# Bachelor Graduation Assignment

Developing a framework of semiotics that support the drafting of construction process visualizations of subsurface utility projects.

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# Preface

This project is carried out as part of the graduation assignment from the bachelor's program in Civil Engineering offered by the University of Twente. The assignment is executed within Siers Infraconsult for approximately ten weeks in which the student, as the researcher, is expected to integrate, apply, and broaden knowledge in civil engineering, particularly in the subfield construction.

The development of this project would not have been possible without the support of the university and the host institution's staff. I wish to acknowledge the help provided by people working at Siers Infraconsult, the experts who participated in the workshops, and everyone who offered their valuable expertise. I want to extend my special thanks to the internal supervisor León olde Scholtenhuis and external supervisor Mechiel van Manen who guided me throughout this project and helped me finalize it. I would also like to thank my family and closest friends who supported me during my study. Finally, I want to acknowledge the Secretaría Nacional de Educación Superior, Ciencia, Tecnología e Innovación (SENESCYT) of Ecuador as the sponsor institution of my study.

## Summary

Visualization techniques such as spatial and spatiotemporal models have added several benefits to infrastructure projects' design and construction phases. The utility sector has also benefited from 2D and 3D spatial models. This has been covered by literature suggesting that prompt detection of conflicts and better communication and coordination among stakeholders is possible. Furthermore, spatial models can be linked to schedules to create 2D+time and 3D+time (4D models) construction process visualizations in which the construction activities are simulated over time. This allows to improve schedule compliance, support resource management, and better understand the construction plan.

Existing literature also suggests that less attention has been given to using visualization techniques in the subsurface utility sector compared to other construction fields. This is because most of the data of underground utility networks are documented in two-dimensional spatial models, for which transforming to three-dimensional models and subsequently linking them to schedules might result time-consuming and even difficult due to the scarcity of data such as pipes geometry and depths.

Usually, theories such as 4D models only contain the physical assets and building objects that can be recognized in the environment. Therefore, spatiotemporal visualizations are not used for project management purposes in utility projects due to the lack of elements representing objects other than the utility network components and existing infrastructure. To this, semiotics is suggested as the means to visualize elements to convey meaning and include physical and non-physical objects that support project management activities in the construction process.

Furthermore, literature and semiotics theory suggests a lack of a standardized way of representing elements, objects, and activities within construction process visualizations. This absence of guidelines can be filled by using existing semiotics classifications as starting point to develop applicable signs that can be used in construction process simulations. Yet, It is unclear to what extent the existing frameworks of semiotics can support the visualization of utility street works, given the different complexity, disciplines, and stakeholders involved in these kinds of projects.

In that context, this project aimed to develop a framework that contains descriptions and examples of commonly used semiotics to support and enhance the drafting of construction process visualizations of street works. This is achieved by first investigating the problem at a general level through literature review, to then determine the issue at a more specific level by analyzing the current situation at Siers Infraconsult, the host institution for this project, with regards to visualization techniques and types of projects carried out. This allowed gathering examples of semiotics that can be used to support project management in construction projects and utility street works. Besides, an initial framework structure was proposed, which, together with the examples from the literature, are used as input to propose semiotics that can be included in the framework.

In a first workshop, objects and activities that can be included in the traditional spatial models to create construction process visualization of utility street works were determined through expert opinion. Project Overtoom in Amersfoort served as a study case for which spatial visualization models and schedules were available, and an initial construction process visualization in 2D+time was developed. Participants in the workshop were consulted about objects and activities that could be added in the existing 2D models and schedules and were requested to document their ideas on semiotics under the proposed initial structure of the framework to subsequently share out and discuss the results in order to achieve consensus in the meaning and representation.

Results from Workshop 1 allowed to develop a framework structure in which the most relevant characteristics of the semiotics can be defined. These include a meaning of the object being visualized;

a presentation of how to visualize the object or activity in the construction process visualization; the type of sign used for the representation, which can be an icon, index, or symbol according to how they convey meaning. The temporal, physical, and geo-referential characteristics of de semiotics are also considered in the framework, as well as an illustrative example in which additional descriptions and situations in which the semiotic can be used are added. Finally, the framework allows categorizing semiotics as utility network components, spatial orientation elements, construction activities, working areas, construction components, utility service provision, work safety and traffic measures, and labels. Which, in turn, can be arranged into categories focused on informing field workers about the construction process and categories directed to informing people who live in the surroundings, clients, suppliers, and field workers.

The framework validation was performed in two sessions in which two study cases were employed. Project Overtoom in Amersfoort and project Bathmense Laden in Deventer. The goal was to empirically validate the designed framework through reflective dialogues with experts working in the design and execution phases of utility projects, so the framework can be used as a standard concept when developing construction process visualizations of future subsurface utility projects carried out by Siers Infraconsult. Five criteria were analyzed: completeness, understandability, representativeness, applicability, and flexibility. Each criterion was measured according to the responses given to a validation question that served to start the discussion. For every criterion, when participants behaved positively about the framework and construction process visualizations, it was suggested that the framework meets the criteria and hence the requirements.

Results from the validation workshops suggest that the framework of semiotics meets the validation criteria depending on the purpose of the construction process visualization in which they will be implemented. The goal can be to inform field workers or to inform citizens and clients about the process of a project. Besides, the results suggest that specific elements and activities of particular utility disciplines (e.g., data) might eventually have to be added to the framework when other study cases are considered.

Overall, the designed framework supports the drafting of construction process visualizations, categorizing the semiotics based on their characteristics, and including elements that support project management activities. However, the framework's performance is limited by its purpose and the availability of construction process visualizations of subsurface utility projects.

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# 1 Introduction

The increasing use of visualization modeling technologies within infrastructure projects has demonstrated benefits in a wide range of fields. By visualizing the end product and the process of constructing it in either two-dimensional or three-dimensional models, prompt detection of conflicts is possible, better communication and coordination among stakeholders [1][2][3], as well as constructability analysis [4]. In the attempt to better understand the sequential relation between activities, schedules are integrated into visualization models [5] to create 2D+time and 3D+time construction process visualizations in which the construction activities are simulated over time. Benefits are added by linking 2D and 3D spatial models to the planning. These include but are not limited to improved schedule compliance, resource management, and a better understanding of the construction plan [4].

Although the implementation of construction process visualization in small-scale projects has been limited, the subsurface utility sector can highly benefit from this technology, for example, by supporting life cycle management, understanding the complexity of the project and existing networks, identifying available space, and detecting physical conflicts and workspace constraints [3]. The elements constituting construction process visualizations, defined as semiotics or semiotic elements, are used to visualize contextual information of different construction activities. These elements have been classified in the literature depending on their meaning and what they aim to represent in icons, indexes, and symbols [6], which can be identified as transient or non-transient based on their temporal characteristics [4].

However, a problem that arises when implementing construction process visualizations is that engineers and designers in charge of developing them need to think about what elements must be displayed and how to visualize them, not only physical objects but also non-physical elements that might support construction project management. This topic, referred to as semiotics, has not been covered by literature to a large extent, limiting the implementation of construction process visualizations in utility street works projects.

Since there is no standardized way of representing objects within construction process visualization, or even within the traditional 2D and 3D spatial models, different semiotic elements are used to visualize the same objects [6], and others might not be considered while designing visualization models. This lack of guidelines may lead to incomplete models or models that are difficult to understand, which limits sharing and getting mutual understanding among stakeholders. This is explained by the theory of semiotics [14], which claims that the meaning of signs is dependent on people's references and experiences. Therefore, developing construction process visualizations under a standardized framework of semiotic elements is essential to enhance the understanding of the involved parties, considering the diverse stakeholders participating in the design and construction processes of utility projects.

The host institution for this project is Siers Infraconsult, located in Oldenzaal, The Netherlands. Siers Groep, of which Siers Infraconsult is part, focuses on the field of utility infrastructure. Its expertise includes gas, water, electricity, telecom, heat, etc., in which several projects are carried out, from small to large, and vary in complexity. Siers offers experience, knowledge, and expertise in all process steps. From consultancy and engineering to project management, delivery, aftercare, and warranty.

Siers Infraconsult is the division for all the supporting services for the construction and management of utility network infrastructure. Its expertise includes, among others, measurement and data revision of installed networks; surveying and geodesy; detection of underground cables and pipes; advice; policy support and implementation of GIS processes; secondment of draftsmen, engineers, and work planners; and engineering and work preparation for the construction of underground networks which relates to the scope of this assignment, subsurface utility works.

Therefore, this project aims to develop a framework of semiotics that can support the drafting of construction process visualizations of subsurface utility street works. The framework includes descriptions of characteristics and examples of physical and non-physical semiotics that can be added to the traditional spatial models to develop construction process visualizations. These semiotics, their characteristics, and representation were defined with the help of experts working closely on utility street works carried by Siers Infraconsult. Finally, the designed framework and its implementation in construction process visualizations were empirically validated so it can be used as a standardized theory in later projects.

This paper is structured as follows; the literature review used as the basis for this design project is presented in the next chapter. The methodology to be followed during this assignment is described in chapter 3, including the problem investigation in chapter 3.1, treatment design in chapter 3.2, and treatment validation in chapter 3.3. Chapter 4 includes the results obtained during the development of this assignment. Finally, discussions, recommendations, and conclusions are presented in chapters 5, 6, and 7 respectively.

# 2 Theoretical framework

## 2.1 Visualization techniques in construction

The design phase of any civil engineering project is a crucial stage in the engineering process. This is because assembling, building, or reconstructing infrastructure are multidisciplinary processes that combine technical and specific knowledge from engineering and non-engineering fields. Therefore, an adequate design from the early stages allows for analyzing a project's constructability and improving its construction planning. In the last years, visualization models have been adopted to manage construction information and facilitate planning and communication [7]. These visualizations methods include two-dimensional spatial models (2D), three-dimensional spatial models (3D), and three-dimensional models over time, also known as four-dimensional (4D).

The benefits of three-dimensional spatial models have been widely documented in the literature, especially for above-ground infrastructure. This three-coordinates kind of visualization serves as a more advanced way of representing a design than the traditional two-dimensional sketches, which only represent two coordinates. For example, engineers use 3D representations to visualize a design, perceive the facility’s performance and field interference, and exchange data between stakeholders. This allows recognizing and addressing challenges in the design process's early stages [8]. Other benefits include design selection [2], the prevention of design misunderstanding and misinterpretation, and the identification of missing data. However, three-dimensional models and 2D representations do not support construction progress control since it is challenging to generate construction schedules from only spatial models [7]. As a solution, planning is linked to visualizations to represent different activities over time as means of Building Information Modelling (BIM) technologies and construction process visualizations.

Construction process visualizations, such as 4D models, link spatial models with construction schedules or sequencing plans [8]. These visualization techniques allow for graphically representing the construction process of a facility by simulating the transformation of space over time [5][9][10]. Additional to the benefits of 3D visualizations, these tools support cost estimation and analysis of construction operations; they help to improve linear task scheduling and workflow scheduling as well as safety and risk management [4][7][9]. Similarly, BIM allows for analyzing and assessing infrastructure performance, enhancing communication, and increasing efficiency and productivity [9]. Such spatiotemporal models display different stages of a project to speed up construction processes, identify time-space mistakes and correct them before the execution [8][11]. Overall, implementing construction process visualization tools has allowed for a better understanding of the design and construction plan reducing extra costs and delays.

## 2.2 Construction process visualization in subsurface utility projects

Even though both 3D and 4D visualizations have been adopted in several fields of civil engineering, this design project focuses on the subsurface utility sector. An extensive range of commodities that sustain society are supplied and disposed through utility networks [12], foe example, freshwater pipes, gas pipes, electricity cables, sewer lines, smart-grids, fiberglass networks, etc. The number of utility networks has increased in the last decades, leading to the underground space becoming scarcer. To this, the fragmentation of knowledge among utility owners [1][3][4] is added to assume that little attention has been given to how to document and share data in this field. As a solution to the complex coordination, it has been suggested that construction process visualization models might support the construction management of subsurface utility networks.

However, most literature has focused on the benefits of construction process visualization in large-scale projects rather than small-scale projects such as utility street works [2][4]. The existing studies on the topic suggests that the implementation of 3D spatial models and 4D models in this field is still limited. One of the reasons is that most of the models used to represent subsurface networks are documented as 2D plans of physical networks that do not represent exact locations, depths, and geometries [3]. Therefore, transforming two-dimensional visualization models to three-dimensional ones and subsequently linking them to schedules might result time-consuming and even difficult due to the scarcity of data. To that end, this project considers 3D spatiotemporal models (2D+time) as the method to visualize construction activities of utility street works over time. 2D+time construction process visualizations facilitate the representation of subsurface utility projects since it does not implicate transforming two-dimensional drawings into three-dimensional, instead, it directly links 2D spatial visualizations to the planning of construction, demolition, and renovation activities.

## 2.3 Semiotics in construction process visualization

Concepts such as 4D models visualize construction processes by linking time to three-dimensional representations. Usually, these visualizations only contain the physical assets and building objects that can be recognized in the environment. Literature, however, suggests semiotics as the means to visualize elements to convey meaning and include physical objects and non-physical objects that support project management.

Within process visualization, semiotic elements are used to visualize contextual information related to different activities in the construction process [4][6] and construction activities themselves. These elements include signs that have been classified based on their meaning, characteristics, and what they aim to represent. Hartmann and Vossebeld [6] developed a semiotic framework that classifies signs as icons, indexes, and symbols that convey meaning by similarity, relation, and convention, respectively. Icons have a physical resemblance to the object being visualized, for example, a photograph; indexes show evidence of the object without resembling it. Instead, indexes resemble something that implies the object; for example, smoke as an index of fire. Lastly, symbols have no physical resemblance to the object; therefore, their arbitrary connection must be culturally learned. Alphabets and numbers are examples of symbols.

Semiotics can also be classified as transient (temporal) elements and non-transient (permanent) objects. More focused on subsurface utility projects, olde Scholtenhuis, Hartmann, and Dorée [4] suggest four categories: (1) transient accessibility and workspace objects that represent conditions that temporally constrain construction space, (2) subsurface assets to be removed and other obstructing objects which represent objects to be altered, (3) designed utility networks and road infrastructure, representing objects to be constructed, and (4) non-transient contextual spatial orientation objects which represent the environment in which the construction process takes place. These classifications are the basis for suggesting new semiotics that can be used for subsurface utility works and therefore developing a semiotics framework.

Semiotic elements, however, do not have a fixed meaning. Ogden C. and Richards I. [14] suggest that understanding comes from within the people rather than from the object they interpret. Therefore, signs have different meanings to different people in different situations. The authors of the Meaning of meaning [14] propose the Semantic Triangle (Figure 1) to explain the relation between sign, referent, and reference. It explains that the referent (object being represented) needs some prior reference (experience, background) about the sign to be comprehensive. Given that the relation between sign and referent is not stable, the same sign might be used to represent different references to different people. This theory supports the claim that proposing a guideline to define semiotics within construction process visualizations is essential to enhance communication and coordination in utility street works.

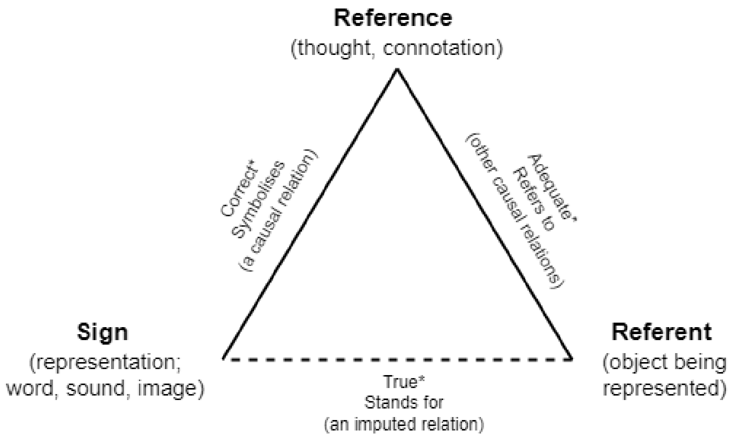



*Figure 1 The triangle of meaning [14]*

Overall, it is suggested that 3D spatiotemporal models (2D+time) of utility street works are not yet used for project management purposes due to the lack of semiotics that represent elements other than the utility network components and existing infrastructure. Furthermore, literature and semiotics theory suggests a lack of a standardized way of representing elements, objects, and activities within construction process visualizations. This absence of guidelines can be filled by using the classifications mentioned above as starting points to develop applicable signs that can be used in construction process simulations [6]. Yet, It is unclear to what extent the existing frameworks of semiotics can support the visualization of utility street works, given the different complexity of these types of projects and the lack of knowledge about which semiotics are actually required for developing utility street works process visualizations.

Therefore, this project aims to develop a framework that contains descriptions and examples of commonly used semiotics to support and enhance the drafting of construction process visualizations of street works. Three sub-goals are established as the means to achieve this goal.

1. Determine, through expert opinion and literature, objects and activities that can be included in the traditional spatial models to create construction process visualization of utility street works.
2. Design a framework of semiotics including physical and non-physical semiotic elements in which their characteristics and representations can be documented.
3. Validate the designed semiotics framework through expert opinion to determine whether the requirements and validation criteria are met, and hence the product can be used as a standard framework in construction process visualizations of future subsurface utility projects.

# 3 Methodology

The design project subject to this report follows Wieringa's Engineering Cycle [13]. This rational problem-solving process consists of five tasks: (1) problem investigation, (2) treatment design, (3) treatment validation, (4) treatment implementation, and (5) implementation evaluation. This report focuses on the first three tasks, which are described below.

## 3.1 Problem investigation

The investigation of the problem involves identifying, describing, and evaluating the current situation and its causes on general and specific levels. The problem investigation is carried out as a preparation for designing a treatment solution. On a general level, the problem suggested by literature and presented in previous chapters is the lack of guidance on what objects and activities to include while developing construction process visualizations and how to represent them. This section focuses on identifying the problem at a more specific level by linking the identified general issue to the actual needs at Siers Infraconsult.

This step was broken down into three main activities: understanding construction visualization models employed at the host institution, investigating the current situation of Siers Infraconsult with regard to construction process visualizations, and identifying projects in which construction process visualizations are and can be implemented.

Sample projects were selected to understand the visualization models currently employed at Siers Infraconsult, and their visualization models were inspected. The projects were chosen based on the scope of this research by people working at Siers Infraconsult who were previously introduced to the goal and subgoals stated in the previous chapter. This activity was performed through meetings in which presentations were given by experts in different fields, for example, 2D models, 3D models, drawing software such as AutoCAD and Revit, and Navisworks as a design review software. Experts were consulted about the types of projects carried out by Siers, who is responsible and how visualization models are developed, what elements are usually included in these models, and where the utility networks data is retrieved from. Similarly, the current situation at Siers Infraconsult regarding construction process visualizations was determined by inspecting existing models and consulting engineers and designers about the use of data and data sharing within utility projects.

The last activity of problem investigation focuses on identifying utility projects in which construction process visualizations are employed, and hence a framework of semiotics can be implemented. Besides meetings with engineers and visualization model designers, this step involved inspecting schedules and discussing them with experts working on the planning and coordination of utility projects (i.e., project coordinators) who explained the process of creating schedules and the activities typically included in them. The outputs of the expert meetings and presentations held during the problem investigation phase served to understand the workflow within utility projects and as a starting point to suggest a workflow to create construction process visualizations. The results of the problem investigation are presented in chapter 4.1.

## 3.2 Treatment design

A framework feasible for the intended objectives needs to meet some requirements. Therefore, the treatment design phase starts with the methodology for requirements specification in chapter 3.2.1 and the initial description of the framework in chapter 3.2.2, which are helpful guidelines for suggesting, evaluating, and choosing solution designs. Then, the procedure to determine which elements to include in the framework is described in chapter 3.2.3.

### 3.2.1 Requirements

Requirements are sent from literature and the current situation at Siers Infraconsult. By review studies on visualization models for construction projects [8][9], utility networks visualizations [2][3], semiotics theory [14], and semiotics on construction process visualizations of utility projects [4][6], the elements that are commonly visualized in spatial models were defined as well as semiotics that might enhance project management while included in construction process visualizations. From previous studies, the main characteristics of semiotic elements were identified as a matter of their classifications as explained in chapter 2.3. This helped to set requirements on the type of elements that might be included in the semiotics framework, for instance, physical, non-physical, temporal and permanent objects. Besides, it was possible to set requirements based on the needs of Siers Infraconsult, the projects the company carries out, and the existing models and available data of utility networks. For this, the analysis of the models, schedules, and workflows performed during the problem investigation helped to suggest requirements that enhance and facilitate the implementation of construction process visualizations and a framework of semiotics in utility projects within Siers Infraconsult.

The list of requirements set for the semiotics framework can be found in chapter 4.2.1.

### 3.2.2 Initial description of the framework

Literature helped to suggest an initial description of the framework of semiotics. As described in chapter 2.3, semiotics has been classified according to their characteristics and what they aim to represent. This step of the treatment design started by compiling examples of semiotics used in construction projects [6] and utility project visualizations [4]. The classifications of semiotics and examples served to propose an initial structure of the semiotics framework in which the temporal and physical characteristics are included in a coherent way, as well as the sign and type of sign used to represent an object or activity. The purpose of suggesting an initial description of semiotics is first to illustrate experts involved in the treatment design with the examples of semiotics that might be included in the framework, and second, to document the results of the experts' participation in an organized way.

The results of this section, including examples of semiotics grouped by their classification and the initial structure of the framework, are presented in chapter 4.2.2.

### 3.2.3 Workshop 1: Elements to be included in the framework

As part of the treatment design, a workshop was organized in which the elements to be included in the framework were determined through expert opinion. The detailed protocol of the workshop can be found in appendix 9.1, while the assessment approval by the Ethics Committee of the University of Twente is presented in appendix 9.3.

During this session, experts working at Siers Infraconsult were consulted on the objects and activities that might be added to the existing 2D visualization models to create construction process visualizations. Five experts participated in the workshop, two experts in 3D/BIM, GIS, and engineering, and two experts in planning, control, and coordination. After introducing the workshop and framing the problem behind this project and its goal and subgoals (chapter 2), the study case was introduced.


*Figure 2 Overview project Overtoom in Amersfoort*

As a study case for Workshop 1, phases 1 and 2 of the project Overtoom in Amersfoort were considered (Figure 2). The selection of this project was due to the availability of planning and 2D visualizations of the utility networks. Besides, the scheduled activities are common construction activities in utility street works. The project is currently being developed and consists of renovating gas and water pipes in 17 phases throughout the city. The available planning of this project included five main activities performed for gas and water lines in every section of every phase.

- Graven sleuf (excavate trench)
- Rooien (remove old pipe)
- Leggen (lay new pipe)
- Overzetten ( connect new line to the existing network)
- Dichten sleuf (close trench)

The construction activities of the two phases are performed from April 19th, 2022, to July 01st, 2022, and encompass the following sections:

*Table 1 Phase 1 and 2 Project Overtoom*

| Phase | Section | Start date | End date |
|---|---|---|---|
| 1 | Nijenrode 157 t/m 173 | 19-04-2022 | 25-04-2022 |
| | Nijenrode 153 / 155 en bocht om | 26-04-2022 | 03-05-2022 |
| | Nijenrode 143 t/m 151 + oversteek Queekhoven | 04-05-2022 | 10-05-20-22 |
| | Nijenrode 125 t/m 141 | 11-05-2022 | 17-05-2022 |
| 2 | Soetendaal deel 1 | 18-05-2022 | 24-05-2022 |
| | Soetendaal deel 2 | 25-05-2022 | 02-06-2022 |
| | Somersbergen even zijde | 03-06-2022 | 10-06-2022 |
| | Spruitenburg even zijde | 13-06-2022 | 17-06-2022 |
| | Spruitenburg oneven zijde | 20-06-2022 | 24-06-2022 |
| | Somersbergen oneven zijde | 27-06-2022 | 01-07-2022 |

In order to create a construction process visualization, the 2D spatial model is linked to the available planning by following the workflow to develop construction process visualizations presented in chapter 4.1.2. A detailed explanation of the construction process visualization of the project Overtoom can be found in appendix 9.4. Then, the initial simulation, containing only elements included in the existing 2D drawings (e.g. utility networks and existing physical infrastructure), was displayed to show the participants where the proposed semiotics could be implemented; it is in a construction process visualization.

Subsequently, the participants were asked to brainstorm and sketch objects and activities that they would add to the initial 2D+time construction process visualization in order to visualize the different steps of the process and enhance project management activities. For this, printed versions of the existing 2D spatial models were provided together with a guide sheet containing the meaning of the elements already included in the visualization model and a description of the semiotics classification. Besides, the activities included in the existing planning were presented, which served as a start point to suggest elements within those activities and additional construction activities not only of project Overtoom but of utility street works in general.

Attendants were requested to register their ideas of semiotics under the initial structure of the framework introduced in chapter 3.2.2 and detailed in chapter 4.2.2. Therefore, the outcome of Workshop 1 is a list of semiotics including meanings, representations, and descriptions indicating the physical and temporal characteristics of the chosen sign as well as if it is an icon, index, or symbol. Finally, to achieve a consensus on the meaning and representations of the proposed semiotics, a discussion was held in which every participant presented their results while others could agree, disagree or suggest changes.

The workshop's results are presented in chapter 4.2.3. Based on those outcomes, the initial structure of the framework was updated with new characteristics in which the suggested semiotics were included. The updated framework of semiotics to support the drafting of construction process visualizations of utility street works is discussed in chapter 4.3.

## 3.3 Treatment Validation

The designed treatment, framework of semiotics, needs to be validated to justify that it meets the requirements and hence contributes to the purpose once it is implemented in the problem context. Therefore, this section consists of defining validation criteria in chapter 3.3.1 and describing the procedure followed to validate the framework of semiotics in chapter 3.3.2.

### 3.3.1 Validation criteria

The framework of semiotics and its implementation in construction process visualization must comply with the requirements introduced in chapter 3.2.1 and detailed in chapter 4.2.1 in order to claim that the framework fulfills its goal and can be used as a standard theory in future utility projects. Therefore, similar to the requirements, validation criteria were defined from reviewing studies on visualization models for construction projects [8][9] and utility networks [2][3], construction process visualization of utility projects [4], semiotics theory [14], and semiotics for construction process simulations [6].

Based on literature and the requirements, five validation criteria are proposed which allow for evaluating the performance of the semiotics framework in different domains named completeness, understandability, representativity, applicability, and flexibility. Each criterion is described in chapter 4.4.1.

### 3.3.2 Workshop 2: Validation of the semiotics framework

The framework validation was done in two sessions; therefore, two validation workshops in which two groups of experts participated. For each session, a different study case is used to demonstrate whether the framework meets the validation criteria and requirements for subsurface utility projects of a different kind. The selected projects were Project Overtoom in Amersfoort for the first session and Project Bathmense Laden in Deventer for the second validation session. The detailed protocol of the workshops can be found in appendix 9.5.

The general structure of both validation sessions consisted of introducing the workshop and its goal, framing the problem behind this project (chapter 2), building understanding on the results obtained in workshop 1 (chapter 4.2.3 and chapter 4.3), and validating the framework around the proposed criteria. The discussion of each criterion started by asking the participants a corresponding question(s) detailed in chapter 4.4.1. Empirical data was collected from reflective dialogues about the framework of semiotics and its performance when implemented in construction process visualizations. Both sessions were video-recorded to subsequently extract the most relevant perspectives expressed by the experts about the validation criteria.

The validation criteria were measured according to the responses to each validation question. For every criterion, when participants behaved positively about the framework and construction process visualizations, it was suggested that the framework meets the criteria and hence the requirements. The responses from specific expertise were highlighted for different criteria. The response from executors about the understandability and applicability in the work field was emphasized, while the posture of engineers about completeness and applicability to support the development of construction process visualizations was stressed. Similarly, extra attention was paid to the criterion understandability when parts of the construction process visualization had to be displayed again to analyze whether the included semiotics are self-explanatory.

In the following sections, the validation session is described in detail. The results of each validation criteria from both sessions are discussed in chapter 4.4.2.

*Workshop 2.1. First validation session*

The first framework validation session focused on validating the framework in a subsurface utility project currently being developed. Participants are selected from experts working on the project Overtoom, introduced in chapter 3.2.3, who have more knowledge about the construction activities performed in the field. The participants were two experts on execution and preparation, two experts on engineering, and one expert on project management and environmental management who helped validate the framework based on the actual development of the project.

The inputs for this session included the designed framework of semiotics, hence its updated structure and description. This information was shared with the participants before the session so they could review it and prepare comments and suggestions beforehand. Other inputs included the validation criteria introduced in chapter 3.3.1 and an updated version of the construction process visualization of project Overtoom, which were described during the session.

The session started by introducing the structure of the workshop and its goal, then the problem and research project were described to subsequently present the results from Workshop 1. In this section, it was explained that the semiotics suggested in Workshop 1 were organized under an updated structure which is the framework of semiotics (chapter 4.3) that was going to be validated. Then, the construction process visualization in 2D+time of the project Overtoom was displayed. This updated simulation included semiotics from the semiotics framework, which represented objects and activities that were not included in the existing 2D spatial model—for example, working areas, traffic measures, and utility service provision signs. Before the validation discussion started, it was highlighted that the session consisted of validating the framework and its implementation in the construction process visualization rather than the construction process visualization itself. Finally, each validation criterion was discussed individually, and empirical data was collected from the reflective dialogues. Attention was paid to the responses of executors about the implementation of the framework and construction process visualizations in the actual construction process.

*Workshop 2.2. Second validation workshop session*

The second validation session was held internally at Siers Infraconsult's offices to validate the framework in a subsurface utility project of a different kind than project Overtoom. Some of the experts who participated in Workshop 1 were requested to attend this session. Their expertise included planning and control, 3D BIM, GIS, and engineering.

Similar to the first validation session, a guide sheet with the designed framework of semiotics, hence its updated structure and description, was shared with the participants before the session so they could review it beforehand. Other inputs included the validation criteria introduced in chapter 3.3.1 and the construction process visualization of project Bathmense Laden, described during the session.

Project Bathmense Laden served as a study case. This already completed project consisted of installing electricity pipes in 15 phases throughout the city of Deventer. The selection of this project was due to the availability of a 2D visualization model and planning in which the scheduled activities, although different from Project Overtoom, are also common construction activities in utility street works. The existing planning for these phases included the following activities:

- Opbouwen opslag (building up storage)
- Graven trace (Digging trench)
- Kabels trekken (laying cables)
- Grond aanbrengen en verdichten (applying and compacting soil)
- Dichtstraten (Putting tiles)

- Verkeerplan kabeltreken (Traffic plan)
- Montage en manteltest (Assembly and sheath test)
- Asfalt zagen en opnemen (removing asphalt)
- Mantelbuis leggen en dichtblokken (Laying protection pipe)
- HDD (Horizontal Directional Drilling)

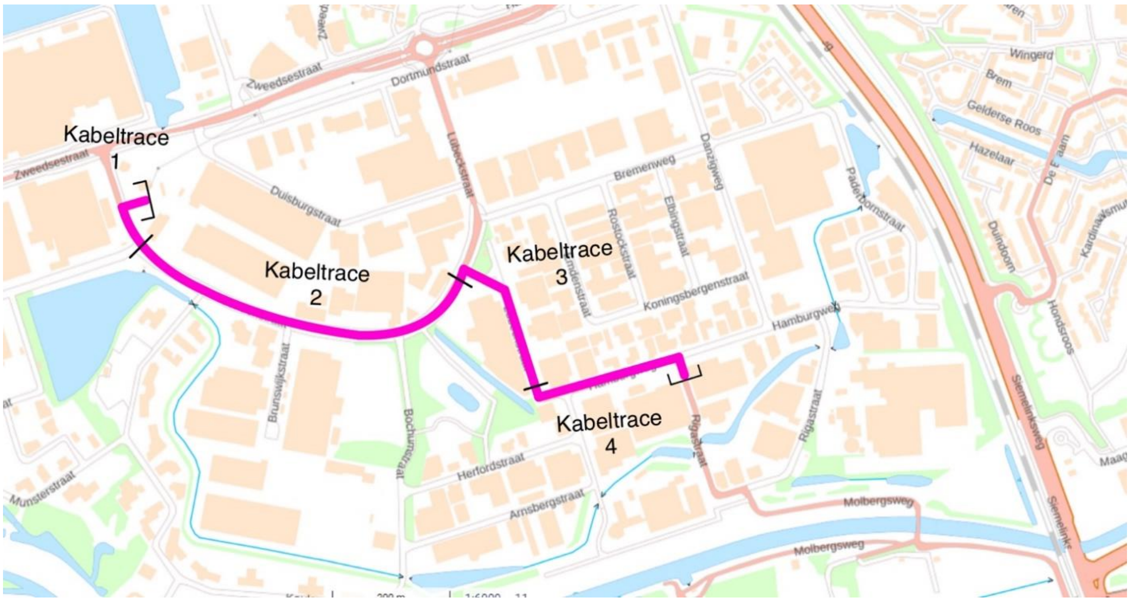



*Figure 3 Overview project Bathmense in Deventer*

Opstarten Project (phase 0) and phases 1 to 4, also defined as kabeltrace (Figure 3), were considered to develop a construction process visualization. The selection of 5 out of 15 phases was because the most representative construction activities of this project can be visualized within those phases. The selected project time took place between October 18th, 2021, and December 01st, 2022, as follows:

*Table 2 Phases 0 to 7 Project Bathmense*

| Phase | Section | Start date | End date |
|---|---|---|---|
| 0 | Opstarten Project | 25-10-2021 | 26-20-2021 |
| 1 | Kabeltrace 1 - EBS terrain | 04-11-2021 | 18-11-2021 |
| 2 | HDD 1 | 18-10-2021 | 19-10-2021 |
| | HDD 2 | 20-10-2021 | 21-20-2021 |
| | HDD 3 | 21-10-2021 | 26-10-2021 |
| | Kabeltrace 2 - Londenstraat | 25-10-2021 | 8-11-2021 |
| 3 | HDD 4 | 27-10-2021 | 27-10-2021 |
| | Kabeltrace 3 - Hamburgweg | 16-11-2021 | 26-11-2021 |
| 4 | HDD 5 | 28-10-2021 | 28-10-2021 |
| | HDD 6 | 29-10-2021 | 29-10-2021 |
| | Kabeltrace 4 - Hamburgstraat/Rigastraat | 23-11-2021 | 01-12-2021 |

In order to create a construction process visualization, the 2D spatial model was linked to the available planning by following the workflow to develop construction process visualization presented in chapter 4.1.2. A detailed explanation of the construction process visualization of the project Bathmense Laden can be found in appendix 9.6.

During this validation session, less attention was given to framing the problem and this research project since the participants were introduced to it during Workshop 1. Then, the session started by introducing the structure of the workshop, briefly recapitulating the goal of this project and summing up the results obtained up to that date. The results included the framework of semiotics to be validated, of which the updated structure and some examples were explained. Subsequently, the study case was described in detail. In this section of the workshop, the difference between how the existing data is currently documented (i.e. schedules and spatial models) and the construction process visualization was highlighted.

Then, the construction process visualization in 2D+time of the project Bathmense Laden displayed. This simulation of the construction over time included semiotics from the semiotics framework which represented objects and activities that were included in the existing 2D spatial model but also management semiotics that were not included. For example, working areas and traffic measures. Similar to the first session, before the validation discussion started, it was emphasized that the session consisted of validating the framework and its implementation in construction process visualization rather than the displayed construction process visualization. Finally, each validation criteria was discussed individually and empirical data was collected from it. Attention was paid to the responses of engineers and project coordinators about the development of construction process visualizations in the design phase of a project.

# 4 Results

## 4.1 Problem investigation

### 4.1.1 State-of-the-arts construction visualizations at Siers Infraconsult

Within Siers Infraconsult, diverse projects are carried out using two-dimensional and three-dimensional spatial visualizations. More often, 2D models serve as the method to represent utility street works, which is this project's scope, while 3D models are implemented in in-building projects. Therefore, this project focuses on developing a framework to support drafting construction process visualizations of utility street works in 2D+time. In any case, the visualization models employed at Siers Infraconsult represent the aimed end product (e.g., utility line to be installed), the existing infrastructure (e.g., utility line to be removed), and spatial referential objects such as buildings and roads. These models are created from data provided by clients, utility databases such as KLIC (Kabels Leidingen Informatie Centrum), and inputs from the designers and engineers developing and working with spatial visualization models. Depending on the type of project, the end-user of the developed construction visualizations are the client or field workers when the company carries out the project.

Regarding the planning of utility projects, schedules are created taking into account the activities involved in the project's execution. From reviewing schedules of projects carried out by Siers Infraconsult, it can be seen that primarily main activities are included in the planning rather than specific ones. For example, excavating a trench, closing a trench, and HDD. One of the project coordinators working at Siers Infraconsult claimed that a reason is that field workers use the plan as a guide for deadlines; however, given their expertise, they would not follow verbatim a planning of more specific activities. Besides, since not all the projects are carried out by Siers, the activities performed in the field are not always recorded or tracked.

From reviewing visualization models and schedules and consulting experts working in the design, preparation, and execution of utility projects, it was noticed that simulations of the construction process are not yet employed in utility street works performed by Siers, which might limit the implementation of a framework of semiotics. Therefore, a workflow to combine the planning and 2D spatial models to develop construction visualizations is proposed in the next section.

### 4.1.2 Workflow to develop construction process visualizations in 2D+time

In order to propose a framework of semiotics, it is essential to first develop visualization models of the construction activities over time. For this, the procedure in Figure 4 is proposed to create construction process visualization considering the available data on subsurface utility projects carried out by Siers. The planning containing activities to be performed during execution of a project and its spatial visualization model are required inputs that are linked together in an animation software that allows simulating the construction process over time, for example, Navisworks. This software was selected for the development of this project since this is the one employed at Siers Infraconsult. Although Navisworks is used for design review of 3D spatial models, this program allows for developing construction visualizations.

In the case of 2D visualizations, it is suggested to employ CAD drawing software compatible with the animation software. At Siers Infraconsult, spatial models are documented in AutoCAD, which is compatible with Navisworks and can be easily imported. As was mentioned in previous sections, the currently employed visualizations contain existing infrastructure, infrastructure to be removed, and infrastructure to be constructed; therefore, adding, removing, and changing elements, such as semiotics, can be done through AutoCAD. Then, when the two-dimensional spatial model is imported to the design review software. Alterations in AutoCAD can be automatically updated on Navisworks.

For the planning, schedules need to be documented in a format compatible with the software in which the simulation is developed. Microsoft Project is the preferred software to document schedules at Siers Infraconsult, which is also compatible with Navisworks. It is suggested to specify at least the Task ID, Task Name, Start Date, and End Date of each activity included in the planning. MS Project schedules can be imported to Navisworks as *Data Sources* in the *TimeLiner* window. Similar to AutoCAD, changes made on the MS Projects can be automatically updated on Navisworks.

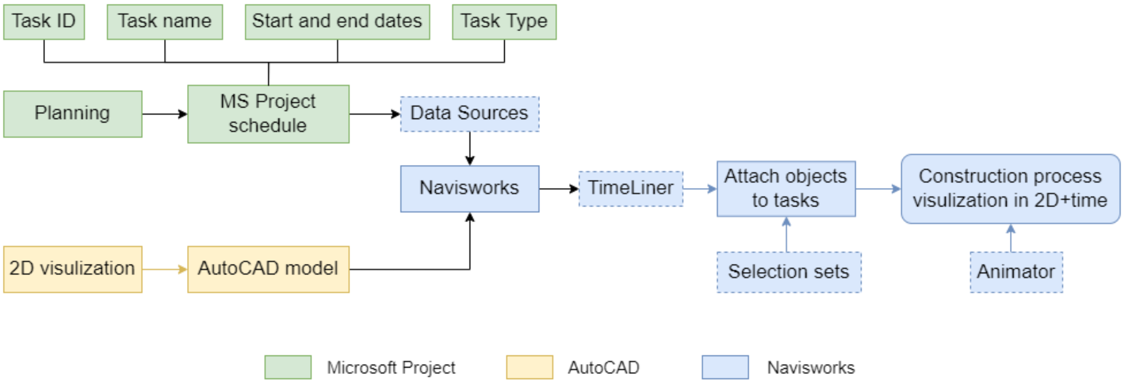



*Figure 4 Procedure to develop construction process visualizations*

Once both the planning and 2D visualization are imported to Navisworks, each task can be linked to specific objects, which allow to automate the construction process and create a standard simulation in the *TimeLiner* window. The simulation might be upgraded with options such as *Sets* to create selection sets of objects from the drawing that are involved in the same task. The windows *Animator* and *View Points* can be used to visualize specific views at specific times. In the *TImeLiner* window, the option *Configure* can be used to define task appearances and *Simulate* for simulation settings such as the duration and export options. The end product is a construction process visualization directly linked to the 2D visualization model of a subsurface utility project and its planning.

## 4.2 Treatment design

### 4.2.1 Requirements

From the current techniques employed at Siers Infraconsult regarding construction visualizations and previous studies on semiotics, such as their classifications, initial requirements are set for the aimed framework as stated in chapter 3.2.1.

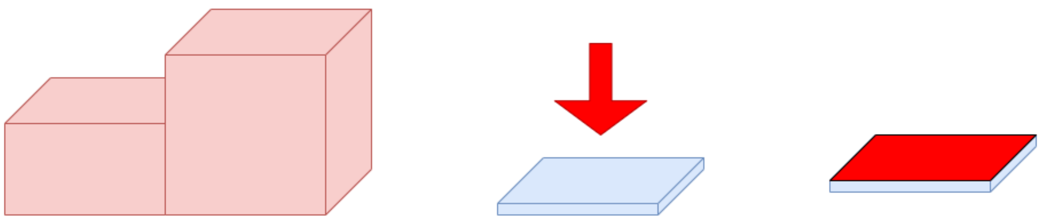
1. The semiotics framework shall include physical and non-physical elements.
2. The semiotics framework shall differentiate between temporal and permanent elements.
3. The semiotic framework shall include descriptions and examples of semiotics.
4. The implementation of semiotics in construction process visualization shall support project management.
5. Semiotics shall have a consensual meaning, and their representation shall be self-explanatory.
6. The semiotics framework shall facilitate the rapid drafting of construction process visualization by reducing the time it would take to design semiotics from scratch.

### 4.2.2 Initial description of the framework of semiotics

Table 3, based on previous studies on semiotics for construction process visualizations [4][6], considers semiotics classifications and includes some examples used as starting points to suggest a structure of the semiotics framework. Besides, it was a helpful guide to introducing experts participating in the development of this project to its goal and expected outcomes. Therefore, the table below was presented during meetings held as part of the problem investigation and during Workshop 1.

*Table 3 Examples of semiotics grouped by their classifications*

<table>
<tr><th></th><th colspan="2">Physical semiotic elements</th><th colspan="2">Non-physical semiotic elements</th></tr>
<tr><th></th><th>Infrastructure to be constructed</th><th>Infrastructure to be removed</th><th>Accesibility objects</th><th>Contextual spatial orientation objects</th></tr>
<tr><td rowspan="3">Represented as</td><td colspan="2" rowspan="2">Solid geometrics<br>Buildings (icons) (figure a)<br>Excavation area (icons)<br>Pipes (icons)<br>Trees (icons)</td><td colspan="2">Arrows<br>Emergency routes (symbols)<br>Specific locations (indexes) (figure b)</td></tr>
<tr><td colspan="2">Textual information<br>Street names (symbols)<br>Building names (symbols)</td></tr>
<tr><td colspan="2">Surfaces<br>Roads (symbols)<br>Work surface (symbols)<br>private property (symbols)</td><td colspan="2">Hatched areas<br>Risk areas (icons) (figure c)</td></tr>
</table>



a) buildings b) specific areas c) risk areas

From examples and categories presented in the literature, an initial structure for the semiotics framework is proposed in Table 4. This structure allows to group semiotics according to their physical and temporal characteristics, as well as the type of sign they use to visualize the object. Table 4 also includes a meaning, representation, and description for each semiotic element. The meaning is the name of the object or activity to be visualized, the representation is the sign used to visualize the object, and the description includes additional information, for example, the start and end of the visualization in case of a transient semiotic. This structure is used to document the results of Workshop 1, in which the elements to be included in the framework are determined.

*Table 4 Initial structure framework of semiotics*

| | Semiotics to support the drafting of construction process visualizations of utility street works in 2D+time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Physical elements | | | | | | Non-physyical elements | | | | | |
| | Transient | | | Non-transient | | | Transient | | | Non-transient | | |
| | Icon | Index | Symbol | Icon | Index | Symbol | Icon | Index | Symbol | Icon | Index | Symbol |
| Meaning/ Object | | | | | | | | | | | | |
| Representation | | | | | | | | | | | | |
| Description | | | | | | | | | | | | |

### 4.2.3 Elements to be included in the framework.

During the workshop organized to determine which elements to include in the semiotics framework, the participants proposed several objects and activities and documented them under the initial structure of the framework presented in chapter 4.2.2. The purpose of the session was to reach an agreement on the meaning and descriptions; therefore, results were shared and discussed.

Given the different expertise of the participants, semiotics were suggested and documented in different ways. For instance, some participants focused on the visuals by using different colors when sketching semiotics. In contrast, others focused the brainstorming on the process itself, starting by enlisting activities and objects involved in the execution process. The diverse expertise also allowed various results ranging from construction activities, construction components, utility network components, working spaces, and traffic measures.

Regarding construction activities, a participant highlighted that 'inbouwing' is an essential step in the construction process of utility street works that were not included in the planning of the project Overtoom. This activity involves closing the valves around the project area to be able to empty the pipes, replace them and make the connection to the existing network. This activity differs from 'overzetten,' which was included in the original planning but only focuses on the connection of the new utility line to the houses, as was claimed by a participant who noted:

> *When you have a gas network, and you want to install a new network, you can place the pipe, and at the end, you need to make the connection; before connecting that, you have to close other valves in the rest of the street. This is the procedure you have to follow. […] Overzetten is the connection to the houses; besides that, you also have big pipes such as transport lines, it is different and is not stated in the plan (of project Overtoom).*

Similarly, horizontal directional drilling (HDD) was mentioned as a construction activity that might be included in the framework. Even though this activity was not part of project Overtoom, it is a common activity among utility street works. A representation was suggested to indicate that HDD is being performed. However, another participant suggested that the whole process of HDD can be divided into more specific sub-activities; therefore, the proposed sign would only be helpful in indicating the location where the drilling machine is placed.

In the case of excavating and closing the trench, also construction activities, the researcher proposed colored surfaces to represent the areas where these activities are being performed. To this, one of the experts suggested combining surfaces with signs that indicate excavation. One of the participants pointed out that different steps within excavating and closing the trench can be visualized, for example putting tiles (dichtstraten).

Furthermore, colored surface areas were suggested to visualize working, safety, and storage spaces. The latter was proposed by two participants as a deposit and hub. One of them claimed:

> *Sometimes when it is pretty crowded, there is just enough space to dig the trench, but the excavated sand should go somewhere to storage or a hub.*

Next to construction activities and working spaces, construction components were proposed by the experts. For example, the trench framework used when shoring trenches were mentioned by two experts, each one with a different representation. One of them proposed representing a stamp between two plates, while the other expert proposed displaying a line next to the excavation area. In the end, it was agreed to consider the latter representation, which is more suitable for visualizing a trench framework in two dimensions. The participant whose representation was not agreed claimed:

> *I think that is better than mine because (a trench framework) is not in a specific location but everywhere or in special sections, so it is easier to visualize in 2D.*

Regarding the elements that are already included in the traditional 2D visualizations, mainly utility network components, an expert referred to the hydrants and valves displayed in the construction process visualization of project Overtoom and suggested not to include the numbers and text accompanying these objects because they would make the visualization crowded and other essential elements might be outweighed. Also related to the utility network components, an expert highlighted that for these objects, there exist standards on how to visualize them, for instance, NLCS (Nederlandse CAD Standaard); therefore, those standards should be followed. As he claimed:

> *You need to use the standards of NLCS or other sector standards for that because it is not only for our purpose, but the visualization is for other stakeholders, so you should use the sector standards.*

Similarly, there exist standards for traffic measures that should be followed to visualize traffic signage. In the same way, there are standard signs to represent the location of emergency organizations, such as fire stations, which were suggested by one of the participants. However, including these organizations in construction process visualizations was not agreed upon, given that they might not be relevant in the construction process of utility networks.

Furthermore, a discussion about representing noise was held when the experts were consulted about whether it is essential to visualize nuisance while developing utility street works. The following question arose:

> *Do you mean the noise for field workers or for the environment? When it is for the workers, they can have headphones, or it could be so loud that it affects the environment.*

To this, one of the participants claimed that if noise for the workers is considered, then many other work safety measures should be added as well, which might not be relevant to the focus of this project. However, if it refers to the nuisance to the environment, then it is important to visualize considering, for example maximum decibels. This discussion led to the question of who the end-users of construction process visualizations are, whether field workers or stakeholders such as citizens and the client. In that context, it was suggested to classify the semiotics into categories (e.g., safety, constructability), similar to plannings developed differently for internal use and requesting permits.

Nine categories are proposed based on the results from Workshop 1, which in turn can be arranged depending on the purpose of the construction process visualization in which semiotics are implemented. This can be directed to only field workers or field workers and citizens (people living in and around the project area, clients, municipalities, etc.). These categories, also based on the classification of semiotics by olde Scholtenhuis, Hartmann, and Dorée [4], are presented in Figure 5.

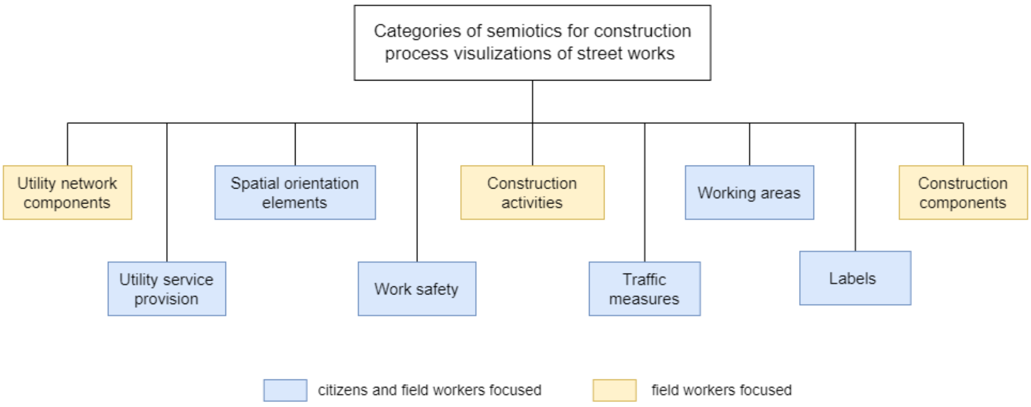



*Figure 5 Categories of semiotics*

Each category is described in Table 5.

*Table 5 Description of categories of semiotics*

| Category | Description | Examples |
|---|---|---|
| Utility network components | Elements that are already visualized in the 2D spatial models. This category includes aged utilities and designed utility networks [4].  | Pipes, valves, hydrants |
| Spatial orientation elements | Objects in the project environment that provide visual cues for navigation through the project [4]. | Buildings, roads, trees |
| Construction activities | General construction activities that are included in the planning of utiltiy projects. | Excavating, laying, and removing pipes |
| Construction components | Elements that support the development of the construction activities | Trench frameworks, drilling machines |
| Working areas | construction site spaces assigned for excavation, work, storage, and safety. This category refers to workspace objects [4] | Excavation, working, safety areas |
| Utility service provision | Availability of utility services for the consumer. | Availability of water or gas |
| Work safety elements |  Components that support safety during the construction process. | Construction fences, hazard excavations |
| Traffic measures | Signage to manage traffic in and around the project area. This category relates to transient accessibility objects [4]. | Alternative route, road closed |
| Labels | Indicators of the project, section, date, and time that are being visualized. | Name and section of the project |

Therefore, the results from workshop 1 are grouped based on these categories and included in the framework of semiotics as described in the next section.

## 4.3 Framework of semiotics

This section explains the framework of semiotics developed from literature (chapter 2) and the results from Workshop 1 (chapter 4.2.3). The initial structure presented in chapter 4.2.2 is updated; hence the final semiotics framework includes characteristics and descriptions, as shown in Table 6.

*Table 6 Structure framework of semiotics*

| Semiotics to support the drafting of construction process visualizations of utility street works in 2D+time | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Category | Meaning | Representation | Sign Type | | | Physical characteristc | | Temporal characteristic | | Georeferenced | | Illustrative example |
| | | | Icon | Index | Symbol | Physical | Non-physical | Transient | Non-transient | Yes | No | |

Each characteristic is described below.

- Meaning is the name of the object or activity being visualized.
- Representation refers to how the object is visualized; therefore the sign used to represent it.
- The sign type is determined according to the classification of signs [6] (also in chapter 2.3) which divides them into:
    - Icons convey meaning by similarity and have a physical resemblance to the object.
    - Indexes show evidence of the object being represented. However, it does not resemble the object. Instead, it resembles something that implies the object.
    - Symbols whose connection to the object is learned by agreement or convention.
    Semiotics may be a combination of two or three signs.
- Physical characteristic refers to the physical state of the object in real life.
- Temporal characteristics indicate whether the presence of the semiotic is during the whole visualization (permanent) or a shorter period (temporal).
- Geo-reference describes whether the semiotic must be georeferenced, therefore, if it has a specific location linked to a specific activity.
- Illustrative example includes the situation(s) in which the semiotics can be implemented. Additional descriptions of the semiotics might be added in this section.

Table 7 contains examples of the semiotics included in the framework. From the category utility components, the semiotics representing water pipes to be constructed, water pipes to be removed, and aansluitcomponent, part of the gas network, are shown. The meaning of these semiotics and their representation were retrieved from the existing visualization models of Project Overtoom. Each of these utility components has a different sign type named icon, index, and symbol, respectively. Besides, the temporal, physical, and geo-referential characteristics are included to finally indicate in the section Illustrative example that the semiotics in this category must follow existing standards. Therefore, representations might vary between projects, clients, and databases.

The structure of the remaining categories and elements is similar. A meaning, representation, characteristics, and illustrative example are described for each semiotics. In some cases, as it is for utility network components, spatial orientation elements, utility service provision, and labels, an illustrative example is set for several elements. This is done because a general statement can summarize the description or the situations in which different semiotics can be used. For instance, the illustrative example of gas and water availability states that using these semiotics makes it possible to see when specific houses do not have access to utility services. Therefore, an individual illustrative example for gas availability and water availability would not be necessary.

Furthermore, the temporal characteristic of semiotics such as trees is set as temporal/permanent*. This indicates that the visualization of these semiotics is dependent on the project. For example, trees are a permanent object in the Project Overtoom; however, they are temporal in project Bathmense, which includes the activities of removing and replanting trees in its planning. It happens the same with pedestrians, vehicles, and bike roads since there might be temporary changes along with projects.

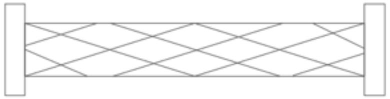
Another point of attention is that a representation of semiotics might consist of more than one sign type. Examples of this are construction activities that combine the index of the activity (e.g., excavating a trench) with colored surfaces as icons. Also, the surface representing roads (icons) are accompanied by the streets' names, which are considered symbols for being textual information. Finally, some semiotics such as shed and hub/storage share the exact representation. This is because, during workshop 1, a distinction in the meaning was pointed out but not a distinction in the representation. A shed is a space assigned for having lunch and storing workers' belongings, while a hub space is used to store excavated soil and machinery. Even though the purpose of these working spaces is different, the same sign might be used to represent both. The complete framework of semiotics developed in the course of this assignment can be found in appendix 9.7.

This framework was designed from the literature and the results of workshop 1. However, the framework needs to be validated to be used in construction process visualizations of future subsurface utility projects. Therefore, the results of the validation workshops are presented in the next chapter.

*Table 7 Framework of semiotics*

| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| **Utility network components** | Water pipe to lay | | Icon | Physical | Temporal | Yes | Utility networks and their components must be visualized under already existing standards such as NLCS. Representation might vary between databases (e.g. KLIC) and institutions. |
| | Water pipe to remove |  | index | Physical | Temporal | Yes | |
| | Aansluitcomponent |  | Symbol | Physical | Temporal | Yes | |
| **Spatial orientation elements** | Vehicle lane |  | Icon Symbol (text) | Physical | Permanent/ Temporal* | Yes | Spatial orientation elements represent the existing infrastructure in the surroundings of the project area. |
| | Trees |  | Icon | Physical | Permanent/ Temporal* | Yes | |
| **Working areas** | Hub/Storage area |  | Icon Index | Physical | Temporal | Yes | When the space is limited in a crowded project area, a hub or space can be used to store excavated soil and machinery. |
| | Safety area | | Icon | Physical | Temporal | Yes | Area next to the working space to assure enough distance between the working space and the surroundings. Also required to request permits. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Construction activities** | Excavation |  | Index<br>Icon | Physical | Temporal | Yes | The activity of excavation itself. Consist of the surface being excavated (icon) and a excavation sign (index).<br>Note that while excavating, the surface has a different colour than when the excavation is completed (excavated area). |
| | Inbouwing |  | Index | Physical | Temporal | Yes | When closing the valves around the project area to be able to empty the pipes, replace them and make the connection to the existing network. Also used when removing or replacing an hydrants. |
| **utility service provision** | No gas availability |  | Index | Non-physical | Temporal | Yes | Useful to visualize that consumers do not have utility service provision. It makes possible to see which houses do not have access to the utility services and when. This relates to the construction activity 'inbouwing' which in some cases require people to be at home to close the valves. |
| | No water availability |  | Index | Non-physical | Temporal | Yes | |
| **Construction components** | Trench framework |  | Symbol | Physical | Temporal | Yes | Used to withstand the collapse forces of a failing trench wall, helpful to safeguard worker's from injury. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Noise |  | Index | Non-physical | Temporal | No | To represent that there is nuisance caused by the construction activities that might affect the environment and people living in the surroundings of the project area. |
| Work safety | Construction fence |  | Icon | Physical | Temporal | Yes | Important for safety, environment, or when the project is being developed in crowded areas. Also used to secure the storage spaces and sheds. |
| | Hazard excavation |  | Index | Non-physical | Temporal | Yes | To indicate areas where extra measures are required, for example, for when there are asbestos in the excavation area. |
| Traffic measures | Parking restriction |  | Index | Physical | Temporal | Yes | The parking spaces, normally available, are used as excavation, working or safety areas, therefore, it is not possible to park there. This is common while working in cities and areas with limited space. |
| | Alternative route |  | Symbol | Physical | Temporal | Yes | When roads are closed due to excavation or works, alternatives routes can be suggested and indicated by this symbol. |
| Labels | Date and time | dinsdag 8:00 AM 18/04/2022 | Symbol | Non-physical | Permanent | No | Additional information to indicate the location and time that is being visualized. |

## 4.4 Treatment validation

### 4.4.1 Validation criteria

Five validation criteria were formulated as described in chapter 3.3.1. These include completeness, understandability, representativity, applicability, and flexibility. Completeness evaluates whether the framework includes semiotics that supports project management activities during the construction process; it refers to requirements 2, 3, and 4. Understandability assesses whether the implementation of semiotics in construction process visualization is self-explanatory and if there is consensus in the meaning and representation (requirement 5). Representativity considers that the framework was developed based on one workshop with one study case, so it evaluates if the semiotics included in the framework could be used to create construction projects visualizations of other subsurface utility project types, for instance, different disciplines such as electricity or data. Applicability refers to the main goal of this project, as well as requirement 6, which states that the framework shall enhance the drafting of construction process visualization; hence, this criterion analyses whether the framework facilitates creating construction simulations and its rapid drafting. Finally, considering that different project types might require new objects and activities, as was seen when developing the construction process visualization of the Project Bathemnse Laden, flexibility assesses the ability of the framework to include new semiotics under the proposed structure and categories, which also refers to requirement 1, 2 and 3 of this project. The validation criteria are summarized in Table 8.

*Table 8 Validation criteria*

| | |
|---|---|
| **Completeness** | Does the framework include semiotics that support project management in the construction process? |
| **Understandability** | Are semiotics self-explanatory when implemented in construction process visualizations? |
| **Representativity** | Can semiotics included in the framework be used to develop construction process visualization of different project types? |
| **Applicability** | Does the framework facilitates the rapid drafting of construction process visualizations? |
| **Flexibility** | Can additional semiotics be included in the framework under the proposed structure? |
| | Can additional semiotics be added to the framework within the proposed categories? |

### 4.4.2 Validation of the semiotics framework

Results from Workshop 2 are presented in this chapter. Each validation criterion is discussed, and the results from both sessions are included.

*Completeness*

To validate the completeness of the semiotics framework, the participants in the two validation sessions were asked the following question: *Does the framework include semiotics that supports project management activities?*.

During the first validation session, it was required to specify what kind of project management activities the criterion referred to. The definition of project management for some participants was related to finances, making schedules, and planning the control of the project, which is difficult to visualize in a construction process visualization since it does not happen during the construction process. However, when referring to project management as stakeholders and surrounding management, some elements such as traffic measures are included in the framework and support project management in the construction process.

Besides, it was emphasized by the experts that the completeness of the framework depends on the purpose of the construction process visualization in which these semiotics will be included. If the goal is to inform the client and citizens living in and around the project area, a construction process visualization made out of semiotics in this framework would be a good way of visualizing the process and informing people what to expect. On the other hand, given the expertise of field workers, they know how the construction process is carried out, and visualizing, for example, utility service provision would not add benefits to their work. When referring to the construction process visualization of project Overtoom, one participant noted:

> *If the purpose is to inform the surroundings, municipalities, and clients, then what you have done is clear. Everyone knows what to expect. But if you ask the technician, men in the field, they need to know how to do it and not where there is no gas or water because they know that when they are digging that there is no gas or water. It has something to do with the purpose.*

Participants in the second validation session agreed that the framework contains several elements that support project management. However, other elements might be added eventually, depending on the project type. This is reflected in the following quote from one of the participants who also participated in Workshop 1:

> *Looking at the framework, overall, it is very complete. Of course, at certain projects there are some specific elements but you cannot include everything in a framework […] while working on a project you will probably miss specific items based on that project, and sometimes you see it once a year, so it is not necessary to have it in the framework.*

Referring to the construction process visualization of the Project Bathmense Laden, another participant pointed out the following example of a semiotic that was not included in the framework but is important in the project environment management:

> *One essential element that is missing is the area needed to lay the pipe above ground before it is drilled and the specific location where the drilling machine is located […] one day before the drilling, they make the connection of the different pipes. The pipe is laid in the sidewalks and perpendicular streets, then people are not quite happy about it.*

To sum up, the framework of semiotics is dependent on the purpose for which it would be implemented. When the goal is informing citizens about the process, the framework includes numerous semiotics that enhances project management, for instance, traffic management. However, according to experts in project execution, the semiotics framework would not add as many benefits when the purpose is to develop construction process visualizations for the field workers. Besides, relaying the completeness of the framework on two study cases did not allow to include semiotics that might support project management in other project types.

*Understandability*

The following question helped start the discussion about the understandability of the framework: *Are the semiotics self-explanatory when implemented in construction process visualizations?*

From the discussion held during the first session, one of the experts indicated that some semiotics can be easily understood, and its implementation is self-explanatory when the purpose is to inform people living in the surroundings—for example, working spaces or traffic signs. On the contrary, another participant criticized the colors chosen to represent conflictive areas and semiotics in the category of working areas in general. The following quote was stated:

> *When looking at the areas where you are working in, if you see at the conflictive area, it does not look like a conflictive area. It is very similar to the working space. So, the colours for me are not self-explanatory for the object that it is use for. People living around the project area, if they see pink they might think it is something good or they are working, and green might mean that they are already done with the works.*

Similarly, during the second validation session, experts also suggested that the selection of colors for surfaces such as working areas and roads might be improved. One of them referred to the construction process visualization of project Bathmense Laden being displayed and noted:

> *There is no contrast between the excavation area and the vehicle lane, which makes it difficult to distinguish between both. When representing working areas there is not a specific color that directly says this is that area. Utility network components are quite well known among the field workers, but for the additional project information such as construction activities and working areas, it can be useful to have a legend additional to the visualization.*

Moreover, it was suggested that when developing a construction process visualization for the field workers, more attention should be given to the utility network components, which might have to be visualized in a different way than they already are in order to be easier to identify them. A participant pointed out the example of afsuiters in the framework and construction process visualization of Project Overtoom and said:

> *Those parts are really important for us because we want to close pipes when working with them, then you have to see clearly where they are so you can see what the impact is in the whole area. Now it just one stripe or the same as the drawings we use (2D spatial model). Maybe also important for people from the surroundings, because they place their cars on the afsuiter, then you cannot use it. This is always a discussion with the mechanics in the field that we have to point them out. If you can see them in the visualization makes it a lot easier.*

Results from both sessions suggest that the framework includes self-explanatory semiotics when implemented in construction process visualization and others that are less. The colors chosen for colored surfaces, such as excavation areas, make it difficult to differentiate between semiotics. This might be solved by including a legend in the construction process visualization.

*Representativeness*

To discuss the representativeness of the framework, participants were asked: *Can the semiotics included in the framework be used to develop construction process visualization of different project types?*

It was agreed by the experts participating in the first validation session that the semiotics in this framework can be used to develop construction process visualization of different types of projects. This was concluded because most of the activities in the planning of project Overtoom are similar to other projects of different disciplines, for example, laying cables instead of pipes, and the way the work is done is almost the same. This is reflected in the following quote:

> *Now you are using it for pipes; if you place new cables, you can use the framework as well. The way we work is almost the same: you dig the trench, throw stuff, close it, then you go to the next section. Same for cables, but then you have longer rounds.*

On the other hand, during the second validation session, it was pointed out that specific activities for specific disciplines might be missing in the framework. The example of data projects was highlighted, of which semiotics are not included in the framework.

Thus, it can be suggested that the framework includes semiotics that can be used to develop construction process visualizations of different utility disciplines. However, specific activities might need to be included eventually. The framework comprises traffic measures, for example, that can be implemented in any project. Because of the study case chosen for suggesting semiotics during workshop 1, the framework includes several elements that can be used for projects involving excavating trenches and laying pipes or cables.

*Applicability*

For the discussion of the framework's applicability, participants were consulted on the following question: *Does the framework facilitate the rapid drafting of construction process visualizations?*

Experts participating in the first validation session suggested that using the framework of semiotics. Therefore construction process visualizations, makes the street works more understandable when the purpose is towards citizens. However, for people working in the field, the application of the framework would not help in the communication or the work itself. Besides, it was highlighted that the current engineering process might limit the implementation of construction process visualization at Siers Infraconsult. As one participant claimed:

> *It Is useful that you proof the merit of using those models, but at the beginning, you need to make those input drawings; you have to make them in another way. In a normal way, it is too much work for us to do them […] for normal work, we have to change parts in the process of engineering.*

In the context of supporting the rapid drafting of construction process visualizations, the participants of the second session were consulted about the possibility of selecting semiotics from the framework, adding them to the existing 2D drawing of a project, and georeferenced them to facilitate and automate the process. To this, one of the engineers who participated in the project Bathmense replied:

> *Yes, you can use it in different layers; if you use the semiotics once or twice in a model, then you have it.*

On the whole, the applicability of the framework is limited by the current engineering process at Siers Infraconsult. Construction process visualizations are not employed in subsurface utility projects carried out by the company; therefore the implementation of these visualization techniques must be enhanced first. Once construction process visualizations are added to the engineering process, the performance of the framework can be facilitated by, for example geo-referencing semiotics.

*Flexibility*

The following questions helped to start the discussion about the framework's flexibility: *Can additional semiotics be included in the framework under the proposed structure? And can additional semiotics be added to the framework within the nine proposed categories?*

In response to the first question, in both sessions, it was agreed that semiotics could be added under the proposed structure, which includes the most relevant characteristics. The answer was similar to the second question. Additionally, participants in the second validation session were consulted on which category the semiotic nuisance should be included. This semiotic, part of the construction process visualization of project Bathmense Laden, was initially included in the category construction components, which might not be the most suitable, but as a participant claimed, considering the nine categories, construction components seem the most fitting. Another expert suggested moving nuisance to the category of utility service provision, to which the following was added:

> *I remember last time (Workshop 1) that we discussed that the noise to the environment should be included and not for the field workers. I agree that it might not be totally fitting in the construction components category since it is not a component. It could be placed in the category utility service provision as proposed but then you might have to change the name of the category to environmental impact, for example. Then, the category includes: no gas availability, no water availability, and noise pollution.*

The results from both sessions regarding the flexibility suggest that the proposed structure (chapter 4.2.3) includes the most relevant characteristics of semiotics. Therefore, the temporal, physical, and geo-referential features of new semiotics to be included in the framework can be easily identified. However, although the categorization of the semiotics (chapter 4.3) was acclaimed, not every semiotic might fit within those categories as it was the case of nuisance, which led to the suggestion of changing the name of the category utility service provision to environmental impact.

Overall, the results from the validation workshops suggest that the semiotics framework meets the validation criteria depending on the purpose of its construction process visualization. As is the case of completeness which, besides being linked to the purpose, results indicate that additional elements might have to be added for specific activities. The main remark regarding understandability is that the colors chosen for colored surfaces limit the understanding of the semiotics when implemented in construction process visualizations. From the results of representativity, it can be noted that general construction activities and objects are included in the framework, which can be used to develop construction process visualization of any project type. However, specific elements from different disciplines are not included. Finally, the structure of the framework allows to include additional elements and their characteristics in the framework; however, the categories might have to be changed to fit specific semiotics.

# 5 Discussion

This study extends existing frameworks and classifications of semiotics used in construction projects and develops a framework of semiotics that support the drafting of construction process visualizations of subsurface utility projects. Findings suggest that visualizing the execution of utility projects enhances the understanding of the process and facilitates complex project coordination, mainly when the purpose is to inform citizens, clients, and suppliers. This aligns with the study on signs in construction process simulations by Hartmann and Vossebeld [6]. However, their study focuses on 4D visualization of large-scale projects, and validation of the framework is not presented. In that sense, this study empirically validated the designed framework in two study cases and with experts working in different disciplines of utility projects.

Related to the subsurface utility projects, the study of olde Scholtenhuis and Doree [4] also suggests that the coordination of construction works is supported by using visualization techniques such as 4D models. These studies are relevant for proving evidence of the benefits of combining visualization models with time. However, to date, literature on construction process visualization in 2D+time is limited, even though most utility network data is recorded in 2D models. This study provides a foundation for the merit of visualizing the construction process in two dimensions over time. Besides the framework of semiotics as its main contribution, this study proposes an approach of how to create construction process visualizations and their practical impact on the management of utility street works.

Nevertheless, the development of this project included some limitations. Siers Infraconsult does not employ construction process visualizations. Hence, construction simulations had to be created with the available models and schedules of the two study cases. From the 2D drawings, only the utility network components that the researcher considered relevant were displayed. Regarding the activities included in the planning, their exact duration in hours was estimated. The focus of this project was not on developing a precise construction process visualization instead on implementing the semiotics framework. Therefore, further research might focus on enhancing the implementation of construction process visualizations by analyzing their advantages when implemented in subsurface utility projects.

Since construction process visualization must exist for the framework to be implemented, spatial models and schedules currently used might need to be adjusted. Particular elements might not be displayed while others need to be added to the drawings—for example, new tasks of construction activities and when specific elements are displayed. How detailed the construction process visualization is will depend on how detailed the visualization models and schedules are. Besides, data needs to be documented in a specific format compatible with the software in which the simulation is created, in the case of this project, Navisworks. Therefore, it is recommended that the workflow to create construction process visualizations proposed in this report is reviewed and improved by designers and engineers working with visualization models to automate the process to a greater extent.

Another problem of this project was the reliance on one study case to suggest semiotics that can be included in the framework. Although the selection of the project Overtoom as a study case was well thought out due to the availability of visualization models and the activities included in the schedules, by considering only one project, other objects and activities that were not part of this project might have been excluded. Furthermore, the validation of the framework is narrowed in two ways. In the first validation session, the same project used for determining the semiotics to include in the framework (Workshop 1) was used to validate the framework. In contrast, in the second session, using project Bathmense Laden as a study case, the framework was validated with the same expert group as

Workshop 1. This results from the limited amount of time, experts, and available data. Then, it is recommended that further studies consider more projects of diverse disciplines to expand the framework and validate it. Those studies can benefit from the approach introduced in this report.

Finally, the lack of data (i.e. 3D drawings and schedules) was infeasible to develop a semiotics framework to support the drafting of construction process visualizations of utility street works in 3D+time. At Siers Infraconsult, the number of subsurface utility projects that employ 3D spatial models is limited because most of the utility network data is recorded in two dimensions. Thus, the focus of this project was directed to construction process visualization in 2D+time in combination with some 3D elements that enhance the visualization, for instance, houses and buildings shown as 3D blocks. This shortcoming can be overcome by investigating the feasibility of employing 3D spatial models to represent utility networks, a topic that has already been discussed in previous studies [2].

The framework proposed in this study can serve as a sound starting for developing a framework of semiotics directed to 3D+time construction process visualizations. Some semiotics would have to be visualized as 3D solids, for example, excavation areas and pipes, but overall the semiotics, classification, and characteristics would be very similar. Similarly, a framework of semiotics that supports the drafting of construction process visualizations for in-building utility networks could use the framework in this report as a starting point. This might be achievable since some of these projects carried out by Siers already employ 3D spatial models.

# 6 Recommendations

Overall, to facilitate the implementation of the designed framework of semiotics and obtain outstanding results, it is suggested first to enhance the utilization of construction process visualizations for subsurface utility projects carried out by Siers. This might involve adapting the engineering process to include the development of construction process visualizations in the design phase and its implementation during the execution stages. To this end, existing drawings and schedules might have to be adjusted. It is recommended to visualize all the utility networks involved in a project in one model and make schedules more detailed by, for example, breaking down general activities such as HDD into more specific . Documenting utility network data in the appropriate format and with the required information would facilitate creating construction process visualizations. Nonetheless, improving the automatization of developing construction process visualizations by reviewing the workflow proposed in this report is also recommended.

The construction process visualizations resulting from this project were exported from Navisworks as a video to be used during the workshops. The quality was not the most optimal, which might limit the understanding of the simulation. For example, the video had to zoom in to specific sections of the project area for some semiotics to be clearly seen, making it difficult to see other sections carried out simultaneously. This is an issue in projects where the sections and phases comprise a large area, as in Project Bathmense Laden. Therefore, it is suggested to improve the video quality of exported construction process visualizations, improve rendering, or use software other than Navisworks to develop the simulation. Navisworks was chosen because it is used within Siers Infraconsult for design review. However, other programs such as Synchro might allow to development of more detailed and visually appealing construction simulations.

The implementation of construction process visualization in 2D+time has shown that utility projects can benefit from visualization techniques that link spatial models with time. This is feasible when considering that utility network data is recorded in two dimensions. Although employing 2D+time simulations in subsurface utility projects already brings several benefits, such as improving coordination and schedule compliance, two-dimensional visualizations do not support time-space conflicts and clash detection, which is also crucial for project management activities. These are features of three-dimensional visualization techniques such as 3D spatiotemporal models. Therefore, it is recommended that 3D spatial models are implemented to visualize utility networks within Siers and to develop 3D+time construction process visualizations subsequently. This way, the benefits of spatiotemporal models can be maximized, and the time and work to develop them can be justified.

# 7 Conclusions

This design project aimed to develop a framework of semiotics that support the drafting of construction process visualizations of utility street works. To that end, existing frameworks and classifications of semiotics were considered as a starting point for identifying examples of semiotics and an initial structure for the framework. Besides, a workflow to develop construction process visualization was proposed by analyzing the current visualization techniques employed at Siers.

A workshop was organized in which participants, experts working on utility network projects at Siers Infraconsult, suggested elements to be included in the framework based on their expertise. This workshop took Project Overtoom in Deventer as an example. Results served to update the framework's structure to one that allows to group different elements under categories and includes their most relevant features. The characteristics included in the framework are category, representation, sign type, temporal characteristic, physical characteristic, geo-referential characteristic, and illustrative example, which are described for each element included in the framework. Besides, the nine proposed categories of semiotics include spatial orientation elements, work safety, working areas, utility service provision, traffic measures, construction activities, utility network components, and construction components. These, in turn, can be arranged depending on the purpose of the construction process visualization in which they will be included as designed for field workers or citizens and clients.

In order to use the designed framework as a standard theory when creating construction process visualizations of other utility street works, the framework was validated. The validation occurred in two sessions in which experts on execution, engineering, planning, and coordination participated. The validation was performed in two study cases, project Overtoom for validating the framework with people working in the execution of utility projects, and project Bathmense Laden, in which people working in the design and preparation phases participated.

The results of both sessions suggest that the completeness of the framework depends on the purpose of its construction process visualization, and additional elements might have to be added for specific project types and disciplines. The understandability of the semiotics, when implemented in construction process visualizations, can be improved, particularly the selection of colors to represent surfaces. It was also agreed that the representativity of the framework allows for developing construction process visualization of several project types; however, specific elements from disciplines different from the study cases are not included. Finally, the flexibility of the framework's structure allows to include additional elements and their characteristics in the framework; however, the name of the categories might have to be changed to fit specific semiotics.

Overall, the designed framework meets its goal of supporting the drafting of construction process visualizations, categorizing the semiotics based on their characteristics, and including elements that support project management activities. However, the framework's performance is limited by its purpose and the availability of construction process visualizations.

To address this limitation, future research should focus on enhancing the utilization of construction process visualizations for subsurface utility projects as well as the implementation of 3D spatial and 3D spatiotemporal models. Finally, further research might focus on extending the designed framework and considering utility projects of different disciplines and types to propose semiotics and for validation purposes.

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# 9 Appendices

## 9.1. Workshop 1 protocol

### Goal of the workshop

The goal of this workshop is to determine which elements should be included in the construction process visualization models in 2D+time of street works, taking an example the project Overtoom in Amersfoort.

### Inputs

*Classification of semiotics*

Classification of semiotics which allows to describe their characteristics. For example, physical and non-physical elements, temporal and permanent, and the classification of signs introduced in chapter 2.3. Therefore, the initial description of the framework of semiotics in chapter 4.2.2.

*Project Overtoom in Amersfoort*

The description of the project Overtoom in Amersfoort and the activities in the existing planning. Besides, the 2D visualization of phases 1 and 2 and the printed 2D visualization of the sections Somersbergen even zijde and Somersbergen oneven zijde which are used for sketching. Finally, the initial construction process visualization was developed from the existing planning and 2D models.

### Expected outcomes

A list of semiotics containing physical and non-physical elements can be included in the construction process visualization of street works carried out for the project Overtoom in Amersfoort.

### Participants

The participants for this workshop and their expertise are listed in this section.

- Mechiel van Manen (3D/BIM)
- Ruby Mombarg (Planning & control, coordination)
- Bernice Overbeek (Planning & control)
- Gerben Wolf (3D/BIM, GIS, district heating)
- Axel Bosman (Engineering)

### Date and location

The workshop was held on May 11th, 2022, at 13h00 for approximately one hour. The session took place at the offices of Siers Infraconsult in Oldenzaal.

### Outline of the workshop and estimated duration

*Opening (5 min)*

During the opening, participants will be provided with an Informed Consent Form that they will sign in case they agree to participate in the workshop and its activities.

The Informed Consent Form that will be used can be found in Appendix 0. An Information Sheet accompanies the consent form, sent to the participants before the workshop, so they have a clearer idea of the topic beforehand.

*Introduction (20 min)*

The introduction will focus on framing the problem on which the BSc project is based and building an understanding of the project and workshop. The background information given in the Information Sheet is elaborated in each section.

During this section, the researcher act as a speaker/moderator. While the participation of the attendants is limited to understanding the problem and structure of the workshop, they are allowed to ask questions.

*Framing the problem*

Description of the problem

In this section, the problem behind this project is presented, and some terms that will be used during the workshop are defined. For instance: 'construction process visualizations' 'semiotics o semiotic elements,' 'street works,' '2D+time', '3D+time', 'physical elements,' and 'non-physical elements.'

Description of the BSc project

In this section, the focus of the BSc, as well as the goals and subgoals, are described.

*Building understanding*

Description of the workshop

During the workshop description, its goal is presented, as well as the inputs and the expected outcomes. Besides, a brief explanation is given about the activities performed to achieve the goal (brainstorm/sketching and sharing out).

Description of the Overtoom project

In this section, the project Overtoom is introduced. Besides, the existing planning (Microsoft Project) containing the construction activities to be performed and the 2D visualizations (AutoCAD) that were provided of the water and gas networks are shown.

*Brainstorm/Sketching (20 min)*

This section is the core of the workshop and is divided into two rounds where the active participation of the attendees is required. The researcher acts as the moderator and participates in the brainstorming and sketching activities.

The first round takes place right after presenting the 2D visualizations of the water and gas lines. It is explained that these types of models are the ones used at Siers Infraconsult, which are not construction process visualizations. This is because the models show the old network, the new network, and the existing infrastructure but not the construction activities. Then, the participants are asked to individually brainstorm objects or activities that they consider important to add in order to create a construction process visualization. The expected outcome from each participant is a list of physical and non-physical elements, including the name of the elements, a description or meaning, and the symbol they would use to represent them. In order to facilitate the sketching and brainstorming, printed versions of the 2D visualization are handed in as well as white paper sheets and markers/pens.

Next, the initial simulation in 2D+time for the project Overtoom is displayed to show the participants the intended purpose of the framework. In the second round, the participants are asked to complement their list of elements if they have new ideas.

*Share out (10 min)*

During this section, the participants present their final results, and there is time for discussion after each presentation. As in the previous section, the researcher is the moderator and participates in the activities.

*Closure (5 min)*

At the end of the workshop, once all the participants have presented their results, it is explained that the elements they have proposed and how to represent them will be implemented in the 2D+time simulation of the Overtoom project. Besides, it is indicated that the outcomes will constitute a framework of semiotics that support the drafting of construction process visualizations. Finally, it is highlighted that the framework must be validated in order to be used in other projects, for which another workshop will be planned.

## 9.2. Informed consent form

In this section, the Informed consent form used during workshops 1 and 2 is presented.

| *Please tick the appropriate boxes* | Yes | No |
|---|---|---|
| **Taking part in the study** | | |
| I have read and understood the study information (information sheet) attached to the invitation email dated dd/mm/yyyy. | □ | □ |
| I have been able to ask questions about the study and my questions have been answered to my satisfaction. | □ | □ |
| I consent voluntarily to be a participant in this workshop and understand that I can refuse to answer questions and I can withdraw from it at any time, without having to give a reason. | □ | □ |
| **Consent to be Audio/Video Recorded** | | |
| I agree to be audio/video recorded | □ | □ |
| I agree to the audio/video recording to be transcribed as text | □ | □ |
| **Use of the information in the study** | | |
| I understand that the information I provide will be used for research purposes only and the recorded video will be deleted once the BSc project is completed. | □ | □ |
| I agree that my information and real name can be quoted in research outputs (report). | □ | □ |
| I give the researchers permission to keep my contact information and to contact me for future research projects. | □ | □ |

**Signature**

________________________________ ___________________________

Name of participant Expertise

________________________________ __________________

Signature Date

**Study contact details for further information:**

Alejandro Chipantaci Angamarca

a.chipantaciangamarca@siersgroep.nl

## 9.3. Ethics committee approval

The approval by the Natural Sciences and Engineering Sciences Ethics committee to carry out workshops during the development of this project is presented below.

**UNIVERSITY OF TWENTE.**

Mr. A.I. Chipantaci Angamarca

| FROM | DATE | PAGE |
|---|---|---|
| A.M. Klijnstra<br>T 053-4895607<br>a.m.klijnstra@utwente.nl | 27 May 2022<br>OUR REFERENCE | 1 of 1 |
| SUBJECT<br>LETTER OF APPROVAL | YOUR REFERENCE | |

Dear Mr. Chipantaci Angamarca,

The Natural Sciences and Engineering Sciences Ethics committee has reviewed your submission for "Developing a framework of semiotics to support the drafting of construction process visualizations in 2D+time and 3D+time of utility street works" and based on the submitted material has formulated a positive advice for the Dean.

On the basis of this advice I approve your application and leave the responsible execution of this project in your hands trusting that you will conduct this research in a manner worthy of the University of Twente.

The request has been registered under **reference number 2022.147**.

I wish you good luck with your research.

Yours sincerely,

Prof.dr.ir. H.F.J.M. Koopman
Dean faculty of Engineering Technology
University of Twente

## 9.4. Construction process visualization Project Overtoom

The development of the construction process visualization of the Project Overtoom follows the workflow in Figure 6.

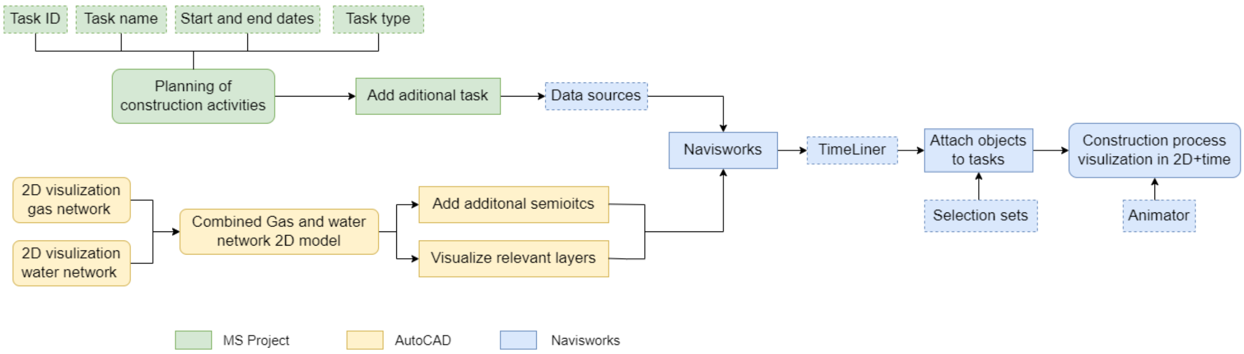



*Figure 6 Workflow construction process visualization Project Overtoom*

Given the availability of data and that water and gas networks were documented in two separate drawings, the first step was to combine the 2D visualization of the gas and water network into one model. From this integrated model, only the relevant layers are displayed, meaning that layers containing elements not part of the construction process to be visualized were hidden, for example, textual information. This process is performed in AutoCAD. Simultaneously, the plan of the project is adjusted in Microsoft Project. In the existing planning, each activity has a task ID, task name, start, and end date, and a task type is added, which determines how each activity is visualized. The task types used for this project are described in Table 9.

*Table 9 Task types Project Overtoom*

| Task type | Start Apperance | End apperance | Simulation start appearance | Description |
|---|---|---|---|---|
| Construct | Red (90% transparent) | Model Appearance | None | Construction of shed |
| Background | Model appearance | None | Model Appearance | Display of exisiting infrastructure outside the project area |
| Digging | Purple (80% transparent) | Model Appearance | Hide | Excavation of the trench |
| Remove | Model Appearance | Hide | Hide | Remove old pipe |
| Place | Model Appearance | Model Appearance | Hide | Instale new pipe |
| Overzetten | Model Appearance | Model Appearance | None | Connection to the exsiting network |
| Closing | Purple (80% transparent) | Hide | None | Closing the trench |
| Sign | Model Appearance | Hide | Hide | Signs pop up |
| No sign | Hide | Hide | Model Appearance | Signs disappear |

Then, the two-dimensional drawing and the planning are imported to Navisworks. The latter through the *Data Sources* window in the *TimeLiner* tool, where every object from the visualization model is subsequently attached to an activity in the window *Task*. In order to facilitate the procedure, *Selection Sets* are created in which it is possible to group elements that are part of the same task. The task types (Table 9) are created in the window *Configure*. Finally, the construction process visualization can be displayed in the window *Simulate*, where the simulation's start and end dates, duration, and views can be adjusted and exported. An animation is created in the Animator tool using viewpoints of each section of the project to enhance the visualization. This allows moving the visualization to every section *Viewpoint* at a specific time.

The construction process visualization used during workshop 1 was developed merely from the activities in the existing planning and the elements in the current 2D drawings. However, for the first session of Workshop 2, this construction process visualization is updated with new elements from the semiotics framework. Therefore, new semiotics are drawn in the AutoCAD model, and new tasks are added to the planning. The activities added to the existing plan are presented in Table 10. In order to create a detailed construction process visualization, the time in hours required for each activity is included in the start and end dates considering a working day from 08:00 AM to 05:00 PM. The duration of activities in the new planning is estimated.

*Table 10 New tasks Project Overtoom*

| Task name | Duration | Task type | Description |
|---|---|---|---|
| Preparing | 1 day | Construct | Construction of shed |
| Securing | 0.5 days | Construct | |
| Excavation signs | 2 days | Sign | Construction activity excavation |
| Other signs | 2 days | Sign | Construction components, traffic measures, working areas |
| No entry | 5 days | No sign | Road closed |
| Water/Gas availability | 0.5 days | Sign | No service provision |

It is essential to highlight those semiotics with hatches in AutoCAD that need to be transformed into 3D solids, so the colored surfaces are visible in the visualization of the construction process. Hatches are not visualized in Navisworks. Besides, 3D blocks are created to visualize houses and buildings to make the simulation more visually appealing. This is done by making 3D solids out of the layer *PAND* and giving them a certain height (e.g., 2.0 m). Then, the two-dimensional AutoCAD drawing was divided into three separate drawings, named layers, that were given a specific elevation in Navisworks. *Layer 0* including roads, green areas, and waterways, was given a height of - 0.03 m from the origin. *Layer 1* at 0.0 m that contains utility networks, semiotics visualized in the ground, and buildings/houses. *Layer 2,* which includes semiotics visualized above the houses (e.g., house number).

## 9.5. Workshop 2 protocol

### Goal of the workshop

The goal of this workshop is to validate the designed semiotics framework through expert opinion in order to determine whether the validation criteria are met and the product can be used as a standard framework in construction process visualization in 2D+time of future street works projects.

### Inputs

*Framework of semiotics*

The framework of semiotics developed from the results of Workshop 1, as well as the description of each characteristic and category. These inputs refer to the final framework presented in chapter 4.3

*Validation criteria*

Validation criteria defined from initial requirements. These criteria include completeness, understandability, representativeness, applicability, flexibility, and specificity, presented in chapter 4.4.1.

*Project Overtoom*

Construction process visualization of phases 1 and 2, including semiotics from the framework, and presented as a matter of a video.

*Project Bathmense*

The description of the project Bathmense in Deventer, the activities in the existing planning, and the 2D models. Besides, a construction process visualization of Kabeltrace 1 to 4 and Opstarten Project, including semiotics from the framework, is presented as a video.

### Expected outcomes

Reflective discussion with experts regarding the framework of semiotics and its implementation in construction process visualizations concerning the proposed validation criteria.

### Participants

The participants for the first session are experts involved in the project Overtoom; their names and expertise are listed below.

- Ruby Mombarg (project coordinator/environment manager)
- Sieger Zeilstra (Executor)
- Travis Vink (executor)
- Guido van Veenen (Preparator/Engineering)
- Mechiel van Manen (3D/BIM)

Participants for the second session are some of the experts participating in Workshop 1; their names and expertise are listed below.

- Bernice Overbeek (Planning & control)
- Gerben Wolf (3D/BIM, GIS, district heating)
- Axel Bosman (Engineering)

### Date and location

The first validation session was held on June 09th, 2022, at 13h30 for approximately one hour. The session took place only through Microsoft Teams.

The second validation session was held on June 20th, 2022, at 14h00 for approximately one hour. The session took place at the offices of Siers Infraconsult in Oldenzaal.

### Outline of the workshops

*Opening (5 min)*

During the opening, participants will be provided with an Informed Consent Form that they will sign in case they agree to participate in the workshop and the activities it involves.

The Informed Consent Form that will be used can be found in Appendix 0. An Information Sheet accompanies the consent form, which is sent to the participants before the workshop, so they have a clearer idea of the topic beforehand.

*Introduction (25 min)*

The introduction will focus on framing the problem on which the BSc project is based and building an understanding of the project and workshop. In this section, the researcher elaborates more in detail on the background information given in the Information Sheet.

During this section, the researcher acts as a speaker/moderator, while the participation of the attendants will be limited to understanding the problem and structure of the workshop; they are allowed to ask questions.

*Framing the problem*

Description of the problem

In this section, the problem behind the BSc project is presented, and terms used during the workshop are defined. For instance: 'construction process visualizations' 'semiotics o semiotic elements,' 'street works,' '2D+time', etc. Besides, the focus of the project and the goal and subgoals are briefly explained.

Description of the workshop

During the description of the workshop, its goal is presented, as well as the inputs and expected outcomes. Besides, the activities to be performed in order to achieve the goal are briefly described.

*Building understanding*

Recap results workshop 1

In this section, workshop 1 and its results are described. Therefore, the framework's structure, the categories in which the semiotics are classified, and some examples of elements included in the framework.

Description of the study cases

During this section, depending on the session, each project is introduced, how the construction process visualization was created is described, and what semiotic elements are included in it. Therefore, the construction process visualization is displayed, and the participants are provided with the framework of semiotics. This section focuses on emphasizing the difference between the current situation (2D models and planning separated) and the aimed product (construction process visualization).

*Discussion (25 min)*

The core of this workshop is the discussion. Here, the researcher acts as the moderator, and the active participation of the attendees is required.

First, the participants are asked about their general opinion and feedback regarding the semiotics framework and the implementation of construction process visualization compared to the traditional 2D visualizations and planning. Then, the validation criteria are introduced, and each criterion is discussed.

*Closure (5 min)*

At the end of the workshop, once all the discussion is completed and all the validation criteria are covered, it is explained that the outputs of the session will be used as part of the validation section of the final report to which they can have access once the project is completed as well as the construction process visualization.

## 9.6. Construction process visualization Project Bathmense

The development of the construction process visualization of the Project Bathmense in Deventer follows the workflow in Figure 7.

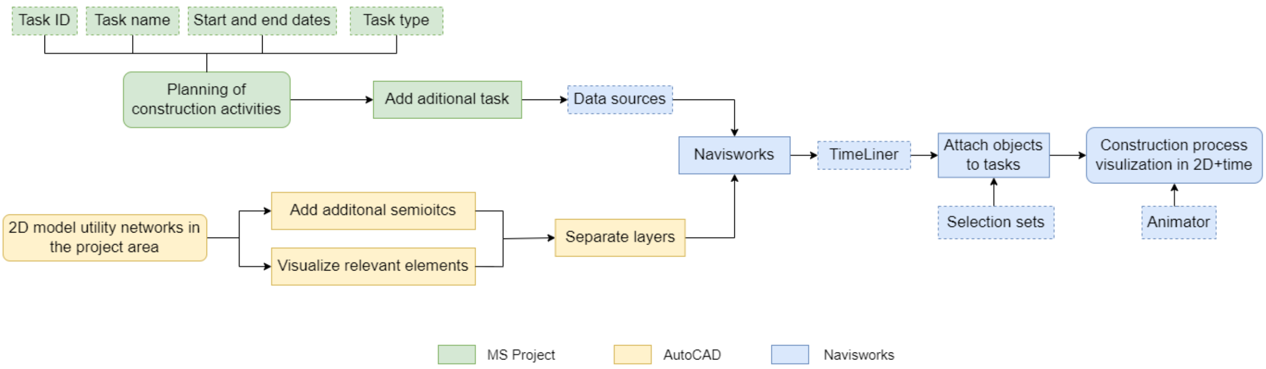



*Figure 7 Workflow construction process visualization Project Bathmense*

The first step is to select and display only the relevant layers in the AutoCAD two-dimensional drawing, including only elements that are part of the construction process of the eight phases for which the construction process visualization will be developed. Only the electricity network is included, while other utility lines are hidden. Then, other semiotics from the framework are included according to the activities in the planning.

In Microsoft Project, the planning of the eight phases is adjusted. A column indicating the *task type* is added, hours are assumed for each activity, and new activities are included that will allow visualizing new semiotics. The task types used for this project are presented in Table 11.

*Table 11 Task types Project Bathmense Laden*

| Task type | Start Apperance | End apperance | Simulation start appearance | Description |
|---|---|---|---|---|
| Construct | Brown (90% transparent) | Model Appearance | None | Construction of shed |
| Background | Model appearance | None | Model Appearance | Display of exisiting infrastructure outside the project area |
| Graven | Purple (80% transparent) | Model Appearance | Hide | Excavation of the trench |
| Trekken | Model Appearance | Model Appearance | Hide | Laying cable |
| Close | Purple (80% transparent) | Hide | None | Closing the trench |
| Dichtstraten | Black (50% transparent) | Hide | None | Putting tiles |
| Mantelbuis | Green (80% transparent) | Model Appearance | None | Installation of protection pipe |
| Sign | Model Appearance | Hide | Hide | Signs pop up |

Then, the two-dimensional drawing and the planning are imported to Navisworks, where the workflow is similar to project Overtoom. The planning is imported in the *Data Sources* window in the *TimeLiner* tool, where every object from the visualization model is subsequently attached to an activity in the window *Task*. In order to facilitate the procedure, *Selection Sets* are created in which it is possible to group elements that are part of the same task. The task types (Table 11) are created in the window *Configure*. Finally, the construction process visualization can be displayed in the window *Simulate*, where the start and end dates, duration, and views of the simulation can be adjusted, and it can be exported. An animation is created in the Animator tool using viewpoints of each section of the project to enhance the visualization. This allows moving the visualization to every section *Viewpoint* at a specific time.

For the development of the construction process visualization of project Bathmense Laden and subsequently implementation of the framework of semiotics, objects and activities were added to the existing 2D drawings and schedule. The activities added to the current plan are presented in Table 12.Then, the time in hours required for each activity was included in the start and end dates considering a working day from 08:00 AM to 05:00 PM. The duration of activities in the new planning is estimated.

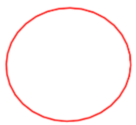
*Table 12 New tasks Project Bathmense Laden*

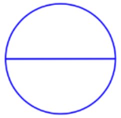
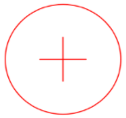
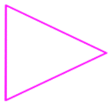
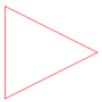
| Task name | Duration | Task type | Description |
|---|---|---|---|
| Preparing | 2 days | Construct | Construction of shed |
| Securing | 1 day | Sign | |
| Working areas | - | Sign | Working and safety areas |
| Nuisance digging trench | 4 days | Sign | Sign of nuisance |
| Nuisance closing trench | 3 days | Sign | |
| Excavation signs | - | Sign | Construction activity graven |
| Closing trench signs | - | Sign | Construction activity closing trench |
| HDD indicator | - | Sign | sign representing the drilled area |

3D blocks are created to visualize houses and buildings to make the simulation more visually appealing. This is done by making 3D solids out of the layer *B-PV-OG-BEBOUWING-GV* and giving them a certain height (e.g., 3.0 m). Then, the two-dimensional AutoCAD drawing is divided into four individual drawings, named layers, that are given a specific elevation in Navisworks. *Layer -0.30* includes roads, green areas, and waterways at an elevation of - 0.3 m from the origin. *Layer 0.15* at -0.15m contains working areas and street names. *Layer -0.03* which includes the semiotics representing protection pipes and trees is given an elevation of -0.03 m. *Layer 0*, placed at the origin contains cables, excavation and drilling signs, as well as traffic measures and safety signs. Buildings are also displayed in this drawing. Finally, at an elevation of 3.0m, *Layer 3* displays the number of the houses.

## 9.7. Framework of semiotics

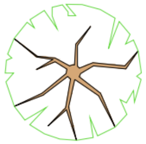
The complete list of semiotics is presented in this section grouped based on their category.

| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| Utility network components | Existing water pipe |  | Icon | Physical | Permanent | Yes | Utility networks and their components must be visualized under already existing standards such as NLCS. Representation might vary between databases (e.g. KLIC) and institutions.<br>The elements included as example in this category are some of the visualized in the 2D model of project Overtoom and Bathmense Laden. |
| | Water pipe to lay |  | Icon | Physical | Temporal | Yes | |
| | Water pipe to remove |  | index | Physical | Temporal | Yes | |
| | Afsluiter |  | Symbol | Physical | Temporal | Yes | |
| | Aanboorpunt |  | Symbol | Physical | Temporal | Yes | |
| | Aftakking |  | Symbol | Physical | Temporal | Yes | |
| | Bocht |  | Symbol | Physical | Temporal | Yes | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Brandkraan |  | Symbol | Physical | Permanent | Yes | |
| | Mantelbuis water |  | Icon | Physical | Permanent | Yes | |
| | Existing gas pipe |  | Icon | Physical | Temporal | Yes | |
| | Gas pipe to install |  | Icon | Physical | Temporal | Yes | |
| | Gas pipe to remove |  | index | Physical | Temporal | Yes | |
| | T-stuk |  | Symbol | Physical | Temporal | Yes | |
| | Aansluitcomponent |  | Symbol | Physical | Temporal | Yes | |
| | Leveringspunt |  | Symbol | Physical | Permanent | Yes | |
| | Verloopstuk |  | Icon | Physical | Permanent | Yes | |
| | Bescherming gas |  | Icon | Physical | Permanent | Yes | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Test range (proefsleuf) | | Index | Physical | Permanent | Yes | |
| | Existing electricity pipe | | Icon | Physical | Permanent | Yes | |
| | Electricity pipe to install | | Icon | Physical | Temporal | Yes | |
| | Mantelbuis electricity | | Icon | Physical | Temporal | Yes | |
| | HDD drilling length indicator | | Index | Non-physical | Temporal | Yes | |

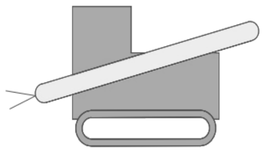
| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| Spatial orientation elements | Houses/buildings | 141 | Icon<br>Symbol (number) | Physical | Permanent | Yes | Spatial orientation elements represent the existing infrastructure in the surroundings of the project area.<br>The elements included as example in this category are |
| | Waterway | | Icon | Physical | Permanent | Yes | |

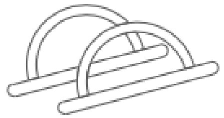
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Trees |  | Icon | Physical | Permanent/ Temporal* | Yes | some of the visualized in the 2D model of project Overtoom. |
| | Bushes |  | | Physical | Permanent/ Temporal* | | |
| | Vehicle lane |   | Icon Symbol (text) | Physical | Permanent/ Temporal* | Yes | It is important to differentiate between vehicles, pedestrian and bike lanes since along the project there are temporary changes (e.g. vehicle road is only accessible to pedestrians) |
| | Bike lane |  | Icon | Physical | Permanent/ Temporal* | Yes | |
| | Pedestrian and bike lane |  | Icon | Physical | Permanent/ Temporal* | Yes | |

*Depends on the project

| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| Working areas | Shed |  | Icon Index | Physical | Temporal | Yes | Space assigned for storing workers' belongings and for break/lunch. |

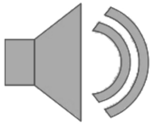
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Hub/Storage area |  | Icon<br>Index | Physical | Temporal | Yes | When the space is limited in a crowded project area, a hub or space can be used to store excavated soil and machinery. |
| | Excavation area |  | Icon | Physical | Temporal | Yes | Surface indicating the trench area. |
| | Conflictive excavation area |  | Icon | Physical | Temporal | Yes | Surface indicating the trench area in spaces where there might be conflict (e.g. excavation in roads, intersections, private property) |
| | Working space |  | Icon | Physical | Temporal | Yes | Area next to the trench assigned for work activities. |
| | Safety area |  | Icon | Physical | Temporal | Yes | Area next to the working space to assure enough distance between the working space and the surroundings. Also required to request permits. |

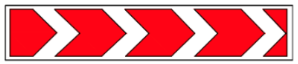
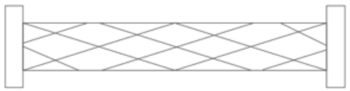
| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Motivation |
|---|---|---|---|---|---|---|---|
| Construction activities | Excavation |  | Index<br>Icon | Physical | Temporal | Yes | The activity of excavation itself. Consist of the surface being excavated (icon) and a excavation index.<br>Note that while excavating, the surface has a different colour than when the excavation is completed. |
| | Closing trench |  | Index<br>Icon | Physical | Temporal | Yes | The activity of closing the trench itself. Consist of the surface being closed (icon) and a excavation index.<br>Note that while closing the trench, the surface has a different colour than when the activity is completed. |
| | Drilling (HDD) |  | Index | Physical | Temporal | Yes | Construction method of installing utility lines under roads, water courses and environmentally sensitive areas without excavating a trench.<br>This process can be divided into specific sub-activities. However, this semiotic can be used to |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | locate a place where to put the drilling machine. |
| | Well drainage |  | Index | Physical | Temporal | Yes | Drainage of the soil by using wells in order to control the water table. |
| | Putting tiles |  | Index | Physical | Temporal | Yes | Represents the compacting of the soil after the trench is closed.<br>Different steps within excavation can be specified. |
| | Overzetten | (components appear/disappear) | Depends on the element | Physical | Temporal | Yes | Indicating the connection of the new line to the houses. |
| | Inbouwing |  | Index | Physical | Temporal | Yes | When closing the valves around the project area to be able to empty the pipes, replace them and make the connection to the existing network. Also used when removing or replacing an hydrants. |
| | Montage and manteltest |  | Index | Physical | Temporal | Yes | Assembly and sheath tests once the pipe is installed. |

| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| Utility service provision | No gas availability |  | Index | Non-physical | Temporal | Yes | Useful to visualize that consumers do not have utility service provision. It makes possible to see which houses do not have access to the utility services and when. This relates to 'inbouwing' and in some cases, people must be at home to close the valves. |
| | No water availability |  | Index | Non-physical | Temporal | Yes | |

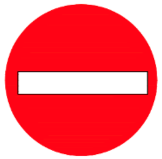
| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| Construction components | Bridge to houses |  | Icon | Physical | Temporal | Yes | Due to excavation it is not always possible for people to access to their houses, therefore a bridge is needed over the trench. |
| | Trench framework |  | Symbol | Physical | Temporal | Yes | Used to withstand the collapse forces of a failing trench wall, helpful to safeguard worker's from injury. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Noise |  | Index | Non-physical | Temporal | No | To represent that there is nuisance caused by the construction activities that might affect the environment and people living in the surroundings of the project area. |

| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| Work safety | Traffic fence |  | Icon | Physical | Temporal | Yes | Used to secure the project area, specially from the traffic. |
| | Direction traffic fence |  | Icon | Physical | Temporal | Yes | Used to secure the project area from the traffic and indicate the direction of the traffic flow. |
| | Construction fence |  | Icon | Physical | Temporal | Yes | Important for safety, environment, or when the project is being developed in crowded areas. Also used to secure the storage spaces and sheds. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Caution |  | Symbol | Non-physical | Temporal | Yes | Areas of attention, for example extra work, works on private property, etc. It can be accompanied by a conflictive area semiotic. |
| | Traffic regulator |  | Index | Physical | Temporal | Yes | When human resources are needed to control traffic. |
| | Hazard excavation |   | Icon<br>Index | Non-physical | Temporal | Yes | To indicate areas where extra measures are required, for example, for when there are asbestos in the excavation area. |

| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| Traffic measures | Bike lane |  | Icon | Physical | Permanent | Yes | To indicate the type of road. It can be accompanied by a type of lane semiotic (spatial orientation elements) |
| | Pedestrian lane |  | Icon | Physical | Permanent | Yes | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pedestrian lane |  | Icon | Physical | Permanent | Yes | |
| | No exit |  | Symbol | Physical | Temporal | Yes | When works are being performed at a specific intersection or street and it is not possible to exit that road. |
| | No entry |  | Symbol | Physical | Temporal | Yes | When a road is closed due to works and access is not allowed. |
| | Parking restriction |  | Index | Physical | Temporal | Yes | The parking spaces, normally available, are used as excavation, working or safety areas, therefore, it is not possible to park there. This is common while working in cities and areas with limited space. |
| | Preference to one way |  | Index | Physical | Temporal | Yes | Part of the road is used as excavation, working or safety area which limits the normal traffic flow. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | Therefore, preference is given to one way. |
| | Traffic light |  | Index | Physical | Permanent | Yes | Showing the location of traffic lights normally located in intersections. |
| | Alternative route |  | Symbol | Physical | Temporal | Yes | When roads are closed due to excavation or works, alternatives routes can be suggested and indicated by this symbol. |

| Category | Meaning | Representation | Sign type | Physical characteristic | Temporal characteristic | Geo-reference | Illustrative example |
|---|---|---|---|---|---|---|---|
| Labels | Project name | Project Overtoom | Symbol | Non-physical | Permanent | No | Additional information to indicate the location and time that is being visualized.<br>The elements included as examples in this category are some of the visualized in the 2D model of project Overtoom. |
| | Project phase | Phase 1 | Symbol | Non-physical | Temporal | No | |
| | Phase section | Soetendaal deel 2 | Symbol | Non-physical | Temporal | No | |
| | Date and time | dinsdag 8:00 AM 18/04/2022 | Symbol | Non-physical | Permanent | No | |