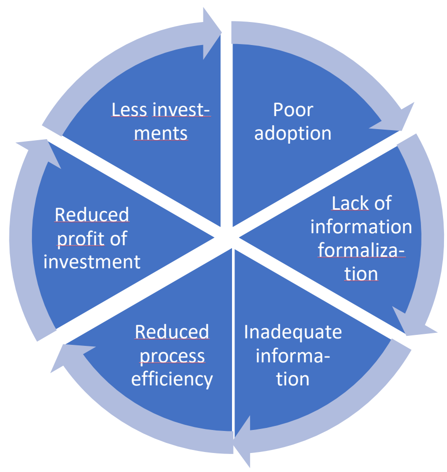


Figure 1: Perpetual circle of poor adoption of 3D modelling in the SU sector

Siers Infraconsult B.V. is one of the Dutch (utility) contractors facing this problem, and consequently struggles to implement this work practice. Siers recognizes the beneficials of (3D) information modelling, but it faces the practical ambiguities during the specification of the utility network elements. Siers hence provides a good context to the problem. Besides, this study can contribute to their adoption and implementation of information models. Appendix A provides a more elaborate description of Siers Infraconsult B.V. as a host organisation and problem owner.

To address the shortcoming, and make more explicit what the different levels of granularity a SU project information model can have, this study aimed to design a design framework that classifies information models in terms of their geometry and semantic richness. For this, the theoretical Level of Development (LOD) framework was used which stems from the construction industry. It can be considered as a (reference) tool in digital data exchange as it defines different levels of how to specify Model Elements and how to interpret these. In essence, it sets out the development of a Model Element which incrementally gain detail in the specification. Since, the focus of the AEC industry and SU sector as well as these artifacts are essentially different (as elaborated in section 3.2; Cheng et al., 2016), this model needs to be tailored to sector needs. Specifically the goal of this study was hence *to design a LOD framework for information modelling of utility network elements in SU projects.*

Designing such LOD framework for utility network elements requires a full understanding of the problem context. Therefore, the characteristics of the SU sector itself needs to be studied and how current practices, both from a theoretical and practical perspective, define the specification of these elements. In addition, available specification frameworks of information models need to be analysed and studied on useable aspect for the Level of Development framework for utility network elements. When synthesized in an adapted LOD for the SU sector, this information was then validated.

The research was limited to complex projects only since most merit of implementing 3D modelling was found in such projects for subsurface utility contractors (van Manen et al., 2021). As defined by Van Manen et al. (2021), these complex projects entail outdoor projects in a crowded urban area in which rigid utilities are designed and constructed, such as water transport, district heating and high-pressure gas.

The report is structured by first describing the research approach in chapter 2. This will be done by presenting the research objectives (section 2.1) and elucidating the methodology (section 2.2). The third chapter will provide the problem context as a result of the *Problem Investigation*-phase. Here, the chapter will dive into the incentives of information modelling in SU projects, and the fundamentals of the LOD framework of the construction industry. The chapter eventually addresses the shortcoming of the SU sector. Chapter 4 then will present the results of the *Treatment design*-phase. In so, it will describe the specified requirements for the LOD framework, how utilities are currently specified (both in terms of geometry and attribute data), what existing specification frameworks are available and how these are used in this design project. At the end of the chapter, section 4.4 will present the final design of the LOD framework. The next chapter (5) will elucidate the results of the validation of this final design. Then, chapter 6 will provide a discussion about the implications, limitations and future works of this research. At last, the seventh chapter will conclude the research.

2. Research approach

This chapter elucidates the research approach by first presenting the research objectives in section 2.1, whereafter section 2.2 explains the methodology.

2.1. Research objectives

Based on the research problem as defined and described in the introduction, this section set the research objectives.

From the problem definition, the main research objective is formulated as follows:

To design a Level of Development framework for information modelling of utility network elements in subsurface utility projects

Since this main research objective is comprehensive, it is decomposed in multiple subobjectives. Fulfilling these subobjectives results in the achievement of the main research objective. Below, these objectives are listed:

1. *To identify the contextual characteristics of the SU sector;*
2. *To identify existing specifications of utility network elements in SU projects;*
3. *To analyse available specification frameworks of information models and identify useable aspects for the Level of Development framework for utility network elements;*
4. *To tailor the Level of Development framework to the setting of utility networks;*
5. *To validate the designed Level of Development framework.*

2.2. Methodology

During the research project, I applied the design cycle (Wieringa, 2014), which makes use of three phases:

I. Problem investigation: What phenomena must be improved and why?
II. Treatment design: Design of artifact(s) to treat the problem.
III. Treatment validation: Does the design(s) treat the problem?

Each design cycle phase consists of different activities and outputs, which are tailored to this research. Figure 2 sets out the design cycle, its activities per phase and the research goals per phase. The upcoming subsections will elucidate these activities.

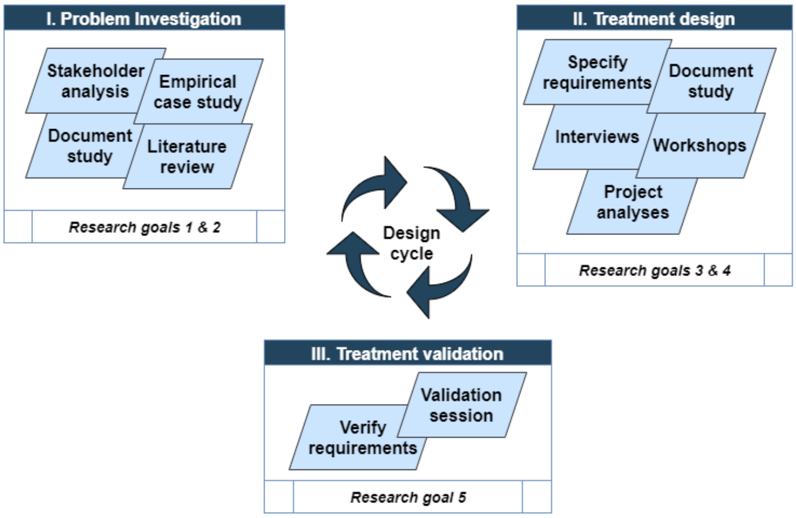


Figure 2: Research strategy including phases, main activities and research goals

2.2.1. Problem investigation

The first phase of problem investigation aimed at, by contrast, the preparation for the design of a treatment by learning more about the problem to be treated. In reaching this, several activities have been performed as explained below.

As a start, a stakeholder analysis was performed. A stakeholder of a problem is a person, group of persons, or institution affected by treating the problem (Wieringa, 2014). For this research, the main stakeholders and their goals were identified. Wieringa (2014) states that the interaction with the product is an essential design part of the artifact. Hence, I established the relationships of the identified stakeholders with the final artifact, the system as a whole and their interfaces via the onion diagram of Alexander (2005).

Second, the related phenomena were investigated. Several phenomena were identified and analysed. In total, four themes of phenomena were scrutinized which are the 1) utility networks and their containing elements, 2) mechanisms during design & construction, 3) 3D model uses and 4) existing 3D specifications. This four themed investigation started with a document study into the composition of utility networks. A selection of theoretical documents were analysed to understand what utility networks are present and how these are built up. These documents were selected as they provide standardized information models and data specifications. Table 1 gives an overview of these documents including a description and an indication whether 2D and 3D are supported. The document study was complemented with practical findings via informal meetings at the host organisation.

Table 1: Overview of analysed theoretical documents – part 1

Name	**2D**	**3D**	**Description**	**Source**
INSPIRE Utility and Government Services	✓	-	A common information model for spatial data for utility and government services to provide cross-border interoperability in Europe.	(Brönnimann et al., 2013)
CityGML Utility Network ADE	✓	✓	International data specification for a common 3D network model for multi-utility simulation including the relevant thematic attribution.	(Becker et al., 2016)
Informatiemodel Kabels en Leidingen (IMKL)	✓	✓	Data specification for (digital) information exchange of cable and pipeline information from the utility grids in the Netherlands and Belgium. Specifically aimed at preventing damages during excavation activities.	(van den Berg & Janssen, 2020)
Modelling utilities by developing a domain ontology	-	-	PhD-document proposing a data specification for utility elements which is specifically focused on operation and maintenance in the Netherlands.	(R. B. A. ter Huurne, 2019)

Then, the mechanisms during the design and construction of subsurface utilities have been studied. It was aimed to understand how information currently is exchanged among the involved stakeholders. Different activities and deliverables were identified. For the purpose of this identification, two research activities were executed at the host organization.

First, insights were gained through observations of works practices. Multiple employees' daily tasks were observed who are involved in the modelling of utility networks. These employees entail project managers, engineers, 2D modellers and 3D modellers. During this inquiry, notes were taken while the employees showed and explained how the host organisation model their utility networks in digital environments. In addition, (informal) talks were held in which the employees elucidated their work routines.

Second, the researcher took on the role of a 3D model developer. During this empirical case study, the researcher was in close contact with involved employees and had to work with different software programmes such as AutoCAD, Civil3D, Navisworks and FME workbench. In this way, the researcher was able to understand the development process of the information model.

Next, it was studied which main (potential) applications hold for information modelling of utility network elements. Why would the sector make use of such models and what are the incentives? The answers to both questions were found via a literature study and interviewing different actors. In this way, both a theoretical and practical point of view was obtained.

Three search engines were used to gain access to appropriate literature: Google Scholar, Scopus, and FindUT. In so, the following (combination of) keywords were used: application, uses, 3D models, 3D modelling, utility network, subsurface utilities, and underground infrastructure. Additionally, interviews were conducted with actors of the SU sector to identify which applications are most prevailing and considered as most valuable in practice. In total, six actors were questioned (Table 5). At first, open questions were raised by the researchers to identify the applications with the highest priority of the actors. Afterwards, the applications found during the literature study were discussed via a semi structured interview.

Furthermore, existing specification efforts were investigated from both a theoretical and practical point of view. The assessment of the existing efforts concerning utility modelling happened through a document study and project analyses.

Starting with the first aspect of the specification, the geometric representation of the Model Elements was studied. Multiple theoretical documents were analysed on the various ways utility network elements are able to be modelled. During this document study, the documents as presented in Table 2 were studied as well as the CityGML Utility Network ADE (Table 1) and the LOD Specification (subsection 2.2.2).

Table 2: Overview of analysed theoretical documents – part 2

Name	2D	3D	Description	Source
Industry Foundation Classes (IFC)	✓	✓	International, open data specification for a standardized, digital description of the built environment, including buildings and civil infrastructure. It also describes 2D and 3D geometries of utility network elements.	(Liebich, 2009)
Presentatie Model Kabels en Leidingen (PMKL)	✓		Data visualisation guide for the data as described in the IMKL (Table 1). It is in line with Dutch regulations on construction drawings (NEN 3116). It describes general visualisation rules as well as tailored rules for specific utility networks.	(mac Gillavry & Janssen, 2020)

In addition to the document study, I also analysed deliverables of projects and their underlying models. These deliverables relate to either the collection of 2D deliverables (Appendix C) or the final information model. However, since Siers had not fully implemented information modelling yet, the analysis mainly covered the former. Table 3 provides a summary of these projects. I studied how elements were modelled in terms of their geometry within a project. In the end, I obtained an overview of the geometry representations of the utility network elements.

Table 3: Overview of analysed projects

Project name	Organisations	2D	3D	Description
Project A	Siers Infraconsult B.V., Eneco	✓	✓	District heating utility system to be constructed
Project B	Siers Infraconsult B.V., Ennatuurlijk	✓	✓	District heating utility system to be constructed
Project C	Siers Infraconsult B.V., Ennatuurlijk, Gemeente Enschede	✓		District heating and sewage system to be constructed
Project D	Siers Infraconsult B.V., Eneco	✓	✓	District heating utility system to be constructed

For the second aspect of the specification, being the attribute data, I thoroughly studied the documents as presented in Table 1. These documents entail data specifications and information models of subsurface utilities. In addition to these documents, I included three more documents in this analysis. These documents are more and more referred to and integrated in the Dutch SU sector as they set out guidelines during the collection of information. Table 4 lists these documents and its description. I analysed which project-related attribute data were included for utility network elements. With project-related attributes, utility attributes relating to subsurface utility project information is meant. This means no attributes are included about modelling information such as ID, date of modelling, modelling version, etc.

Table 4: Overview of analysed theoretical documents – part 3

Name	Description	Source
PAS 128	British standard which specifies requirements for detection, verification and location of existing and new underground utilities.	(British Standards Institution, 2014)
PAS 256	British standard which gives recommendations for capturing, recording, maintaining and sharing location information and data for underground utilities. It is intended to be used alongside PAS 128.	(British Standards Institution, 2017)
ASCE 38-02	American standard guideline on the collection and depiction of utility information. It incorporates a classification of the quality of existing utility data.	(American Society of Civil Engineers, 2002)

Next, I complemented these outcomes with the results of the project analyses to ensure interference of practice. Insights obtained from the document study eased the analysis by for example the recognition of terminology and semantics. These case studies entail finished projects to obtain a complete set of information (Table 3). During the analysis, I inventoried which attribute data was enclosed in the current practices.

Afterwards, I categorized the total list of found attribute data following the product attribute classification of El-Diraby & Osman (2011; Appendix G). In so, I examined which attribute categories are predominant and which not. In other words, the relevance of inclusion of these attribute categories for SU projects is obtained. The relevance is divided into three degrees: basic, optional and not. The meaning of these different degrees of relevance speaks for itself. I set the attribute categories to basic in case of recurring (in more than three times) in both practice and theory; optional when it was included in at least one theoretical document or project; and not relevant in case of no attributes were mentioned in theory or included in practice. This relevance provided insights in the evolvement of project information using this attribute classification.

2.2.2. Treatment design

The second phase of the design cycle focused on the actual design of the treatment. The designed LOD framework had been established in an iterative nature. The findings of several activities served as input for the design. In addition to the activities, many (informal) meetings held during the entire thesis study supported the design process. In this way, the designed LOD framework became more comprehensive and representative over time by gaining input from different perspectives. Below, the activities will be elucidated.

First, the requirements of the LOD framework were defined. The requirements have been collected during the entire thesis study and followed from induction of findings and consultation with practitioners. A requirement is a property of the treatment desired by some stakeholder, who has committed resources (time and/or money) to realize the property. In other words, it is a goal for the to-be-designed treatment (Wieringa, 2014). In this, Wieringa (2014) makes a distinction in functional and non-functional requirements. The first entails requirements for desired functions of the treatment, whereas the latter entails the requirements for non-functional properties. Hence, the functional requirements are often considered as essential components of the treatment. Non-functional properties are usually global properties of the interaction between the treatment and its context such as the usability and accuracy of the output. For each non-functional requirement its operationalisation had been set by defining its indicator and norm. An indicator refers to a variable that can be measured which indicates the presence of that property. A norm, on its turn, is a set of required values of the indicator (Wieringa, 2014).

Second, these requirements were used to define numerous dimensions of the designed LOD framework. These dimensions are in essence specific aspects which together constitute the LOD framework. It refers to a distinct feature or element in a problem or situation (The Free Dictionary, n.d.). In so, the requirements were analysed on their nature and assessed whether those fall under certain corresponding dimensions. This resulted in the identification of three dimensions: structure, geometry and attribute data. These dimensions were used during the designing process of the LOD framework as a systematic approach.

Third, available treatments were studied. In total, I identified three documents as such: AEC LOD Framework (American Institute of Architects, 2013), AEC LOD Specification (Bedrick et al., 2020) and CityGML's Level of Detail concept as used in CityGML Utility Network ADE (Table 1). I reviewed these specification frameworks by means of a systematic document study as these were scrutinized with regard to their specific content and the afore-identified dimensions. Besides, this review also incorporated the identification of facets mentioned in those document being relevant for the designed LOD framework for utility network element during SU projects. In specific, I studied the AEC LOD framework on how the distinctive levels are defined, what they exactly hold, what they imply, and on what basis these are distinguished. The definition of these levels served as an initial definition of the LOD framework for utility network elements during SU projects. In addition, I studied the AEC LOD specification and CityGML's Level of Detail concept in terms of their explicit implementation. These documents namely includes example implementations which set out what the narrative descriptions imply. For the AEC LOD specification, this study is limited to building elements similar to the ones prevailing in the SU sector as described in Appendix I.2 By doing so, I gained an understanding of cumulative specifications and implementations of utility network like elements.

Fourth, to facilitate the implementation of the eventual LOD framework, it is important that all direct stakeholders (being in *The System* as defined in Appendix B, Figure 9) participate in the design process. For this reason, I involved numerous actors during the research. I held individual workshop sessions with representatives of a utility operator, excavation contractor and utility owners. Table 5 lists these involved actors including their role and organisation. During these sessions, I gathered stakeholders' views on the specification of utility network elements. The earlier findings in specifications served as input (as described in subsection 2.2.1). In specific, I discussed which possible geometry representations they acknowledge for the different utility network elements (Appendix D). In addition, I questioned them about which attribute data to include during a SU project using an Excel sheet. For both specification aspects, the evolving nature (i.e. graduality) was incorporated. Besides, I recorded the sessions and took notes while attendees showed and explained their viewpoints. In so, I stimulated them to support their views with (digital) sketches to diminish the risk of wrong interpretation. This also allowed direct reaction and solution-oriented discussions.

Table 5: Overview of involved actors

ID	Organisation name	Type of organisation	Role
1	Siers Infraconsult B.V.	Utility contractor	Project manager
2	Siers Infraconsult B.V.	Utility contractor	Engineer
3	Siers Infraconsult B.V.	Utility contractor	Practitioner & project manager
4	Siers Leiding & Montage B.V.	Excavation contractor	Practitioner
5	Stedin	Utility owner	Engineer electricity
6	Eneco	Utility owner	Engineer district heating
7	ENnatuurlijk	Utility owner	Engineer district heating

2.2.3. Treatment validation

The goal of validation was to predict how an artifact will interact with its context, without actually observing an implemented artifact in a real-world context. By validating the LOD framework it was justified if it would contribute to stakeholders goals if implemented (Wieringa, 2014). In the context of this research, this related to the defined requirements of the LOD framework (as presented in section 4.1).

First, while designing the LOD framework, a continue process of verifying the defined functional requirements was done. These functional requirements are considered as the core components of the LOD framework and hence needed to be evaluated. The verification results followed from informal discussions with experts.

On the other hand, the non-functional requirements were more considered as properties which need evaluation of (future) end-users. These non-functional requirements were validated based on five criteria which came from the analysis of the defined requirements and Wieringa (2014): understandability, usability, completeness, structure, and utility. These criteria are described Appendix E.1. As a crucial (future) characteristic of the LOD framework, the interaction between the designed LOD framework and its (future) end-users was validated as well. In other words, it is tested if future end-users understand the LOD framework and if they come to the expected implementations. This latter entailed three type of questions: I tested if attendees 1) were capable to understand what the narrative LOD definitions actually implies when specified and modelled, 2) were capable to define a Model Element’s LOD based on how it is specified in the information model, and 3) knew when to use which LOD.

All criteria were tested during an online end-user validation session via Microsoft Teams. This human centred validation method made use of subject matter experts who evaluated all elements of the instrument. Four of the seven actors involved during the design process of the LOD framework (Table 5; IDs: 2, 4, 6 & 7) attended this validation session.

During the session, I questioned the attendees via Microsoft Forms on these criteria via multiple choice questions and ranking questions. Attendees were stimulated to explain their viewpoint when their answers were significantly striking according to the researcher. Appendix E.1 presents the total set-up and list of questions. The session was held in the attendees’ mother language (Dutch) to ensure attendees focus on the content on their answers rather than focussing on choosing the rights words.

The chapters below will explain, based on the stages in the cycle of Wieringa, what the design outcomes were.

3. Problem Investigation

This chapter will provide the reader a description of the problem context. Laymen can consult Appendix B and C for the basic contextual characteristics of the Dutch SU sector and the design and construction processes of the subsurface utility networks, respectively. This chapter will first elaborate on the incentives of information modelling in SU projects, followed by an explanation of the fundamentals of the LOD framework as used in the AEC industry. The chapter will conclude with a statement regarding the SU sector's shortcoming in information modelling.

3.1. Information modelling incentives and applications

This thesis research embroiders the belief of information modelling potentially being an added value for SU projects. But why and for what purposes could such models be used? This section elucidates the applications and incentives to adopt information modelling in subsurface utility projects.

Table 6 summarizes all found applications.

In the last decades, many researchers stated that information modelling could support the current workflow as it provides several benefits. Especially in relation to the upcoming future issue of the subsurface getting saturated in urban areas, information modelling might play a key role (Cobouw, 2020). To kick off, information models enable improved communication via photorealistic renderings. 3D walkthroughs, short movie clips that simulate the view from the perspective of a human that walks through the facility, can additionally help to communicate the proposed design to a range of stakeholders (Hartmann et al., 2008; van Manen et al., 2021).

Furthermore, information modelling supports engineering tasks such as (virtual) design review (Hartmann et al., 2008). It helps to grasp the complexity of existing underground networks, which assists the maintenance and incident management of subsurface infrastructure (J. Lee & Zlatanova, 2018; Xu & Zlatanova, 2007). The detection of physical conflicts, and hence the identification of free underground space, and analysis of excavation workspace constraints are supported since engineers can overlay information models of designed and existing buried infrastructures. In so, engineers obtain an understanding of the underground's spatial complexity. In addition, modelling utility networks in 3D also supports the assessment of the design with respect to meeting codes and standards. As an example from practice, a water line is not allowed to be closer than 1 metre to a thermal line (Appendix J.1).

Besides, design engineers can use information models as input for design analysis and simulation. Multiple design alternatives can be modelled and compared such that their performance(s) can be understood better (Cheng et al., 2016; Hartmann et al., 2008; van Manen et al., 2021).

Moreover, information models can even be integrated with construction schedules (4D) during planning stages to support multi-stakeholder coordination of utility street works (Olde Scholtenhuis et al., 2016). It allows project managers to determine overall site management strategies during the construction phase, the planning of site logistics or access routing.

At last, information models support cost estimation by the generation of a bill of quantities. This is only valid when object-oriented semantic modelling is applied and a cost database is incorporated. In so, cost estimating is shown to be more accurate than with take-offs from 2D construction drawings.

The accumulation of these benefits can hence be considered as the underlying incentive of this study.

Table 6: Applications of information modelling for SU projects

Application of information model	Source
Photorealistic renderings (improved communication)	(Hartmann et al., 2008; van Manen et al., 2021)
Virtual design review • Meeting codes and standard • Clash detection • Understanding spatial complexity	(Cheng et al., 2016; Hartmann et al., 2008; J. Lee & Zlatanova, 2018; Olde Scholtenhuis et al., 2016; van Manen et al., 2021; Xu & Zlatanova, 2007)
Analysing design options/building operations • Design analysis of alternatives • Design simulations	(Cheng et al., 2016; Hartmann et al., 2008; van Manen et al., 2021)
Analysing construction operations (4D)	(Cheng et al., 2016; Hartmann et al., 2008; Olde Scholtenhuis et al., 2016)
Cost estimating (5D)	(Cheng et al., 2016; Hartmann et al., 2008)

Despite the multiple incentives, the current application of information modelling in practice is still at its outset. In specific, current practices (at Siers) focus more at 3D visualisation rather than information modelling.

The current SU sector does not make use of Building Information Modelling (BIM). As earlier defined by Azhar et al. (2012), BIM is both a technology and a process. The technology component of BIM helps project stakeholders to visualize what is to be built in a simulated environment to identify any potential design, construction or operational issues. The process component enables close collaboration and encourages integration of the roles of all stakeholders on a project. Although the first is, the latter is not the case and hence current practices can rather be considered as (semantically) enriched 3D modelling. Therefore, this thesis encompasses the latter.

Moreover, the vast majority of practitioners among the SU sector (Table 5) acknowledges the main reason to use the information modelling is for the purpose of virtual design review. Especially with regard to understanding the spatial complexity and clash detection. According to practitioners, this has to do with the sector's prevailing problem of lack of documentation and location accuracy of subsurface utilities. In addition, information models also ease communication with other stakeholders resulting in more targeted and efficient discussions. Besides, the possibility to enrich information models with performance, planning or cost information is said to be interesting but future. Integrating such in the current working practices requires a change of process, which is currently considered as a bridge too far.

But, although this section highlights the merits of information modelling for the SU sector, this highly depends on its specification and implementation in practice. In so, there is no clear description of how an information model gets built up as projects emerge. The specification of an information model progresses through project time due to different information needs for decision-making at different project stages (Ewenstein & Whyte, 2009). Although multiple initiatives from the last decade(s) in the SU sector emphasized on the implementation of information models by the development of data standards, guidelines and more, there exists no sector wide uniform specification of information models (Bradley et al., 2016; R. B. ter Huurne & Olde Scholtenhuis, 2018). This results in no shared understanding among the SU sector in terms of the geometry and attribute data of the Model Elements, resulting in miscommunication and inadequate information provision within the SU sector.

3.2. Fundamentals of the LOD concept in the AEC industry

The problem as experienced in the SU sector is however not unique. Among the Architecture, Engineering and Construction (AEC) industry, where information modelling is more advanced and integrated in current practices, this same problem was experienced. In tackling this problem, the American Institute of Architects (2013) developed a framework of Levels of Development (LOD), hereafter referred to as AEC LOD framework. This section first dives into the fundamentals of this LOD concept and ends with answering why this framework is not suitable for the SU sector.

The AEC LOD framework describes the level of completeness to which a Model Element is modelled by narrative, standardized definitions of six progressively detailed levels. The AEC LOD framework can be considered as a (reference) tool in digital data exchange as it defines different levels of how to specify Model Elements and how to interpret these. This latter relates to the reliability of the specified Model Element, being the extent of which the (downstream) users can rely on the content. It is used bilaterally: by the model designer specifying the Model Element and the ones observing and interpreting the specified Model Element.

In essence, the Levels of Development refer to the amount of information which is relevant to the concrete development of the project and necessary to make tangible decisions, i.e. the maturity of the model. Therefore also referred to *as 'the depth of thinking applied to the model'* and *'the degree to which project team members may rely on the information when using the model'* (Mavreli, 2018).

The AEC LOD framework is structured to minimize errors with the help of a numerical lexicon which the designers and the end-users of a (3D) information model share for common understanding. In so, it defines the Model Elements' geometry and associated numeric and/or textual attribute data within six general but distinctive levels. It progresses from 1) a concept design to 2) general modelling with semantic design, to 3) accurate modelling and detailed design, to 4) greater detail and construction documentation, to 5) fabrication and assembly, and at last to 6) as-built models. These distinctive levels can therefore be considered as the development of the specification of Model Elements over time. Figure 3 gives a visual example of the implementation of the cumulative AEC LOD framework of an office chair (McPhee, 2013).

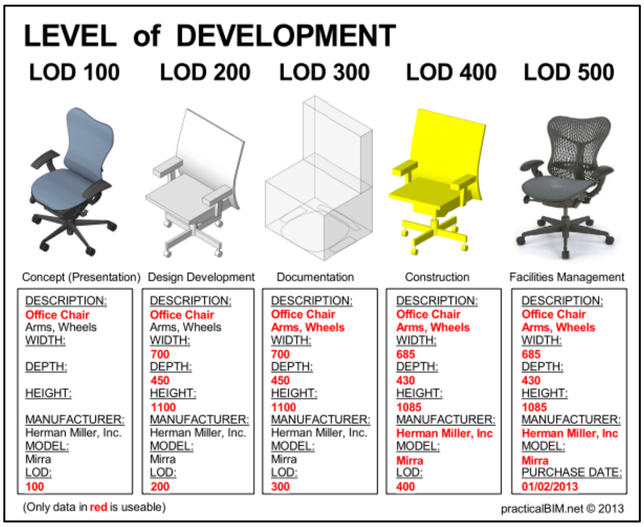


Figure 3: Example implementation of the LOD concept of an office chair (McPhee, 2013)

Fundamental to this LOD concept is that it should be applied to Model Elements. There is no such thing as an "LOD ### model" (Bedrick et al., 2020). As previously noted, project models will invariably contain Model Elements at various levels of development as these progress at different rates. In addition, the LODs are not defined by design phases. Rather, design phase completion, as well as any other milestone or deliverable, can be defined through the LOD language.

The LOD definitions are used to cover several issues that happen in a design project (Bedrick et al., 2020). This is because it is easy to misinterpret the precision of a Model Element to be modelled. Besides, it allows model users to define the use of the building models, as well as to allow construction players to clearly understand the usability and the limitations of the received building models (Bedrick et al., 2020; Latiffi et al., 2015b; Mavreli, 2018). Next to this, using LOD, teams working under different disciplines were found to communicate with each other in a better way with greater clarity (United BIM, 2021). Overall, the use of LOD improves the communication by reducing the problems due to inadequate information needed in projects by providing a stepwise approach (Bedrick et al., 2020; Latiffi et al., 2015b).

In the context of information models and the Levels of Development, the abbreviation LOD is usually interpreted as a Level of Detail instead of Level of Development (United BIM, 2021). These both concepts are different in nature but interrelated as Level of Detail uses the concept of Level of Development. Level of Detail is actually what proportion detail is enclosed within the Model Element. It originates from computer graphics models and aims at efficient visualization, reduction of computational complexity and increasement of the efficiency of rendering purely geometrical graphical aspects (Cheng et al., 2016). Besides, because the Level of Detail is only a measure of quantity, the underlying assumption is that all provided information is relevant to the project and so can be relied upon with certainty. In essence, the Level of Detail can be considered as input to the element, while the Level of Development is a reliable output. For this reason, the core of this report relates to the Level of Development.

As a follow-on product of the LOD framework in the AEC industry, the BIMForum used the AEC LOD framework to develop a LOD specification, mainly focused on the building sector (Bedrick et al., 2020). This sets out an organized collection of interpretations of the AIA's LOD definitions describing input and information requirements and providing graphical examples of the different Levels of Development of a broad variety of building element classes. The LOD Specification is not a set of requirements as to what is modelled when or by whom. Rather it is a language by which end-users can define these requirements for their own firms or projects.

The LOD Specification makes use of the phenomenon of a Model Element only containing two types of information: 1) the element's geometry and 2) associated numeric and/or textual attributes. Hence, it contains two parts which both address one type of information. The first part consists of narrative descriptions and illustrations of specific Model Elements for each LOD. Second, a workbook is incorporated which uses a Model Element Table and references to related attribute tables for various building systems.

Cheng et al. (2016) articulate that there are however some vital differences between the building sector and SU sector: the structure and components of buildings are different from those of subsurface utility networks. Furthermore, other than with the construction of a building, the construction of subsurface utilities presents many interferences with the surrounding (geometrical) environment (Cassino et al., 2012; Vignali et al., 2021). Hence, it has a more topographic nature with precise georeferencing.

In addition, the focus of the AEC LOD framework mainly lays on the construction of surface structures rather than underground structures. Elements of subsurface utility networks are minimally elaborated, causing the overall focus of the AEC industry and the SU sector to be different. In other words, the existing AEC LOD artifacts are not suitable for the SU sector since it is not tailored to its contextual characteristics. So, the SU sector lacks a specification regarding 3D utility data modelling. Stakeholders like Siers hence encounter practical ambiguities in exchanging this data causing involved organisations communicate ineffective.

3.3. Shortcoming of the SU sector

Section 3.1 discussed the applications and incentives for information modelling within the SU sector. Despite the multiple incentives, the current application of information modelling in practice is still at its outset. An explanatory argument is the lack of a sector wide uniform specification of information models (Bradley et al., 2016; R. B. ter Huurne & Olde Scholtenhuis, 2018). The non-shared understanding among the SU sector in terms of the geometry and attribute data of the Model Elements caused a fragmented implementation of information modelling, with several negative consequences as a result such as miscommunication and inadequate information provision within the SU sector.

Section 3.2 then introduced the LOD framework which was developed to tackle the same issue but experienced in the AEC industry. This framework however is not suitable for the SU sector since it is not tailored to the SU sector's contextual characteristics (Cassino et al., 2012; Cheng et al., 2016; Vignali et al., 2021).

Therefore, the next chapter will present the findings of the solution-oriented study into these issues. These findings cumulatively led the researcher to a final design of a LOD framework for utility network elements suitable for utility design and construction (section 4.4).

4. Treatment design

This chapter will present the results of the second phase of the design cycle: the *Treatment Design*. The result that is presented here is the outcome of various design iterations. During each, the design incrementally changed based on feedback that was obtained from practitioners. To this end, this chapter first defines the requirements of the LOD framework (section 4.1), reviews existing available specification frameworks (section 4.2), addresses the 3D specification of the elements as observed in theory and practice (section 4.3), and presents the final designed LOD framework in section 4.4.

4.1. Requirements of LOD framework

Multiple requirements were defined after consultation of the literature and discussions with practitioners. This section will present these requirements. Appendix F presents the full list of identified requirements.

First, nine functional requirements are set as presented in Table 7. The definition of these functional requirements is rather binary; it is easy to determine if such requirement is incorporated in the design. In short, it addresses requirements on the specification of Model Elements (both geometry and attribute data), structure (hierarchy, cumulative and standardized) and implementation. This latter refers to the possibility to use to LOD framework for each utility network element type (cf. Appendix D) for every utility discipline such as water, electricity and district heating.

Table 7: LOD framework functional requirements incorporated in thesis study

ID	Functional requirement
1	The LOD framework must describe geometric data.
2	The LOD framework must describe attribute data.
3	The LOD framework must describe the degree of reliability.
4	The LOD framework must capture the graduality of the specification.
5	The LOD framework must allow modelling of every utility discipline.
6	The LOD framework must allow modelling of every utility network element type.
7	The LOD framework must hold hierarchy among the levels.
8	The LOD framework must be cumulative: each LOD definition includes the requirements of previous LODs.
9	The LOD framework must provide a standard definition of the specification of Model Elements that can be referenced during projects.

Second, five non-functional requirement are defined. Table 8 presents these non-functional requirements with their corresponding indicators and norms as the operationalisation of the requirements is often multiple.

Table 8: LOD framework non-functional requirements incorporated in thesis study

ID	Non-functional requirement	Indicator	Norm
10	The LOD framework is clearly defined and easy to understand by its end-users.	Effort to understand	Low
11	The number of Levels within the LOD framework must be limited.	# of levels	As low as possible
12	The implementation of the LOD framework must result in the specified output of all Model Elements.	Compliance	Yes
13	The output resulting from the LOD framework must be traceable by the end-users to the relevant LOD.	Compliance	Yes
14	The LOD framework must be supported by the direct stakeholders through reaching consensus in which definition and implementations of LODs.	Consensus reached	Yes

The above tables show that the LOD framework covers topics like its content, structure, usability, and utility. Considering the usability, the LOD framework should be understandable for its end-users and not too extensive.

This prevents processes from becoming very complex while using the LOD framework such that the end-users do not get caught up in the extensity.

Next, the LOD framework should ensure that the output of the end-users' implementation is as prescribed. Hence, two requirements capture this compliance. It covers the end-user's capability to specify Model Elements as prescribed by the LOD framework and the capability to interpret Model Elements accordingly. In addition, it should be known by the end-users which LOD when to use.

Moreover, a consensus must be reached among the direct stakeholders in the definition (and implementation) of the LODs. In so, the artifact will be supported by the utility sector.

4.1.1. Dimensions of LOD framework

Based on all the listed requirements, three main dimensions are identified which together form the backbone of the LOD framework for utility network elements in SU projects. These are:

- Structure; how is the artifact formalized and how is the distinctive capacity of the specification captured?
- Geometry; what ways of representing the geometry of utility network elements do exist?
- Attribute data; which utility attributes are relevant in SU projects?

In the upcoming sections, multiple documents will be assessed on these dimensions allowing a structured and systematic approach.

4.2. Existing specifications

This section will cover the findings on existing utility data specifications. This holds as an additional study into two dimensions of the LOD framework: the element's geometry and attribute data. Present ways of specifying utility network elements relevant to the design of the LOD framework of the SU sector are analysed and inventoried. First, the geometry will be discussed followed by the attribute data. Both parts will conclude with a summary of their most important insights with regards to the final design of the LOD framework for utility network elements in SU projects as presented in section 4.4.

Geometry

During the study into the geometry specification multiple ways of representing utility network elements in 3D are identified, varying from very conceptual to real-life representations. In this subsection, the observed ways of representing the geometry from both theory and practice are combined and summarized. The separate findings regarding theory and practice can be found in Appendix H.1.

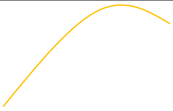
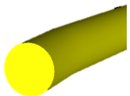
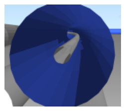
In total, seven different and distinctive representations of the geometry hold within the SU sector. Below, a brief description is given of these geometry representations. Besides, the found representations are listed with an increased degree in detail going downwards:

- Line – 2D polyline indicating the location of the centreline of a linear Model Element;
- Node / Symbol – 2D point indicating the location of the centre point of a functional Model Element. These can be semantically enriched and specified via the use of symbols or icons;
- Footprint – 2D polygon indicating the planar (x, y) surface area of a Model Element;
- Sphere – 3D solid of a sphere indicating the existence and location of a Model Element;
- Generic placeholder – 3D solid of a Model Element with an approximate exterior geometry (length, width, height);
- Outer dimensions – 3D solid of a Model Element with a representative exterior geometry;
- Exact geometry – 3D solid of a Model Element with a representative exterior and interior geometry. Material layer specification possible.

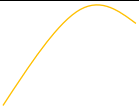
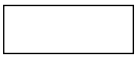
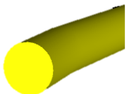
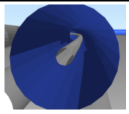
Every way of representing the geometry however does not specifically hold for all utility network elements. Hence, the total collection of utility network elements is distinguished into four generalized types based on their topological characteristic: *Utility Link, Utility Link Container, Utility Node,* and *Utility Node Container.* Appendix D describes this distinction and each individual type.

Below, the findings per type of utility network element are summarized. The found series of different representations are shown with an increased degree in detail from left to right. Each distinctive representation is annexed with a visual example. The used colours have no explicit meaning. In addition, the origin of each representation is indicated using endnotes. Note that for the current example representations of the *Utility Nodes*, the examples of *'outer dimensions'* and *'exact geometry'* look similar, but in fact are different as at this latter also incorporates the interior geometry.

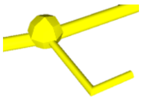
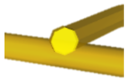
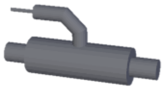
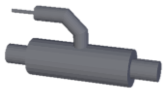
- *Utility Link*

Geometry representation	Line	Outer dimensions	Exact geometry
Example	 [i]	 [ii]	 [iii]

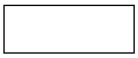
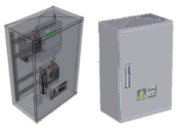
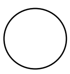
- *Utility Link Container*

Geometry representation	Line	Footprint	Outer dimensions	Exact geometry
Example	 [i]	 [i]	 [ii]	 [iii]

- *Utility Node*

Geometry representation	Node/ Symbol	Sphere	Generic placeholder	Outer dimensions	Exact geometry
Example #1 – Valve	 [i]	 [ii]	 [i]	 [iv]	 [iv]
Example #2 – Parallel T-piece	 [i]		 [ii]	 [iii]	 [iii]

- *Utility Node Container*

Geometry representation	Node/ Symbol	Footprint	Generic placeholder	Outer dimensions	Exact geometry
Example #1 – Electricity cabinet	 [i]	 [i]	 [i]	 [i]	 [iv]
Example #2 – Manhole	 [i]	 [i]	 [i]	 [v]	 [v]

These different representations have different incentives in information models during SU projects:

- In general, the 2D representations indicate approximately what kind of Model Elements are in which location;

- The spheres and generic placeholders serve as indication of the presence of Model Elements and their approximate size, mainly with regards to rough area reservation. These representations were mainly observed for existing infrastructure present at the total project area ;
- For existing utilities close to the new designed network, their exact size is desirable with regard to their exact area reservation. This also holds for utility information as acquired by excavation (test trenches). Hence, here, the representation of the correct outer dimensions was implemented in practice;
- At last, when the design of the new network is finished, most detail is enclosed in Model Elements used in the design of the to be constructed network. These are either new constructed utilities or (re)used existing utilities. Here, the exact geometry is desired. Note that here the end of the design process is meant. During the preliminary process of design exploration and development, it could be modelled using representations with lower geometrical detail.

The following subjects were used within the design process of the LOD framework for utility network elements within SU projects:

- The individual ways of representing a Model Element's geometry and their incentives;
- The overall evolving degree of geometrical detail as used in SU projects;
- The differences between the existing underground infrastructure, as acquired from the KLIC, and the to be constructed network. Within the latter more details are enclosed compared to the existing networks.

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[i] Example representation created by researcher based on findings in both theory and practice.
[ii] Example representation obtained from Project B.
[iii] Example representation obtained from Project D.
[iv] Example representation obtained from CAD Forum (2021).
[v] Example representation obtained from Revit City (2021).

Attribute data

Model Elements can be provided with various attributes. In fact, there is no limit in the addition of attribute data to the Model (Element). In this subsection, the findings regarding attribute data from both theory and practice are summarized. The separate findings regarding theory and practice can be found in Appendix H.2.

To kick-off, attribute data highly depends on the project setting. Which exact attribute data is relevant to include namely depends on the project nature and environment. This is in line with the statement of the SU sector being project-based sector (Appendix C) and is acknowledged by practitioners. Next to this, which information when to use also depends on the application. Section 3.1 stated that information models currently gain most value through 3D visualisation (by clash detection, understanding spatial complexity, and improved communication) during the design and construction processes.

This observation makes it however difficult to specifically address certain attribute data within the design of the LOD framework for utility network elements. For this reason and to gain insights in the overall collection of attribute data, this thesis study makes use of the attribute categorization as defined by El-Diraby & Osman (2011). They defined a classification of infrastructure product attributes which is utility discipline and utility type independent and hence ensures a consistent and unambiguous approach of the complete set of elements among the utility networks. In addition, this classification is in line with the LOD concept as it is an abstract (yet extendable) philosophical (yet practical) conceptualization of the essence of knowledge that relates to construction aspects of infrastructure products.

The attribute categorization by El-Diraby & Osman (2011) classifies attributes into eleven main categories: dimensional, spatial, material, shape, cost, performance, surrounding soil, dependency, redundancy, state of operation, and impact attributes. Appendix G provides the definitions of these attribute categories. However, this classification is incomplete for SU projects since some attributes did not fit the classification. Hence, three more attribute categories are defined and included in this thesis study: actor, functional and survey attributes. Appendix H.2 describes these attribute categories.

Furthermore, there is a significant difference in the extent of attribute data between practice and theory. While the theoretical documents provides a detailed, comprehensive list of attributes, practice only includes limited attribute data of the utilities. In short, theory includes over hundred attributes regarding the Model Element's dimensions, spatial extent, material, performance, state of operation, actor(s), functionality and performed survey(s). Practice, on the other hand, only includes twelve attributes. A possible declaration of the minimal extent of the attribute data in current practices is the focus on 3D visualisation rather than information modelling (section 3.1). For detailed attribute information of practice and theory, Table 19 and Table 20 in Appendix H.2 can be consulted respectively.

Besides, regarding the evolvement of attribute data over project time, the analysed theoretical documents (of Table 1, Table 2 and Table 4) do not embody the evolving aspect of information over project time: they rather provide a full list of attributes rather than incorporating the time aspect. Practice however does via the design deliverables (as elucidated in Appendix C). But although these 2D deliverables progress along the project timeline, it showed minimal differences in attribute data. In addition, there is no clear, fixed approach or pattern in the extent and evolvement of the attribute data. These deliverables included nearly identical utility information, but at later deliverables this information can be associated with more certainty as the design comes to its final stage. In general sense, these deliverables rather state more about the thoughtfulness of the Model Elements rather than the exact attribute data to include.

Moreover, there exist a difference in the relevance of inclusion during a SU project between the attribute data. Below, Table 9 provides a summary of these findings. Here, every attribute category is included and presented with its relevance as found in both theory and practice.

Table 9: Summary of the relevance of inclusion of attribute categories as found in theory and practice

ID	Attribute category	Theory			Practice			Comment
		Basic	Optional	Not	Basic	Optional	Not	
1	Dimensional	✓			✓			
2	Spatial	✓			✓			
3	Material		✓			✓		
4	Shape		✓				✓	
5	Cost			✓			✓	
6	Performance		✓				✓	Only if relevant
7	Surrounding soil			✓		✓		In specific cases useful in design
8	Dependency			✓			✓	
9	Redundancy			✓			✓	
10	State of operation	✓			✓			
11	Impact			✓			✓	
12	Actor		✓		✓			Newly added
13	Functional	✓				✓		Newly added
14	Survey		✓				✓	Newly added

The above table shows that dimensional, spatial, state of operation, actor, and functional attributes are basic information. In relation to the LOD framework, this basic information can be considered as a parallel of the LOD's minimum content requirements of the attribute data (section 4.3). Material, shape, performance and survey attributes are considered as optional data. Attributes regarding a Model Element's costs, dependency, redundancy and impact have no direct relevance of inclusion within the information model for SU projects. This does not mean these attributes are not relevant at all, but that these attributes are not relevant within its current application (3D visualisation). These attributes can be added to the model for additional purposes or applications. In addition, these attributes can hence be considered as additional information which could enrich the Model (Elements) rather than being attribute data within direct development of the Model Element.

Furthermore, the attribute data gradually evolves along the project time according to practitioners. Starting with a first orientation of the project area, the nature of the utilities is of most importance. This relates to the classification of the present utility network elements (i.e. functionality and discipline). Here, the location and depth of the utilities are also wished to be obtained. When continuing the design process, the assets' dimensional and spatial extent become of more importance. Besides, it should be known what the state of operation of the utilities are and which actors are involved. In addition, some existing utilities' performance characteristics should be known as these might danger construction activities. Think for example about careful excavating near high voltage electricity networks. When the route of the new network then is designed, an allocation of the actual construction elements can be performed, including definitions of the used materials, connections and other additional information for construction.

Overall, during the study into utility attribute data, the following subjects were used within the design process of the LOD framework for utility network elements:

- The total collection of (possible) involved attribute data as prescribed in theory and used in practice;
- Differences were observed in practice in the extent of attribute data of utilities with a different origin (Appendix H.2). Although the LOD uses standardized definitions, this is good to be aware of;
- The extent and relevance of inclusion of the attribute data highly depends on the project setting and application of the information model;
- The gradual evolvement of attribute data along project time.

4.3. Available specification frameworks

This section entails the review of the available treatments: the AEC LOD documents (both the Framework and Specification) and Level of Detail framework of CityGML. In so, it treats the specific content of each specification framework and assesses these documents on the identified LOD framework dimensions as described in subsection 4.1.1. In other words, this section identifies what basic properties the available specification frameworks hold and which are relevant for the LOD framework for utility network elements in SU projects. Below, all observations considered as relevant for this thesis design study are discussed. The review of each document concludes with a summary of their most important insights with regards to the final design of the LOD framework for utility network elements in SU projects as presented in section 4.4. First, the AEC LOD framework will be elucidated, followed by the LOD Specification and CityGML's LODetail.

AEC LOD framework

As mentioned earlier, the AEC LOD framework consists of narrative definitions of different, distinctive ways of specifying Model Elements. Regarding its structure, there exists six distinctive LODs which are distinguished with regard to specific minimum content requirements and the reliability. This latter refers to the associated authorized uses for a Model Element in a certain LOD and the extent of which the (downstream) users can rely on the content. The different LODs are referred to using 'LOD ###' system, where '###' indicates the distinctive levels. This system includes hierarchy as it assumes Model Elements pass through these level and therefore become more enriched with details. Moreover, the framework is of cumulative nature as lower LODs are prerequisites for following LODs. Below, brief, general descriptions are presented. For detailed LOD descriptions American Institute of Architects (2013) and Bedrick et al. (2020) (LOD 350 only) can be consulted.

LOD 100: The Model Element may be graphically represented in the Model with a symbol or other generic representation. Information related to the Model Element can be derived from other Model Elements. Any information derived from LOD 100 elements must be considered approximate.

LOD 200: The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. Any information derived from LOD 200 elements must be considered approximate.

LOD 300: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. This information can directly be measured from the model and is representative. Non-graphic information may also be attached to the Model Element.

LOD 350: The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.

LOD 400: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.

LOD 500: The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

This staircase wise approach defines the geometry as being approximate representations towards copies of reality. It is defined to shift from generic or symbolic representation (LOD 100) via a generic system, object, or assembly (LOD 200) towards design specific representation including quantities, size, shape, location, and orientation with greater certainty (LOD 300). In addition, in the lower LODs the focus is on (the collection of) standalone Model Elements itself. Interfaces with other Model Elements are only included from LOD 350. Then, within the geometry of LOD 400 Model Elements, also detailing, fabrication, assembly, and installation information is included. At LOD 500, Model Elements is an exact copy of reality.

Next, the attribute data is moderately addressed within the LOD definitions. This is due to the huge variety in buildings systems in the AEC industry and since it should always be agreed upon by its end-users. There exists no fixed list of attributes per LOD per building system element as it is project dependent. Nevertheless, still a general view on its extent could be obtained which are in line with the beforementioned geometry. Starting, LOD 100 prescribes no specific attributes. From LOD 200 onwards, it specifically addresses five (geometry related) attributes: size, shape, location, quantity, and orientation. In addition, it is stated that the Model Elements could be enriched by non-graphical data. This general wording implies the difficulty of the attributes specification in the framework. Nevertheless, in general, it holds the higher the LOD, the more detailed attributes. Here, the graduality is in line with the geometry: from generic (LOD 200), to Model Element specific (LOD 300), to the inclusion of interfaces with other building systems (LOD 350), to the inclusion of detailing, fabrication, assembly, and installation information (LOD 400).

Moreover, each LOD represents a certain level of reliability. Starting at the two lower LODs (LOD 100 and 200), any information derived should be considered as approximate. Hence, it provides rather an indication than a correct measurement. From LOD 300, direct measurement from the Model Element is allowed of graphic information and is representative. At LOD 500 maximum reliability is incorporated as these Model Elements are field verified. On the right, the overall graduality is summarized (Figure 4).

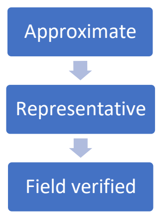


Figure 4: Scale of reliability as observed in the AEC LOD framework

The reliability of the Model Elements relates to its authorized uses. The U.S. General Service Administrator (2020) states that this concept implies what can be done with the model at each LOD. It accommodates amongst others (performance) analysis, cost estimating, schedule, and coordination uses. The scale within the aforementioned geometry, attribute data and reliability is also incorporated as these listed authorized uses range from gross, conceptual usages to specific, exact use cases.

Besides, this also includes a selection of the identified application of information modelling for SU projects (section 3.1). For instance, Model Elements with LOD 400 may be used for design certainty coordination and exact pricing. As context information, Appendix I.1 provides an overview of the authorized uses per LOD as context to this aspect.

Moreover, the AEC LOD framework formalized from geometrical design with a focus on housing and facility construction. In the SU sector, however, the focus is rather at the integration of the new network into the project environment. In addition to this, section 3.2 already stated that the SU sector differs from the building sector as it consists of only one single type of building system, namely utility networks. Hence, regarding the LOD framework for the SU sector, this offers the potential for a more specific allocation of the content.

From the deepening of this document, the following subjects were used within the design process of the LOD framework for utility network elements:

- The individual definitions of the LODs and their distinctive ground: minimal content requirements (geometry + attribute data) and the reliability;
- The overall graduality among the LODs regarding the geometry, attribute data and the reliability;
- The hierarchical scale and cumulative nature of the multiple LODs ranging from 100 being very conceptual towards 500 being field-verified;
- The potential for a more specific allocation of the content of the LOD framework (tailored to the SU sector);
- The *'LOD ###'* system for indicating and referring to a certain Level of Development of a Model Element;
- The *'LOD ###'* system is currently implemented and recognized among multiple organizations in the building sector. Using the same system allows recognition of actors and possible interoperability with disciplines other than subsurface infrastructure. With this in mind, the current definition of the LODs can be tailored to the SU sector but these definitions cannot be changed fundamentally because it would conflict with the formalization of the AEC LOD framework.

LOD Specification

In 2013 BIMForum aimed to make the AEC LOD framework more concrete and tangible for its end-users (Bedrick et al., 2020). In so, BIMForum first interpreted and redefined the LOD definitions using the same structure as the LOD framework. The LOD Specification only addresses LOD 100 through LOD 400 of the AIA's LOD framework, along with a new level – LOD 350 – which was added between LOD 300 and LOD 400 to better address the information levels required for effective trade coordination (Bedrick et al., 2020). LOD 500 is excluded since this LOD relates to field verification and is not an indication of progression to a higher level of geometry or attribute data. In addition, as this thesis study focuses on the design and construction of utility networks this is also out of the scope and hence excluded from further reporting. BIMForum's interpretation of the LOD definitions are as follows:

LOD 100: The Model Elements are not geometric presentations. They may be symbols or other generic representations of information that can be derived from other Model Elements. Any information derived from LOD 100 elements must be considered approximate.

LOD 200: The Model Elements are represented graphically but are generic placeholders, e.g., volume, quantity, location, or orientation. Any information derived from LOD 200 elements must be considered approximate.

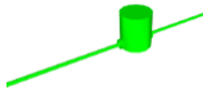
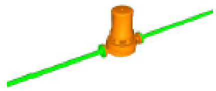
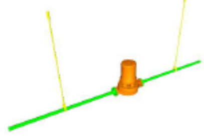
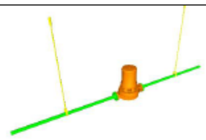
LOD 300: The Model Elements are graphically represented as specific systems, objects, or assemblies from which quantity, shape, size, location, and orientation can be measured directly, without having to refer to non-modelled information such as notes or dimension call-outs.

LOD 350: The Model Elements are enhanced beyond LOD 300 by the addition of information regarding interfaces with other building systems. Parts necessary for coordination of the Model Element with nearby or attached Model Elements are modelled such as supports and connections.

LOD 400: The Model Elements are modelled at sufficient detail and accuracy for fabrication of the represented component.

The above definitions of the LODs are in essence similar but made more explicitly when comparing to the AEC LOD framework. It uses different terminology which allows better interpretation by end-users and less ambiguities.

Considering the element's geometry, the LODs were presented in narrative and graphical format in the first part of the LOD Specification. To be illustrative, an example from the official document is included of a domestic water equipment: a water pump. In case more examples are wanted, Bedrick et al. (2020) can be consulted.

	Narrative description	Graphical example
LOD 100:	Diagrammatic or schematic Model Elements; conceptual and/or schematic layout/flow diagram;	
LOD 200:	Schematic layout with approximate size, shape, and location of equipment;	
LOD 300:	Modelled as design-specified size, shape, spacing, and location of equipment;	
LOD 350:	Modelled as actual construction elements size, shape, spacing, and location/connections of equipment;	
LOD 400:	Supplementary components added to the model required for fabrication and field installation.	

The above example shows a clear, distinctive view of the different ways of representing the geometry. In this, the graduality of detailed representation can be easily obtained from both the narrative descriptions and the graphical examples.

Here, LOD 100 is set as not a geometric presentations. It is rather a 2D symbol or generic representation, as is currently the sector's standard. To be more specific, diagrammatic or schematic Model Elements are included and conceptual or schematic layout/flow diagram could be included. From LOD 200 onwards, Model Elements are represented in 3D. This first entails approximate layout (LOD 200) which mainly entails the area reservation. LOD 300 represents design-specified size, shape, spacing, and location. Connections and interfaces with other elements are added in LOD 350 and LOD 400 includes any supplementary components added to the model required for fabrication and field installation. Besides, following the findings, each LOD is given a general entitlement as listed below:

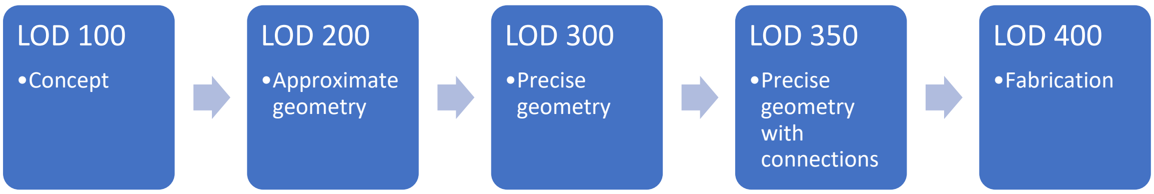


Figure 5: General entitlements of individual AEC LODs based on Bedrick et al. (2020)

The extent of attributes on the other hand, was not allocated to certain LODs. Rather, the second part of the LOD Specification, provides a Model Element Table which references Attribute Tables that contain attribute information for various building systems. These attribute tables lists attributes relevant to the associated building system(s). In this, baseline and additional attributes are distinguished. Next, the Model Element Table also allows to mark the attributes required for specific milestones and deliverables within a project. This allocation is project dependent and should always be agreed upon by its end-users. In other words, there exists no list of attributes per LOD per building system element.

In short, the attributes found in the LOD Specification relate to the dimensions, component manufacturing characteristics, service life, warranty and object-specific attributes. The list of attributes hence mainly relates to the operation and maintenance phase of a project. In addition, some attributes are specific for the AEC industry. One could think of attributes like *Room Number* or *Story Number.* These AEC-specific attributes are excluded from further research as these do not hold for SU projects. Furthermore, there exists a LOD designation, as each Model Element is provided with the attributes: *Target LOD* (the LOD specified for that Model Element in the

Model Element Table) and *Current LOD* (the actual LOD of the Model Element). This method offers flexibility and reliability, allowing differentiation between individual elements within a single model (Bedrick et al., 2020).

Overall, the LOD specification shows similarities with the LOD framework like its structure, but the latter elaborates more on the actual implementation. Therefore, only the topics that shed new or different light for the design of the LOD framework for utility network elements are listed below:

- The different interpretation (and hence definition) of the LODs using different terminology;
- The specific allocation of connections within or with other building systems as defined in LOD 350;
- The exclusion of LOD 500 since this LOD holds field verification and is not an indication of progression to a higher level of geometry or attribute data. This is in line with the scope of this thesis study.
- The implementation of the LOD framework at SU sector-like building systems, both as a narrative description and as a graphical example.

CityGML Utility Network ADE

Another available specification framework is the CityGML Utility Network ADE. This document uses to the concept of Level of Detail (LODetail) as described in the Conceptual Model Standard of the core CityGML model (Kolbe et al., 2021). However, as elucidated in section 3.2, this concept interrelates Level of Development, but is different in nature. This Level of Detail framework is developed for multiscale modelling of Model Elements in 3D city models; i.e. it has varying degrees of spatial abstractions resulting in different visualisations. In so, it differentiates four well-defined consecutive Levels of Detail, referred to using the 'LODetail#' where '#' indicates the distinctive corresponding level. Same as in AEC LOD framework, these Levels are cumulative and hierarchical of nature. Below, these Levels of Detail are described:

LODetail0: Volumetric real-world objects can be spatially represented by a single point, by a set of curves, or by a set of surfaces. LODetail0 surface representations are typically the result of a projection of the shape of a volumetric object onto a plane parallel to the ground, hence, representing a footprint. LODetail0 curve representations are either the result of a projection of the shape of a vertical surface (e.g., a wall surface) onto a grounding plane or the skeleton of a volumetric shape of longitudinal extent such as a road or river segment.

LODetail1: Volumetric real-world objects are spatially represented by a (vertical) extrusion solid, i.e., a solid created from a horizontal footprint by vertical extrusion. Also known as block models.

LODetail2: Volumetric real-world objects can be spatially represented by a set of curves, a set of surfaces, or a single solid geometry. The shape of the real-world object is generalized and smaller details are typically neglected. LODetail2 curve representations are skeletons of volumetric shapes of longitudinal extent like an antenna or a chimney.

LODetail3: Volumetric real-world objects can be spatially represented by a set of curves, a set of surfaces, or a single solid geometry. LODetail3 is the highest level of detail and respective geometries include all available shape details.

From the above given definitions, one should note that the definition of the LODetails only focus on the representation of the geometry and does not include any association of attribute data. Hence, it can be stated that the levels are differentiated by the complexity of the geometries only.

Objects described by LODetails become more detailed with increasing Level of Detail with respect to their geometry. The definitions of these LODetails are relatively explicitly formulated and can therefore be considered less prone to ambiguity. At some Levels, it distinguishes in specific types of geometrical representations (i.e. curve, surface, solid).

As an example, Kolbe et al. (2021) provides an implementation of this concept to a building as presented in Figure 6.

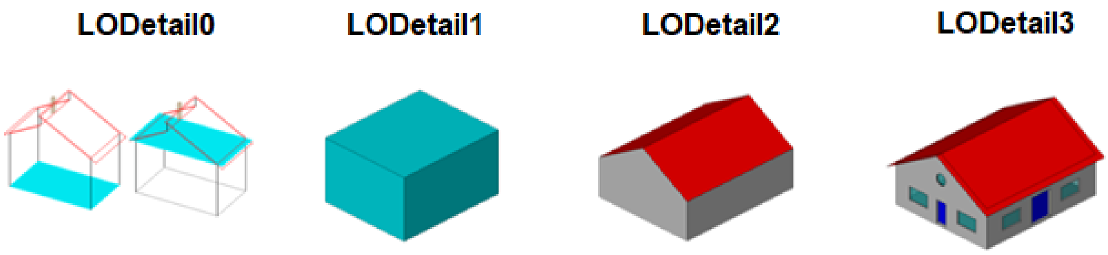


Figure 6: Implementation of CityGML's LODetail concept to a building (Kolbe et al., 2021)

Biljecki (2013) defined the relation between the LODetails as: $\xrightarrow{\text{footprint}} 0 \xrightarrow{\text{block model}} 1 \xrightarrow{\text{coarse exterior}} 2 \xrightarrow{\text{fine exterior}} 3$

Next to its initial implementation at 3D city Model Elements, the LODetail concept can also be applied to any CityGML ADE such as the Utility Network ADE. Here, it does not provide a narrative description of its implementation on the utility network elements explicitly; it only provides one graphical example. Besides, the CityGML Utility Network ADE however uses an earlier version (2.0) of CityGML which includes (slightly) different definitions in the LODetail framework (Becker et al., 2016; Gröger et al., 2012). Figure 7 presents an adapted implementation of CityGML Utility Network ADE 2.0. In specific, the LODetail definitions from the most recent (3.0) core model are used.

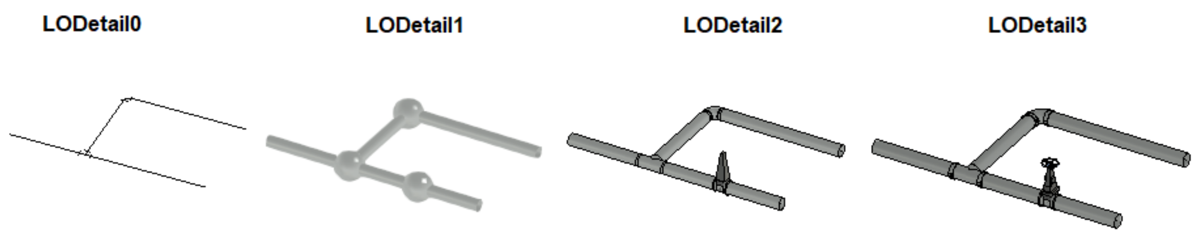


Figure 7: Geometrical representations of a segment of a Utility Network using an adapted LODetail framework (Becker et al., 2016; Kolbe et al., 2021)

From the above Figure, it can be observed that LODetail0 partly corresponds with the 2D modelling practices. It incorporates the use of arcs (*Utility Links* and *Utility Link Containers*) and nodes (*Utility Nodes* and *Utility Node Containers*), but does not include the use of symbols or icons. It hence represents the topology of the network rather than its semantics. In LODetail1 these arcs and nodes are extruded (3D). In specific, the arcs are extruded along their paths resulting in cylindrical or rectangular shaped representations. The nodes are represented by spheres. In the first place, this indicates the existence and location of the elements. In addition, it provides a very coarse area reservation. Next, LODetail2 comprises a generalized shape representation in 3D in which smaller details are excluded. In essence, this relates to the modelling of the element's body corresponding with its outer dimensions (either diameter or width x height). Smaller details like nails and specific edges are not modelled. At last, LODetail3 includes all available shape details and hence holds the highest level of detail. These could potentially stem from the specified design or by field verification.

From the deepening of this document, the following findings were used within the design process of the LOD framework for utility network elements:

- The definitions of the geometrical complexity of the LODetails and its use of more explicit terminology;
- The specified single ways of representing a Model Element's geometry;
- The overall graduality/evolvement of the geometrical complexity;
- The graphical implementation of the LODetails for SU sector-like building systems.

4.4. Designed LOD framework

This section comprises the outcome of this thesis study: the LOD framework for utility network elements in complex SU projects. Table 10 presents the final design of the LOD framework. This is the result of several design choices made during this thesis project.

The designed LOD framework will serve as a standardized reference tool in digital information exchange which implies that the LOD framework should be applicable to every utility network discipline and their total collection of elements. So, despite differences exist in the specification of subsurface utilities with a different origin (KLIC, test trench and new network; as described in Appendix H), the LOD framework provides one set of LOD definitions which covers all specifications. The total collection of these specifications is accommodated within the framework via six Levels of Development. In so, the LOD framework incorporates the overall development of the specification of a Model Element during a SU project. In general, this evolves from 1) schematic to 2) conceptual to 3) exact exterior geometry to 4) exact geometry 5) exact geometry with connections to 6) fabrication.

Furthermore, the exact extent of the attribute data highly depends on the project, its application and its end-users. Hence, the attribute data is captured in a relatively broad definition via several attribute categories (as described in Appendix G) which incorporates its gradual evolvement (section 4.2). However, not every attribute category is incorporated as some are not related to the actual development of the Model Element (as being the core of the LOD framework), but rather serves as additional information.

Moreover, existing LOD frameworks lack a definition of specification where the focus is at the exact exterior geometry of Model Elements, rather than at its semantically richness. This phenomenon is desired in the SU sector for existing (KLIC) utilities near the to be constructed network. Hence, the designed LOD framework includes a new LOD between LOD 200 and LOD 300 which exactly tackles this issue: LOD 250.

Overall, this has led to a LOD framework including six Levels of Development which are distinguished on minimum content requirements and the reliability. Besides, at the outer right of the framework, each LOD is typified by a corresponding brief, all-embracing description. The extent of the geometry, attribute data and reliability is separately defined per LOD. Note that it relates to minimum content requirements, meaning the Model Element can be enriched within SU projects after agreement between end-users.

Table 10: Designed LOD framework for utility network elements in SU projects

LOD 100	**Geometry:** The Model Elements are not geometric but topology presentations. They are represented by diagrammatic or schematic Model Elements via arcs, nodes, symbols or icons. It may contain a conceptual and/or schematic layout/flow diagram. *Utility Link Containers* and *Utility Node Containers* may be represented by footprints. **Attribute data:** Information is provided about the functionality of the Model Element such that component classification is allowed. If available, its discipline is included. The Model Elements are associated with its location and depth. If not available, the standard depth is added. **Reliability:** Any information derived from LOD 100 elements must be considered approximate.	**Schematic**
LOD 200	**Geometry:** The Model Elements are represented graphically but are generic placeholders. A schematic layout is presented via their draped solid/block model. **Attribute data:** Its dimensional and spatial extent should minimally include a definition of the approximate size, shape, location, or orientation. If available, actor attributes need to be incorporated as well. If relevant, attributes regarding its state of operation and performance are included. **Reliability:** Any information derived from LOD 200 elements must be considered approximate.	**Conceptual**
LOD 250	**Geometry:** The Model Elements are represented graphically as 3D solid with correct exterior geometry. **Attribute data:** Its dimensional and spatial extent should minimally include a definition of the approximate size, shape, location, or orientation. If available, actor attributes need to be incorporated as well. If relevant, attributes regarding its state of operation and performance are included. **Reliability:** Any information derived from LOD 250 elements must be considered approximate.	**Exact exterior geometry**

LOD 300	**Geometry:** The Model Elements are design-specified representations of both the exterior and interior geometry. **Attribute data:** Its dimensional and spatial extent should minimally include a definition of the designed size, shape, spacing, location, and orientation. Besides, the designed material(s) are set. **Reliability:** Any information derived from LOD 300 elements must be considered representative on individual object level.	**Exact geometry**
LOD 350	**Geometry:** The Model Elements are actual construction elements including size, shape, spacing, location, orientation and connections with other Utility network elements. It includes for example couplings, bolts and weld locations. **Attribute data:** Additional information or documents may be attached with regard to the connections or interfaces between other Model Elements. **Reliability:** Any information derived from LOD 350 elements must be considered representative on individual object level and its connections.	**Exact geometry with connections**
LOD 400	**Geometry:** The Model Elements are modelled at sufficient detail and accuracy for fabrication. Any supplementary components are added to the model required for fabrication and field installation. **Attribute data:** Additional information or documents may be attached for field installation purposes. Examples include surrounding soil attributes. **Reliability:** Any information derived from LOD 400 elements must be considered representative for construction.	**Fabrication**

As explained earlier, the LOD framework uses relatively abstract definitions of the six distinctive levels. Although this is intentionally designed as, it potentially allows misinterpretation. This explicitly holds for the narrative definition of the representation of the geometry. In preventing such and make the implementation of the LOD framework explicit, additional specification documentation are included and provided in Table 12 via example implementations. The origin of each representation is indicated using footnotes. The used colours have no explicit meaning.

During the design process, multiple (interim) versions of the LOD framework were developed. These versions were the result of the findings during the entire thesis study. These findings served as input for the refinement(s) of the LOD framework. These refinements were kept track and captured in a changelog. This changelog is presented in Table 11. In this, only the most important changes are included.

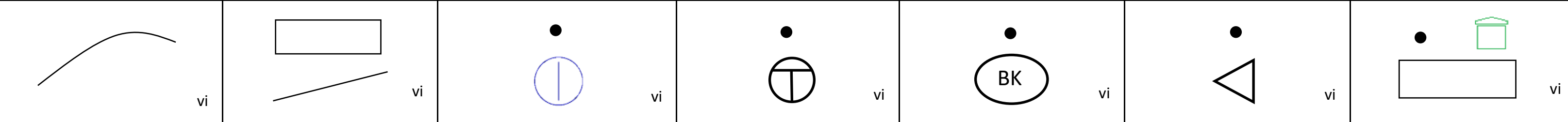
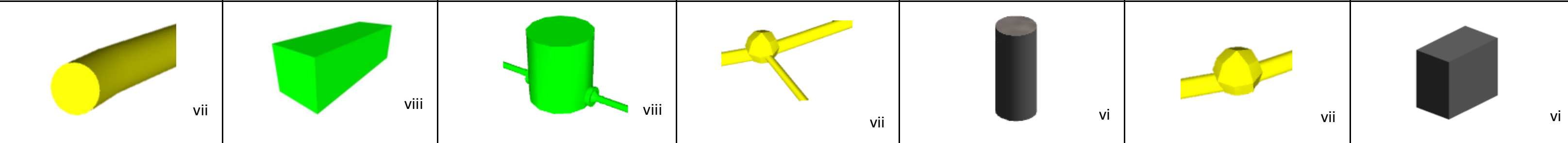
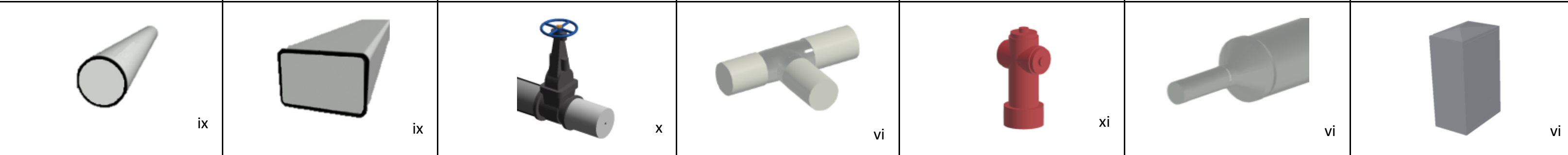
Table 11: Changelog of the LOD framework design

Version	Change(s) implemented
1.0	Original definition as in AEC industry by (American Institute of Architects, 2013)
1.1	Change of terminology and description; more tailored to contextual characteristics of SU sector
2.0	Added LOD 250 as a new LOD
3.0	Added attribute categories to the attribute data description
4.0	Added typical descriptions of each LOD

Overall, this thesis outcome consists of three important characteristics comparing to the conventual AEC LOD framework:

- The accompanying specification documentation of the visual exposure of the evolving geometry in LODs of multiple utility network elements via implementation examples;
- A tailored and more specific allocation of the attribute data by referring utility attribute categories;
- A new LOD has been added between LOD 200 and LOD 300: LOD 250, which represents an exact exterior geometry with relatively low semantics.

Table 12: Example implementations of designed LOD framework for utility network elements

Utility Network Element category	Utility Link	Utility Link Container	Utility Node				Utility Node Container
Element	**Pipe**	**Duct**	**Valve**	**T-piece**	**Fire hydrant**	**Transition**	**Cabinet**
Example ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**
LOD 100 	[vi]	[vi]	[vi]	[vi]	[vi]	[vi]	[vi]
LOD 200 	[vii]	[viii]	[viii]	[vii]	[vi]	[vii]	[vi]
LOD 250 	[ix]	[ix]	[x]	[vi]	[xi]	[vi]	[vi]
LOD 300 	[ix]	[ix]	[x]	[vi]	[xi]	[vi]	[x]
LOD 350 	[vi]	[vi]	[x]	[vi]	[xi]	[vi]	[x]
LOD 400 	[vi]	[vi]	[x]	[vi]	[xi]	[vi]	[x]

[vi] Example representation created by researcher based on findings in theory and practice.
[vii] Example representation obtained from project Project B.
[viii] Example representation obtained from Bedrick et al. (2020).
[ix] Example representation created by researcher based on Becker et al. (2013).
[x] Example representation created by researcher based on CAD Forum (2021).
[xi] Example representation created by researcher based on Revit City (2021).

5. Treatment validation

This chapter encompasses the validation of the designed LOD framework, i.e. it relates to the third phase of the design cycle (Figure 2). Following the methodology as described in subsection 2.2.3, the LOD framework was assessed on its readiness for implementation within its context. This relates to the set functional and non-functional requirements as summarized in Table 7 and Table 8. Section 5.1 will first verify the functional requirements, whereafter section 5.2 will validate the non-functional requirements and test the design via defined criteria.

5.1. Functional requirements

First, the functional requirements as defined during the start of this thesis study (section 4.1) are verified. In other words, it was evaluated whether or not the designed artifact complies with these specified requirements. Table 13 presents the results of this verification process including a verification argument per requirement. This table shows that all functional requirements are verified.

Table 13: Verification of the functional requirements of the designed LOD framework

ID	Functional requirement	Verified	Verification argument
1	The LOD framework must describe geometric data.	✓	The LOD framework describes for each LOD the minimal geometrical extent.
2	The LOD framework must describe attribute data.	✓	The LOD framework describes for each LOD which attribute data minimally should be included.
3	The LOD framework must describe the degree of reliability.	✓	The LOD framework describes the reliability for each LOD.
4	The LOD framework must capture the graduality of the specification.	✓	The LOD framework uses different Levels to capture graduality of the specification.
5	The LOD framework must allow modelling of every utility discipline.	✓	The LOD framework uses standardized descriptions which are applicable to every utility discipline.
6	The LOD framework must allow modelling of every utility network element type.	✓	The LOD framework uses standardized descriptions which are applicable to every utility network element type.
7	The LOD framework must hold hierarchy among the levels.	✓	The LOD framework starts with LOD 100 being schematic and gradually develops to LOD 400 as representative for construction.
8	The LOD framework must be cumulative: each LOD definition includes the requirements of previous LODs.	✓	The higher the LOD, the more developed the Model Element. Lower LODs hold as prerequisites for higher LODs.
9	The LOD framework must provide a standard definition of the specification of Model Elements that can be referenced during projects.	✓	Using the LOD ###-system, end-users are allowed to refer to a standardized definition of the specification.

5.2. Non-functional requirements and criteria

Second, the LOD framework is validated on its performance regarding the non-functional requirements and tested with respect to the interaction with the (future) end-users on five identified criteria: understandability, usability, completeness, structure, and utility. A description of these criteria is provided in Appendix E.1. Both validations however partly overlap since the first is actually based on the results of the latter. In addition, three of the nine functional requirements were discussed and validated as well (Table 13: ID 4-6). Table 14 provides an overview of the results of the validation of the five criteria. Here, average scores are presented per criterion and range from very bad (1) to very good (5), except for the criterion of structure. Appendix E.4 provides the total results of the validation session.

Table 14: Overview of criteria validation results

Criterion	Average score (1-5)	Comments
Understandability	4,0	
Usability	3,5	
Completeness	4,8	
Structure	3,5	Adjusted scale: 3 = perfect, 4 = slightly too many levels
Utility	3,8	

Starting the with understandability of the LOD framework, attendees indicated that crucial terms and concepts within the LOD framework are (very) clear, such as the geometry and attribute data. Two out of the four indicated that is not totally clear what is meant with Model Element. This also holds for one attendee regarding the concept of reliability. Besides, all attendees perceived the separate LOD definitions (LOD 100, LOD 200, etc.) as clear and understandable.

Second, regarding the criterion *'usability',* two of the four attendees indicated that medium effort was needed to understand the LOD framework. On the other hand, the other two attendees argued that relatively low effort was needed. One of the attendees stated that the effort will be minimized when working more than once (as is the case while validating) with the LOD framework, which all other attendees agreed on.

Next, attendees considered the LOD framework as complete. They stated that it can be applied to every type of utility network element of every utility discipline. Besides, three of the four argued that the LOD framework reflects a good evolvement of the geometry, while the other rates this as perfect. This latter also holds for the attribute data according to all attendees.

Fourth, the structure of the LOD framework is satisfying. Two of the four attendees perceived the number of Levels as slightly too many, while the other two assessed this as just perfect.

Fifth, the LOD framework is able to be utilized in its intended use. Despite some flaws, in general, attendees correctly implemented the LOD framework bilaterally. This means that attendees showed that they could implement the narrative LOD definitions into the correct graphical extent and vice versa. On the other hand, attendees scored different on the understanding of the usage of each LOD. At least two of the four attendees answered (partly) incorrectly for the three accompanying scenario questions.

At last, all attendees acknowledged that they had limited time to study both the LOD framework as a whole as its containing concepts. Consequently, the attendees indicated that if they had had more time, they would most likely have more understanding and could assess better and in more detail.

Based on the above results, the non-functional requirements are validated. Table 15 presents an overview of each non-functional requirements and its validation argument.

Table 15: Validation of the non-functional requirements of the designed LOD framework

ID	Non-functional requirement	Indicator	Norm	Validated	Validation argument
10	The LOD framework is clearly defined and easy to understand by its end-users.	Effort to understand	Low	✓	Attendees indicated medium to low effort was needed, which is expected to be minimized while working more often with the LOD framework.
11	The number of Levels within the LOD framework must be limited.	# of levels	As low as possible	✓	Attendees were satisfied with the current number of Levels.
12	The implementation of the LOD framework must result in the specified output of all Model Elements.	Compliance	Yes	✓	Attendees showed correct LOD allocating based on the way Model Elements are modelled.

13	The output resulting from the LOD framework must be traceable by the end-users to the relevant LOD.	Compliance	Yes	✓	Attendees showed correct LOD allocating based on the way Model Elements are modelled.
14	The LOD framework must be supported by the direct stakeholders through reaching consensus in which definition and implementations of LODs.	Consensus reached	Yes	✓	The LOD framework was first developed by a shared understanding of direct stakeholders and then validated in a group.

6. Discussion

This chapter will discuss the thesis outcome in three ways. The first part will discuss the interpretation of the results, followed by the implications of the results in the second part. Third, the limitations of the research will be addressed. At last, future work of this thesis study will be elucidated.

6.1. Interpretation of the results

This section reflects how the outcomes of this thesis study should be interpreted.

Section 4.4 presented the final design of the LOD framework. This design is the result of an iterative process executed by the researcher and guided by inputs from theory and practice along the SU sector (section 2.2). During this process, the researcher continue searched to a consensus regarding the design. Design choices were reflected with theory and practice and discussed with practitioners. In this way, the impact of the researcher was limited making the output reliable and representative to the SU sector.

Next, the LOD framework was validated during this thesis study. Nonetheless, practitioners argued that if they had more preparation time they were most likely to have a better understanding and hence to assess the designed framework better. Hence, the concept of 'learning by doing' might be an outcome via providing the practitioners with more preparation time, an additional explanatory meeting, or some training exercises might have resulted in a better assessment.

Moreover, the LOD framework was designed with respect to complex utility construction projects. However, it is expected to be applicable for less complex projects as well since the corresponding information models entail similar utilities but with a lower density. The merit of 3D visualisations is less perceived in such projects (van Manen et al., 2021), so it would be more the question whether information modelling should be used in the project rather than whether to use the LOD framework or not.

6.2. Implications of the results

Preliminary research showed that the SU sector currently lacks a uniform specification of utility network elements within information models (Bradley et al., 2016; R. B. ter Huurne & Olde Scholtenhuis, 2018). This section discusses the implications of this thesis' results. In other words, it explains why the results matter to theory and practice.

Scientific implications

This thesis outcome contributes to literature via three important characteristics. First, the description of the attribute data within the LOD framework covers the evolvement of assets' semantical richness. This is tailored and more specified to the SU sector by referring to utility attribute categories based on El-Diraby & Osman (2011). As a first in literature, the evolvement of utility attribute data is established and captured in the LOD framework with the use of attribute categories.

Second, this thesis study captures how utilities incrementally gain geometrical detail. In so, the representation of the geometry is depending on the type of utility network element. In addition to its narrative description as incorporated in the designed LOD framework, this thesis study incorporates accompanying specification documentation of this evolving geometry in LODs of multiple (types of) utility network elements by visually exposing implementation examples. This minimizes misinterpretation of the narrative descriptions.

Third, existing specificity frameworks lack a LOD definition which entails an exact exterior geometry but relatively low semantics while this was observed in current SU modelling practices. Hence, this thesis study introduces a new LOD: LOD 250, which has been added between LOD 200 and LOD 300. The addition of this LOD is unique and new to existing literature.

Fourth, the thesis outcome overall entails a shared understanding of the evolving specification of utility network elements. In so, it provides insights about how utilities incrementally gain geometrical detail and semantic richness during SU projects.

Practical implications
Next to its scientific implications, this thesis study also contributes to practice in several ways.

The designed LOD framework shares one of the main purposes with the AEC LOD framework: it is structured to minimize errors with the help of a numerical lexicon which the model designers and the end-users of a (3D) information model share for common understanding. This will support the communication between Siers and its supply chain regarding the content of the information model (United BIM, 2021).

Next, the LOD framework allows to classify existing utility network elements within projects via the LOD language. This helps to make better agreements about the use of the information model and what needs to be delivered during a project. At the outset of a project, the end-users of the information model agree about the degree of specification of the Model (Elements) using the LOD language. It allows construction players to clearly understand the usability and the limitations of the received information models (Bedrick et al., 2020; Latiffi et al., 2015b; Mavreli, 2018). In so, it creates better expectations about the information model among all end-users, resulting in fewer errors during the subsequent project progress.

Besides, these modelling agreements, in turn, also minimize the amount of inadequate information within the delivery of an information model (Bedrick et al., 2020; Latiffi et al., 2015b). This results in a clear and more efficient information exchange approach.

Moreover, using the designed LOD framework also allows a rectilinear modelling approach as it incorporates clear, yet extendable (in agreement with the other end-users) boundaries for the specification of the utility network elements. This results in an efficient modelling approach since the model designer exactly knows how to specify the Model Elements.

So overall, the designed LOD framework can help prevent (practical) ambiguities during the specification of information models in future SU projects. Besides, it supports a better and efficient information exchange among end-users. Hence, this thesis study recommends implementing the designed LOD framework in future utility design and construction projects at Siers. Once applied in a structural manner, and endorsed and used by a larger group of stakeholders in the industry, this design furthermore supports the adoption of information models within the SU sector.

6.3. Limitations

Next, this section addresses the limitations of this research.

First, this thesis study only considered practice from the host organization. Here, information modelling was just introduced by Siers and hence not fully developed which could result in a misrepresentation. Besides, the project analysis was limited to district heating projects due to availability issues. Although still other disciplines were included in the project areas, their design evolvement was not studied. In addition, as stipulated in the introduction, among the sector arise several organisational initiatives which could be the case at Siers. Although still a consensus was reached about the specification of utility network elements among representatives of different organisations, incorporating only the practices of Siers could potentially threaten the representativity of the whole SU sector. Including information models of other organizations and other disciplines than district heating, could hence increase this study's support base.

Second, during the design process of this thesis study, several actors were involved from different organisations and roles (Table 5). Although the main direct actors took part in this research, still some stakeholders were not involved. This holds amongst other authorities, CAD software developers and planners (in Dutch: '*werkvoorbereiders'*). Involving representatives of these organisations and roles could have resulted in different insights, needs and hence outcomes.

Third, Wieringa (2014) states that the central problem of treatment validation is that no real world implementation is available to investigate whether the treatment contributes to stakeholder goals. During this thesis study, only one stakeholder goal could be validated (being easy utilization of the artifact). In so, this was only tested in a simulated (artificial) situation with a limited number of direct stakeholders (four). The eventual LOD framework is intended to be used among the whole SU sector, while the validation is based on the collective opinion of four actors. Having more stakeholders involved during this validation would significantly increase the value of the validation and hence its representativeness.

6.4. Future work

This section discusses possible future directions of research.

As a start, this thesis study resulted in a validated design of the LOD framework in which also the interaction with actors was validated. The designed LOD framework is however not implemented in the context of a real-world situation. In other words, it is not tested if the use of the LOD framework during SU project results in the believed advantages such as better understanding of what is modelled and improved communication. Back in 2008, Ebert & Man stated that the success of engineering of products is driven by the interaction of three pillars: tools, process, and people. Hence, it is recommended to use the LOD framework during, for example, some pilot projects; i.e. implement Wieringa's engineering cycle instead of sticking to the design cycle.

Furthermore, this thesis study set its scope at the use of information modelling during the design and construction processes of subsurface utilities. This means that processes after construction are excluded from this research such as operation and maintenance. As found in section 4.3, the AEC LOD framework, however, set a distinctive level, LOD 500, which incorporates field-verified representations. This LOD was intended to support Facility Management. Hence, in the future, it could be researched whether an extension of the designed LOD framework with such LOD 500 is of added value for the SU sector and how it would be defined.

Next, this thesis study solely focuses on the (information) modelling of utility network elements. (Chapman et al., 2020) and multiple practitioners in this study, however, stated that an information model for SU projects is much more than just the utility network elements. To be more specific, during the design and construction processes the information model should consist (3D) information regarding the project environment as well since this is of equal importance. It is considered as essential information since the locational accuracy of subsurface utilities is lacking. In this way, one is able to analyse and estimate if information is missing or incorrect. One could think of buildings, vegetation (inclusive its roots), public benches, and more. These non-utility components are however excluded in this research. Future research could look into the functioning of the designed LOD framework in combination with surrounding components in the information model. Albeit, one can imagine that it is not desirable to use two different frameworks in an information model.

Moreover, within the current use of information models for SU projects, spatial data of utility infrastructure and its accuracy is essential and fundamental to the sector (Olde Scholtenhuis & Zlatanova, 2018). On the one hand this is one of the main incentives in current practices to use 3D visualisation, but on the other hand it also causes difficulties in the interpretation and reliability of the (accuracy of the) spatial data in itself. Hence, this data is highly related to the obtained merits of information modelling. Practitioners indicated a practical request of the definition of this spatial data and a potential integration of a spatial data statement with the LOD framework. This thesis study proposed several options to practitioners (Appendix E.2) but they indicated more it needed more time, attention and research (Appendix E.4). Future research could dive into this topic and propose a solution for the integration with the designed LOD framework.

At last, as a fundamental characteristic of the (AEC) LOD framework, Bedrick et al. (2020) stated that the LODs are not defined by design phases. Rather, design phase completion, as well as any other milestone or deliverable, can be defined through the LOD language. However, these project stages are indirectly related since the LOD was found to relate to the different project deliverables (SD, CD, DD) which are the end result of the design phases. This is also acknowledged by Latiffi et al. (2015a). Although this thesis study designed a LOD language suitable for utility network elements, it does not make the LOD allocation explicit for Model Elements per project stage. In supporting practice, future research could hence study this equivalence/relation by identifying which LODs apply for certain Model Elements along these project stages. In this way, a practical translation of the LOD framework will be made and integrated in current working practices. Nonetheless, one should be aware of the LOD allocation remaining dependent on the model application and project setting (section 4).

7. Conclusion

In the current SU sector information models are used in an increasing number of projects. However, to this end, the sector lacks a sector wide uniform specification of these information model (Bradley et al., 2016; R. B. ter Huurne & Olde Scholtenhuis, 2018) causing inadequate and inefficient information exchange. In enhancing this phenomenon, *the main objective of this thesis was to design a Level of Development framework for information modelling of utility network elements in subsurface utility projects*. In reaching this main objective, in total five subobjectives were defined and answered via the three-phased design cycle of Wieringa (2014).

Within the scope of this thesis study, in total fourteen requirements were defined for the LOD framework for utility network elements, which all relate to three identified dimensions: the structure, the geometry and the attribute data. These dimensions have been studied from both a practical and theoretical perspective: seven direct stakeholders were consulted, four existing projects were analysed, and nine existing specifications and three available specification frameworks were studied. The cumulative of the findings led the researcher, after several interim versions, to the final design of the LOD framework.

In short, the final LOD framework covers the identified development of the specification of utility network elements. In so, it defines six distinctive Levels each providing standardized descriptions of the corresponding geometrical detail, extent of attribute data and its reliability: LOD 100, LOD 200, LOD 250, LOD 300, LOD 350, and LOD 400. The LODs are typified as respectively schematic, conceptual, exact exterior geometry, exact geometry, exact geometry with connections, and fabrication. Here, a new LOD is introduced: LOD 250, which was added between LOD 200 and LOD 300 to allow the modelling of subsurface utilities' exact exterior geometry with relatively low semantical richness, required for existing (KLIC) infrastructure near the design of the to be constructed network. In preventing misinterpretation of these standardized LODs and make the implementation of the LOD framework explicit, example implementations are included in the report. Besides, a tailored and more specific allocation of the attribute data is introduced by referring utility attribute categories.

The designed LOD framework is verified on nine functional and three non-functional requirements and evaluated by (future) end-users on five criteria: understandability, usability, completeness, structure, and utility. While the LOD framework was already positively evaluated, the (future) end-users expected an increase through the concept of "*Learning by doing*". In addition, end-users claimed that the LOD framework is applicable to the total collection of utility network elements among the SU sector.

The output of this research could have been strengthened by including information models of other organizations (than Siers) and other disciplines than district heating. In addition, involving representatives of different organisations and roles could have resulted in different insights, needs and hence outcomes. Moreover having more stakeholders involved during this validation would significantly increase the value of the validation and hence its representativeness.

Future research could look into five aspects. First, the designed LOD framework could be implemented in a real-world context to test if its use indeed yields the believed advantages such as improved communication and efficient information exchange. Second, the scope of this thesis study was limited to the design and construction of subsurface utilities. The LOD framework of the construction industry however also includes post construction via field-verified representation (i.e. LOD 500). It could be researched whether such an extension of the designed LOD framework is of added value for the SU sector and how it would be defined. Third, practitioners argued that an information model for SU projects is much more than only utility network elements and requires the modelling of the project environment. Hence, future research could look into the functioning of the designed LOD framework in combination with the specification of the surrounding components within an information model for SU projects. Fourth, the spatial extent (and its accuracy) of assets is a fundamental issue within the SU sector (Olde Scholtenhuis & Zlatanova, 2018) and the main incentive of information modelling. Practitioners indicated a practical request of the definition of this spatial data and a potential integration of a spatial data statement with the LOD framework. This thesis study proposed several options to practitioners but they indicated it needed more time, attention and research (Appendix E.4). Future research could dive into this topic and propose a solution for the integration with the designed LOD framework. Fifth, in supporting practice, future research could study the relation between the LODs and project stages by identifying which LODs apply for certain Model Elements along project stages. In this way, a practical translation of the LOD framework will be made which support integration in current working practices.

Overall, this thesis study has a scientific contribution since the designed LOD framework is a sector shared and representative understanding about how utilities incrementally gain geometrical detail and semantic richness during SU projects. The design of the LOD framework is unique as it uses utility attribute categories to specifically address the evolvement of assets' semantical richness. In addition, the LOD framework includes a new defined LOD: LOD 250. This level fits between LOD 200 and LOD 300 to allow the modelling of subsurface utilities' exact exterior geometry that have low semantical richness. These are needed to represent the existing infrastructure in a project space (that is commonly represented on statutory records, such as KLIC-drawings). Besides, the thesis outcome incorporates accompanying specification documentation of the identified evolving geometry in LODs of multiple (types of) utility network elements by visually exposing implementation examples. This minimizes misinterpretation of end-users of the narrative descriptions.

This, in turn, contributes to practice as it helps overcome the practical ambiguities during the specification of utility network elements within information models, since it produces a reference description of how these evolves over time. Hence, using this framework will improve communication and minimize inadequate and inefficient information exchange between end-users. Once applied in a structural manner, this thesis outcome furthermore supports the implementation and adoption of information models of Siers and, if endorsed and used by a larger group of stakeholders in the industry, within the SU sector.

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Appendices

A. Description host organisation & problem owner

The study is executed in agreement with Siers Infraconsult BV. Siers Infraconsult BV is part of the umbrella company Siers Groep Oldenzaal which is a medium-sized contractor within the subsurface utility sector. It is located and mainly executive in the Netherlands. Projects including gas, water, electricity, telecommunication and (central) district heating utilities are executed in different sizes and varying complexity.

Siers Infraconsult BV, in the report referred to as Siers, especially focuses on the discipline of infrastructure consultation and provides supportive services for the purpose of the construction and maintenance of infrastructures (Siers Groep Oldenzaal B.V., 2021). This includes amongst others engineering, planning, field, and data management tasks for clients with perspective to the earlier mentioned utilities. During these activities, Siers puts four values at the core: quality, safety, cost control and delivery in time. Besides, Siers aims at chain integration in combination with innovation contracts in pursuing continue development in multiple areas.

In doing so, Siers is currently orienting on the adoption of information modelling practices in SU projects. Its benefits, as described in section 3.1, and hence its added value is recognized by the management team and already some pilot projects were introduced, but better insights in the 3D processes is aimed to be obtained. Adopting information modelling practices is considered as a valuable innovative approach in further developing the existing working practices in relation to the four core values. On the long term, it is strived for full adoption of information modelling within Siers. This study can therefore contribute to their successful adoption and implementation.

B. Basic contextual characteristics of the Dutch SU sector

This appendix describes the basic contextual characteristics of the Dutch SU sector. Laymen of the SU sector could use this appendix to gain an understanding of the core of the sector.

The SU sector is the overall term for all companies that provide basic amenities (Murphy & Scott, 2021). All these amenities are provided through utility networks. In addition to these basic amenities, there is also unhampered access to telecom networks essential for the functioning of society. Considering the Netherlands only, there is approximately 2 million kilometres network located in the underground which represents a value of about 100-300 billion euros (Boonsma et al., 2019). Figure 8 presents an example of a rough sketch of a (ring) structure of a gas network.

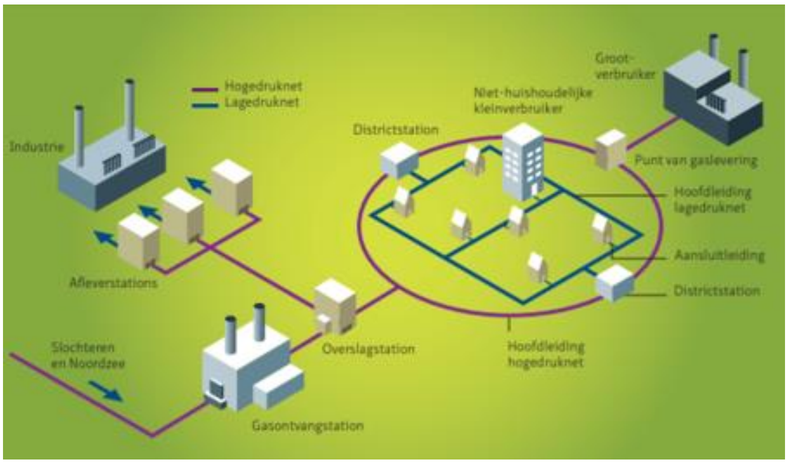


Figure 8: Example ring structure of gas network (Dutch) (Taselaar, 2009)

According to (van den Berg & Janssen, 2020), a utility network is a collection of network elements belonging to one type of utility network. This latter refers to the multi-disciplinary nature of the sector as it includes 1) electricity, 2) telecommunication, 3) (oil,) gas and chemicals, 4) water, 5) district heating (thermal) and 6) sewage networks.

Each utility network consists of multiple utility elements which are all included for different purposes. Each elements serves a specific functionality which together guarantee the provision of the service. This holds for example the utility elements for the transportation of commodities (e.g. pipe or cables) or to access buried elements via a specific utility element, e.g. a manhole.

During the design, construction and operation of these utility networks, multiple organizations are involved which all have a different role. Each individual stakeholder has its own degree of interaction with the LOD framework and hence associates different goals than others. Table 16 presents an overview of the stakeholders involved in this design research project, including a description and their goal(s). No conflicting goals among the stakeholders are identified.

Table 16: Stakeholders description and goal(s)

	Stakeholder	Description	Goal(s)
1	Authorities	Organizations concerned with monitoring and regulating the construction (process) of utilities.	• Improving system interoperability of utility data.
2	Excavation contractors	Organizations performing excavation activities.	• Reducing excavation damages to utilities. • Improving effectiveness and efficiency of activities. • Easy utilization of artifact.
3	Software developers	Organizations developing CAD software.	• Development of sector-wide supportive CAD software.
4	Utility operators/ contractors	Organizations responsible for operations and maintenance related activities on utilities. Often contracted.	• Improving effectiveness and efficiency of activities. • Easy utilization of artifact.
5	Utility owners	Organizations which own utilities.	• Easy utilization of artifact. • Prevent down-time of utility service. • Improving effectiveness and efficiency of activities. • Reducing damages to utilities.
6	Utility users	End-user of the utilities.	• Reliable use of the services by utilities.

Wieringa (2014) states that the interaction of stakeholders with the product is an essential design part. Hence, the relationships of the identified stakeholders with the final artifact is needed to be established. This is done following the onion diagram of Alexander (2005) as it formalizes a stakeholder taxonomy and provides insights in the relevance of the stakeholders with regard to the final artifact. The result of this stakeholder mapping is shown in Figure 9.

The first and innermost circle 'The Product' relates to artifact under development: the LOD framework. The second circle 'The System' entails the utility owners, utility operators and excavation contractors as these organisations will exchange the information model designs with the LOD framework incorporated. The next circle, 'The Containing System', involves authorities and software developers. These stakeholders do not have a direct say in the design choices, but have an indirect influence as the artifact needs to cohere the authorities' set regulations and should be feasible in CAD software of the software developers. The last and outer circle, 'The Wider Environment', includes the utility users, since they might benefit from less down-time of the service of the utilities as a result of less miscommunication and tailored information.

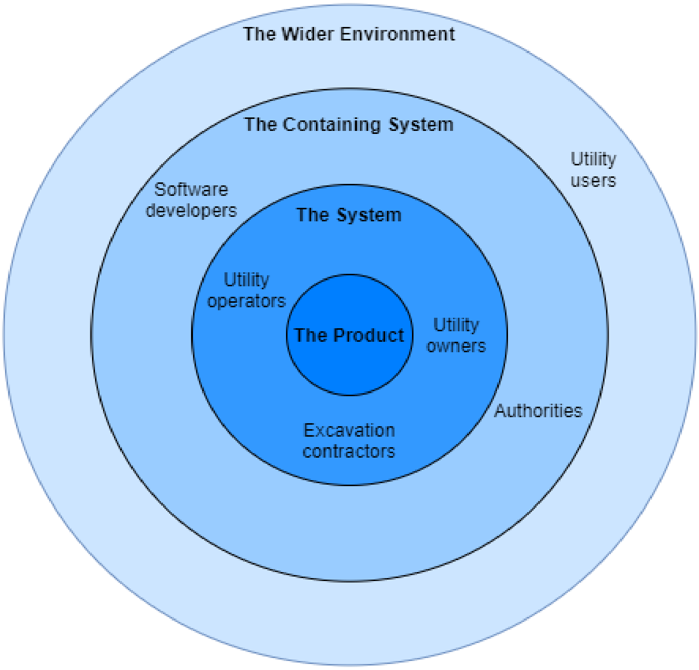


Figure 9: Stakeholder onion diagram (Alexander, 2005)

C. The design and construction process of subsurface utility networks

This appendix elaborates on the current practices and processes during the design and construction of subsurface utility networks. Laymen of the SU sector could use this appendix to gain an understanding of existing processes and deliverables of the sector. Moreover, it provides a view into the context where the designed LOD framework will be utilized.

The construction of the utility networks is realized in a project-based approach. This means that for every project a different solution is sought for which fits best the set requirements. This is mainly due to the fact that the construction of subsurface utilities presents many interferences with the surrounding environment (Cassino et al., 2012; Vignali et al., 2021).

Utility operators, or to be more specific engineers, use information of these surrounding environment to come to different designs of the to be constructed utilities. Data needs to be collected of all different aspects of the (project) area such as terrain surfaces, sites, vegetation, infrastructure, buildings, city furniture and more. Besides, in the Netherlands, it is legally obliged to submit a KLIC report prior to excavation activities. This report contains information about existing cables and pipelines in the project area, aiming to prevent damages to those utilities during excavation. The collection of all data ranges from specific (attribute) data of the Model Elements such as material and utility owner to spatial information about the location and its environment. Depending on these surroundings, different mechanisms occur and activities take place. Figure 10 presents a generalized overview of the subsurface utility project workflow at Siers, and the resulting design deliverables:

- Schematic design (SD): Based on the analysis of the surrounding environment multiple design alternatives are created. These design alternatives often vary in routing and material use. Also known as functional design.
- Conceptual design (CD): The first spatial and aesthetic elaboration of one of the design alternatives that is presented to the client. The client can respond to this with comments, feedback and additional wishes and there is still plenty of opportunity for adjustments.
- Detailed design (DD): Resulting from the discussion of the CD, a detailed elaboration of the utility network to be constructed is performed. The to be used element types are determined and exact

dimensions and materials and element types are set. This design is also used during the execution of construction activities.

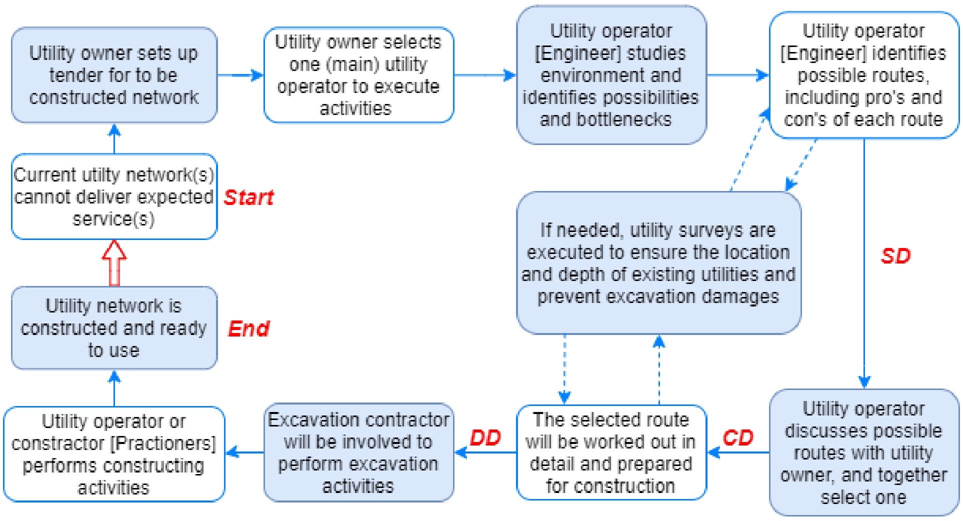


Figure 10: Generalized workflow design & construction of utility networks

Utility owners initially formalize tenders based on general (project) information, which then becomes more comprehensive as the utility operator studies the project through analysis and execution of tasks in the project area. Hence, due to a different nature of decisions being made at different stages in a project, the extent of the (utility) information will progress over time. At the start of a project, a lower information density and quality is expected to be included compared to the end of a project (Ewenstein & Whyte, 2009).

This is also reflected in the 2D and 3D models that utility contractors use. As the project progresses, more details about the design solution will be known such as the exact location, used material, and more. In this way the model becomes not only richer, but also comes closer – whether or not similar – to reality. In other words, the model transforms from being a conceptual to as-built. As an example, where an element can first be represented by only a location reservation (by its coarse outer boundaries), it can later be replaced by its exact geometry. Within the information model, there however might exists some differences. Building systems (i.e. Model Elements) namely progress from concept to precise definition at different rates, so at any given time different elements will be at different points along this progression.

D. Composition of utility networks

This Appendix provides the results of the theory review into the composition of utility networks. The purpose of this review is to gain insight in what should be modelled; which elements together make up utility networks? Multiple relevant theoretical documents (Table 1) are reviewed of which the results are briefly described below.

Each utility network consists of multiple utility elements which are all included for different purposes. Each elements serves a specific functionality which together guarantee the provision of the service. This holds a variety of elements such as for the transportation of commodities (e.g. pipe or cables) or to access buried elements via a specific utility element, e.g. a manhole.

In capturing the composition of utility networks, theory uses a generalisation in the definition of their containing elements. This generalization is added to allow modelling of every kind of utility network. Further detailing of the utility disciplines, for example towards a high-pressure gas network, is thereby possible through the addition of attributes to each discipline.

However, differences were observed in the taxonomy among the multiple documents. On the one hand, CityGML and Ter Huurne structure their data specification by the distinction in functionality of the utility elements. It defines for example distribution, functional and protective elements. On the other hand, IMKL and INSPIRE use the topological characteristic of the utility elements as a network is composed out of arcs (links) and nodes. As described at INSPIRE, it is especially designed for utility networks managers willing to describe their data into a structured modulization that allows its business use. In addition to this, this taxonomy is in line with the current modelling practices (2D) and valid in the same context as the host organisation (Dutch SU sector). Hence, this latter taxonomy of utility network elements is persisted in this thesis.

The figure on the right shows the main elements within a utility network using the taxonomy of IMKL and INSPIRE. As presented, it distinguishes four generalized elements which are applicable to all utility disciplines.

Utility Links represent the elements within a network intended for the transmission of energy, matter or data. In practice, it comes down to all types of cables and pipes. Utility Links are of single nature, which means it does not represent a bundle or collection of cables/pipes.

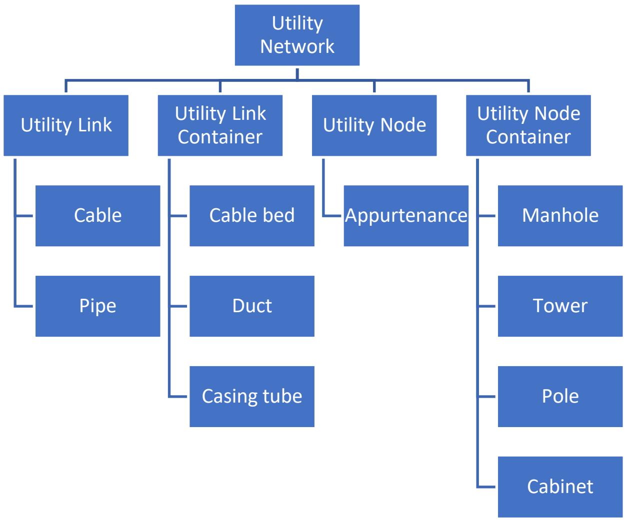


Figure 11: : Utility Network – Main elements as based on IMKL and INSPIRE

Next, *Utility Link Containers* are defined as elements which group and guide *Utility Links*. In practice, this relates to three elements, namely a cable bed, duct and casing tube. It depends on the discipline of the utility network which of these *Utility Link Containers* are applicable. In addition, the grouped elements do not necessarily belong to the same utility network.

The *Utility Node*-category represents all elements which are used for connectivity of the *Utility Links*. This also implies that it can relate to both underground and aboveground elements of the network. The different types of *Utility Nodes* are not included as separate elements, but accommodated under the collective term *Appurtenance*. These elements can then be specified by the addition of attribute data. Examples of practice are valves, transitions, and T-pieces.

As a last generalized categorization, the *Utility Node Container* accommodates all elements which are used for connectivity and may contain and group *Utility Nodes*. Same as for the *Utility Link Containers,* these do not necessarily belong to the same utility network. In total, four concrete elements can be distinguished for all utility networks: Manhole, Tower, Pole and Cabinet. One should note that these elements are surface oriented objects.

E. Validation session

This Appendix provides additional information of the end-user validation session. First, Appendix E.1 describes the identified validation criteria. Next, Appendix E.2 describes the elaboration on spatial data and accuracy. Then, Appendix E.3 provides the question list (in Dutch) of the validation session. At last, Appendix E.4 presents an overview of the answers given by each actor.

E.1.Criteria description

Below, the five criteria used to validate the design of the LOD framework for utility network elements are described. This does not include a description of how these criteria are tested; this is presented in the next part of this Appendix (E.3). The criteria are described via a central question.

1. Understandability: To what extent is the LOD framework understandable?
2. Usability: To what extent is the LOD framework fast and easy to use?
3. Completeness: To what extent does the LOD framework capture the full possibilities in terms of the specifications of all utility network elements?
4. Structure: To what extent is the structure of the LOD framework suitable?
5. Utility: To what extent are end-users capable to apply the LOD framework in the intended way?

E.2.Spatial data and accuracy

Next to the validation of the basis of the designed LOD framework (i.e. the requirements), the validation discussed the phenomenon of spatial data and accuracy within information models and a possible integration of a spatial statement within the LOD framework. Section 4.2 argued that the accuracy of spatial data of the surroundings is essential in the design and construction of utility networks. Comparing this with the building subsector for which the existing AEC LOD framework is designed for (Bedrick et al., 2020), the focus is less emphasized on the locational accuracy of the surroundings but rather puts the to be constructed entity at the core in the information model.

For this reason, six propositions were presented to the attendees which included the combination of the way of defining the accuracy and the way of including it into the LOD framework. The first refers to the 1) CityGML's location and depth quality, 2) IMKL's accuracy classes, and 3) PAS 128's quality levels (as explained in Appendix H.2). The latter refers to 1) explicit definition of the spatial accuracy per LOD and 2) the addition as an extra dimension to the LOD framework resulting in a *LOD ###-X* system, where '*###*' indicates the LOD and '*X*' the spatial accuracy statement.

E.3.Question list (Dutch)

This Appendix provides the total list of questions asked to the attendees of the validation session (in Dutch). Besides, the possible answers per question are indicated as well. The list is structured in the same order as treated during the session plus it is listed per criteria.

Voorbereiding aanwezigen:

0. Wie heeft zich kunnen voorbereiden op deze meeting?
   - Ik heb mijzelf goed kunnen voorbereiden
   - Ik heb mijzelf voorbereid, maar wel vluchtig
   - Ik heb mijzelf helaas niet kunnen voorbereiden

Begrijpelijkheid

1. In hoeverre is voor jou helder wat Model Element inhoudt?
   - Schaal 1-5 met 1= erg onduidelijk en 5 = erg duidelijk
2. In hoeverre is voor jou helder wat geometrie in de context van het LOD raamwerk inhoudt?
   - Schaal 1-5 met 1= erg onduidelijk en 5 = erg duidelijk
3. In hoeverre is voor jou helder wat attribuut data in de context van het LOD raamwerk inhoudt?
   - Schaal 1-5 met 1= erg onduidelijk en 5 = erg duidelijk
4. In hoeverre is voor jou helder wat betrouwbaarheid in de context van het LOD raamwerk inhoudt?

   - Schaal 1-5 met 1= erg onduidelijk en 5 = erg duidelijk
5. In hoeverre zijn de losse LOD beschrijvingen helder genoeg geformuleerd?
   - Schaal 1-5 met 1= erg onduidelijk en 5 = erg duidelijk

Bruikbaarheid

6. In hoeverre moet je moeite doen om te begrijpen wat het LOD raamwerk en de specifieke Levels inhouden?
   - Schaal 1-5 met 1= erg veel moeite en 5 = erg weinig moeite

Volledigheid:

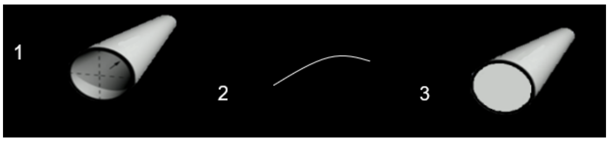
7. In hoeverre kan het LOD raamwerk toegepast worden op elke nutsdisclipline?
   - Op alle disciplines
   - Op de meeste disciplines, behalve …
   - Voor veel disciplines is dit niet mogelijk, namelijk …
8. In hoeverre kan het LOD raamwerk toegepast worden op elk type nutsnetwerkelement?
   - Op alle type nutsnetwerk elementen
   - Op de meeste type nutsnetwerk elementen, behalve …
   - Het kan niet worden toegepast op de meeste type nutsnetwerk elementen, namelijk …
9. In hoeverre weerspiegelen de LOD definities de correcte mate opbouw van geometrie?
   - Schaal 1-5 met 1= erg slecht en 5 = erg goed
   - Indien neutraal/slecht, mist er een specifieke duiding?
10. In hoeverre weerspiegelen de LOD definities de correcte mate opbouw van attribuut data?
    - Schaal 1-5 met 1= erg slecht en 5 = erg goed
    - Indien neutraal/slecht, mist er een specifieke duiding?

Structuur

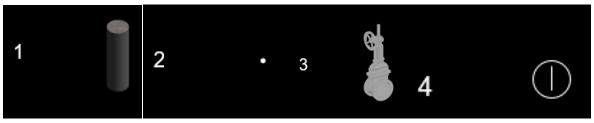
11. In hoeverre is de structuur (opsplitsing in aantal Levels) van het raamwerk voldoende? (3 = goed)
    - Schaal 1-5 met 1= te weinig en 5 = te veel

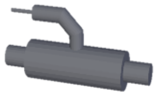
Toepasbaarheid:

12. In het ontwerpen van een nieuw te leggen netwerk wil je de bestaande ondergrondse infrastructuur (KLIC) graag in 3D weergeven om te kijken waar in de ondergrond ruimte is om het netwerk te plaatsen. Welke LOD is geschikt om de KLIC data te modelleren?
    - Keuze uit LODs
13. In project X is een ontwerp van een nieuw te leggen netwerk volledig tot in detail uitgewerkt. Om deze details omtrent fabricatie en constructie te communiceren naar overige betrokkenen/stakeholders, ontstaat er de vraag om dit weer te geven in een 3D model. Welke LOD is hier voor geschikt?
    - Keuze uit LODs
14. In project X is een ontwerp van een nieuw te leggen netwerk volledig tot in detail uitgewerkt. Tijdens een projectmeeting wil je de hoofdlijnen van het ontwerp weergeven in een 3D model. Welke LOD is hier voor geschikt?
    - Keuze uit LODs
15. In project X is in overleg bepaald dat een leiding met LOD 200 gemodelleerd wordt. Hoe zal dit element er visueel uit komen te zien?



16. In project X is in overleg bepaald dat een afsluiter met LOD 300 gemodelleerd wordt. Hoe zal dit element er visueel uit komen te zien?



17. Op de afbeelding is een parallel T-stuk weergegeven. Van welke LOD(s) is hier mogelijk sprake?
    -  Keuze uit LODs
18. Op de afbeelding is een (elektriciteits)kast weergegeven. Van welke LOD(s) is hier mogelijk sprake?
    -  Keuze uit LODs
19. Op de afbeelding is een mantelbuis weergegeven. Van welke LOD(s) is hier mogelijk sprake?
    - Keuze uit LODs

Toevoeging statement over locatie en diepte

20. Zou de toevoeging van een statement over de locatie en diepte nauwkeurigheid in het LOD raamwerk van toegevoegde waarde zijn?
    - Ja
    - Nee
    - Het is erg belangrijk, maar ik weet niet of het LOD raamwerk de juiste plek hiervoor is
    - Anders, namelijk …
21. Welke manier van het aanduiden van de locatie en diepte nauwkeurigheid heeft jullie voorkeur?
    - CityGML's locatie/diepte kwaliteit
    - IMKL's nauwkeurigheidsklassen
    - PAS128's kwaliteitsniveaus (QL) van uitkomsten onderzoek
    - Anders, namelijk …
    - Ik weet het niet
22. Welk voorstel van de toevoeging in het LOD raamwerk van de locatie en diepte nauwkeurigheid heeft jullie voorkeur?
    - Expliciet per LOD vastleggen en omschrijven
    - LOD ###-X systeem
    - Anders, namelijk …
    - Ik weet het niet

E.4. Overview of all answers

This Appendix presents the answers given by each attendee on each question. Here, a reference is included to the corresponding actor via the actor IDs following Table 5. Besides, for the questions regarding criteria Utility, the correct answers are given and their corresponding score is provided. In this, the following scoring system is applied: 1 = only wrong and/or missing answers, 2 = many wrong and/or missing answers, but also some good answers, 3 = Both wrong and good answers, 4 = many good answers, but also some wrong and/or missing answers, and 5 = only good answers. The outer right column then presents the average score at each question (at a 1-5 scale). The table is followed by the general points mentioned by the attendees.

ID	Criteria	Question (Dutch)	Answer (actor ID = 2)	Answer (actor ID = 6)	Answer (actor ID = 4)	Answer (actor ID = 7)	Correct answer	Average score
0	Attendees' preparation	Wie heeft zich kunnen voorbereiden op deze meeting?	Ik heb mijzelf voorbereid, maar wel vluchtig	Ik heb mijzelf voorbereid, maar wel vluchtig	Ik heb mijzelf voorbereid, maar wel vluchtig	Ik heb mijzelf voorbereid, maar wel vluchtig	n/a	n/a
1	Understand-ability	In hoeverre is voor jou helder wat Model Element inhoudt?	4	3	4	3	n/a	3,5
2	Understand-ability	In hoeverre is voor jou helder wat geometrie in de context van het LOD raamwerk inhoudt?	5	4	4	4	n/a	4,25
3	Understand-ability	In hoeverre is voor jou helder wat attribuut data in de context van het LOD raamwerk inhoudt?	5	4	5	5	n/a	4,75
4	Understand-ability	In hoeverre is voor jou helder wat betrouwbaarheid in de context van het LOD raamwerk inhoudt?	3	4	4	4	n/a	3,75
5	Understand-ability	In hoeverre zijn de losse LOD beschrijvingen helder genoeg geformuleerd?	4	4	4	4	n/a	4
6	Usability	In hoeverre moet je moeite doen om te begrijpen wat het LOD raamwerk en de specifieke Levels inhouden?	4	3	3	4	n/a	3,5
7	Complete-ness	In hoeverre kan het LOD raamwerk toegepast worden op elke nutsdisclipline?	5 (Op alle disciplines)	5 (Op alle disciplines)	5 (Op alle disciplines)	5 (Op alle disciplines)	n/a	5
8	Complete-ness	In hoeverre kan het LOD raamwerk toegepast worden op elk type nutsnetwerkelement?	5 (Op alle typen nutsnetwerk elementen)	5 (Op alle typen nutsnetwerk elementen)	5 (Op alle typen nutsnetwerk elementen)	5 (Op alle typen nutsnetwerk elementen)	n/a	5
9	Complete-ness	In hoeverre weerspiegelen de LOD definities de correcte mate opbouw van geometrie?	4	4	4	5	n/a	4,25

10	Complete-ness	In hoeverre weerspiegelen de LOD definities de correcte mate opbouw van attribuut data?	5	5	5	5	n/a	5
11	Structure	In hoeverre is de structuur (opsplitsing in aantal Levels) van het raamwerk voldoende?	3	4	4	3	n/a	3,5
12	Utility	In het ontwerpen van een nieuw te leggen netwerk wil je de bestaande ondergrondse infrastructuur (KLIC) graag in 3D weergeven om te kijken waar in de ondergrond ruimte is om het netwerk te plaatsen. Welke LOD is geschikt om de KLIC data te modelleren?	4 (LOD 100;LOD 200;LOD 250)	4 (LOD 100;LOD 200;LOD 250)	3 (LOD 200)	5 (LOD 200;LOD 250)	Evt LOD 100; LOD 200; LOD 250	4
13	Utility	In project X is een ontwerp van een nieuw te leggen netwerk volledig tot in detail uitgewerkt. Om deze details omtrent fabricatie en constructie te communiceren naar overige betrokkenen/stakeholders, ontstaat er de vraag om dit weer te geven in een 3D model. Welke LOD is hier voor geschikt?	5 (LOD 400)	2 (LOD 250;LOD 300;LOD 350;LOD 400)	1 (LOD 300)	1 (LOD 250;LOD 300;LOD 350)	LOD 400	2,25
14	Utility	In project X is een ontwerp van een nieuw te leggen netwerk volledig tot in detail uitgewerkt. Tijdens een projectmeeting wil je de hoofdlijnen van het ontwerp weergeven in een 3D model. Welke LOD is hier voor geschikt?	2 (LOD 250)	4 (LOD 350;LOD 400)	2 (LOD 250)	4 (LOD 300)	Evt LOD 250; LOD 300; LOD350; evt LOD400	3
15	Utility	In project X is in overleg bepaald dat een leiding met LOD 200 gemodelleerd wordt. Hoe zal dit element er visueel uit komen te zien?	5 (Afbeelding 3)	3 (Afbeelding 1;Afbeelding 3)	5 (Afbeelding 3)	5 (Afbeelding 3)	Afbeelding 3	4,5
16	Utility	In project X is in overleg bepaald dat een afsluiter met LOD 300 gemodelleerd wordt. Hoe zal dit element er visueel uit komen te zien?	5 (Afbeelding 3)	5 (Afbeelding 3)	5 (Afbeelding 3)	1 (Afbeelding 1)	Afbeelding 3	4
17	Utility	Op de afbeelding is een parallel T-stuk weergegeven. Van welke LOD(s) is hier mogelijk sprake?	3 (LOD 250)	3 (LOD 250;LOD 300;LOD 350;LOD 400)	5 (LOD 250;LOD 300)	5 (LOD 250;LOD 300)	LOD 250; LOD 300	4

18	Utility	Op de afbeelding is een (elektriciteits)kast weergegeven. Van welke LOD(s) is hier mogelijk sprake?	5 (LOD 350;LOD 400)	4 (LOD 300;LOD 350;LOD 400)	5 (LOD 350;LOD 400)	3 (LOD 400)	LOD 350; LOD 400	4,25
19	Utility	Op de afbeelding is een mantelbuis weergegeven. Van welke LOD(s) is hier mogelijk sprake?	5 (LOD 100)	1 (LOD 200)	5 (LOD 100)	5 (LOD 100)	LOD 100	4
20	Extra - spatial data	Zou de toevoeging van een statement over de locatie en diepte nauwkeurigheid in het LOD raamwerk van toegevoegde waarde zijn?	Ja	Ja	Ja	Ja	n/a	Ja
21	Extra - spatial data	Welke manier van het aanduiden van de locatie en diepte nauwkeurigheid heeft jullie voorkeur?	CityGML's locatie/diepte kwaliteit	PAS128's kwaliteitsniveaus (QL) van uitkomsten onderzoek	Anders, namelijk …	PAS128's kwaliteitsniveaus (QL) van uitkomsten onderzoek	n/a	n/a
22	Extra - spatial data	Welk voorstel van de toevoeging in het LOD raamwerk van de locatie en diepte nauwkeurigheid heeft jullie voorkeur?	Anders, namelijk …	Expliciet per LOD vastleggen en omschrijven	LOD ###-X systeem	LOD ###-X systeem	n/a	n/a

Algemene (verbeter)punten

- Aangaande de vraag omtrent de bruikbaarheid, geven de aanwezigen aan dat zij verwachten dat het alleen maar beter/makkelijker zal worden naarmate zij meer hier zijn ingeleid in het onderwerp en vaker met het LOD raamwerk zullen werken.
- Actor (ID = 7): *"De opzet en verdeelbaarheid in het raamwerk is goed, maar voor de leesbaarheid zou je de typeringen aan het raamwerk kunnen toevoegen met eventueel ook nog enkele voorbeelden om weer te geven hoe dit er visueel uitziet. Op die manier spreek het raamwerk veel beter en wordt het voor iedereen herkenbaar door dezelfde interpretaties en daardoor implementaties."*
- De aanwezigen geven aan dat het aan te raden is om de extra kolom, waarin het LOD getypeerd wordt, mee te communiceren in het raamwerk.

Locatie en diepte:

- Vraag 21 antwoord actor (ID = 4): *"Ik denk misschien wel dat de combinatie van de 3 aanduidingen misschien nog wel de beste oplossing is. Als je puur kijkt naar de gemeten waarden dan hoeft dat over een aantal jaar niet meer de gemeten waarde te zijn. Je kan nooit met 100% zekerheid de locatie nauwkeurigheid behouden; wel vastleggen, maar niet behouden.* Actor (ID = 2) *geeft aan dat hij het hier mee eens is."*
- Vraag 22 antwoord actor (ID = 2): *"Het zal altijd project specifiek bepaald moeten worden hoe nauwkeurig je bent. Ik denk dat het overkoepelend is hoe nauwkeurig de model elementen moeten zijn, en niet per model element hoeft te worden vastgelegd. Het expliciet vastleggen en omschrijven per LOD is hierin geen optie."*
- Reactie actor (ID = 7) op actor (ID = 2): *"Er zit ook een verschil in nauwkeurigheid in wat je zelf modelleert en wat er al in de grond ligt. Bij deze laatste is het erg fijn om juist een bandbreedte te hebben aangezien de locatie door verschillende factoren kan verplaatsen."*
- Al met al geven de actoren aan dat er meer tijd, aandacht en onderzoek nodig is voor deze toevoeging.

F. Total list of LOD framework requirements

This Appendix presents a total list of LOD framework requirements. In total, twenty-two requirements were defined after consultation of the literature and discussions with practitioners.

First, twelve functional requirements are identified and presented in Table 17. The definition of these functional requirements is rather binary; it is easy to determine if such requirement is incorporated in the design. Additionally, it is shown whether or not the requirement is covered in this thesis study due to the fact it only includes the design cycle which not incorporates the actual implementation in its context (section 2.2).

Table 17: LOD framework functional requirements

ID	Functional requirement	Scope
1	The LOD framework must describe geometric data.	Yes
2	The LOD framework must describe attribute data.	Yes
3	The LOD framework must describe the degree of reliability.	Yes
4	The LOD framework must capture the graduality of the specification.	Yes
5	The LOD framework must allow modelling of every utility discipline.	Yes
6	The LOD framework must allow modelling of every utility network element type.	Yes
7	The LOD framework must hold hierarchy among the levels.	Yes
8	The LOD framework must be cumulative: each LOD definition includes the requirements of previous LODs.	Yes
9	The LOD framework must provide a standard definition of the specification of Model Elements that can be referenced during projects.	Yes
10	The LOD framework must help teams to specify deliverables and to get a clear picture of what will be included in a deliverable.	No
11	The LOD framework must help design managers explain to their teams the information and detail that needs to be provided at various points in the design process, and to track progress of their models.	No
12	The LOD framework must allow downstream users to rely on specific information in models they receive from others.	No

Second, the non-functional requirements are presented in Table 18. In total, nine non-functional requirement are defined. In addition, as the operationalisation of the requirements are often multiple, indicators and norms are set.

Table 18: LOD framework non-functional requirements

ID	Non-functional requirement	Indicator	Norm	Scope
13	The LOD framework must add value to the current information exchanging process of 3D utility data models.	Stakeholder opinion	Opinion is favourable	No
14	The LOD framework is clearly defined and easy to understand by its end-users.	Effort to understand	Low	Yes
15	The LOD framework must be usable by stakeholders in their (3D) modelling practices.	Accessibility	High	No
16	The number of Levels within the LOD framework must be limited.	# of levels	As low as possible	Yes
17	The LOD framework must allow an easy and non-time-intensive reasoning process to the end-users.	Stakeholder opinion	Opinion is favourable	No
18	The implementation of the LOD framework must result in the specified output of all Model Elements.	Compliance	Yes	Yes
20	The output resulting from the LOD framework must be traceable by the end-users to the relevant LOD.	Compliance	Yes	Yes
21	The LOD framework must comply with existing CAD software used in the SU sector.	Compliance	Yes	No

22	The LOD framework must be supported by the direct stakeholders through reaching consensus in which definition and implementations of LODs.	Consensus reached	Yes	Yes

The above requirements were formulated based on the findings in this thesis study. One should not that this thesis study focuses on the design aspect solely as the actual implementation of the LOD framework is out of scope. Although still some requirements could be formulated regarding this topic, one should be aware of this list of requirements might not be complete due to this limited scope.

G. Attribute data categorization

As mentioned earlier, the specification of Model Elements is characterised by the geometry and attribute data. This Appendix elaborates on the categorization of utility attribute data as defined by El-Diraby & Osman (2011).

The phenomenon of attribute data is of a very comprehensive nature as there exists no restriction on the amount of attribute data associated with the modelled elements. Several practical and scientific efforts aimed to capture this data within (domain) ontologies for the SU sector. One of these efforts is the domain ontology for construction concepts in urban infrastructure products of El-Diraby & Osman (2011). Here, a classification of infrastructure product attributes was defined which is utility discipline independent and hence ensures a consistent and unambiguous approach of the complete set of elements among the utility networks. It classifies attributes into 11 main types:

- Dimensional attributes: Relate to describing a measurable dimension of a product.
- Spatial attributes: Relate to describing a location-related attribute of a product.
- Material attributes: Relate to describing one or more attributes of the infrastructure product material.
- Shape attributes: Relate to describing the shape of an infrastructure product.
- Cost attributes: Relate to the monetary value associated with a product.
- Performance attributes: Describe the various engineering, operational, safety and sustainability performance a product.
- Surrounding soil attributes: The interaction between buried infrastructure products and their surrounding environment is of utmost importance. These attributes are used to describe the various soil-related properties, soil types and ground water properties of surrounding soils.
- Dependency attributes: Describe the various interdependencies between infrastructure products and other products using four main groups of dependency (physical, cyber, geographic, and logical).
- Redundancy attributes: Used to describe the need for the particular infrastructure product within the greater infrastructure network in case a breakdown of that product occurs.
- State of operation attributes: Used to describe the state of operation of an infrastructure product at a particular state in time.
- Impact attributes: Describes the environmental, economic and social impacts of products.

However, some attributes did not fit in the El-Diraby & Osman's classification (2011). Hence, this thesis study added three new categories representing (a combination of) the unclassified attributes. Below, these categories are briefly described:

- Actor attributes: Relate to describing an actor-related attribute of a product. This includes amongst others contact details of the utility owner or manufacturer;
- Functional attributes: Relate to describing use- and functional-related attributes of a product;
- Survey attributes: Relate to the quality and reliability of utility information by describing a survey-related attribute of a product. It originates from the additional documents PAS128, PAS256, and ASCE 38-02.

This categorisation is in line with the LOD concept as it is an abstract (yet extendable) philosophical (yet practical) conceptualization of the essence of knowledge that relates to construction aspects of infrastructure products.

H. Findings of existing 3D specification

This Appendix presents all findings regarding the specification of Model Elements in an information model. This relates to the document studies and project analyses as described in the research approach (subsection 2.2.1). First, the findings regarding the geometry are given, followed by the ones regarding attribute data. At each aspect of specification, findings from theory and practice are separately presented. The combination and summary of the final outcomes are presented in section 4.2.

H.1. Geometry

Theory

During the study into the geometry specifications from theory multiple ways of representing utility network elements in 3D are identified. The findings regarding the LOD specification are excluded from this section as this is described in section 4.3.

The IFC states that a Model Element's geometry can be modelled via various representation types, both in 2D and 3D. Which representation type is needed to be used, depends on its application and nature of the Model Element. This means that a Model Element is not limited to one type but may have one or many representations. This phenomenon is in line with the underlying notion of this thesis study. However, these representation types do not relate to the core of this study since it concerns the modelling approach (i.e. how to model) rather than the graduality within the output. Nevertheless, this latter is extracted from these representation types and described below. For detailed descriptions and examples of these representation types, Liebich (2009) can be consulted.

The lowest detail in geometry representation is 2D representation. This current predominant practice in the SU sector consists of arcs and nodes which together constitute the topological structure of the utility network (Appendix D). In so, these arcs and nodes are located at the centre of the utility. In addition, specific objects of *Utility Nodes*, being types of appurtenances, and *Utility Node Containers* are potentially represented by symbols or icons. The PMKL provides a list of these elements and their representing symbols or icons. Besides, the PMKL defines four graphical variables regarding the representation style for 2D modelling of utility network elements:

1. Colour: Used to distinguish the different disciplines of utility networks as it is most eye-catching.
2. Shape: Used to distinguish the Utility Network elements. For *Utility Node(s) (Containers)*, this is expressed in a node, or the symbol or icon used for an element. The shape of *Utility Link(s) (Containers)* is reflected in their pattern which distinguishes the differences in status from each other.
3. Size: Used to realize the visual impression. For *Utility Link(s) (Containers)* this is indicated with line thickness.
4. Opacity: Used to indicate the extent of the utility network element without obscuring too much of the underlying drawing.

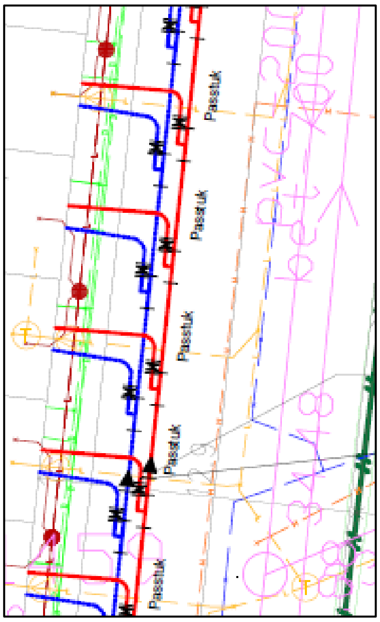


Figure 12: Snapshot of 2D drawing of project Project B

As an example, Figure 12 presents a snapshot of a 2D drawing of Project B (Table 3). Here, it can be observed that at the construction site different utility network elements are present (indicated by arcs, nodes and symbols) belonging to multiple disciplines (indicated by colours). Besides, on the one hand, the to be constructed district heating network are highlighted via an increased line thickness and, on the other hand, the existing utility networks as acquired from KLIC, are presented with a reduced opacity. Using these variables, the utility network elements can be identified from the 2D model and drawings by its end-users and gain an understanding of what is present in the subsurface project area.

Moreover, a 2D polygon (closed polyline) is used to represent the footprint of the Model Element. This shows its outer spatial extent in a planar view (x, y).

The next geometrical representation allows a simplistic 3D representation given by a bounding box. This entails a cuboid box with the smallest measure within which the actual shape of the element lies. It may be added as an additional representation to enable the display of the shape by application not being able to handle complex shape. In addition, in this way, insights can be obtained by the area reservation without going into detail, for example in the underground.

Then, the element's geometry can be represented by its body, i.e. outer boundaries. This is normally used to describe the (explicit) 3D shape of an object. Using this representation, its exact contour and hence area representation is obtained. This results in insights in the spatial (underground) complexity with more certainty compared to the bounding box.

At last, the use of voids is also allowed in 3D shapes. This allows the modelling of the internal dimensions of Model Elements, resulting in a more detailed representation of the geometry. In essence, the use of voids could potentially be applied to every element. Considering *Utility Links*, a visual impression can be obtained of the flow capacity as the interior dimensions are included. In addition, for elements grouping other utility network elements (*Utility Link Containers* and *Utility Node Containers*), this is relevant as these elements house and protect other elements of which location is necessary to know for coordination purposes.

To recall, these representations are applicable to each individual element or entity. It varies from a valve entity to a specific bolt used for the connection of this entity with its network. It is up to the modeller which elements, i.e. details, to in- or exclude. There exists no bad or good in this. Hence, the degree of detail is prone to the intent of the modeller.

Practice

Second, the findings obtained from practice are presented. For 2D modelling, all drawings were in line with the PMKL principles. In other words, arcs, nodes and symbols were used to model the project situation. On the other hand, although the LOD concept is not integrated in the analysed projects (Table 3), still multiple graduality's in and ways of modelling the geometry in information models were identified. Below the most important findings are described per utility network element category. If found supportive, graphical examples are presented.

- *Utility Links*

Starting with *Utility Links*, in the vast majority of the corresponding pipes and cables are modelled as a 3D Solid with corresponding outer diameter as guiding parameter. Graphical examples of such visualisations are given in snapshots A and B of Figure 13.

Only at one information model, the decomposition of the *Utility Links* of to be constructed thermal network was modelled. This implied both the pipe itself as well as its insulation. As a graphical example, this is also illustrated in the right snapshot (C) of Figure 13. In so, a visual impression can be obtained from the element composition, i.e. the thickness per material. Other existing utility links (KLIC) within that information model were modelled as a single 3D Solid like snapshot A and B.

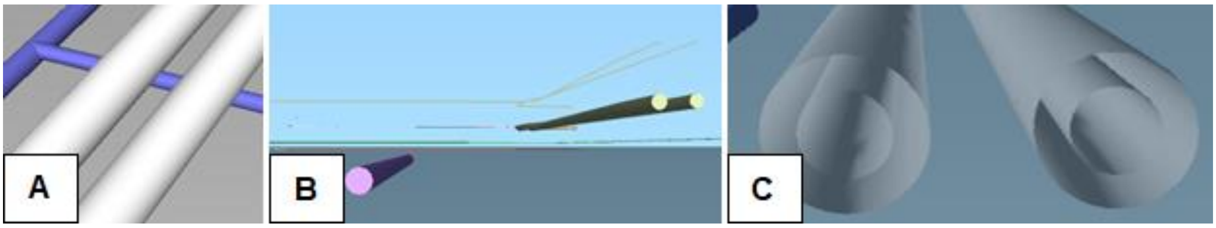


Figure 13: Snapshots from practice of Utility Links

- *Utility Link Containers*

Considering the *Utility Link Containers*, two different approaches were observed.

It was found that in 2 of the 3 information models such elements are represented by their footprint instead of a volumetric appearance. Only the planar (x, y) outer boundaries of the *Utility Link Containers* are modelled at the right depth. Snapshot A of Figure 14 presents such an example of a low voltage electricity cable protected and transported via a casing tube.

Next to this, at one information model *Utility Link Containers* were represented by 3D solids. In so, the characteristic of being hollow is neglected. In other words, only the exterior diameter is considered; the interior diameter(s) not. This is visualised in snapshot B of Figure 14.

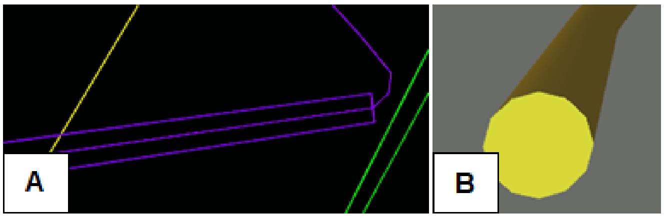


Figure 14: Snapshots from practice of Utility Link Containers

- *Utility Nodes*

Next, within the *Utility Node* categorization, in total three ways of visualisation were identified. Figure 15 presents a collection of graphical examples.

First, it is observed that the symbology as used in 2D modelling is also being applied within the information models. In so, it gave an indication of the appurtenance type at certain locations along the present utility networks. This was found in 2 of the 3 information models. Snapshots A and B (Figure 15) show respectively a valve at a water pipe and a T-piece at the intersection of three low pressure gas pipes.

Second, the use of spheres for *Utility Nodes* was found in one information model. These spheres were not representative in terms of size, but it rather makes the end-users aware of the presence of appurtenances at certain locations. Examples include a cable sleeve of low voltage electricity cables (snapshot C), a T-piece and a blowoff at a low-pressure gas network (snapshot D).

Third, real-life representative *Utility Nodes* were found at one information model. In specific, this included only *Utility Nodes* of the to be constructed network; existing *Utility Nodes*, as acquired from the KLIC, were modelled as either one of the two phenomena described above. Such a real-life representation of the outer dimensions of a parallel T-piece is given in snapshot E (Figure 15).

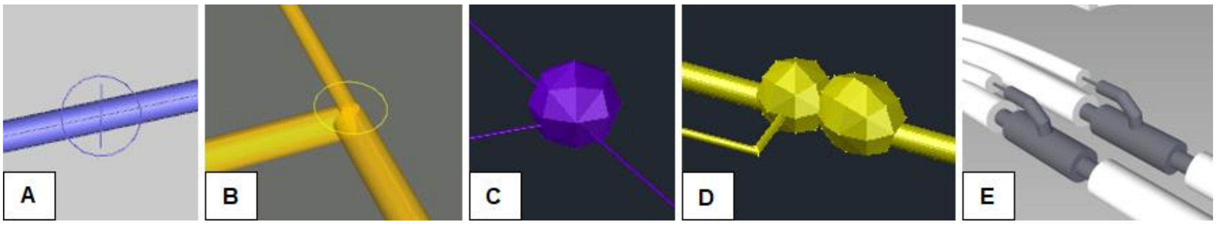


Figure 15: Snapshots from practice of Utility Nodes

- *Utility Node Containers*

At last, two ways of representation for the *Utility Node Containers* are observed. Figure 16 provides two graphical examples.

First, same as for the *Utility Nodes*, representation by 2D symbols and icons was found in two information models. Snapshot A displays such an occasion of a cabinet with data communication cables approaching.

In the other information model, a new phenomenon was found. Here, extruded symbols were used to indicate the appearance of these elements (Snapshot B, Figure 16). This extrusion is however not according to approximate or correct dimensions. Extruding the icon as presented in snapshot B only causes the element being more eye-catching.

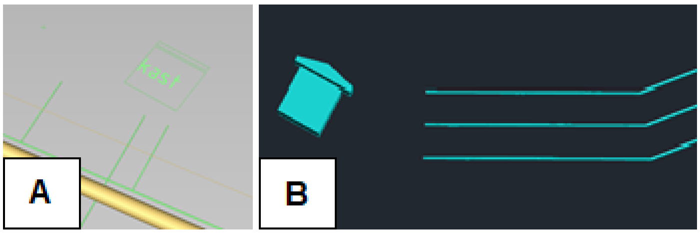


Figure 16: Snapshots from practice of Utility Node Containers

Practitioners from Siers, however, acknowledged that within their exiting information models no particular focus is laid upon *Utility Node Containers*. Rather Siers sticks to the other subsurface utilities. In addition, since it was modelled with no full awareness, the extruded icon is perceived as an organisational initiative.

Besides, one should note that no representations were observed in practice which indicate either approximate or correct dimensions of these elements.

H.2. Attribute data

Theory

Following the document study of Table 1 and Table 4, multiple attributes were found and classified according to El-Diraby & Osman (2011). The findings are summarized in a table as presented at the end of this appendix (Table 20). This table is structured following the taxonomy IMKL and INSPIRE (Appendix D) and includes objects as specifically referred to in these documents. To the understanding of this study, these objects form the core of the utility networks. Each object is then listed with attributes as prescribed in the theoretical documents. For the definition and description of the listed attributes, the respective theoretical documents can be consulted.

Analysing the total list of attribute data, four attribute types were excluded from the scope of the theoretical documents: cost, surrounding soil, redundancy and impact attributes. On the other hand, some attributes did not fit in the El-Diraby & Osman's classification (2011). Hence, three new categories were added representing (a combination of) the unclassified attributes. Below, these categories are briefly described:

- Actor attributes: Relate to describing an actor-related attribute of a product. This includes amongst others contact details of the utility owner or manufacturer;
- Functional attributes: Relate to describing use- and functional-related attributes of a product;
- Survey attributes: Relate to the quality and reliability of utility information by describing a survey-related attribute of a product. It originates from the additional documents PAS128, PAS256, and ASCE 38-02.

Furthermore, some documents give an indication of the relevance of inclusion within a SU project of the attribute data. This was found in the IMKL, INSPIRE and PAS256. Within the attribute viewer of the IMKL, the likelihood the attribute value will be filled is incorporated. In this, it distinguishes mandatory (=basic) and optional attribute data. Next, the INSPIRE Utility Networks ADE is structured into two profiles: a Utility Networks-profile and an Extended Utility Networks-profile. The profiles use the same structure, but the first focuses on the basic characteristics whereas the latter presents annexed proposals for richer models (=optional attributes). Furthermore, PAS256 recommends a list of both minimum (=basic) and optional attribute data. This distinction of relevance given in the documents is incorporated in the summarizing table via Yb (basic attribute) and Yo (optional attribute).

Here, attributes belonging to the functional, state of operation, and spatial attribute category are mostly claimed to be basic information. In addition, this also holds for material and dimensional attributes in case of rigid utilities.

Besides these single attributes, the IMKL also allows the use of attachments of additional project information. The nature of the attachments is up to the end-user(s), but examples include information requests, specific 2D drawings, precaution measures, and more.

All documents however do not embody the evolving aspect of project information. In other words, it rather provides a full list of attributes rather than incorporating the time aspect. Hence, from these documents no conclusions can be drawn on the graduality of attribute data during a SU project.

Moreover, as already discussed in several literature studies such as Olde Scholtenhuis & Zlatanova (2018), the spatial data is a fundamental issue in the current sector. This mainly entails the spatial data of the existing utility infrastructure as the design of the to be constructed network highly depends on it. Theory includes a collection of many attributes describing a spatial characteristic of subsurface utilities, either the horizontal or vertical position (see Appendix H.2: Table 20). Next to the description of these characteristics, (Chapman et al., 2020) claims that the accuracy of spatial data is also a crucial aspect. Theory includes definitions of such in three different ways as observed in CityGML, IMKL, and PAS 128 & ASCE 38-02. First, CityGML uses qualitative definitions of the location and depth quality. It includes four options: unknown, standard, estimated, and surveyed. Although these definitions provide an indication of the accuracy, it allows the end-users to decide for themselves how to interpret the accuracy. Second, in the IMKL this is captured in accuracy classes, being accurate up to 30cm, 50cm, 100cm and unknown. This is hence rather a quantitative definition of the spatial accuracy. Third, PAS 128 and ASCE 38-02 use quality levels which indicate a professional opinion of the quality and reliability of utility information. Such reliability is determined by the means and methods of the professional. Each of the four existing utility data quality levels is established by different methods of data collection and interpretation. It distinguishes four survey types which have an increased spatial accuracy: 1) desktop utility records search, 2) site reconnaissance, 3) detection, and 4) verification.

Practice

Next to the several theoretical documents, practice at Siers is also investigated. Here, the association of attribute data to Model Elements is currently very minimal. This appendix will present a summary of these findings. In case specific findings per project is wished to be obtained, the researcher can be contacted.

Currently, attributes are enclosed in (CAD) 2D models and drawings through the use of labels, dimension call-outs, symbols, icons, colour coding, line types or text. Besides, some attribute data could be derived from the context provided in the drawings such as spatial data. In other words, this latter data was not explicitly stated, but are indirectly represented within the model and drawings. This was also found for the information models. Only at a small part of one model, few attributes were directly associated to Model Elements. In all other information models, the data of the Model Elements was incorporated in the same way as of 2D.

In so, no clear, fixed approach of the inclusion of certain dataset; it depends on the project nature and environment which attribute data is relevant to include. This is in line with the statement of the SU sector being project-based sector (Appendix C). Besides, the extent of the attributes also depends on the application information model.

Nevertheless, still several findings were done regarding the attribute data. One of the main findings was the elaboration of the attribute data for utilities with a different origin. With this latter, the nature of information is meant. In total three different origins of utilities were found: KLIC, test trenches and the design of the to be constructed network.

First, within both 2D and 3D deliverables, no attribute data was explicitly added to the KLIC Model Elements. Only a few attributes were included by the use of PMKL representation principles (colour-coding, icons, symbols). In any of the projects, the location, status, utility network discipline, owner, and type of present elements (especially appurtenances) was indicated. Moreover, it sometimes also included a diameter and material definition for rigid linear utilities. In addition, some of the projects indicated when precaution measurements are needed, but this did not include detailed information. Saying this, one should note that relatively few information originating from KLIC was included despite an elaborative database being available (and compulsory to consult prior to excavating).

Second, subsurface utilities obtained from test trenches were accompanied with few attributes. From its geometrical representation its discipline and diameter could be obtained. Besides, the definition of its material and colour were indicated by text in both a 2D and 3D environment. Moreover, the identified utilities were placed in the model at their surveyed position and depth, such that its location could be obtained as well. Note that this data is field verified as these utilities are exposed by excavation.

Third, similar findings were done for Model Elements of the to be constructed network. Here, from the representation of the Model Elements (cf. PMKL), it's discipline, function of line, diameter, and length could be indirectly obtained. Next, from the context provided in the 2D and information models, its spatial extent is derived. Besides, for some Model Elements its position (x, y), depth/elevation, dimensions (either internal, external or both), length, and type of appurtenances were specified using supportive text and labels. Only at one project, attribute data was associated to Model Elements. However, this only included four attributes: discipline, ID, length, and invert elevation. Moreover, additional 2D drawings were included to entail certain details more specific. For example, at one project, a specific 2D drawing was provided which specifically stipulates the locations of the welds meant for construction.

In the table below, the specific attributes are listed per origin.

Table 19: Attribute data found in practice listed by origin

Attribute	KLIC		Test trench		To be constructed network	
	2D	3D	2D	3D	2D	3D
Discipline	✓	✓	✓	✓	✓	✓
Location	✓	✓	✓	✓	✓	✓
Status	✓	✓				
Owner	✓	✓				
Type of element	✓	✓			✓	✓
Diameter	✓	✓	✓	✓	✓	✓
Material	✓	✓	✓	✓		
Colour			✓	✓		
Length					✓	✓
Function of line					✓	✓
Precaution measurement	✓	✓				
Additional 2D drawings					✓	✓

Next, limited evolvement of attribute data over project time was observed in practice. Although the 2D deliverables progress along the project timeline, these showed minimal differences in attribute data. No clear, fixed approach or pattern was observed in the extent and evolvement of the attribute data. These deliverables included nearly identical utility information, but at later deliverables this information can be associated with more certainty as the design comes to its final stage. In general sense, these deliverables rather state more about the thoughtfulness of the Model Elements rather than the exact attribute data to include.

At last, the extent and accuracy spatial data is one of the main issues in current working practices according to practitioners. The vast majority of the involved actors (Table 5) states that spatial information and its accuracy is one of, if not the most important, information during the design and construction processes. To quote an actor: *"It is not possible to 100% assure the spatial accuracy over time; it can be captured, but not retained over time."* This statement implies that earlier spatial accuracy statements can also be questioned on their accuracy, making this fundamental issue even more complex. How this issue should be denoted with what approach (according to CityGML, IMKL and PAS 128 & ASCE 38-02; as elucidated in the theory section above) differs among the actors.

This table presents the findings of the document study of Table 1 and Table 4 towards attribute data. This relevance of inclusion to information models for SU projects given in the documents is incorporated via Yb (basic attribute) and Yo (optional attribute).

Table 20: Attribute data found in theory

ID	Abstract Utility Network	Abstract Network Element	Object type	Attribute	IMKL 2.0	CityGML UN ADE	INSPIRE	Ter Huurne (2019)	PAS128	PAS256	ASCE 38-02
1	Utility Network			**Functional attributes**							
2				Utility Network Type	Yb	Y	Yb	Y			
3				Function		Y		Y			
4				Usage		Y		Y			
5				**Spatial attributes**							
6				Standard depth	Yo						
7				**Performance attributes**							
8				Commodity details				Y			
9				Commodity classifier		Y		Y			
10				Disclaimer	Yo		Yb				
11				**Actor attributes**							
12				Related Party	Yo		Yb	Y			
13				**Dependency attributes**							
14				Utility Facility Reference	Yo		Yb				
15	Utility Network Element	Utility Link	Electricity cable	**Functional attributes**							
16				Function		Y		Y		Yb	
17				Usage		Y		Y			
18				Function of Line		Y		Y			
19				Utility Delivery Type	Yo		Yb	Y			
20				Type			Yo	Y			
21				**Spatial attributes**							
22				Position (x and y coordinate)	Yb				Y	Yb	
23				Location						Yb	
24				Location accuracy	Yo						
25				Location quality		Y		Y			
26				Vertical Position	Yb		Yb	Y			
27				Depth	Yb			Y	Y	Yb	
28				Standard depth				Y			

29				Depth Point of Measurement	Yb			Y			
30				Depth accuracy	Yb			Y			
31				Date of depth measurement	Yo			Y			
32				Depth quality				Y			
33				Elevation	Yb			Y			
34				Elevation point of measurement	Yb			Y			
35				Elevation accuracy	Yb			Y			
36				Elevation quality		Y		Y			
37				Date of elevation measurement	Yo			Y			
38				Elevation surface	Yo						
39				Date of elevation surface measurement	Yo						
40				**Survey attributes**							
41				Quality level					Y	Yo	Y
42				Date of quality level					Y	Yo	Y
43				Detection method					Y		
44				**Dimensional attributes**							
45				Diameter (external)	Yo				Y	Yb	
46				Conductor size		Y	Yo	Y			
47				Number of conductors				Y			
48				**State of operation attributes**							
49				Status	Yb	Y	Yb			Yb	
50				Condition					Y		
51				Date of construction	Yb	Y	Yb				
52				Date of expiration	Yo		Yb				
53				**Performance attributes**							
54				Voltage				Y	Y	Yb	
55				Operating voltage	Yb		Yb				
56				Nominal voltage	Yb		Yb				
57				Capacity (max)			Yo	Y			
58				WarningType	Yb		Yb				
59				**Actor attributes**							
60				Owner					Y	Yb	
61				Related Party		Y		Y			
62				**Material attributes**							

63				Material		Y	Yo		Y	Yb	
64				**Dependency attributes**							
65				Utility Facility Reference	Yo		Yb				
66				Governmental Service Reference	Yo		Yb				
67			Telecom cable	**Functional attributes**							
68				Function		Y		Y			
69				Usage		Y		Y			
70				Function of Line		Y		Y			
71				Type	Yb		Yb	Y		Yb	
72				Utility Delivery Type	Yo		Yb				
73				**State of operation attributes**							
74				Status	Yb	Y	Yb	Y		Yb	
75				Condition					Y		
76				Date of construction	Yb	Y	Yb				
77				Date of expiration	Yo		Yb				
78				**Spatial attributes**							
79				Position (x and y coordinate)	Yb					Yb	
80				Location accuracy	Yo						
81				Location quality		Y		Y			
82				Vertical Position	Yb		Yb	Y			
83				Depth	Yb			Y	Y	Yb	
84				Depth Point of Measurement	Yb			Y			
85				Standard depth				Y			
86				Depth accuracy	Yb			Y			
87				Date of depth measurement	Yo			Y			
88				Depth quality				Y			
89				Elevation	Yb			Y			
90				Elevation point of measurement	Yb			Y			
91				Elevation accuracy	Yb			Y			
92				Elevation quality		Y		Y			
93				Date of elevation measurement	Yo			Y			
94				Elevation surface	Yo						

95				Date of elevation surface measurement	Yo						
96				**Survey attributes**							
97				Quality level					Y	Yo	Y
98				Date of quality level					Y	Yo	Y
99				Detection method					Y		
100				**Performance attributes**							
101				Capacity (max)			Yo	Y			
102				Impedance				Y			
103				Attenuation				Y			
104				Warning type	Yb		Yb				
105				**Dimensional attributes**							
106				Diameter (external)	Yo					Yb	
107				Conductor size		Y		Y			
108				Number of conductors				Y			
109				**Actor attributes**							
110				Owner					Y	Yb	
111				Related Party		Y		Y			
112				**Material attributes**							
113				Material		Y				Yb	
114				**Dependency attributes**							
115				Utility Facility Reference	Yo		Yb				
116			OilGasChemicals pipe	**Functional attributes**							
117				Function		Y		Y			
118				Usage		Y		Y			
119				Function of Line		Y		Y			
120				Utility Delivery Type	Yo		Yb	Y			
121				isGravity		Y		Y			
122				Product Type	Yb	Y	Yb				
123				Pipe Type			Yo	Y			
124				**Material attributes**							
125				Material	Yo	Y	Yo		Y	Yb	
126				Coating type			Yo				
127				Cathodic protection				Y			
128				**Spatial attributes**							
129				Position (x and y coordinate)					Y	Yb	
130				Location accuracy	Yo			Y			

131				Location quality		Y		Y			
132				Location						Yb	
133				Vertical Position	Yb		Yb	Y			
134				Depth	Yb			Y	Y	Yb	
135				Depth Point of Measurement	Yb			Y			
136				Standard depth				Y			
137				Depth accuracy	Yb			Y			
138				Date of depth measurement	Yo			Y			
139				Depth quality				Y			
140				Elevation	Yb			Y			
141				Elevation point of measurement	Yb			Y			
142				Elevation accuracy	Yb			Y			
143				Elevation quality		Y		Y			
144				Date of elevation measurement	Yo			Y			
145				Elevation surface	Yo						
146				Date of elevation surface measurement	Yo						
147				**Survey attributes**							
148				Quality level					Y	Yo	Y
149				Date of quality level					Y	Yo	Y
150				Detection method					Y		
151				**State of operation attributes**							
152				Status	Yb	Y	Yb	Y		Yb	
153				Condition					Y		
154				Date of construction	Yb	Y	Yb				
155				Date of expiration	Yo		Yb				
156				**Shape attributes**							
157				Shape type			Yo				
158				**Dimensional attributes**							
159				Diameter (external)	Yb	Y	Yb			Yb	
160				Dimensions (external)		Y					
161				Diameter (internal)		Y					
162				Dimensions (internal)		Y					
163				Angle of rotation				Y			
164				**Performance attributes**							

165				Volume (average)			Yo				
166				Capacity (max)			Yo	Y			
167				Pressure	Yo		Yb	Y			
168				Warning type	Yb		Yb				
169				**Actor attributes**							
170				Owner					Y	Yb	
171				Related Party		Y		Y			
172				**Dependency attributes**							
173				Utility Facility Reference	Yo		Yb				
174				Governmental Service Reference	Yo		Yb				
175			Water pipe	**Functional attributes**							
176				Function		Y		Y			
177				Usage		Y		Y			
178				Function of Line		Y		Y			
179				Utility Delivery Type	Yo		Yb	Y			
180				Product Type	Yb	Y	Yb				
181				Pipe Type			Yo	Y			
182				isGravity		Y		Y			
183				**Material attributes**							
184				Material	Yo	Y	Yo		Y	Yb	
185				Coating type			Yo				
186				Cathodic protection				Y			
187				**Spatial attributes**							
188				Position (x and y coordinate)	Yb				Y	Yb	
189				Location						Yb	
190				Location accuracy	Yo			Y			
191				Location quality		Y		Y			
192				Vertical Position	Yb		Yb	Y			
193				Depth	Yb			Y	Y	Yb	
194				Depth Point of Measurement	Yb			Y			
195				Standard depth				Y			
196				Depth accuracy	Yb			Y			
197				Date of depth measurement	Yo			Y			
198				Depth quality				Y			
199				Elevation	Yb			Y			

200				Elevation point of measurement	Yb			Y			
201				Elevation accuracy	Yb			Y			
202				Elevation quality		Y		Y			
203				Date of elevation measurement	Yo			Y			
204				Elevation surface	Yo						
205				Date of elevation surface measurement	Yo						
206				**Survey attributes**							
207				Quality level					Y	Yo	Y
208				Date of quality level					Y	Yo	Y
209				Detection method					Y		
210				**State of operation attributes**							
211				Status	Yb	Y	Yb	Y		Yb	
212				Condition					Y		
213				Date of construction	Yb	Y	Yb				
214				Date of expiration	Yo		Yb				
215				**Shape attributes**							
216				Shape type			Yo				
217				**Dimensional attributes**							
218				Diameter (external)	Yb	Y	Yb		Y	Yb	
219				Dimensions (external)		Y					
220				Diameter (internal)		Y					
221				Dimensions (internal)		Y					
222				Angle of rotation				Y			
223				**Actor attributes**							
224				Owner					Y	Yb	
225				Related Party		Y		Y			
226				**Performance attributes**							
227				Pressure	Yo		Yb	Y			
228				Volume (average)			Yo				
229				Capacity (max)			Yo	Y			
230				Warning type	Yb		Yb				
231				**Dependency attributes**							
232				Utility Facility Reference	Yo		Yb				
233				Governmental Service Reference	Yo		Yb				

234			Sewerage pipe	**Functional attributes**							
235				Function		Y		Y			
236				Usage		Y		Y			
237				Function of Line		Y		Y			
238				Utility Delivery Type	Yo		Yb	Y			
239				Product Type	Yb	Y	Yb				
240				Pipe Type			Yo	Y			
241				isGravity		Y		Y			
242				**Material attributes**							
243				Material	Yo	Y	Yo		Y	Yb	
244				Coating type			Yo				
245				Cathodic protection				Y			
246				**Spatial attributes**							
247				Position (x and y coordinate)	Yb				Y	Yb	
248				Location						Yb	
249				Location accuracy	Yo			Y			
250				Location quality		Y		Y			
251				Vertical Position	Yb		Yb	Y			
252				Depth	Yb			Y	Y	Yb	
253				Depth Point of Measurement	Yb			Y			
254				Standard depth				Y			
255				Depth accuracy	Yb			Y			
256				Date of depth measurement	Yo			Y			
257				Depth quality				Y			
258				Elevation	Yb			Y			
259				Elevation point of measurement	Yb			Y			
260				Elevation accuracy	Yb			Y			
261				Elevation quality		Y		Y			
262				Date of elevation measurement	Yo			Y			
263				Elevation surface	Yo						
264				Date of elevation surface measurement	Yo						
265				**Survey attributes**							
266				Quality level					Y	Yo	Y
267				Date of quality level					Y	Yo	Y

268				Detection method					Y		
269				**State of operation attributes**							
270				Status	Yb	Y	Yb	Y		Yb	
271				Condition					Y		
272				Date of construction	Yb	Y	Yb				
273				Date of expiration	Yo		Yb				
274				**Shape attributes**							
275				Shape type			Yo				
276				**Dimensional attributes**							
277				Diameter (external)	Yb	Y	Yb			Yb	
278				Dimensions (external)		Y					
279				Diameter (internal)		Y					
280				Dimensions (internal)		Y			Y		
281				Angle of rotation				Y			
282				**Actor attributes**							
283				Owner					Y	Yb	
284				Related Party		Y		Y			
285				**Performance attributes**							
286				Pressure	Yo		Yb	Y			
287				Volume (average)			Yo				
288				Capacity (max)			Yo	Y			
289				Warning type	Yb		Yb				
290				**Dependency attributes**							
291				Utility Facility Reference	Yo		Yb				
292				Governmental Service Reference	Yo		Yb				
293			Thermal pipe	**Functional attributes**							
294				Function		Y		Y			
295				Usage		Y		Y			
296				Function of Line		Y		Y			
297				Utility Delivery Type	Yo		Yb	Y			
298				Product Type	Yb	Y	Yb				
299				Pipe Type			Yo	Y			
300				isGravity		Y		Y			
301				**Material attributes**							
302				Material	Yo	Y	Yo			Yb	
303				Coating type			Yo				
304				Cathodic protection				Y			

305				**Survey attributes**							
306				Quality level					Y	Yo	Y
307				Date of quality level					Y	Yo	Y
308				Detection method					Y		
309				**State of operation attributes**							
310				Status	Yb	Y	Yb	Y		Yb	
311				Condition					Y		
312				Date of construction	Yb	Y	Yb				
313				Date of expiration	Yo		Yb				
314				**Shape attributes**							
315				Shape type			Yo				
316				**Dimensional attributes**							
317				Diameter (external)	Yb	Y	Yb			Yb	
318				Dimensions (external)		Y					
319				Diameter (internal)		Y					
320				Dimensions (internal)		Y					
321				Angle of rotation				Y			
322				**Spatial attributes**							
323				Position (x and y coordinate)	Yb					Yb	
324				Location						Yb	
325				Location accuracy	Yo			Y			
326				Location quality		Y		Y			
327				Vertical Position	Yb		Yb	Y			
328				Depth	Yb			Y		Yb	
329				Depth Point of Measurement	Yb			Y			
330				Standard depth				Y			
331				Depth accuracy	Yb			Y			
332				Date of depth measurement	Yo			Y			
333				Depth quality				Y			
334				Elevation	Yb			Y			
335				Elevation point of measurement	Yb			Y			
336				Elevation accuracy	Yb			Y			
337				Elevation quality		Y		Y			
338				Date of elevation measurement	Yo			Y			

339				Elevation surface	Yo						
340				Date of elevation surface measurement	Yo						
341				**Actor attributes**							
342				Owner						Yb	
343				Related Party		Y		Y			
344				**Performance attributes**							
345				Pressure	Yo		Yb	Y			
346				Capacity (max)				Y			
347				Warning type	Yb		Yb				
348				**Dependency attributes**							
349				Utility Facility Reference	Yo		Yb				
350				Governmental Service Reference	Yo		Yb				
351		Utility Link Container	Duct	**Functional attributes**							
352				Function		Y		Y			
353				Usage		Y		Y			
354				Utility Delivery Type	Yo		x				
355				**Spatial attributes**							
356				Position (x and y coordinate)	Yb					Yb	
357				Location						Yb	
358				Location accuracy	Yo			Y			
359				Location quality		Y		Y			
360				Vertical Position	Yb		Yb	Y			
361				Depth	Yb			Y	Y	Yb	
362				Depth Point of Measurement	Yb			Y			
363				Standard depth				Y			
364				Depth quality				Y			
365				Depth accuracy	Yb			Y			
366				Elevation	Yb			Y			
367				Elevation point of measurement	Yb			Y			
368				Elevation accuracy	Yb			Y			
369				Elevation quality		Y		Y			
370				Date of elevation measurement	Yo			Y			
371				Elevation surface	Yo						

372				Date of elevation surface measurement	Yo						
373				Visible at surface	Yo						
374				**Survey attributes**							
375				Quality level					Y	Yo	Y
376				Date of quality level					Y	Yo	Y
377				Detection method					Y		
378				**State of operation attributes**							
379				Status	Yb	Y	Yb	Y		Yb	
380				Condition					Y		
381				Date of construction	Yb	Y	Yb				
382				Date of expiration	Yo		Yb				
383				**Actor attributes**							
384				Owner					Y	Yb	
385				Related Party		Y		Y			
386				**Dimensional attributes**							
387				Diameter (external)		Y					
388				Dimensions (external)		Y					
389				Diameter (internal)		Y					
390				Dimensions (internal)		Y					
391				Width	Yb		Yb				
392				No. of cables/pipes	Yo			Y			
393				Pipe columns			Yo				
394				Pipe rows			Yo				
395				Spacer size			Yo				
396				**Performance attributes**							
397				Warning type	Yb		Yb				
398				**Material attributes**							
399				Material		Y			Y	Yb	
400				Cathodic protection						Yb	
401				**Dependency attributes**							
402				Utility Facility Reference	Yo		Yb				
403				Governmental Service Reference	Yo		Yb				
404			Casing tube	**Functional attributes**							
405				Function		Y		Y			
406				Usage		Y		Y			
407				**Spatial attributes**							

408				Position (x and y coordinate)	Yb				Y	Yb	
409				Location						Yb	
410				Location quality		Y		Y			
411				Location accuracy	Yo			Y			
412				Vertical Position	Yb		Yb	Y			
413				Depth	Yb			Y	Y	Yb	
414				Depth Point of Measurement	Yb			Y			
415				Standard depth				Y			
416				Depth quality				Y			
417				Depth accuracy	Yb			Y			
418				Elevation	Yb			Y			
419				Elevation point of measurement	Yb			Y			
420				Elevation accuracy	Yb			Y			
421				Elevation quality		Y		Y			
422				Date of elevation measurement	Yo			Y			
423				Elevation surface	Yo						
424				Date of elevation surface measurement	Yo						
425				Visible at surface	Yo						
426				**State of operation attributes**							
427				Status	Yb	Y	Yb	Y		Yb	
428				Condition					Y		
429				Date of construction	Yb	Y	Yb				
430				Date of expiration	Yo		Yb				
431				**Survey attributes**							
432				Quality level					Y	Yo	Y
433				Date of quality level					Y	Yo	Y
434				Detection method					Y		
435				**Performance attributes**							
436				Warning type	Yb		Yb				
437				**Dimensional attributes**							
438				Diameter (external)	Yb	Y				Yb	
439				Dimensions (external)		Y					
440				Diameter (internal)		Y					
441				Dimensions (internal)		Y					

442				No. of cables/pipes	Yo			Y			
443				**Material attributes**							
444				Material	Yo	Y				Yb	
445				**Actor attributes**							
446				Owner					Y	Yb	
447				Related Party		Y		Y			
448				**Dependency attributes**							
449				Utility Facility Reference	Yo		Yb				
450				Governmental Service Reference	Yo		Yb				
451			Cable bed	**Functional attributes**							
452				Function		Y		Y			
453				Usage		Y		Y			
454				Utility Delivery Type	Yo						
455				**Spatial attributes**							
456				Position (x and y coordinate)	Yb					Yb	
457				Location						Yb	
458				Location quality		Y		Y			
459				Location accuracy	Yo			Y			
460				Vertical Position	Yb		Yb	Y			
461				Depth	Yb		Yb	Y		Yb	
462				Depth Point of Measurement	Yb			Y			
463				Standard depth				Y			
464				Depth quality				Y			
465				Depth accuracy	Yb			Y			
466				Elevation	Yb			Y			
467				Elevation point of measurement	Yb			Y			
468				Elevation accuracy	Yb			Y			
469				Elevation quality		Y		Y			
470				Date of elevation measurement	Yo			Y			
471				Elevation surface	Yo						
472				Date of elevation surface measurement	Yo						
473				Visible at surface	Yo						
474				**State of operation attributes**							

475				Status	Yb	Y	Yb	Y		Yb	
476				Condition					Y		
477				Date of construction	Yb	Y	Yb				
478				Date of expiration	Yo		Yb				
479				**Survey attributes**							
480				Quality level					Y	Yo	Y
481				Date of quality level					Y	Yo	Y
482				Detection method					Y		
483				**Performance attributes**							
484				Warning type	Yb		Yb				
485				**Dimensional attributes**							
486				Width	Yb	Y		Y		Yb	
487				No. of cables/pipes	Yo			Y			
488				**Material attributes**							
489				Material		Y				Yb	
490				**Actor attributes**							
491				Owner						Yb	
492				Related Party		Y		Y			
493				**Dependency attributes**							
494				Utility Facility Reference	Yo		Yb				
495				Governmental Service Reference	Yo		Yb				
496		Utility Node	Appurtanance	**Functional attributes**							
497				Function		Y		Y			
498				Usage		Y		Y			
499				Type	Yb	Y	Yb	Y			
500				Specific type	Yo	Y	Yb	Y			
501				**State of operation attributes**							
502				Status	Yb	Y	Yb	Y		Yb	
503				Condition					Y		
504				Date of construction	Yb	Y	Yb				
505				Date of expiration	Yo		Yb				
506				**Survey attributes**							
507				Quality level					Y		Y
508				Date of quality level					Y		Y
509				Detection method					Y		
510				**Spatial attributes**							

511				Position (x and y coordinate)	Yb					Yb	
512				Location						Yb	
513				Location accuracy	Yo			Y			
514				Location quality		Y		Y			
515				Vertical Position	Yb		Yb	Y			
516				Depth	Yb			Y		Yb	
517				Depth Point of Measurement	Yb			Y			
518				Standard depth				Y			
519				Depth accuracy	Yb			Y			
520				Depth quality				Y			
521				Date of depth measurement	Yo			Y			
522				Elevation	Yb			Y			
523				Elevation point of measurement	Yb			Y			
524				Elevation accuracy	Yb			Y			
525				Elevation quality		Y		Y			
526				Date of elevation measurement	Yo			Y			
527				Elevation surface	Yo						
528				Date of elevation surface measurement	Yo						
529				**Dimensional attributes**							
530				Diameter (external)						Yb	
531				Height	Yo						
532				Visible at surface	Yo						
533				isAccessible				Y			
534				**Material attributes**							
535				Material		Y				Yb	
536				**Actor attributes**							
537				Owner					Y	Yb	
538				Related Party		Y		Y			
539				**Dependency attributes**							
540				Utility Facility Reference	Yo		Yb				
541				Governmental Service Reference	Yo		Yb				
542		Utility Node Container	Manhole	**Functional attributes**							

543				Function		Y		Y			
544				Usage		Y		Y			
545				**Spatial attributes**							
546				Position (x and y coordinate)	Yb				Y	Yb	
547				Location						Yb	
548				Location accuracy	Yo			Y			
549				Location quality		Y		Y			
550				Vertical Position	Yb		Yb	Y			
551				Visible at surface	Yo						
552				Cover level						Yo	
553				Bottom level						Yo	
554				Depth quality				Y			
555				isAccessible				Y			
556				Access method			Yo			Yo	
557				**Survey attributes**							
558				Quality level					Y		Y
559				Date of quality level					Y		Y
560				Detection method					Y		
561				**Actor attributes**							
562				Owner						Yb	
563				Related Party		Y		Y			
564				**State of operation attributes**							
565				Status	Yb	Y	Yb	Y		Yo	
566				Condition					Y	Yo	
567				Date of construction	Yb	Y	Yb				
568				Date of expiration	Yo		Yb				
569				**Material attributes**							
570				Material		Y	Yo		Y	Yo	
571				**Shape attributes**							
572				Cover shape type			Yo		Y	Yo	
573				**Dimensional attributes**							
574				Dimensions (internal)			Yo		Y	Yb	
575				Depth to base/invert			Yo		Y	Yb	
576				No. of covers						Yb	
577				Cover						Yb	
578				Cover size			Yo		Y	Yo	
579				Cover weight					Y		
580				No. of ducts per face					Y		

581				Size of each duct					Y		
582				**Dependency attributes**							
583				Utility Facility Reference	Yo		Yb				
584				Governmental Service Reference	Yo		Yb				
585			Tower	**Functional attributes**							
586				Function		Y		Y			
587				Usage		Y		Y			
588				**Spatial attributes**							
589				Position (x and y coordinate)	Yb						
590				Location							
591				Location accuracy	Yo			Y			
592				Location quality		Y		Y			
593				Vertical Position	Yb		Yb	Y			
594				Standard depth				Y			
595				Depth quality				Y			
596				Visible at surface	Yo						
597				isAccessible				Y			
598				**Survey attributes**							
599				Quality level							Y
600				Date of quality level							Y
601				Detection method							
602				**Actor attributes**							
603				Related Party		Y		Y			
604				**State of operation attributes**							
605				Status	Yb	Y	Yb	Y			
606				Date of construction	Yb	Y	Yb				
607				Date of expiration	Yo		Yb				
608				**Dimensional attributes**							
609				Height	Yb		Yb				
610				**Dependency attributes**							
611				Utility Facility Reference	Yo		Yb				
612				Governmental Service Reference	Yo		Yb				
613			Pole	**Functional attributes**							
614				Function		Y		Y			

615				Usage		Y		Y			
616				Type			Yo				
617				Foundation type			Yo				
618				hasAnchorGuy			Yo				
619				hasPushBrace			Yo				
620				hasRiser			Yo				
621				**Spatial attributes**							
622				Position (x and y coordinate)	Yb						
623				Location							
624				Location quality		Y		Y			
625				Location accuracy	Yo			Y			
626				Vertical Position	Yb		Yb	Y			
627				Standard depth				Y			
628				Depth quality				Y			
629				Visible at surface	Yo						
630				isAccessible				Y			
631				**Survey attributes**							
632				Quality level							Y
633				Date of quality level							Y
634				Detection method							
635				**Actor attributes**							
636				Related Party		Y		Y			
637				**State of operation attributes**							
638				Status	Yb	Y	Yb	Y			
639				Date of construction	Yb	Y	Yb				
640				Date of expiration	Yo		Yb				
641				**Dimensional attributes**							
642				Height	Yb		Yb				
643				Diameter (external)			Yo				
644				**Material attributes**							
645				Material			Yo				
646				**Dependency attributes**							
647				Utility Facility Reference	Yo		Yb				
648				Governmental Service Reference	Yo		Yb				
649			Cabinet	**Functional attributes**							
650				Function		Y		Y			

651				Usage		Y		Y			
652				**Spatial attributes**							
653				Position (x and y coordinate)	Yb						
654				Location							
655				Location quality		Y		Y			
656				Location accuracy	Yo			Y			
657				Vertical Position	Yb		Yb	Y			
658				Standard depth				Y			
659				Depth quality				Y			
660				Visible at surface	Yo						
661				isAccessible				Y			
662				**Survey attributes**							
663				Quality level							Y
664				Date of quality level							Y
665				Detection method							
666				**Dimensional attributes**							
667				Height			Yo				
668				Length			Yo				
669				Width			Yo				
670				**Actor attributes**							
671				Related Party		Y		Y			
672				**State of operation attributes**							
673				Status	Yb	Y	Yb	Y			
674				Date of construction	Yb	Y	Yb				
675				Date of expiration	Yo		Yb				
676				**Dependency attributes**							
677				Utility Facility Reference	Yo		Yb				
678				Governmental Service Reference	Yo		Yb				

I. LOD documents in AEC industry

I.1. Authorized uses AEC LOD framework

This appendix captures the authorized uses per LOD for the AEC industry in a matrix as defined by U.S. General Service Administrator (2020). One should note that these uses are focused on AEC industry as a whole. Some uses are hence not representative for the SU sector. Nevertheless, the essence of the coupled authorized uses to certain LODs could be obtained.

MODEL CONTENT	LOD 100	LOD 200	LOD 300	LOD 400	LOD 500
3D Model Based Coordination	Site level coordination	Major large object coordination	General object level coordination	Design certainty coordination	N/A
4D Scheduling	Total project construction duration. Phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring, etc.)	N/A
Cost Estimating	Conceptual cost allowance. Assumptions on future content	Estimated cost based on measurement of generic element (i.e. generic interior wall)	Estimated cost based on measurement of specific assembly (i.e. specific wall type)	Committed purchase price of specific assembly at buyout	Record costs
Program Compliance	Gross departmental areas	Specific room requirements	FF&E, casework, utility connections		
Sustainable Materials	LEED strategies	Approximate quantities of materials by LEED categories	Precise quantities of materials with percentages of recycled and/or locally purchased materials	Specific manufacturer selections	Purchase documentation
Analysis/ Simulation	Strategy and performance criteria based on volumes and areas	Conceptual design based on geometry and assumed system types	Approximate simulation based on specific building assemblies and engineered systems	Precise simulation based on specific manufacturer and detailed system components	Commissioning and recording of measured performance

I.2. Summary of identified similar buildings systems of AEC industry i.r.t. SU sector

This appendix summarizes the identified similar buildings systems within the AEC industry, as defined in the LOD Specification, in relation to the SU sector (as elucidated in Appendix D). Below, these buildings systems are enumerated with their range of LODs according to BIMForum's official document (Bedrick et al., 2020).

Building systems	LOD range
Plumbing - Domestic Water Distribution - Facility Potable-Water Storage Tanks - Domestic Water Equipment - Domestic Water Piping - Plumbing fixtures - Domestic Water Distribution Supplementary Components	100, 200, 300, 350, 400
Sanitary Drainage - Sanitary Sewerage Equipment - Sanitary Sewerage Piping - Sanitary Drainage Supplementary Components	100, 200, 300, 350, 400
Building Support Plumbing Systems - Sanitary Sewerage Equipment - Stormwater Drainage Piping - Facility Stormwater Drains - Gray Water Systems - Building Support Plumbing System Supplementary Components	100, 200, 300, 350, 400
Fire Protection - Water-based fire-suppression - Fire-Extinguishing	100, 200, 300, 350, 400
Electrical - Power generation - Electrical service and distribution	100, 200, 300, 350, 400
Communications - Data communications network equipment	100, 200, 300, 350, 400
Liquid and Gas Site utilities - Water utilities (domestic water, sewerage, drainage, etc) - Energy Distribution (gas, fuel) - Supplementary Components	100, 200
Electrical Site Improvements - Site Electric distribution systems - Site Lighting	100, 200, 300, 350, 400
Site Communications - Site communications systems (e.g. telecom. cables)	100, 200, 300, 350, 400

J. Transcripts of sparring sessions [Dutch]

This Appendix provides the transcripts of the sparring sessions. These sparring sessions include both the interviews regarding the use of information models as well as the workshops regarding the Model Element specification (as both elucidated in section 2.2). The summaries are presented in a chronological order. The sessions were held in Dutch, so are the transcripts. In addition, every transcript commences with the sparring session's date and attendees. For privacy reasons, the names of the interviewees are anonymized and referred to as 'de geïnterviewde' (Dutch for 'interviewee'). Note that the content of the sparring sessions might not fully correspond with the final outcome of this thesis project as each session is just a piece of input for final outcome.

J.1. Siers Infraconsult B.V.

Datum: 18-08-2021

Aanwezigen:

Naam	Organisatie	Rol
Gerben Wolf	Universiteit Twente, Siers Infraconsult BV	Student; uitvoerder onderzoek
Geïnterviewde	Huidig: Siers Infraconsult BV; Voormalig: ENnatuurlijk	Huidig: Projectleider; Voormalig: Manager engineering

Voordat de inhoudelijke sparsessie aanvangt, stellen beide aanwezigen zich kort voor.

Gerben opent de sparsessie door een korte uitleg te geven over zijn onderzoek. Hieronder licht hij het volgende toe:

- *Voordelen 3D modellering*
- *Aanleiding onderzoek*
- *Scope onderzoek*
- *Uitkomst onderzoek*
- *Plan van aanpak*
- *Doel van sparsessie*

Doelen en gebruik 3D model:

Gerben introduceert het eerste thema van deze sessie en stelt open vragen aangaande het gewenste moment van oplevering van een 3D model en het achterliggende doel.

De geïnterviewde geeft aan dat een 3D model waarde toevoegt op het moment dat je in binnenstedelijk gebied zit en beperkte vrije ruimte hebt om de nieuw te leggen infra in te passen. Het 3D model ondersteunt hierin aangezien je aan alle kanten eromheen kan kijken om te kijken waar (mogelijke) clashes hebt.

Daarnaast legt de geïnterviewde uit dat dit ook erg handig kan zijn met het zicht op geldende ontwerpregels. Als voorbeeld: Een nieuw te leggen warmtenet dient altijd 1 meter van een waterleiding vandaan te liggen en hier zou je dan ook meer grip op kunnen krijgen door bijvoorbeeld het gebruik van buffers om leidingen. Op deze manier kan de clash detectie veel meer geautomatiseerd kunnen worden.

Verder stipt de geïnterviewde aan dat 3D modellen mogelijkheden biedt voor de uitvoering met het oog op Augmented Reality: de uitvoerder kan exact zien waar de onderdelen geplaatst moeten worden en kan op deze manier ook verschillen met de realiteit identificeren. Daarnaast zegt de geïnterviewde dat ook de volgorde van werken hierin ondersteund kan worden. De geïnterviewde beargumenteert zijn punt met het kostenplaatje: alles wat in de realisatiefase gebeurd of gewijzigd wordt aan je ontwerp, is een factor 10 in kosten van de wijzigingen in de ontwerpfase.

Na het beantwoorden van de open vragen, stelt Gerben nogmaals de vraag, maar nu met in literatuur gevonden 3D model toepassingen. Op basis van de gegeven antwoorden van de geïnterviewde is onderstaand tabel ingevuld (Engels).

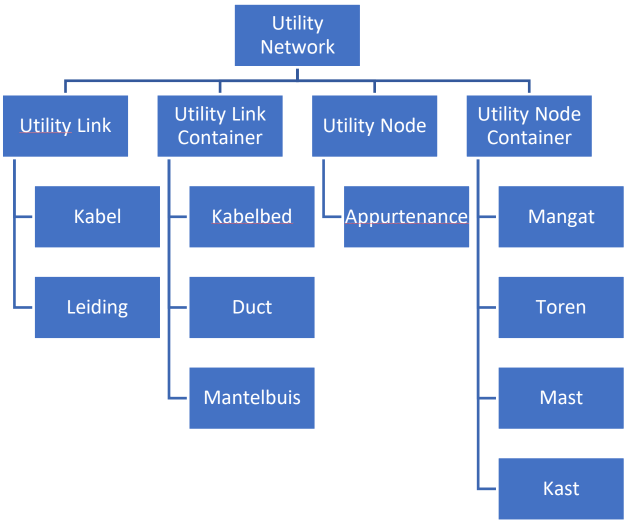
Theme	Application	Made use of?
Photorealistic renderings	Improved communication	Yes
Virtual design review	Meeting codes and standard	Yes
	Clash detection	Yes
	Understanding spatial complexity	Yes
Cost estimating	5D, Bill of quantities	Possible, not sure
Analysing design options/ building operations	Design analysis of alternatives	Yes
	Design simulations	No
Analysing construction operations	4D, Sequencing, etc	Yes, but for the future.

De geïnterviewde geeft na het zien van bovenstaand tabel aan dat ook de *Photorealistic renderings* erg nuttig kunnen zijn m.b.t. oriëntatie van de omgeving.

Specificatie 3D Model Elementen

Gerben introduceert het tweede thema van deze sessie. Daarnaast wordt er expliciet uitgelegd wat er met de termen 'specificatie' en '3D Model Elementen' wordt bedoeld.

Gerben legt uit dat tijdens het bespreken van de specificering van de verschillende elementen wordt gebruik gemaakt van een generalisatie/abstractie van de netwerk elementen om zodoende alle elementen te omvatten. Het maakt gebruik van 4 categorieën: Utility Link, Utility Link Container, Utility Node en Utility Node Container. Gerben legt uit dat de specificatie per categorie besproken zal worden.



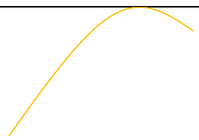
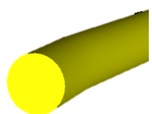
Voorafgaand aan het inhoudelijke gesprek over de specificatie geeft de geïnterviewde aan geen expert te zijn op dit gebied aangezien hij een bedrijfskundige achtergrond heeft.

Als opmerkingen over de opsplitsing in de vier categorieën, geeft de geïnterviewde allereerst aan dat het diagram alomvattend is en dat het alle elementen dekt. Wel stelt De geïnterviewde voor om de *Utility Node* iets verder uit te werken i.p.v. alleen *Appurtenance*. Als disclaimer geeft hij wel toe dat dit enorm per discipline verschilt.

Geometrie

De resultaten van de discussie van de geometrische specificatie zijn na het diagram weergegeven per categorie inclusief de belangrijkste punten.

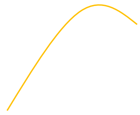
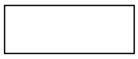
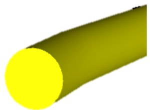
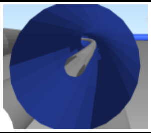
- Utility Link

Geometry representation	Line	Outer dimensions	Exact geometry
Example			

De geïnterviewde geeft aan dat hij graag één ding toegevoegd ziet worden, namelijk de beïnvloedingszone. Dit zou gemodelleerd kunnen worden d.m.v. buffers. Gerben geeft vervolgens aan dat dit inderdaad een nuttige, extra mogelijkheid is van 3D modelleren en dat dit in de praktijk uitvoerbaar kan zijn, maar dat dit buiten de scope van het onderzoek valt.

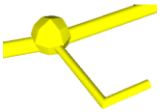
Met beïnvloedingszone bedoelt De geïnterviewde een zone om een element welke een bepaalde omgeving beïnvloedt. Voorbeeld: een elektrakabel kan door het vervoeren van stroom een stalen leiding elektrisch laden (door het magnetische veld) wanneer het te dichtbij ligt. Hetzelfde geldt voor het aanleggen van een warmtenet t.o.v. waterleidingen.

- Utility Link Container

Geometry representation	Line	Footprint	Outer dimensions	Exact geometry
Example				

Volgens de geïnterviewde geldt hier hetzelfde voor als bij *Utility Link.*

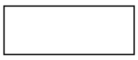
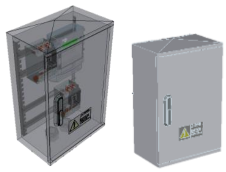
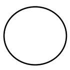
- Utility Node

Geometry representation	Node/ Symbol	Sphere	Area reservation	Outer dimensions	Exact geometry
Example – valve					

De geïnterviewde geeft aan dat de benaming *As-built* niet geheel representatief is in de ontwerpfase, aangezien er in de uitvoering altijd wel kleine dingen veranderen. Een benaming als *Exact geometry* zou passender zijn.

N.a.v. deze suggestie is de naamgeving 'As-built' vervangen door 'Exact Geometry' bij alle vier de categorieën.

- Utility Node Container

Geometry representation	Node/ Symbol	Footprint	Area reservation	Outer dimensions	Exact geometry
Example #1 – Electricity cabinet					
Example #2 – Manhole	•				

De geïnterviewde verklaart dat het 3D model niet per se baat heeft bij de modellering van de indeling van een kast, maar dat de buiten afmetingen wel belangrijk zijn. Verder heeft de geïnterviewde geen opmerkingen.

Attribuut data

Gedurende de bespreking van de geometrie van 3D model elementen heeft de geïnterviewde aangegeven weinig kennis te hebben van de exacte gerelateerde informatie. Daarom is in samenspraak besloten dat de attribuut data niet wordt besproken.

Tijdens de bespreking heeft de geïnterviewde verschillende overige punten aangestipt omtrent het 3D model. Deze zijn hieronder samengevat:

- In essentie dient het medium voerend element (kabel/leiding) gemodelleerd worden en de hierbij horende verbindingen.
- In het geval van aan elkaar te lassen elementen dienen deze lassen ook gemodelleerd te worden. Hierin gaat het met name om de locatie en het bijbehorende rapport met karakteristieken, niet de exacte visualisering.
- Het 3D model draait vooral om de clash detectie en daar is in 90% van de gevallen is een bol voldoende mits hier type informatie aan toegevoegd is.

De werkelijke weergave kan echter wel nuttig zijn tijdens de aanlevering van werktekeningen voor uitvoerders.

J.2. Eneco

Datum: 19-08-2021

Aanwezigen

Naam	Organisatie	Rol
Gerben Wolf	Universiteit Twente, Siers Infraconsult BV	Student; uitvoerder onderzoek
Geïnterviewde	Eneco (stadswarmte)	Engineer renovatieprojecten

Voordat de inhoudelijke sparsessie aanvangt, stellen beide aanwezigen zich kort voor.

De geïnterviewde licht kort toe dat hij zich met name focust op renovatieprojecten zijnde het vervangen van oude leidingen door nieuwe leidingen.

Gerben opent de sparsessie door een korte uitleg te geven over zijn onderzoek. Hieronder licht hij het volgende toe:

- *Voordelen 3D modellering*
- *Aanleiding onderzoek*
- *Scope onderzoek*
- *Uitkomst onderzoek*
- *Plan van aanpak*
- *Doel van sparsessie*

Doelen en gebruik 3D model:

Gerben introduceert het eerste thema van deze sessie en stelt open vragen aangaande het gewenste moment van oplevering van een 3D model en het achterliggende doel.

De geïnterviewde geeft aan dat in geval van renovatieprojecten de vraag naar 3D model vanuit De geïnterviewde/Eneco gefocust is op de voordelen omtrent ruimtelijk inzicht en ontwerp (visual review). Specifiek is dit van toegevoegde waarde in geval van:

- Drukke ondergrond;
- Aanwezige ondergrondse infrastructuur met grote diameters;
- Wanneer de desbetreffende leiding kort op een gevel ligt.

Gedurende een project is een 3D model nooit een eenmalige oplevering aangezien dit hoogstwaarschijnlijk discussiepunten naar de voorgrond haalt. Het 3D model zal in een gezamenlijk proces tot stand komen. Als voorbeeld: in eerste instantie ontvangt Eneco een voorlopig ontwerp tekening. Hierna worden knel-/discussiepunten geïdentificeerd waarna deze samen worden uitgewerkt in een definitief ontwerp.

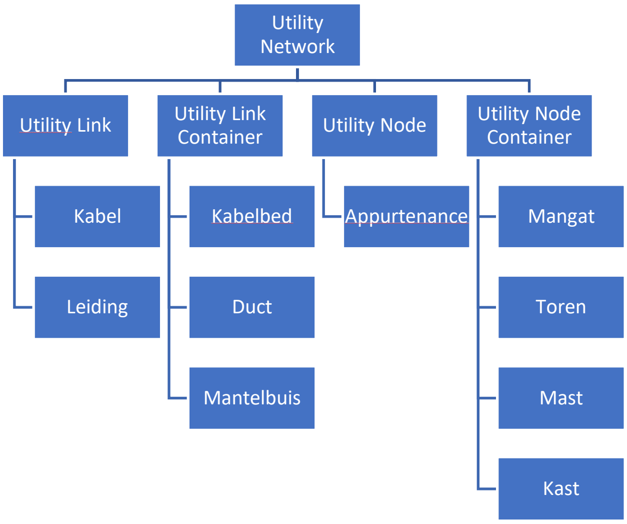
Na het beantwoorden van de open vragen, stelt Gerben nogmaals de vraag, maar nu met in literatuur gevonden 3D model toepassingen. Op basis van de gegeven antwoorden van de geïnterviewde is onderstaand tabel ingevuld (Engels).

Theme	Application	Made use of?
Photorealistic renderings	Improved communication	Yes
Virtual design review	Meeting codes and standard	No, but could be nice
	Clash detection	Yes
	Understanding spatial complexity	Yes
Cost estimating	5D, Bill of quantities	No
Analysing design options/ building operations	Design analysis of alternatives	Yes
	Design simulations	No
Analysing construction operations	4D, Sequencing, etc	No

Specificatie 3D Model Elementen

Gerben introduceert het tweede thema van deze sessie. Daarnaast wordt er expliciet uitgelegd wat er met de termen 'specificatie' en '3D Model Elementen' wordt bedoeld.

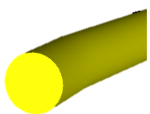
Gerben legt uit dat tijdens het bespreken van de specificering van de verschillende elementen wordt gebruik gemaakt van een generalisatie/abstractie van de netwerk elementen om zodoende alle elementen te omvatten. Het maakt gebruik van 4 categorieën: Utility Link, Utility Link Container, Utility Node en Utility Node Container. Gerben legt uit dat de specificatie per categorie besproken zal worden.



Geometrie

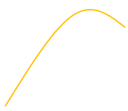
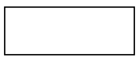
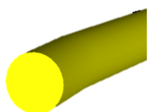
De resultaten van de discussie van de geometrische specificatie zijn na het diagram weergegeven per categorie inclusief de belangrijkste punten.

- Utility Link

Geometry representation	Line	Outer dimensions	Exact geometry
Example			

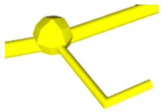
De geïnterviewde geeft aan dat de exacte geometrie (inclusief diktes verschillende lagen, bijv. leiding en isolatie) niet heel relevant zijn; ruimtebeslag is essentieel.

- Utility Link Container

Geometry representation	Line	Footprint	Outer dimensions	Exact geometry
Example				

De geïnterviewde geeft aan dat hier hetzelfde voor geldt als bij *Utility Link.*

- Utility Node

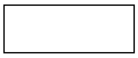
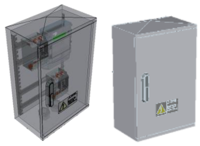
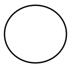
Geometry representation	Node/ Symbol	Sphere	Area reservation	Outer dimensions	Exact geometry
Example – valve					

De geïnterviewde geeft aan dat het afhankelijk is per element, maar dat zijn voorkeur uitgaat naar een modellering waarin de omvang van het element duidelijk wordt. '*Voor een afsluiter bijvoorbeeld; dan is het handig om de (opbouw)hoogte van de kop te weten zodat deze niet boven het maaiveld uit gaat steken. De huidige vormgeving met draaiwiel is niet nodig, maar zolang de opbouwhoogte zichtbaar is, bijvoorbeeld d.m.v. het schematisch modelleren via een cilinder.'*

N.a.v. deze suggestie is een extra modelleervorm toegevoegd aan het tabel en betiteld als 'Area reservation'.

De geïnterviewde stipt aan dat in geval van nieuw te leggen elementen t.b.v. verbindingen/aansluitingen het relevant is om de exacte buitenafmetingen te modelleren aangezien dat heel veel inzicht geeft in het ontwerp.

- Utility Node Container

Geometry representation	Node/ Symbol	Footprint	Area reservation	Outer dimensions	Exact geometry
Example #1 – Electricity cabinet					
Example #2 – Manhole	•				

De geïnterviewde stipt nogmaals het belang van de buiten afmetingen aan, ook in het geval van deze categorie elementen. *'Ik ben meer geïnteresseerd in de globale afmetingen dan de exacte geometrie.'*

De geïnterviewde geeft aan dat hij van het gepresenteerde modelleeroverzicht een specificatie mist welke de globale afmetingen weergeeft wat als het ware een blokkenmodel inhoudt.

N.a.v. deze suggestie zijn beide voorbeelden uitgewerkt conform beschrijving en is toegevoegd aan het tabel en betiteld als 'Area reservation'.

Attribuut data

Gerben (her)introduceert het tweede aspect van de specificatie van model elementen. Hij legt uit dat attribuut data erg alomvattend kan zijn en dat er in feite geen beperkingen zijn in het toevoegen van informatie aan het model, maar dat dit meer draait om de relevantie ervan.

Gerben legt uit dat in het onderzoek gebruik wordt gemaakt van een product attribuut classificatie om grip te krijgen op de alomvattendheid. Gerben legt elke categorie uit en geeft enkele voorbeelden. Hieronder zijn de categorieën van product attributen welke gebaseerd is op (El-Diraby & Osman, 2011) *weergegeven (in het Engels):*

1. *Dimensional attributes*
2. *Spatial attributes*
3. *Material attributes*
4. *Shape attributes*
5. *Cost attributes*
6. *Performance attributes*

7. *Surrounding soil attributes*
8. *Dependency attributes*
9. *Redundancy attributes*
10. *State of operation attributes*
11. *Impact attributes*
12. *Actor attributes*
13. *Use attributes*
14. *Survey attributes*

Hierna legt Gerben uit dat hij de input van de geïnterviewde over de relevantie van de attribuut data zou willen ontvangen via een voorbereid Excel-bestand. Gerben ligt hierbij het Excel-bestand toe en de verwachtingen hierbij. Aan het einde van de afspraak stuurt Gerben het bestand naar de geïnterviewde op.

Tijdens de bespreking heeft de geïnterviewde verschillende overige punten aangestipt omtrent het 3D model. Deze zijn hieronder samengevat:

- Ruimte inname is een van de belangrijkste punten;
- Punten van attentie binnen een project dienen duidelijk in het oog te springen in het 3D model. Bijvoorbeeld wanneer leidingen aanwezig zijn gemaakt van asbestcement welke gevaarlijk zijn voor de uitvoerders hun gezondheid en hier in het ontwerp ook rekening mee kan worden gehouden;
- Dezelfde kleurcodes dienen gebruikt worden als wordt gehanteerd in de KLIC;
- Het toevoegen van proefsleuven in 3D zijn van toegevoegde waarde om daarna de KLIC op exacte hoogte te plaatsen;
- De modellering van de elementen is vanuit het perspectief van de geïnterviewde onafhankelijk van de projectontwerpen (schetsontwerp (SO), voorlopig ontwerp (VO) en definitief ontwerp (VO)). In alle gevallen is ruimte inname het grootste belang.
- Het maaiveld (inclusief hoogte) is erg van belang en dient te worden toegevoegd in het 3D model.

J.3. Stedin

Datum: 01-09-2021

Aanwezigen:

Naam	Organisatie	Rol
Gerben Wolf	Universiteit Twente, Siers Infraconsult BV	Student; uitvoerder onderzoek
Geïnterviewde	Stedin	Tracé engineer elektriciteit

Voordat de inhoudelijke sparsessie aanvangt, stellen beide aanwezigen zich kort voor.

Gerben opent de sparsessie door een korte uitleg te geven over zijn onderzoek. Hieronder licht hij het volgende toe:

- *Voordelen 3D modellering*
- *Aanleiding onderzoek*
- *Scope onderzoek*
- *Uitkomst onderzoek*
- *Plan van aanpak*
- *Doel van sparsessie*

Doelen en gebruik 3D model:

Gerben introduceert het eerste thema van deze sessie en stelt open vragen aangaande het gewenste moment van oplevering van een 3D model en het achterliggende doel.

De geïnterviewde geeft aan dat in essentie het 3D model draait om de identificatie van lege ondergrond ten behoeve van de inpassing van het nieuw te leggen netwerk, met name in drukke stedelijke gebieden.

Daarnaast kan een 3D model ook nuttig zijn voor de communicatie richting de stakeholders. Visualisatie ondersteunt hierin enorm.

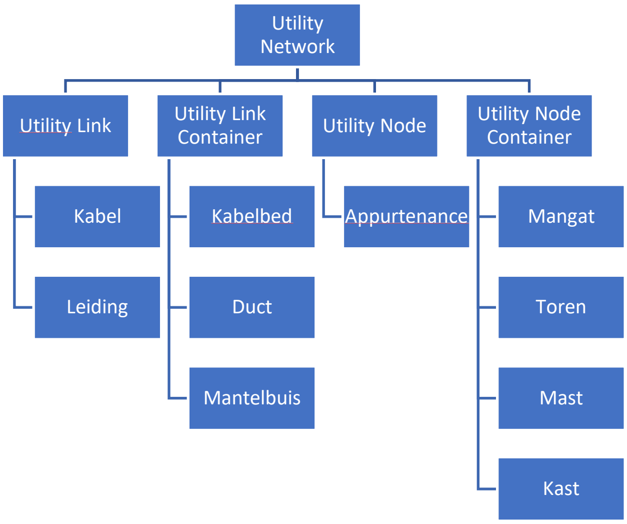
Na het beantwoorden van de open vragen, stelt Gerben nogmaals de vraag, maar nu met in literatuur gevonden 3D model toepassingen. Op basis van de gegeven antwoorden van de geïnterviewde is onderstaand tabel ingevuld (Engels).

Theme	Application	Made use of?
Photorealistic renderings	Improved communication	Yes
Virtual design review	Meeting codes and standard	Could be nice in future
	Clash detection	Yes
	Understanding spatial complexity	Yes
Cost estimating	5D, Bill of quantities	No, but could be nice in future for financial department
Analysing design options/ building operations	Design analysis of alternatives	Yes
	Design simulations	No
Analysing construction operations	4D, Sequencing, etc	No, but could be nice for future for other departments

Specificatie 3D Model Elementen

Gerben introduceert het tweede thema van deze sessie. Daarnaast wordt er expliciet uitgelegd wat er met de termen 'specificatie' en '3D Model Elementen' wordt bedoeld.

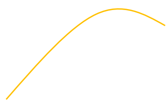
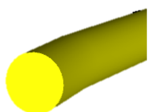
Gerben legt uit dat tijdens het bespreken van de specificering van de verschillende elementen wordt gebruik gemaakt van een generalisatie/abstractie van de netwerk elementen om zodoende alle elementen te omvatten. Het maakt gebruik van 4 categorieën: Utility Link, Utility Link Container, Utility Node en Utility Node Container. Gerben legt uit dat de specificatie per categorie besproken zal worden.



Geometrie

De resultaten van de discussie van de geometrische specificatie zijn na het diagram weergegeven per categorie inclusief de belangrijkste punten.

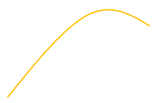
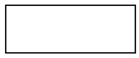
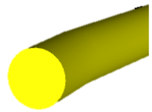
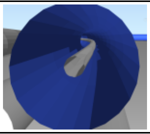
- Utility Link

Geometry representation	Line	Outer dimensions	Exact geometry
Example			

De geïnterviewde legt uit dat bij engineering van elektriciteitsnet de buiten diameter het belangrijkste is. Hierin zou nagedacht kunnen worden om hiervoor een standaardwaarde te hanteren aangezien er nauwelijks verschil zit tussen een 53, 55 en 58 millimeter.

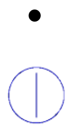
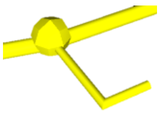
- Utility Link Container

Geometry representation	Line	Footprint	Outer dimensions	Exact geometry

Example				

De geïnterviewde geeft aan dat voor deze elementen de buitenafmetingen het belangrijkste zijn, maar dat de binnendiameter ook interessant kan zijn aangezien er dan bepaald kan worden of er nog ruimte is in bijvoorbeeld een mantelbuis.

- Utility Node

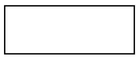
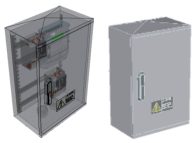
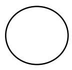
Geometry representation	Node/ Symbol	Sphere	Area reservation	Outer dimensions	Exact geometry
Example – valve					

De geïnterviewde geeft aan dat het afhankelijk is van de situatie en de hierbij aanwezige elementen. De geïnterviewde legt uit dat wanneer er veel op één plek ligt dat het nuttig is om de buitenafmetingen te weten aangezien de ruimte dan schaars wordt. Wanneer er sprake is van een relatief rustig gebied in de ondergrond kan een dergelijke bol voldoende zijn.

De geïnterviewde benadrukt dat het in essentie draait om de ruimte inname: *'Vanuit onderhoudsoogpunt is het wel van belang dat de data achter het element goed op orde is, dus precies weten waar welk element zit met welke eigenschappen, zodat er snel gehandeld kan worden. Qua geometrie hoeft dit niet inclusief alle toeters en bellen gemodelleerd te zijn.'*

Afhankelijk van de situatie zouden dus alle vierde opties (*sphere, area reservation, outer dimensions* en *exact geometry,* red.) gebruikt kunnen worden.

- Utility Node Container

Geometry representation	Node/ Symbol	Footprint	Area reservation	Outer dimensions	Exact geometry
Example #1 – Electricity cabinet					
Example #2 – Manhole	●				

De geïnterviewde stipt nogmaals het belang van de buiten afmetingen aan (lengte x breedte x hoogte). Ook geeft hij aan dat het aanzien van deze elementen interessant is voor de vergunningaanvragen. *'Het gaat mij niet zo zeer om wat er exact in zit, maar wel hoe de buitenkant eruit ziet zodat de inpassing in het stadsbeeld ook duidelijk wordt.'*

Attribuut data

Gerben (her)introduceert het tweede aspect van de specificatie van model elementen. Hij legt uit dat attribuut data erg alomvattend kan zijn en dat er in feite geen beperkingen zijn in het toevoegen van informatie aan het model, maar dat dit meer draait om de relevantie ervan.

Gerben legt uit dat in het onderzoek gebruik wordt gemaakt van een product attribuut classificatie om grip te krijgen op de alomvattendheid. Gerben legt elke categorie uit en geeft enkele voorbeelden. Hieronder zijn de categorieën van product attributen welke gebaseerd is op (El-Diraby & Osman, 2011) *weergegeven (in het Engels):*

1. *Dimensional attributes*
2. *Spatial attributes*
3. *Material attributes*
4. *Shape attributes*
5. *Cost attributes*
6. *Performance attributes*
7. *Surrounding soil attributes*
8. *Dependency attributes*
9. *Redundancy attributes*
10. *State of operation attributes*
11. *Impact attributes*
12. *Actor attributes*
13. *Use attributes*
14. *Survey attributes*

Hierna legt Gerben uit dat hij de input van de geïnterviewde over de relevantie van de attribuut data zou willen ontvangen via een voorbereid Excel-bestand. Gerben ligt hierbij het Excel-bestand toe en de verwachtingen hierbij. Aan het einde van de afspraak stuurt Gerben het bestand naar de geïnterviewde op.

Tijdens de bespreking heeft de geïnterviewde verschillende overige punten aangestipt omtrent het 3D model. Deze zijn hieronder samengevat:

- Voor Stedin is de bovengrond net zo belangrijk als de ondergrond. In de toekomst kan dit ook belangrijker worden m.h.o.o. beïnvloeding van stakeholders en de eisen die zij stellen.
- Bij de modellering van de elementen in het 3D model is het gewenst om dezelfde kleurencodes aan te houden zoals dat momenteel bij 2D tekeningen in de sector gebeurd (NLCS).
- Betreffende aansluitingen en verbindingen is het met name van belang dat de achterliggende (attribuut)data kloppend is zodat de materiaallijst volledig is en je doeltreffende onderhoud kan uitvoeren. De geometrie hoeft daarmee niet een werkelijke presentatie te zijn.
- Er zit verschil in de modellering van de KLIC en het nieuw te leggen netwerk. Over het algemeen, is het praktisch om de KLIC relatief abstract te blijven modelleren en het nieuw te leggen netwerk met meer detail. Hiermee blijft de bestandsgrootte ook beperkt.
- De huidige manier van fasering/opleveringen binnen een project (studiefase, voorontwerp (VO), definitief ontwerp (DO)) is verwacht niet te veranderen met de invoeging van 3D modellen. Een mogelijkheid hierin is ook om de nieuw te leggen elementen in de studiefase en het VO relatief abstract te houden en deze in het DO van meer detail te voorzien.

J.4. Siers Leiding & Montage B.V.

Datum: 07-10-2021

Aanwezigen

Naam	Organisatie	Rol
Gerben Wolf	Universiteit Twente, Siers Infraconsult BV	Student; uitvoerder onderzoek
Geïnterviewde	Siers Leiding & Montage BV	Uitvoerder; tussenpersoon engineer en uitvoerders

Voordat de inhoudelijke sparsessie aanvangt, stellen beide aanwezigen zich kort voor.

Gerben opent de sparsessie door een korte uitleg te geven over zijn onderzoek. Hieronder licht hij het volgende toe:

- *Voordelen 3D modellering;*

- *Aanleiding onderzoek;*
- *Scope onderzoek;*
- *Uitkomst onderzoek;*
- *Plan van aanpak;*
- *Doel van sparsessie.*

Doelen en gebruik 3D model:

Gerben introduceert het eerste thema van deze sessie en stelt open vragen aangaande het doel en gebruik van een 3D model vanuit het uitvoerdersperspectief.

De geïnterviewde geeft aan dat het voor de uitvoering met name gaat om grip te krijgen op de indeling van de ondergrond met het oog op de werkzaamheden die zij moeten uitvoeren. Een 3D model vermakkelijkt de communicatie op de werkvloer van de aanwezige objecten en identificatie van mogelijke pijnpunten. Visualisatie ondersteunt hierin enorm.

Soms is het erg lastig om de details van 2D tekeningen af te lezen; uit ervaring spreek ik dat dit met 3D veel makkelijker én sneller is. Ook met het oog op de coördinatie met andere disciplines in de ondergrond biedt een 3D model voordelen.

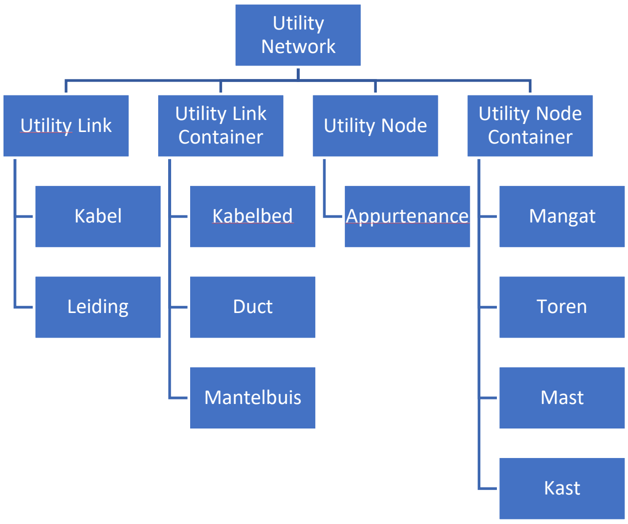
Na het beantwoorden van de open vragen, stelt Gerben nogmaals de vraag, maar nu met in literatuur gevonden 3D model toepassingen. Deze toepassingen zijn met name gericht op het ontwerpproces en kent slechts enkele welke gelden voor tijdens de constructie. Op basis van de gegeven antwoorden van de geïnterviewde is onderstaand tabel ingevuld (Engels). De toepassingen waar de geïnterviewde geen direct voordeel uithaalt (ontwerpproces) zijn aangegeven als niet van toepassing (n/a; not applicable)

Theme	Application	Made use of?
Photorealistic renderings	Improved communication	Yes
Virtual design review	Meeting codes and standard	n/a
	Clash detection	n/a
	Understanding spatial complexity	Yes
Cost estimating	5D, Bill of quantities	n/a
Analysing design options/ building operations	Design analysis of alternatives	n/a
	Design simulations	n/a
Analysing construction operations	4D, Sequencing, etc	n/a

Specificatie 3D model elementen

Gerben introduceert het tweede thema van deze sessie. Daarnaast wordt er expliciet uitgelegd wat er met de termen 'specificatie' en '3D model elementen' wordt bedoeld. Gerben ligt toe dat hij gedurende deze sessie beide aspecten van de specificatie los van elkaar wil behandelen (geometrie en attribuut data).

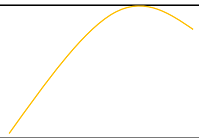
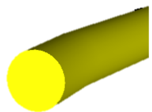
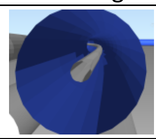
Gerben legt uit dat tijdens het bespreken van de specificering van de verschillende elementen wordt gebruik gemaakt van een generalisatie/abstractie van de netwerk elementen om zodoende alle elementen te omvatten. Het maakt gebruik van 4 categorieën: Utility Link, Utility Link Container, Utility Node en Utility Node Container. Gerben legt uit dat de specificatie per categorie besproken zal worden..



Geometrie

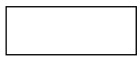
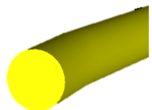
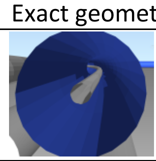
De resultaten van de discussie van de geometrische specificatie zijn na het diagram weergegeven per categorie inclusief de belangrijkste punten

- Utility Link

Geometry representation	Line	Outer dimensions	Exact geometry
Example			

De geïnterviewde legt uit dat de uitvoerders niet met teveel detail en informatie overspoeld moeten worden. Daarom is de modellering van de buitenste afmetingen hierin voldoende; de kabel/leiding hoeft niet laagje voor laagje weergegeven te zijn, zolang maar duidelijk is wat het gemodelleerde voor moet stellen.

- Utility Link Container

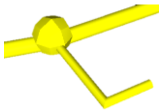
Geometry representation	Line	Footprint	Outer dimensions	Exact geometry
Example				

De geïnterviewde geeft aan dat hierin onderscheid kan worden gemaakt in hoe de elementen gebruikt worden in het project. Indien de Utility Link Container gebruikt wordt in het ontwerp van het aan te leggen netwerk kan het nuttig zijn om de exacte geometrie en opbouw van dit element te weten (bijvoorbeeld hoeveel en waar kabels/leidingen in de Utility Link Container aanwezig zijn). Hierbij vraagt de geïnterviewde zich nog steeds af in hoeverre dit van toegevoegde waarde is voor de uitvoerder. De geïnterviewde geeft aan het ook mogelijk is dat de opbouw van het element in een bijlage aan het element kan worden toegevoegd terwijl alleen de buitenafmetingen zijn gemodelleerd.

Indien de Utility Link Container enkel aanwezig is in de ondergrond, maar niet gebruikt wordt in het aan te leggen netwerk, is een representatie van de buitenafmetingen voldoende. Hierin draait het met name om de lokalisatie en ruimte inname van het element. Ofwel, het model element wordt gebruikt ter coördinatie van de ondergrond.

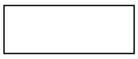
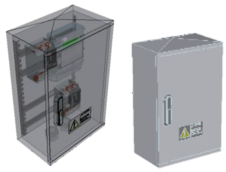
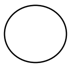
Daarnaast stipt de geïnterviewde aan dat in de huidige 2D modellering van kabelbedden er vaak vraagtekens zijn in de uitvoering. Momenteel worden kabelbedden in 2D weergegeven met een lijn, maar in feite zijn het meerdere verbindingen naast elkaar welke wel 1,5 meter breed en 40 centimeter hoog kunnen zijn. Daarom zou een vlak representatie of een representatie van de buitenafmetingen uitkomst bieden met het oog op de ruimte inname. De kabels hoeven dus niet apart gemodelleerd te worden.

- Utility Node

Geometry representation	Node/ Symbol	Sphere	Area reservation	Outer dimensions	Exact geometry
Example – valve					

De geïnterviewde geeft aan dat voor de uitvoering de ruimte inname al voldoende is. Voor de exacte engineering is echter de exacte geometrie, of buiten dimensies, wél van belang met name met het oog op het ontwerp en de communicatie naar actoren. Een uitvoerder weet daarentegen echt wel hoe een afsluiter eruit ziet.

- Utility Node Container

Geometry representation	Node/ Symbol	Footprint	Area reservation	Outer dimensions	Exact geometry
Example #1 – Electricity cabinet					
Example #2 – Manhole	•				

De geïnterviewde geeft aan dat dit in dezelfde lijn zit als de vorige categorie elementen. Het hangt van de gebruiker van het model af hoeveel detail er toegevoegd moet worden. Een uitvoerder hoeft niet alle exacte details te zien, maar heeft met een footprint of ruimte inname voldoende indicatie van de geometrie. Andere actoren hebben mogelijk geen parate kennis van hoe een dergelijk element er in werkelijkheid uit ziet.

Na het bespreken van de verschillende typen elementen in een netwerk, vraagt Gerben of er nog andere specifieke punten zijn binnen het 3D model betreffende de geometrie. Hierbij noemde de geïnterviewde de volgende punten:

- De aansluitingen worden momenteel niet geometrisch gerepresenteerd in modellen of tekeningen, maar als separate bijlage toegevoegd. Daarom stelt de geïnterviewde: *"Aansluitingen zijn het ondergeschoven kindje binnen de KLIC"*. Volgens de geïnterviewde zijn de meeste graafschadegevallen ook bij aansluitingen en daarom zou het erg nuttig zijn om deze ook weer te geven. Een andere optie is om een simpel blok te modelleren (niet geometrisch representatief) waarbij deze separate bijlagen aan zijn toegevoegd.
- Ook al is het buiten de scope van het onderzoek; uitvoerders krijgen vooral ook met de bovengrond te maken. Bijvoorbeeld, bij het graven van proefsleuven kunnen bovengrondse objecten belemmerend zijn in het graafproces. Denk aan een bankje, een openbaar vervoer-mast etc. Meestal komen de uitvoerders hier ter plekke achter, maar zouden dit graag van tevoren willen weten. Een indicatie van aanwezigheid en hoe dit zich verhoudt tot de sleuf is hierin voldoende. Ook de mogelijkheid tot het dumpen van het gegraven zand is soms een issue. Dat zijn praktische struikelpunten waar een engineer nog wel eens overheen kijkt.

Attribuut data

Gerben (her)introduceert het tweede aspect van de specificatie van model elementen. Hij legt uit dat attribuut data erg alomvattend kan zijn en dat er in feite geen beperkingen zijn in het toevoegen van informatie aan het model, maar dat dit meer draait om de relevantie ervan.

Gerben legt uit dat in het onderzoek gebruik wordt gemaakt van een product attribuut classificatie om grip te krijgen op de alomvattendheid. Gerben legt elke categorie uit en geeft enkele voorbeelden. Hieronder is de categorieën van product attributen welke gebaseerd is op (El-Diraby & Osman, 2011) *weergegeven (in het Engels):*

1. *Dimensional attributes*
2. *Spatial attributes*
3. *Material attributes*
4. *Shape attributes*
5. *Cost attributes*
6. *Performance attributes*
7. *Surrounding soil attributes*
8. *Dependency attributes*
9. *Redundancy attributes*
10. *State of operation attributes*
11. *Impact attributes*
12. *Actor attributes*
13. *Use attributes*
14. *Survey attributes*

Voordat de attribuut data per type element wordt besproken, stelt Gerben enkele algemene open vragen. Door tijdgebrek is dit echter slechts beperkt besproken. Hieronder zijn de uitkomsten die wel besproken zijn opgesomd:

- Kosten zijn niet interessant; het maakt niet uit of iets in gebruik is, maar wel waar het ligt.
- (Contact)informatie over actoren zoals eigenaren is wel van belang in het geval van schade.
- Informatie over de omliggende grond is in sommige gevallen ook gewenst; sommige kabels wordt in speciaal zand gelegd. Dit is echter wel projectafhankelijk.
- Afhankelijk van het project kan het ook nuttig zijn om additionele informatie (als bijlage) toe te voegen aan het 3D model. Voorbeeld is de eerder genoemde huisaansluiting, maar bijvoorbeeld ook detailtekeningen.
- Indien beschikbaar, is het nuttig om proefsleufdata binnen een projectgebied toe te voegen aan het 3D model om zo de juistheid van de locatie van de KLIC-data te checken.

Vanwege het tijdgebrek spreken Gerben en de geïnterviewde af dat Gerben de overige vragen per mail opstuurt en dat de geïnterviewde hier vervolgens op reageert.

Tijdens de bespreking heeft de geïnterviewde verschillende overige algemene punten aangestipt omtrent het 3D model. Deze zijn hieronder samengevat:

- De geïnterviewde geeft aan dat het 3D model niet te gedetailleerd aangeleverd moet worden. Dit maakt het 3D model onnodig te zwaar.
- De geïnterviewde kaart het menselijke aspect van de uitvoering aan. Er zijn relatief oude werknemers welke momenteel met veel ervaring de 2D tekeningen aanschouwen en in hun hoofd zelf omschakelen naar 3D. Zij zijn meestal wel inventief genoeg, maar dit leidt af en toe ook tot problemen.
- De beschikbaarheid en betrouwbaarheid van de (KLIC) data blijft een enorm punt van verbetering binnen de sector. Ook al is de informatie inbegrepen in het 3D model, bestaat er een kans dat deze informatie foutief is. Dit heeft dus ook invloed op de betrouwbaarheid van de 3D modellen.

Het interactieve karakter van een 3D model kan het proces van het opnemen van projectinformatie ondersteunen en versnellen doordat men in het 3D model kan navigeren en elementen kan aanklikken voor de desbetreffende informatie in plaats van losse bestanden en bijlagen.

J.5. Ennatuurlijk

Datum: 08-10-2021

Aanwezigen

Naam	Organisatie	Rol
Gerben Wolf	Universiteit Twente, Siers Infraconsult BV	Student; uitvoerder onderzoek
Geïnterviewde	Ennatuurlijk	Project engineer stadswarmte

Voordat de inhoudelijke sparsessie aanvangt, stellen beide aanwezigen zich kort voor.

Gerben opent de sparsessie door een korte uitleg te geven over zijn onderzoek. Hieronder licht hij het volgende toe:

- *Voordelen 3D modellering;*
- *Aanleiding onderzoek;*
- *Scope onderzoek;*
- *Uitkomst onderzoek;*
- *Plan van aanpak;*
- *Doel van sparsessie.*

Doelen en gebruik 3D model:

Gerben introduceert het eerste thema van deze sessie en stelt open vragen aangaande het doel en gebruik van een 3D model vanuit zijn perspectief als project engineer.

De geïnterviewde geeft aan dat dit tweeledig is. Allereerst wordt bij Ennatuurlijk 3D nu al gebruikt in gebouwen voor bijvoorbeeld de locatie van de meterkast, maar dit zouden zij idealiter ook willen zien voor de ondergrond. Dit met het voornaamste doel om inzicht te krijgen in de ondergrond; waar moeten zij rekening mee houden en welke objecten moeten ze kruizen in het ontwerp? 3D is hierin veel beter te begrijpen dan 2D. Dit geldt overigens ook voor ondergrondse objecten anders dan kabels en leidingen zoals containers en boomwortels.

Ten tweede is de koppeling met de bovengrond in 3D van uiterste belang i.v.m. de praktische zaken van het project. Als voorbeeld noemt de geïnterviewde netwerkaansluitingen met de bovengrond of gebouwen; deze koppeling is momenteel nog een grijs gebied waardoor men automatisch terugkeert naar 2D.

Daarnaast geeft de geïnterviewde aan dat 3D ook een voordeel is i.c.m. gestuurde boringen en sleufloze technieken.

Na het beantwoorden van de open vragen, stelt Gerben nogmaals de vraag, maar nu met in literatuur gevonden 3D model toepassingen. Deze toepassingen zijn met name gericht op het ontwerp- en constructieproces. Op basis van de gegeven antwoorden van de geïnterviewde is onderstaand tabel ingevuld (Engels).

Theme	Application	Made use of?
Photorealistic renderings	Improved communication	Yes
Virtual design review	Meeting codes and standards	Potentially, but keep it limited
	Clash detection	Yes
	Understanding spatial complexity	Yes
Cost estimating	5D, Bill of quantities	Not directly
Analysing design options/ building operations	Design analysis of alternatives	Yes
	Design simulations	Not used, but could be supportive
Analysing construction operations	4D, Sequencing, etc	Not used, but interesting i.r.t. environmental management

Bij het bespreken van de eerste toepassing *'Improved communication'* zegt de geïnterviewde het volgende: *"Het gezegde 'Beelden spreken meer dan woorden' is hier echt wel van toepassing. Het maakt het vele malen makkelijker om discussie te voeren over iets wat je ziet en weet. Het jargon van de betrokkenen tijdens een project zit meestal verschil in en 3D schetst hierin eenduidig een beeld."*

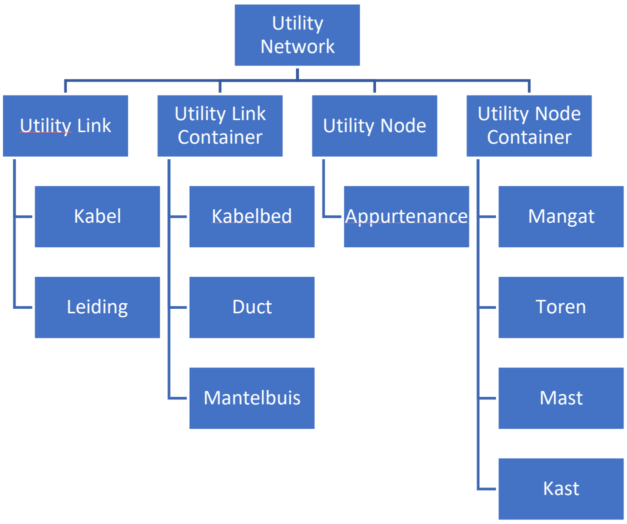
Bij de toepassing *'Meeting codes and standards'* geeft de geïnterviewde aan dat dit veel potentie heeft, maar dat dit niet te uitgebreid behandeld dient te worden aangezien het model dan veel te complex wordt. Indien dit tot de belangrijkste regels kan worden gehouden kan dit tijdens de ontwerpfase een voordeel zijn.

Bij de toepassing over de kosten beraming legt de geïnterviewde uit dat dit met name indirect zal zijn. De kosten zullen niet linea recta uit het model gehaald worden via een materiaallijst, maar het opstellen van een 3D model helpt wel enorm bij het beter inzicht krijgen in waar de kosten vandaan komen en de mate hiervan.

Specificatie 3D model elementen

Gerben introduceert het tweede thema van deze sessie. Daarnaast wordt er expliciet uitgelegd wat er met de termen 'specificatie' en '3D model elementen' wordt bedoeld. Gerben ligt toe dat hij gedurende deze sessie beide aspecten van de specificatie los van elkaar wil behandelen (geometrie en attribuut data).

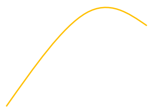
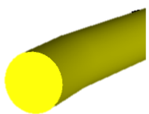
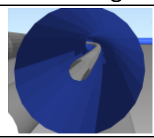
Gerben legt uit dat tijdens het bespreken van de specificering van de verschillende elementen wordt gebruik gemaakt van een generalisatie/abstractie van de netwerk elementen om zodoende alle elementen te omvatten. Het maakt gebruik van 4 categorieën: Utility Link, Utility Link Container, Utility Node en Utility Node Container. Gerben legt uit dat de specificatie per categorie besproken zal worden..



Geometrie

De resultaten van de discussie van de geometrische specificatie zijn na het diagram weergegeven per categorie inclusief de belangrijkste punten

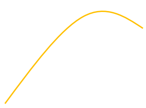
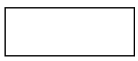
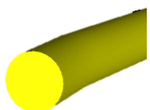
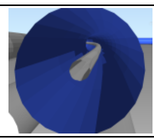
- Utility Link

Geometry representation	Line	Outer dimensions	Exact geometry
Example			

De geïnterviewde zegt dat er allereerst hier een verschil zit in de bestaande infrastructuur en het nieuw te leggen net. Voor de bestaande infrastructuur is de weergave van de buitendiameter voldoende aangezien het hier met name draait om de identificatie van de beschikbare ruimte voor het nieuwe tracé. In essentie geldt dit ook voor het nieuwe tracé, maar deze kan gedetailleerder worden gemaakt wanneer dit nodig blijkt; dat is afhankelijk van de situatie.

De geïnterviewde geeft aan dat dit parallel loopt aan de ontwerptekeningen (SO, VO, DO). Voor een SO is de modellering van enkel de buitendiameter al voldoende. Voor VO geldt niet wellicht ook nog wel, maar kan er extra informatie bij worden gevoegd en voor DO zou de modellering van de exacte geometrie passend zijn. Hier kan dan in detail worden laten zien hoe het definitieve tracé ontwerp er daadwerkelijk uitziet en zich oriënteert in de omgeving. Als voorbeelden noemt de geïnterviewde dat je o.b.v. het 3D model dan kan zien hoe de verschillende componenten zicht tot elkaar verhouden en waar laspunten aanwezig zijn. Het is dus meer een algemeen punt dan specifiek op dit type element gericht.

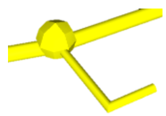
- Utility Link Container

Geometry representation	Line	Footprint	Outer dimensions	Exact geometry
Example				

De geïnterviewde geeft aan dat hij het kabelbed graag de buitendimensies wil zien, dus als een vlak of rechthoekig blok. De exacte geometrie is voor een inpassingsproject van stadswarmte niet relevant.

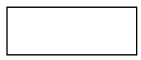
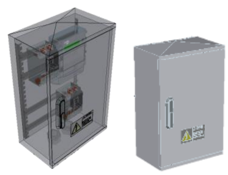
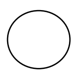
Betreffende de overige twee elementen, mantelbuis en duct, zegt de geïnterviewde dat het voor het ontwerpproces vooral nuttig is om te weten of er nog beschikbare ruimte is om door het element heen te gaan. Op deze manier kan een engineer bepalen of dit element gebruikt kan worden voor het nieuw te leggen netwerk.

- Utility Node

Geometry representation	Node/ Symbol	Sphere	Area reservation	Outer dimensions	Exact geometry
Example – valve					

De geïnterviewde geeft aan dat dit in lijn met is het vorige gezegde: bij het opvragen van de KLIC is een bol in eerste instantie wel voldoende, maar wanneer hij naar een verdere uitwerking zoals het DO wil gaan dat dan de modellering van de exacte geometrie de voorkeur heeft.

- Utility Node Container

Geometry representation	Node/ Symbol	Footprint	Area reservation	Outer dimensions	Exact geometry
Example #1 – Electricity cabinet					
Example #2 – Manhole					

De geïnterviewde geeft aan dat het voor deze objecten vooral interessant is om de area reservation, al dan niet de buitendimensies, te zien. Dit vooral i.c.m. de coördinatie van de bovengrond tijdens de werkzaamheden.

Daarnaast zeg de geïnterviewde dat de exacte geometrie interessant kan zijn wanneer de koppeling met het ondergrondse net wordt gemaakt. Dit geldt alleen voor de elementen waar deze koppeling mee wordt gemaakt. Dergelijke elementen welke wel in het projectgebied aanwezig zijn, maar niet gebruikt worden kunnen op de hiervoor besproken manier gemodelleerd worden.

Na het bespreken van de verschillende typen elementen in een netwerk, vraagt Gerben of er nog andere specifieke punten zijn binnen het 3D model betreffende de geometrie. Hierbij noemde de geïnterviewde de volgende punten:

- Het is ook van belang de verbindingen van alle elementen weer te geven. Als voorbeeld noemt de geïnterviewde de laspunten tussen leidingen. Deze wordt momenteel wel ingemeten, maar het zou ook nuttig zijn om dit in het 3D model te kunnen zien; ook met het oog op onderhoud en beheer.

Attribuut data

Gerben (her)introduceert het tweede aspect van de specificatie van model elementen. Hij legt uit dat attribuut data erg alomvattend kan zijn en dat er in feite geen beperkingen zijn in het toevoegen van informatie aan het model, maar dat dit meer draait om de relevantie ervan.

Gerben legt uit dat in het onderzoek gebruik wordt gemaakt van een product attribuut classificatie om grip te krijgen op de alomvattendheid. Gerben legt elke categorie uit en geeft enkele voorbeelden. Hieronder is de categorieën van product attributen welke gebaseerd is op (El-Diraby & Osman, 2011) *weergegeven (in het Engels):*

1. *Dimensional attributes*
2. *Spatial attributes*
3. *Material attributes*
4. *Shape attributes*
5. *Cost attributes*
6. *Performance attributes*
7. *Surrounding soil attributes*
8. *Dependency attributes*
9. *Redundancy attributes*
10. *State of operation attributes*
11. *Impact attributes*
12. *Actor attributes*
13. *Use attributes*
14. *Survey attributes*

Vanwege het tijdgebrek spreken Gerben en de geïnterviewde af dat Gerben de vragen per mail opstuurt inclusief toelichting en dat de geïnterviewde hier vervolgens op reageert.

Tijdens de bespreking heeft de geïnterviewde verschillende overige algemene punten aangestipt omtrent het 3D model. Deze zijn hieronder samengevat:

- Ennatuurlijk maakt gebruik van de ontwerptekeningen zoals bekend in de sector: schets- (SO), voorlopig (VO) en definitief ontwerp (DO).
- Het is voor de sector interessant dat alle gegenereerde ondergrondse 3D modellen vanuit alle organisaties terecht komen in een centrale database zodat dit gecoördineerd kan worden naar andere partijen. Een beetje zoals momenteel met de 2D data wordt gedaan door de KLIC.
- De betrouwbaarheid van de data blijft een enorm twijfelpunt binnen de sector. Dit geldt al helemaal in gebieden welke geen stevige ondergrond hebben waardoor een netwerk kan gaan verschuiven in de ondergrond zonder dat men het doorheeft en ziet.

J.6. Siers Infraconsult B.V.

Datum: 14-10-2021

Aanwezigen

Naam	Organisatie	Rol
Gerben Wolf	Universiteit Twente, Siers Infraconsult BV	Student; uitvoerder onderzoek
Geïnterviewde	Siers Infraconsult BV	Team manager uitvoering stadswarmte; projectleider

Voordat de inhoudelijke sparsessie aanvangt, stellen beide aanwezigen zich kort voor.

De geïnterviewde geeft aan dat betreffende zijn rol als projectleider hij ook betrokken is bij het ontwerpproces voor de praktische knelpunten van het project. Hier draait het ook met name om de relatie met en de verandering in de omgeving.

Gerben opent de sparsessie door een korte uitleg te geven over zijn onderzoek. Hieronder licht hij het volgende toe:

- *Voordelen 3D modellering;*
- *Aanleiding onderzoek;*
- *Scope onderzoek;*
- *Uitkomst onderzoek;*
- *Plan van aanpak;*
- *Doel van sparsessie.*

Doelen en gebruik 3D model:

Gerben introduceert het eerste thema van deze sessie en stelt open vragen aangaande het doel en gebruik van een 3D model vanuit het uitvoerdersperspectief.

De geïnterviewde geeft aan dat voornamelijk clash detectie met de bestaande ondergrondse infra erg belangrijk is. Dit vooral om knelpunten tijdens de aanleg van een nieuw netwerk te voorkomen en vooraf te identificeren zoals aanvullende acties ondernomen kunnen worden.

Daarnaast stipt de geïnterviewde hierbij ook de financiële bewustwording aan. Voorafgaand aan elk project dienen er proefsleuven gegraven worden ter controle van de locatie van de KLIC elementen en ter indicatie van het project gebied. Daarnaast geeft een 3D model ook inzicht in het effect van de werkzaamheden op de bovengrond. Op deze manier kan er een beter inzicht worden verkregen over de gehele situatie en daarom kan er een betere schatting van de kosten worden gemaakt. Dit geldt zelfs al voor het opstellen van de offerte. Als voorbeeld geeft de geïnterviewde een situatie met een proefsleuf waarbij in de uitvoering leidingen met gevaarlijke vloeistof, het riool of een AC leiding vermeden moeten worden en welke aanvullende werkzaamheden hierdoor gedaan moeten worden.

Daarnaast geeft de geïnterviewde aan dat hij verwacht dat 3D modellen ook enorm kunnen helpen met het proces van dataverwerking. Momenteel gebeurt dit vrij separaat op verschillende plekken door verschillende personen. Hierin kunnen nog veel stappen gezet worden waar De geïnterviewde denk dat 3D modellering bij kan ondersteunen.

Na het beantwoorden van de open vragen, stelt Gerben nogmaals de vraag, maar nu met in literatuur gevonden 3D model toepassingen. Op basis van de gegeven antwoorden van de geïnterviewde is onderstaand tabel ingevuld (Engels).

Theme	Application	Made use of?
Photorealistic renderings	Improved communication	Yes
Virtual design review	Meeting codes and standards	No, but could be useful in specific cases
	Clash detection	Yes
	Understanding spatial complexity	Yes
Cost estimating	5D, Bill of quantities	No
Analysing design options/ building operations	Design analysis of alternatives	No
	Design simulations	No
Analysing construction operations	4D, Sequencing, etc	No, but could be useful in specific cases

Tijdens de bespreking van bovenstaand tabel gaf de geïnterviewde ook extra opmerkingen. Deze zijn hieronder weergegeven:

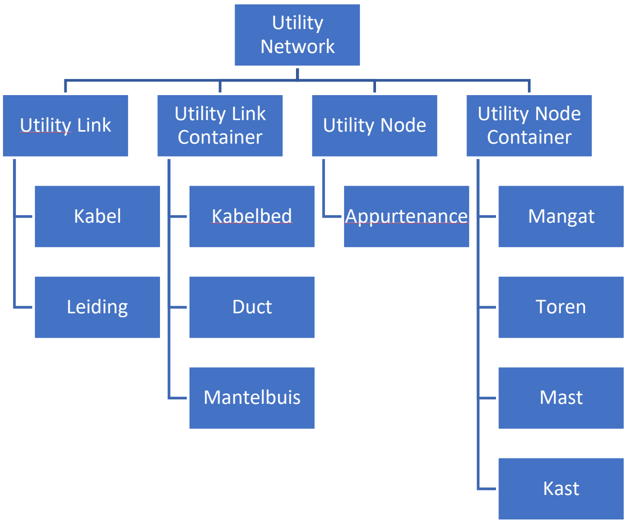
- 3D modellen zorgen voor verbeterde communicatie richting de gemeente tijdens vergunningsaanvragen zoals bijvoorbeeld betreffende de geldende regels en wetten;
- *'Meeting codes and standards'* wordt momenteel niet toegepast, maar kan in specifieke gevallen nuttig zijn om weer te geven, zoals de afstand tussen elementen. In principe geldt dit meer voor tijdens het ontwerpproces dan voor de uitvoering.
- Kostenschatting is voor de uitvoering zelf niet noodzakelijk, maar is voor Siers als organisatie wel erg interessant. Volgens de geïnterviewde zijn hier relatief makkelijk ook stappen in worden gezet.
- De omgeving van het tracé, ofwel de bovengrond, is voor de uitvoering net zo van belang als de ondergrond. Op basis hiervan kun je namelijk ook de uitvoerbaarheid controleren. Moeten er bomen gekapt worden; hoe ziet je bouwplaats eruit; waar zijn je rijstroken? Dat moet voorbereid worden en achteraf hersteld worden.

- Het toevoegen van het tijdaspect (4D) is vooral van toegevoegde waarde bij zwaar stedelijke gebieden waar veel stakeholders in het spel zijn en meerdere bouwactiviteiten in een klein gebied worden uitgevoerd. De geïnterviewde geeft ook aan dat veel stakeholders geen inzicht of gevoel hebben voor de omvang van een dergelijk project. Denk aan de duur van het project of de ruimte die nodig is voor de werkzaamheden. Door dit in 4D weer te geven creëer je meer inzicht en daarom ook meer begrip van de stakeholders.

Specificatie 3D model elementen

Gerben introduceert het tweede thema van deze sessie. Daarnaast wordt er expliciet uitgelegd wat er met de termen 'specificatie' en '3D model elementen' wordt bedoeld. Gerben ligt toe dat hij gedurende deze sessie beide aspecten van de specificatie los van elkaar wil behandelen (geometrie en attribuut data).

Gerben legt uit dat tijdens het bespreken van de specificering van de verschillende elementen wordt gebruik gemaakt van een generalisatie/abstractie van de netwerk elementen om zodoende alle elementen te omvatten. Het maakt gebruik van 4 categorieën: Utility Link, Utility Link Container, Utility Node en Utility Node Container. Gerben legt uit dat de specificatie per categorie besproken zal worden..

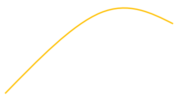
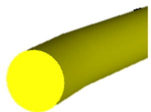
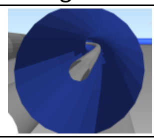


Geometrie

De resultaten van de discussie van de geometrische specificatie zijn na het diagram weergegeven per categorie inclusief de belangrijkste punten

Tijdens de bespreking van de geometrie geeft de geïnterviewde aan dat hij het lastig vindt om een concrete mening te vormen over de geometrie van de elementen aangezien hij hier nauwelijks ervaring mee heeft in 3D modellen.

- Utility Link

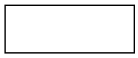
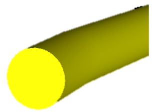
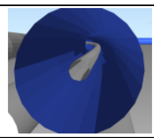
Geometry representation	Line	Outer dimensions	Exact geometry
Example			

De geïnterviewde geeft aan dat er tijdens een project verschil zit tussen deze elementen. Het ene deel van de elementen wordt alleen ter indicatie gebruikt met het oog op hun ligging en ruimte inname en het andere deel waar daadwerkelijk mee gewerkt wordt en waar actief rekening mee moet worden gehouden. Met dit laatste bedoelt de geïnterviewde de niet-flexibele nutsvoorzieningen zoals gas, water, of het riool. Een kabelbed van glasvezelkabels kan, als het om een paar cm gaan, altijd nog iets vertild worden zonder dat er schade wordt gemaakt.

Al met al komt het dus neer op dat voor het eerste deel is dus de *Outer dimensions* al voldoende en voor het tweede deel zou de exacte geometrie beter van toepassing zijn.

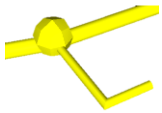
- Utility Link Container

Geometry representation	Line	Footprint	Outer dimensions	Exact geometry

Example				

De geïnterviewde legt uit dat dit wat hem betreft een twijfelgeval is tussen de *footprint* en de *outer dimensions*. Als voorbeeld geeft hij aan dat hij geen waarde hecht aan de exacte modellering van een glasvezelbox; tijdens de ontvoering moet ik alleen om dat element heen.

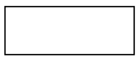
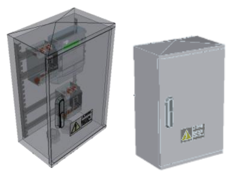
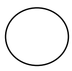
- Utility Node

Geometry representation	Node/ Symbol	Sphere	Area reservation	Outer dimensions	Exact geometry
Example – valve	• 				

De geïnterviewde geeft aan dat het hier met name gaat om de ruimte inname. De manier van weergave, een bol of ruimte inname, is afhankelijk van de daadwerkelijke omvang van het element. Wanneer het een relatief klein element is, zou een bol volstaan. Wanneer er sprake is van een vrij groot element wil je dat deze ingenomen ruimte ook wordt aangegeven, dus dan is *Area reservation* geschikter.

De toegevoegde waarde van de exacte geometrie ziet de geïnterviewde met name voor de inpandige werkzaamheden.

- Utility Node Container

Geometry representation	Node/ Symbol	Footprint	Area reservation	Outer dimensions	Exact geometry
Example #1 – Electricity cabinet					
Example #2 – Manhole	•				

De geïnterviewde legt uit dat dit in lijn is met de vorige categorieën, dus dat het hier de *Area reservation* en de *Outer dimensions* volstaat.

De modellering van de exacte geometrie is voor de stadswarmte niet direct belangrijk, maar kan voor elektriciteitsaansluitingen wel nuttig zijn.

Na het bespreken van de verschillende typen elementen in een netwerk, vraagt Gerben of er nog andere specifieke punten zijn binnen het 3D model betreffende de geometrie. Hierbij noemde de geïnterviewde de volgende punten:

- Bij de uitvoering is de betrouwbaarheid van de ligging van de elementen ook essentieel met het oog op het vooromen van graafschade.
- Na de constructie van het warmtenet wordt het net onder druk gezet waardoor de leidingen zullen gaan uitzetten. Met het oog op het ontwerp en de daadwerkelijke ruimte inname, is het interessant om dit ook mee te nemen in het 3D model. Nu gebeurt dit separaat.

- De elementen van een warmtenet worden verbonden d.m.v. lassen. Deze lassen worden vervolgens geïsoleerd met moffen. Deze kunnen om de leiding worden heen geklapt of worden op de leiding geschoven. Dit wil nog eens wat praktische knelpunten opleveren en dit zou voor de uitvoering ook nuttig zijn als dit ook in het 3D model wordt meegenomen zodat dit van tevoren gecontroleerd kan worden.
- In de beginfase van een project worden er ondergrondse knelpunten geïdentificeerd die gecontroleerd worden d.m.v. proefsleuven (door uitvoerders). Het is hierbij nuttig om de sleufbekisting aan te geven ter indicatie van de werkruimte. Op die manier kan vooraf al de uitvoerbaarheid worden bekeken.

Attribuut data

Gerben (her)introduceert het tweede aspect van de specificatie van model elementen. Hij legt uit dat attribuut data erg alomvattend kan zijn en dat er in feite geen beperkingen zijn in het toevoegen van informatie aan het model, maar dat dit meer draait om de relevantie ervan.

Gerben legt uit dat in het onderzoek gebruik wordt gemaakt van een product attribuut classificatie om grip te krijgen op de alomvattendheid. Gerben legt elke categorie uit en geeft enkele voorbeelden. Hieronder zijn de categorieën van product attributen welke gebaseerd is op (El-Diraby & Osman, 2011) *weergegeven (in het Engels):*

1. *Dimensional attributes*
2. *Spatial attributes*
3. *Material attributes*
4. *Shape attributes*
5. *Cost attributes*
6. *Performance attributes*
7. *Surrounding soil attributes*
8. *Dependency attributes*
9. *Redundancy attributes*
10. *State of operation attributes*
11. *Impact attributes*
12. *Actor attributes*
13. *Use attributes*
14. *Survey attributes*

Hierna legt Gerben uit dat hij de input van de geïnterviewde over de relevantie van de attribuut data zou willen ontvangen via een voorbereid Excel-bestand. Gerben ligt hierbij het Excel-bestand toe en de verwachtingen hierbij. Aan het einde van de afspraak stuurt Gerben het bestand naar de geïnterviewde op.

Tijdens de bespreking heeft de geïnterviewde verschillende overige algemene punten aangestipt omtrent het 3D model. Deze zijn hieronder samengevat:

- Tijdens de uitvoering moeten de uitvoerders extra opletten en rekening houden met bepaalde elementen of situaties. Dit wordt ook wel *Eis voorzorgsmaatregelen* genoemd. Aangezien dit erg belangrijk is, is het gewenst dat deze informatie ook in het 3D model zit en ook in het oog springt.
- Een 3D model biedt ook mogelijkheden in de vertaalslagen van engineering naar uitvoering naar het reviseren ervan. Het is dus niet alleen voor de visualisatie relevant, maar ook voor het verwerkingsproces.
- De geïnterviewde wordt al relatief vroeg wordt betrokken in het ontwerpproces van complexe, stedelijke projecten aangezien er proefsleuven voorafgaand aan ieder project gegraven moet worden om te knelpunten in de ondergrond te onderzoeken en verifiëren. Op dat moment zie ik ook de omgeving en kan ik al starten met verkeersplannen, bomen kappen, etc.

De geïnterviewde denkt dat 2D tekeningen zullen blijven bestaan, ook al worden de 3D modellen geavanceerder. Dit zit ingebakken bij de huidige uitvoerders die de exacte coördinaten en diepte aflezen van de tekeningen (zoals aangegeven met labels en tekst) en dan de activiteiten uitvoeren gaan. De geïnterviewde geeft wel aan dat hier mogelijkheden liggen om dit te vervangen in 3D modellen.