



Visualisation in Civil Engineering Design Projects

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ABSTRACT

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The purpose of this thesis is to introduce the reader to the world of civil engineering visualisation processes. All the examples presented are from various projects across Finland. The goal is to showcase civil engineering projects in a way that is accessible and understandable to everyone, regardless of their background. Detailed examples of common visualisation techniques used in civil engineering today, along with a few less conventional methods, will be provided.

This thesis will address the following questions: How can understandable and realistic visualisations be created for the general public, city officials, and clients when the data produced by engineers is highly technical and requires expertise in multiple fields to interpret? How are visualisations designed to facilitate meaningful conversations between civil engineers and the communities living in the areas affected by these designs? The projects and examples discussed in this thesis are drawn from my experience working at the Finnish civil engineering company, Sitowise.

The empirical part consists of case examples on how visualisations were created for the clients and how the visualisation materials were used. The creation process will provide information on how to create visualisations, using methods such as pictures and videos, and in some projects, even virtual reality and simulations. Explaining the workflow for visualisation projects that can range from simple screenshots of the model to fully interactive, real-time digital twin simulations.

The results of this thesis suggest that visualisations are a key element to allow meaningful collaboration with common people living in the affected areas where the design projects will take hold. Locals can better understand and comment on the design phases in public meetings without previous knowledge of civil engineering in general.

Furthermore, while there are standard practices, the characteristics of visualisations in civil engineering are constantly evolving due to programme developments and advancements in technology. With these developmental trends, it appears that in the future, even AI-assisted visualisations could become part of the standard practices in the field. New technology might even create greater opportunities for more immersive visualisations that allow the public to give feedback for civil engineering designs in a more meaningful way.

Key words: civil engineering, visualisation, collaboration

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ABBREVIATIONS AND TERMS

2D	Two dimension
360°	360 degrees
4k	4k resolution, 3840 × 2160 pixel
AR	Augmented reality
BIM	Building information model file format
Digital twin	Digital version of the existing area
DWG	Drawing file format. File that contains two- and three-dimensional vector graphics
HD	High-definition resolution, 1920x1080 pixels
IFC	Industry foundation classes file format
IoT	Internet of things
Mesh model	Collection of vertices, edges, and faces that together form a three-dimensional object
MR	Mixed reality
SVG	Scalable vector graphic file
VR	Virtual reality
XR	Extended reality

1 INTRODUCTION

Visualisation is transforming civil engineering design from a discipline of calculations and blueprints into one where complex concepts are rendered with clarity, reshaping the way we design, communicate, and build the world around us. By harnessing advanced modelling tools and immersive technologies, engineer design work can now visualise every detail of a project before even a single brick of a pavement is laid, enabling more accurate decision-making, enhanced collaboration, and innovative solutions to complex challenges in the design process.

This thesis explores the conversion of complex engineering data into clear, impactful visualisations that play a vital role in bridging the communication gap between civil engineers and the public. These visualisations ensure that cities, clients, and communities can actively participate in the design and decision-making processes, with further details on the various design phases provided later. The visualisation projects and examples presented in this thesis are based in Finland and were collected over several years of experience working as a visualisation expert at the Finnish civil engineering and consultation company called Sitowise. During my time working there, I was surprised to see how diverse the work methods were in the visualisations of the build environment design world. It became clear that the process of how visualisations are made and needed to be written down to show visualisations are made for the engineering designers and for the public. There is a lot of silent information about these processes and how the visualisations are made keeps evolving at a high pace. This thesis focuses more on infrastructure design projects than renovation and construction designs while visualisations are done differently and the scale in collaboration is wider in the infrastructure side which are the one key elements in this thesis.

First we are going through generally what civil engineering visualisation is and what kind of design phases it includes with open explanations of each design phase. These are the base structure of how design works in Finland; going from wider design making preliminary designs to closer to structural design which is used to build the target design. After that is explained what visualisation pictures

and videos are in the concept of civil engineering design visualisations. There are detailed examples when which methods are used and some case examples to further explain the chosen methods with detail. After that there are briefly explained what virtual, augmented and mixed realities are, what types there are and how those are used in civil engineering design visualisations. This will include examples of how virtual reality has been used in various cases, as well as potential future applications in civil engineering design, drawing on current uses of the technology in other fields. Following this, the thesis will highlight some of the less common types of visualisations, such as CAVE systems and digital twins, accompanied by a few illustrative examples.

The section on visualisation programs will guide the reader through the key tools used throughout the visualisation process. Several of those programs can be used to make visualisation pictures in one project while some of the programs are used more in the data gathering and other more in the visual parts.

After identifying the programs there are a few different case project examples opened for more detail of how the visualisation pictures and videos are made with in details and examples, how the project executed the work, showcased the final products, and provided examples of the process itself. Thesis provides examples of how various software programs are integrated, demonstrating how they work together throughout the visualisation process. It also explores the workflow of transferring data between programs and the rationale behind these transitions. There are examples about the cases itself to bring wider understanding of the overall workflow. There are few mentions of the collaboration with the other designers and clients. All of these case examples and process images were completed at Sitowise.

After examples there is a discussion part where cases are analysed in a deeper level and how visualisations generally are working the way they are now. In the future section there are thoughts of how AI, which means Artificial Intelligence and new technology may change the workflows of visualisations completely in the future. Predictions about current trends shaping emerging technologies. This thesis will open especially the visualisation world more and give the idea of how the videos and pictures are made and also what are the differences while creating

from design data. How reliable are the pictures based on design data compared to those that are artistic renderings of the project?

The aim of this thesis is to provide a comprehensive overview of civil engineering from a visualisation perspective, including the processes involved in creating visualisations for various projects in Finland. It will also discuss the implementation of virtual reality, recommend suitable software for analysing data obtained from clients or civil engineering designers, and explore the various visualisation methods currently available. How the workflow changes drastically depending on what programs are used. How can the public's opinions on the process be gathered for the design progress?

In brief, this thesis goes into civil engineering design visualisations in three themes: Which kinds of visualisations are used, which technologies are relevant and in case examples which kinds of solutions are used in the projects.

After every title, there comes a wide explanation of what is going to be discussed in the chapter while going a bit deeper in the details of the specific subject. Then there will be examples of discussed materials and conclusions.

1.1 Civil engineering design briefly

This chapter will provide a brief overview of how civil engineering projects operate, using the Raide-Jokeri tram project as an example to illustrate the overall costs associated with civil engineering designs within the total budget. This will give a guideline to understand the design phase role in the whole construction. After that, the design phases will be shown on what are used in Finland in infrastructure design so these can be referred later on visualisation projects to understand the difference in technique compared to the visualisation final product.

According to Institution of Civil Engineers (ICE n.d.) civil engineering center around the design, construction, and maintenance of infrastructure, from bridges to flood defences, wind turbines to tunnels, and more. Civil engineers are creative problem solvers. They design the man-made environment.

In order to get a sense of how much civil engineering design costs where the visualisation costs are also included in the total construction budget of the project plan here is an example. Raide-Jokeri was a speed tram design and construction project affecting the city of Helsinki and city of Espoo. The design was about 7 % of the total price of the whole project.

	Helsinki	Espoo	Total
Track costs			
Rails and surfacing	25 170 000	13 930 000	39 100 000
Track support structure	14 090 000	7 870 000	21 960 000
Switches and fixtures	2 420 000	1 650 000	4 070 000
Traffic signal systems	4 490 000	3 170 000	7 660 000
Electrification			
Overhead line equipment	11 290 000	5 050 000	16 340 000
Power supply	16 200 000	9 900 000	26 100 000
Switch control	340 000	180 000	520 000
Cabling	1 690 000	870 000	2 560 000
Control room systems	1 430 000	740 000	2 170 000
Stops and stations	2 900 000	1 430 000	4 330 000
Street modifications	20 020 000	7 860 000	27 880 000
Utility relocation	4 910 000	5 320 000	10 230 000
Subgrade reinforcement	13 630 000	11 640 000	25 270 000
Structures			
Bridges	12 540 000	5 870 000	18 410 000
Retaining walls	1 870 000	100 000	1 970 000
Other specialist structures	7 360 000		7 360 000
Real time information and traffic control systems	2 230 000	1 120 000	3 350 000
Total	142 580 000	76 700 000	219 280 000
Design and planning 7%	9 981 000	5 369 000	15 350 000
Construction management and client responsibilities 7%	10 679 000	5 745 000	16 424 000
Unforeseen costs 10%	15 256 000	8 207 000	23 463 000
Total	35 916 000	19 321 000	55 237 000
TOTAL COST OF RAIDE-JOKERI	178 496 000	96 021 000	274 517 000

PICTURE 1. Cost of building a speed tram in Helsinki and Espoo (Helsinki & Espoo 2015, 6).

Even though the whole project is going to be built from the design documents and the data being a really important phase of the project, it is relatively small percent. Next we are going to see the four design phases which determine the project details.

There are four design phases in civil engineering projects in Finland:

1. Preliminary investigation phase

2. Preliminary design
3. Road and railway design
4. Structural plan (Väylävirasto 2023)

Preliminary investigation phase involves gathering essential information, assessing site conditions, evaluating potential environmental impacts, analysing regulatory requirements, estimating costs, and exploring various design alternatives. The goal is to provide a solid foundation for decision-making and planning before moving forward with detailed design and construction phases. In this phase visualisation can be used if there is previous design done before or the customer is delivering the source data. The visualisation in this phase is rough estimation.

Preliminary design refers to a comprehensive and overarching plan that outlines the overall vision, objectives, and strategies for a development project or urban area. This plan typically includes land use zoning, transportation infrastructure, utilities, environmental considerations, and other key components necessary for the sustainable development of an area. In this phase the designs are still broad but have more detail than in the preliminary investigation phase. With the delivered data from the customer there can be a visualisation picture from 3D data.

The main design phase when thinking about visualisation is the road and railway design phase. This design phase refers to the integrated planning process that considers both road and railway infrastructure in a coordinated manner. This planning involves designing the layout, alignment, and specifications for both roads and railways to ensure efficient transportation networks and safe interactions between different modes of transportation. This is the phase in the planning process where a proposed plan, such as a development plan or infrastructure project plan, is made publicly accessible for review and comment so the design process can proceed with the local info. In this phase there are usually a few weeks period where the design is available for public viewing. This allows stakeholders, such as residents, organisations, and authorities, to examine the plan and provide feedback or raise concerns before it is finalised. In this phase there are a lot of more details in the civil engineering designs and it's

crucial to make the design understandable for everyone. Comments gathered from the public viewing are gathered and implemented to the designs.

Structural planning phase in civil engineering and architecture refers to the detailed plan or design that specifies the structural elements and systems of a building or structure. This includes the layout and specifications of components such as beams, columns, walls, slabs, foundations, and other structural elements, as well as considerations for load-bearing capacity, stability, and safety. This phase is finalised and is the model where the construction workers build the design in the real world. This phase doesn't require visualisations while the design is not going to change except in minor ways because the earlier phases have been thoroughly investigated and decisions were made just for this last phase (Väylävirasto 2023).

During working in the Sitowise company, visualisations were rarely made in the first preliminary investigation phase while there is not much data to create the visualisation pictures, videos or models. In the preliminary design phase pictures are used to get the idea of the design area and purpose of the project. Although when visualisation pictures are used in this phase it's a rough estimate from the data how the outcome of the design will look like. Mainly the visualisations are made in the road and railway design phase, where there is more data and design itself can provide the information needed for visualisations. In this design phase there might be needed to create visualisations a few times while the design and project progress to more defined versions. After that in the structural plan only minor things might change and design is at its end, so visualisation pictures are rarely needed. The comments from clients and citizens are integrated from the previous phases to serve the final phase.

2 VISUALISATION IN CIVIL ENGINEERING DESIGN

This section will be going to a deeper level of what visualisation is in civil engineering design and what the civil engineering studies include in a basic level.

There are many ways to visualise the civil engineering design concepts. Depending on the situation and budget of the project there are multiple types to choose from; simple screenshot from the design program like Civil 3D to rendered high quality pictures or videos. Visualisations can be from still images to digital twins meaning as a virtual model of a physical object or area, simulated and real time interactive models meaning you can control the model or build yourself. “Visualisation enables the graphical presentation of intricate concepts to any audience, regardless of the location or time. “ (Stothard & Laurence 2014). This is what makes the visualisations a powerful way to reach more audiences.

To understand the progress that civil engineers must internalise during their studies: Civil engineering requires a comprehensive understanding of nature’s complex behaviour, structural elements and their behaviour at full scale, unseen physical principles, technical decision-making, and the prediction of problems and their corresponding solution. (Arif 2021.) While creating the designs you need to understand a lot of physics and city guidelines. Civil engineering is a study based on science. This makes creating the visualisations a more complex process while the scientific data created on scientific design tools doesn’t convert directly to entertainment base programs like game engines which could be less time consuming to create civil engineering design-based visualisations.

Next we are taking a deeper look at the most common types of visualisations in civil engineering which clients usually order. These visualisation types are chosen for different needs that client and project have.

2.1 Visualisation pictures

Civil engineers can export location-based lines from design programs like AutoCAD and Civil 3D as PDF files, which can then be printed to showcase their work. These prints can be bright coloured lines of the borders of the design materials just like they are on the design program and can have simple textures to identify like asphalt, pavement and grass areas. These prints provide a clear idea of the design and serve as a useful tool for discussions among designers. Understanding these prints can be challenging without a background in civil engineering, as interpreting 2D scale and basic visual representations of different materials may not fully convey the spatial aspects of the design.

Visualisation pictures are commonly used, and they are also cheapest to create. Pictures can be taken directly from the design program for visualisation purposes, but they are often lower in resolution than PDF prints and contain many structural layers rather than visual elements, making the screenshots harder to interpret. To render better quality images there are usually visualisation models created separately on different programs using the design data, retextured and then rendered to a picture. The visualisation pictures concretize the thoughts underlying plans and visions and promote their integration into urban development practices and shared ways of understanding urban development. The first relates to the role of images in marketing, and the latter two to the strategic use of images in comprehensive planning (Jokela & Laine 2020).

Visualisation pictures are done in several ways depending on the used location data created by designers. The location in the data helps to get all the design drawings in the same spot in designer software and also with the visualisation programs. There can be pictures taken on the actual site in real life where the design is going to be for example where the road is going to be designed. A 3D model of the design is then created in a different program, and location data from civil engineers is placed in the correct position within the visualisation program. There are several types of visualisations pictures:

1. Creating a picture about the design in an imaginary landscape.

2. Creating a picture using a photo taken on the site and rendering the design in the picture and editing it to seem more realistic.
3. Rendering a picture from virtual model, visualisation program or digital twin, meaning digital double of a real site
4. Simply taking a screenshot of a video.

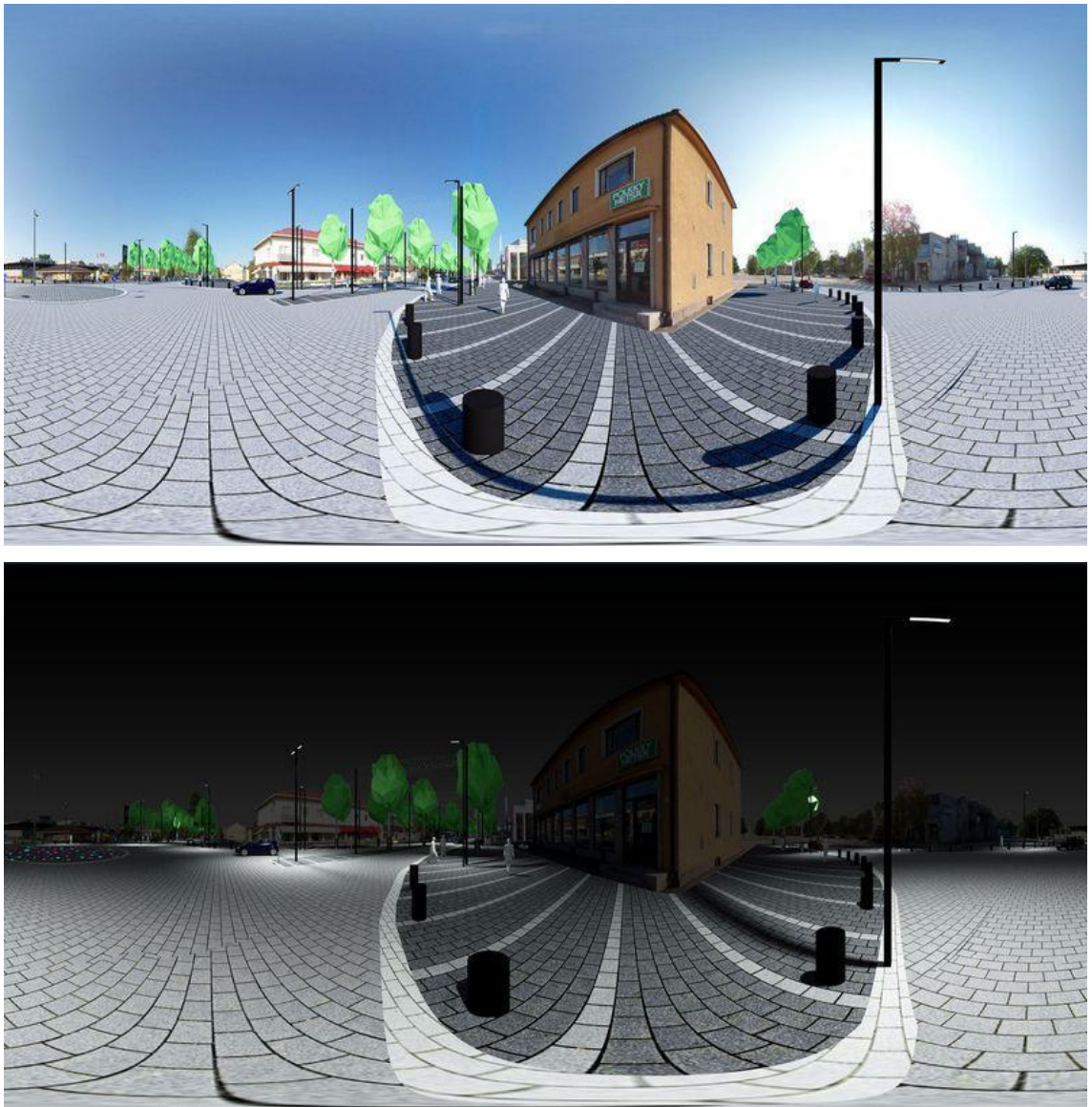


PICTURE 2. Example of a project where the original picture is edited to show future design (Fingrid 2024, 187).

There are also 360° pictures as an option to create visualisation. The term 360° refers to viewing of prerecorded photos or videos in a manner that there is a wide view of the recorded area. This method involves moving the location data closer to the program's origin, where the centre point for the X and Y axes is set to 0, to

facilitate visualisation and 3D modelling. The 3D programs have XYZ dimensions in the program where Z is not needed to change while the height comes from how much from sea level the design is. The original coordinates are located millions of units away from the centre and allows you to rotate your view's direction to reveal content that was just outside your field of view. (Linowes 2018, 310). This is similar to virtual reality where the content is changing and moving in real time.

To create these 360° pictures, programs like 3Ds Max from Autodesk or Blender are typically used for 3D rendering, while Photoshop from Adobe is employed to combine the original 360° picture with the rendered image from the 3D program. Another approach involves creating scenes in game engines like Unity, where we use location data from civil engineering designs and map coordinates from metadata to align with the same spot in the programme, similar to how it works in Photoshop. This method requires moving the location data closer to the programme's origin, which serves as the centre point where the X and Y coordinates are set to 0. This adjustment allows us to work on visualisation and 3D programmes, even though the original coordinates may be millions of units away from the centre, as the content points in design programmes are often far removed from this central point. Afterward, the picture is rendered and finalised in Photoshop, where the lighting and shadows are adjusted to closely match the original image shot on-site. Original picture and version with design can also be combined as video to show the transition situation now to the design. These kinds of 360° are already in use when selling and leasing an apartment by some realtors. These virtual tours are also implemented for example in the Louvre Museum in France where you can see the art anywhere in the world just with internet access and a browser.



PICTURE 3. Example of 360° of Kitkantie roundabout design during day and night (Koillissanomat & Sitowise 2018).

2.2 Visualisation videos

Visualisation videos show the design area progress so far. In the videos the camera usually flies the length of the design area showing the design data more visually than in design programs with textures, assets like humans, trees and city objects. The videos typically include text overlays in the street designs to help viewers understand the direction in which the video is progressing. Difference to the pictures, in video the viewer gets more feeling of space with the movement, different angles and scale while there are familiar objects to show height.

When the project is made as a virtual or visualisation model or digital twin, it's usually easy to render video and pictures while the data is already visualised inside the program. Programs like InfraWorks from Autodesk and Twinmotion from Epic Games have built in video tools for creating simple animation sequences where the camera follows a smooth flying path above the design area, capturing the breathtaking scene from various angles, adding captions and even changing daytime during the flight. If the flight path were made with game engines like Unity or Unreal Engine from Epic Games the video paths are made inside of the program which makes the video production harder to create without knowledge of the program architecture. The video tools are more complex to use, as you need to both build and utilise them in addition to using the game engine itself.

There are also possibilities to create in some cases 360° visualisation videos. To understand the difference between 360° and virtual reality, in 360° video, the consumer functions as a passenger in the storyteller's world; in virtual reality, the consumer takes the wheel (Dolan 2016). In other words, in the 360° experience the viewer is stationary while watching the video with the possibility to turn in any direction while in virtual reality the viewer can move in virtual space and in some cases interact with the content she or he is seeing.

Civil engineering videos show the design area inserted in a mesh model as a collection of vertices, edges, and faces that define the shape of a 3D object of the city or surface shape of the forest ground. Depending on the client's needs there can be exported regular 2D video in HD as high definition, 4k or higher resolution and if there is the possibility to use virtual reality glasses then 360° video 4k or higher resolution.

Producing a 360° video requires additional effort while the file size is going to be larger because of the wider recorded viewing angle. Depending on where the video is going to be published it might need a method called injecting extra metadata to make the 360° viewer read the data correctly as a sphere and it involves a method called stitching. According to Petrov, Sytnik and Rubcov "the purpose of stitching panoramic video is to create a panoramic seamless video using several overlapping video streams that capture different parts of the scene

at the same time.” (Petrov, Sytnik & Rubcov 2018.) Basically, after shooting or recording the 360° video you will need to edit the edges of the video in order to appear seamless.

Regular 2D video is better in situations where the video is posted in YouTube, Facebook or other social media sites for easy access for the public. 360° is a more immersive experience while the viewer is inside the design area with full vision with virtual reality glasses or 360° glasses. 360° can be watched without glasses for example with YouTube and VLC player by rotating the view with a cursor. However, it becomes more of a neat trick than an immersive experience.

In civil engineering design projects the 360° videos are commonly used especially in public meetings to show the proposed design in a new way. Those are also good marketing materials to be used in fairs and expos for giving the opportunity to the visitors to test virtual glasses for the first time.

2.3 Extended realities

Virtual reality is “...software that immerses users in a three-dimensional, virtual interactive environment — usually by headset with special lenses — to simulate a real-life experience. Many virtual reality experiences take place in 360 degrees.” (Brecker 2022). There are 3 types of virtual realities: VR as virtual reality, AR as augmented reality and MR as mixed reality (Mealy 2018). When talking about all of them as an umbrella term, is used XR as an extended reality term. (Mealy 2018).

Virtual realities as a visualisation tool are getting more common in civil engineering design. It is exciting for the viewer to get to experience the video where they can watch it in an immersive way in every direction during the video or can interact with the design inside the virtual world. Based on experiences from public meetings, virtual reality tends to be the main attraction in discussions surrounding design commentary. In this section, we will explore various types of virtual realities, highlighting some popular examples beyond the civil engineering realm. However, not all techniques have been fully explored for comprehensive application in this field.

As virtual reality visualisations become increasingly popular, design data is transitioning from 2D lines to a more immersive 3D environment. When the data is already in 3D format it's easier to convert the information from design programs to visualisation ones which are less about the metadata and more about the textures, the visual aspects of the design. There are also civil engineering design programs where users can export 360° pictures and videos directly from the program. However, the visual quality is not as high as that produced by game engines and visualisation programmes, where the design is more thoroughly refined.

When distinguishing between XR realities, mixed reality combines the real world with graphics that closely resemble reality, creating a real-time, realistic immersive experience. Virtual reality is like in your own world, everything the viewer sees is the simulation or video with possibility to interact. AR is just putting virtual elements on a real world which are not usually intractable and doesn't look like it fits in reality. Mixed reality basically combines all the realities; AR, VR, real life and mixes it to one reality looking combination (Gesi et al. 2024, 1)



PICTURE 4. Examples of the VR, AR and MR and their differences (Rocks 2020).

While XR is becoming increasingly popular in civil engineering visualisations, the VR aspect is currently the most prominent. The workflow is smoother as it transitions from design software to game engines and ultimately to virtual reality simulations. With some coding knowledge it's possible with a few tweaks to make the virtual model to function in virtual reality programs.

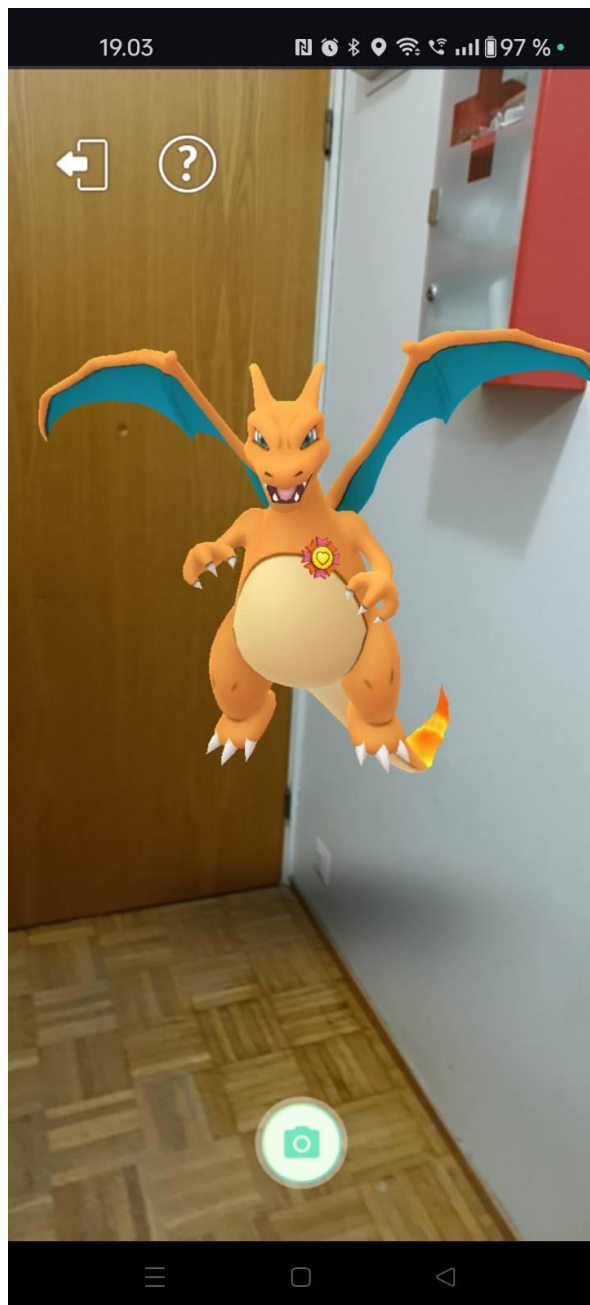
In the next sections we dig deeper into how AR, VR and MR are used at the moment in different fields to get an understanding how those work with real examples and how those are used or could be used in the civil engineering design visualisation world if we would make demos and tests further. While not every XR is used in civil engineering yet it's good to know how those work to get basic knowledge about those and how those could be used for visualisations in the near future.

2.3.1 Augmented reality

“Augmented reality is a way of viewing the real world (either directly or via a device such as a camera creating a visual of the real world) and “augmenting” that real-world visual with computer-generated input such as still graphics, audio, or videos. AR is different from VR in that AR augments (adds to) a real-world or existing scene instead of creating something new from scratch.” (Mealy 2018). In other words when viewing with a phone or tablet, the AR is when the elements are added on top of what the viewer is already seeing.

AR as augmented reality is quite rarely used in the civil engineering design world. One experiment conducted while working at the Sitowise company involved using AR to display IFC as Industry Foundation Classes file format from construction design file types. The AR application would recognise the building’s blueprint from printed paper and display the corresponding IFC model of the building on the AR application. The viewer could rotate the phone or tablet where the AR applications were used to see the building on all sides.

Most known example of the usage of the AR is Niantic company’s Pokémon Go game where using the camera in game ads Pokémon called animal on the phone screen where you can feed, pet and catch the Pokémon.



PICTURE 5. Charizard in Pokémon Go's AR picture mode (Taken by the author).

AR in civil engineering and architecture has some use cases. In the design phase the 3D model is exported in IFC format and shown in applications like Trimble's SiteVision. What makes it unique is its precision, as the building model can be placed with centimetre accuracy onto the real location. (Anttila n.d). It gives a sense of how the construction design could fit in the specific spot in the real-life space. It is also used in construction design to show on site where the water and sewer pipes are inside the structure when the pipes have been exported for AR application. When moving the phone or tablet around, the viewer can see where

the pipes and electricity lines are located which can be a useful tool in construction sites.



PICTURE 6. You can see the IFC model shown in the location where the future building is designed (Geotrim 2024).

AR can be good to show an approximate understanding of how the design could work. In infrastructure design it's harder to use this kind of technology while roads are so much bigger elements, and it doesn't give such a good perspective of the full design from the eye's height. At least this leaves room for the future to create demos for a working road design application with AR.

2.3.2 Virtual reality

Virtual reality is most used in civil engineering visualisations as extended realities. While many of the visualisation projects are done with game engines like Unity and Unreal reality it requires bit coding to make VR function on the model. While you can create simulations without VR, for public meetings it is a great way to showcase the projects done in the company and be remembered well after the event.

Virtual reality usually involves VR-glasses and handheld joysticks. Virtual reality has been used in the game industry for entertainment purposes like video

gaming. VR is getting more popular in industries like logistics, aviation industries and construction.



PICTURE 7. Erottaja square visualisation model project in VR (BuildingSmart Finland 2021, 48).

In civil engineering the VR has been used in various sized projects from smaller to bigger ones. Picture 7 showcases a VR project developed for Erottaja Square in Helsinki, where the player can change the time from day to night, navigating the square and interacting with the food kiosk models, transforming them into three different design types. The player can see how the square will look with the new design in first person perspective.

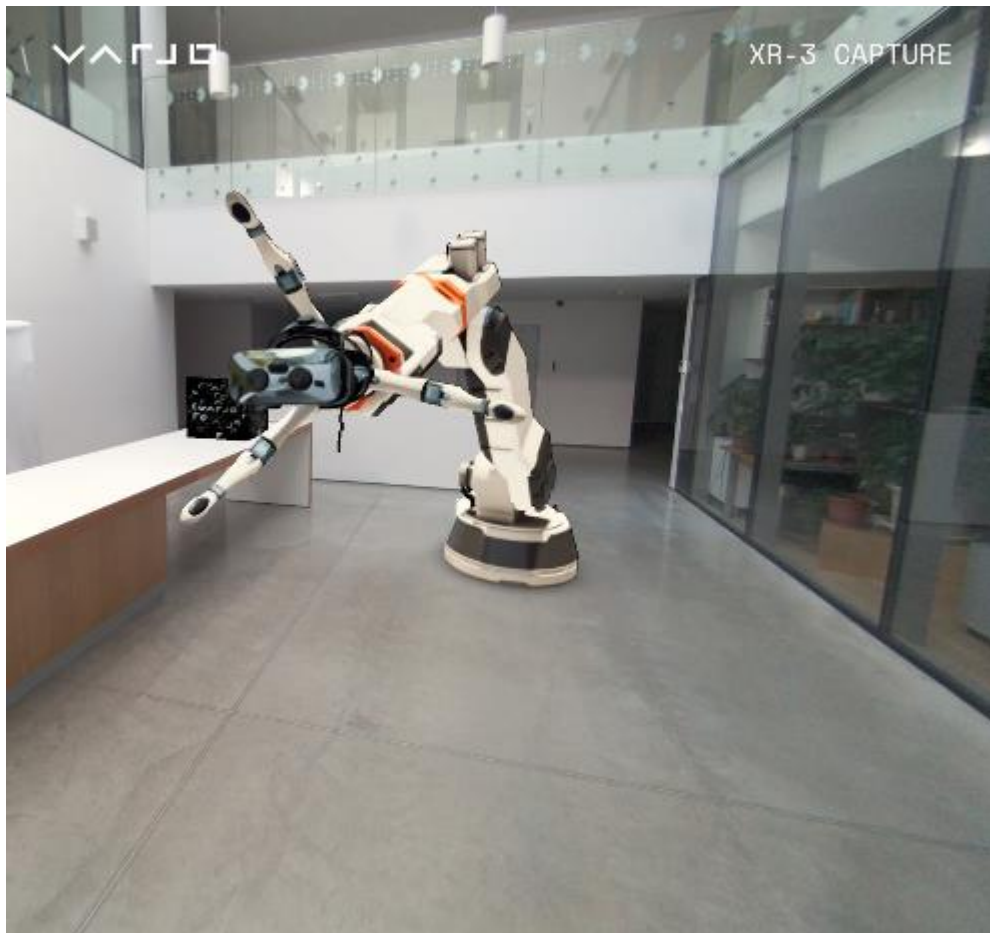
While working on Sitowise there was created a street design simulation tool for the Verkkosaari area in Helsinki, new street layouts, lighting, and park designs were showcased using tools that facilitate design directly within the model. There were created catalogues of Finnish trees and Helsinki's street objects where the player could place the objects anywhere. These kinds of simulations could be new immersive tools for civil engineers to use while designing the urban areas.

2.3.3 Mixed reality

According to Sobota and Cvetković the “mixed reality (MR) is an area of computer research that deals with the combination of real-world and computer-generated data (virtual reality), where computer generated graphical objects are visually mixed into the real environment and vice versa in real time. MR is the newest virtual reality technology. It usually uses 3D computer graphics technologies for visual presentation of the virtual world.” (Sobota & Cvetković 2020, 13). So in other words the MR combines all the realities in one reality, where the player can be in a situation where they can't fully know if the object or entity is really in the room with them or is it a 3D model.

Mixed reality is the newest technology in the XR family. From a civil engineering visualisation perspective, MR is currently utilised in a manner similar to VR. However, the simulations have not yet reached a point where they can fully take advantage of the transparency provided by MR glasses, which allow users to see their surroundings while also visualising, for example, a designed 3D road on the floor. While MR has been present for several years, there is a strong possibility that the first fully integrated demo of mixed reality in civil engineering design visualisation is just around the corner.

This kind of mixed reality glasses are still quite expensive for the regular consumer to have while the technology is expensive and the subscription yearly, but in private sections there are demos already done for in the car industry and factories.



PICTURE 8. Example how virtual objects are inserted into see through mixed reality classes (Varjo 2024).

In the future, the MR technology might open interesting cases in the civil engineering design world. There could be possibly shown the whole designed small city block on the floor where the player could see tiny humans walking on the pavement and see the simulations happen in a delightful way.

2.4 Uncommon visualisations techniques

In this section will be given examples of more rare cases of visualisations done in the civil engineering design world. Uncommon visualisations refer to technologies and methods that are still largely experimental and not yet widely adopted. However, this doesn't mean they won't become mainstream in the future. When exploring ways to visualise civil engineering designs, it's important to recognise these less common approaches, as each offers unique advantages and may be better suited to future projects. While most visualisations are created using the latest technology, it's valuable to consider all the current possibilities to

get inspiration for the future. These examples highlight the extent to which new technologies have been explored in visualisations so far and illustrate how visualisations evolve alongside technological advancements.

2.4.1 CAVE

CAVE means cave automatic virtual environment (Ronchi et al. 2019, 1). It is built with walls front, left and right connected to ceiling and floor pieces. These areas are reflected from the projector image to create an immersive space. It can be used with 3D glasses for the 3D effect or without one to just walk in the space inside of the CAVE space. Inside CAVE it feels like users are in the design itself getting the real-life scale. Compared to VR-glasses, users can be in the CAVE as a group, and everyone can see the presented model and other people at the same time while with VR glasses only one is experiencing the visualisation with VR glasses.

Oulu Hospital and Tampere virtual model projects are just a few examples of how IFC models utilise CAVE technology to create immersive user visualisations. In the Oulu case the nurses, doctors and other hospital employees were shown the IFC model of the hospital rooms for them to give comments on how the current design could serve their needs. This was reviewed by the medical professionals as a good way to get really see how the space for different operations were designed in the current model and they could understand way better the rooms layout compared to 2D PDF prints about the area.

Other case examples, such as the Tammela virtual model from Tampere, were exported as CAVE models from Unity. In the CAVE model, users could explore the Tammela environment, flying through to view the IFC buildings and massing, providing a glimpse of how the future of Tammela might appear.



PICTURE 9. Tammela virtual model in CAVE environment (Sitowise 2019).

2.4.2 Cube

Cube is a cubical room with 4 walls and has a screen and ceiling made by Nokia Bell Labs. The walls are interactable with touch so the user can control the simulation with every wall. Users are like in their own universe inside of the cube environment. During my time at Sitowise, a demo was created featuring a basic user interface that allowed users to navigate through the model. This was just one test case to experiment how the Cube room could be used for civil engineering visualisations.



PICTURE 10. Operating a demo on the Cube's touchscreen (Sitowise 2019).

The key takeaway from this demo is its potential application in interior design, allowing users to visualise group settings and how the design might look in the future. Additionally, it would be intriguing to develop a user interface feature enabling visitors to leave comments on the model at specific points by pressing an interactive screen. In the future, this type of technology could be used more extensively in intimate settings, allowing investors to make informed decisions about designs.

2.4.3 Igloo Vision

Igloo Vision is one of the examples where civil engineering design visualisations are not done yet but it is interesting as an inspiration to visualisations to be used. Igloo Vision is used e.g., in Tampere University of Applied Sciences as the 360° cylinder room where people can stand inside the cylinder and experience the same content without VR-headsets. This makes it good for group settings for better interaction between the visitors.



PICTURE 11. 360° cylinder view inside the Igloo (Igloo Vision 2021).

Igloo Vision is similar to Cube but has a narrower view and is more sphere shaped. In Igloo Vision there are no sharp corners. This could be a really good visualisation tool for sightseeing simulations for high-rise buildings with the wide cylinder screen. In the future visualisations could be implemented to this view to make new kinds of experience about the design visualisations.

2.4.4 Digital twin

Grieves first defined the concept of the digital twin as comprising three key elements: a physical product in real space, a virtual counterpart in digital space, and the data and information links that connect the physical and virtual versions. (Grieves 2014, 1). In other words, a digital twin is a virtual replica of a real area that offers interactive possibilities. In digital twins, IoT meaning Internet of Things, is typically implemented to create functionalities and provide real-time data from sensors. Essentially, this involves placing sensors on-site to collect data, which is then reflected in the digital twin. Basically, putting a sensor on the site and reading the results in a digital twin.

Digital twins are more and more common these days. “The various capabilities of digital twin technology make it a powerful tool that can be used to effectively boost different sectors of the healthcare, automotive, and construction industries

among others. Although this technology has been making its way into various sectors, unfortunately it has yet to receive the kind of exposure necessary to increase awareness of its potential in these industries.” (Vohra 2023, 4.) Digital twins have a lot of potential, but it is still rather new and it's not yet implemented so strongly in the civil engineering section. Digital twins in civil engineering have been used for data management, visualisations and IoT.



PICTURE 12. Screenshot example of Turku science park digital twin with new masses of the new buildings in the distance (Sitowise 2020).

In the picture there is a Turku science park digital twin which had the functionalities with IoT to see construction cameras at site and showing temperature, humidity from a sensor. There is also a feature that uses real-time GPS data from buses, displaying a 3D model of the bus in the system with a 3-second delay to match its actual movement. With proficient coders and unrestricted access to data, digital twins can effectively demonstrate a wide range of concepts and functionalities.

The future capabilities are enormous with digital twins; benefits of the digital twin concept, including reducing costs and risk, improving efficiency, improving service offerings, security, reliability and resilience and supporting decision-making (VanDerHorn & Mahadevan 2021). With the digital twin model the user could control and analyse the whole city block without the need to go into the real life area. Although the possibilities are vast, creating a fully functional digital twin

remains a task for the future. Achieving this will require seamless collaboration across various sectors designers, security experts, developers, and policymakers to ensure the creation of a secure and well managed digital twin. When these roadblocks are sorted there are infinite possibilities how we could benefit from digital twins in the future.

2.5 Visualisation programs

Visualisation programs are software applications that translate complex data and technical information into intuitive visual representations, such as 2D and 3D models or simulations, making it easier for professionals and non-experts alike to interpret and engage with intricate designs and concepts. The programs can be technical and serve the designers well with a lot of possibilities to input data and calculate for example building strength. Also, there are visualisation tools built for game engines where the simulations and realistic visualisations can be made. Depending on the project needs and phase the design is on, both kinds of programs have their valuable usage.

In this section we will get to know the programs used in civil engineering visualisations and what purposes each program serve. Depending on the project there can be used several of these programs simultaneously or just one program for specific visual outcome. Basic workflow is that simple visualisations usually use one program and when the visualisations are wanted to reach high realistic outcomes, there can be several used to combine all data for the final visualisation tool to make the outcome look highly realistic.

There are many programs to visualise designs which the main ones are going to be listed and their function from preliminary design phase to visually life-like models and simulations.

2.5.1 InfraWorks

InfraWorks from Autodesk is a planning and modelling software that helps civil infrastructure professionals improve project outcomes. InfraWorks supports connected BIM as Building Information Modelling meaning the use of a common

digital representation of a building object (including buildings, bridges, roads, manufacturing plants, etc.) to facilitate design, construction and operation to provide a sound basis for decision-making (Borkowski 2023, 2). The program can also read data from Civil 3D and AutoCAD, where civil engineering designers create their designs. In InfraWorks there can be the data obtained from public data banks like aerial shots, maps and 3D mesh models from the shape of the terrains to get a better idea of the environment where the design is going to be designed. InfraWorks is usually used in preliminary investigation and preliminary design phases when the design process is not that defined yet but there is a need for simple pictures and videos about the design.

In InfraWorks it is easy to create and modify source data provided by clients when starting a project and it's a fast way to get something representable for investors and citizens about the project. InfraWorks is also used later in the road and railway design phase as one of the tools for data management to create high end visualisations in other visualisation programs.

2.5.2 Twinmotion and Enscape

As a high-end visualisation tool Twinmotion from Epic Games and Enscape from Enscape GmbH are the good programs to use. They vary a bit how those are operated and which situations they should be used.

Twinmotion is a 3D rendering tool designed for real-time immersive experiences. Primarily used to produce high-quality images and videos, it also supports the creation of virtual reality environments and detailed presentations. With the capacity to manage large-scale projects, such as urban developments and airport planning, Twinmotion seamlessly integrates with BIM-based software like SketchUp from Trimble, Revit from Autodesk, and Archicad from Graphisoft which makes the workflow more straightforward without the need to convert the data.

Enscape is not a standalone program, but a robust plug-in designed to work alongside other modelling software like Rhino, Revit, SketchUp, and Archicad. It enables users to create everything from static images to 3D animations and

panoramas. Additionally, Enscape supports real-time virtual reality and offers impressive productivity features, allowing users to simultaneously edit and review their projects.

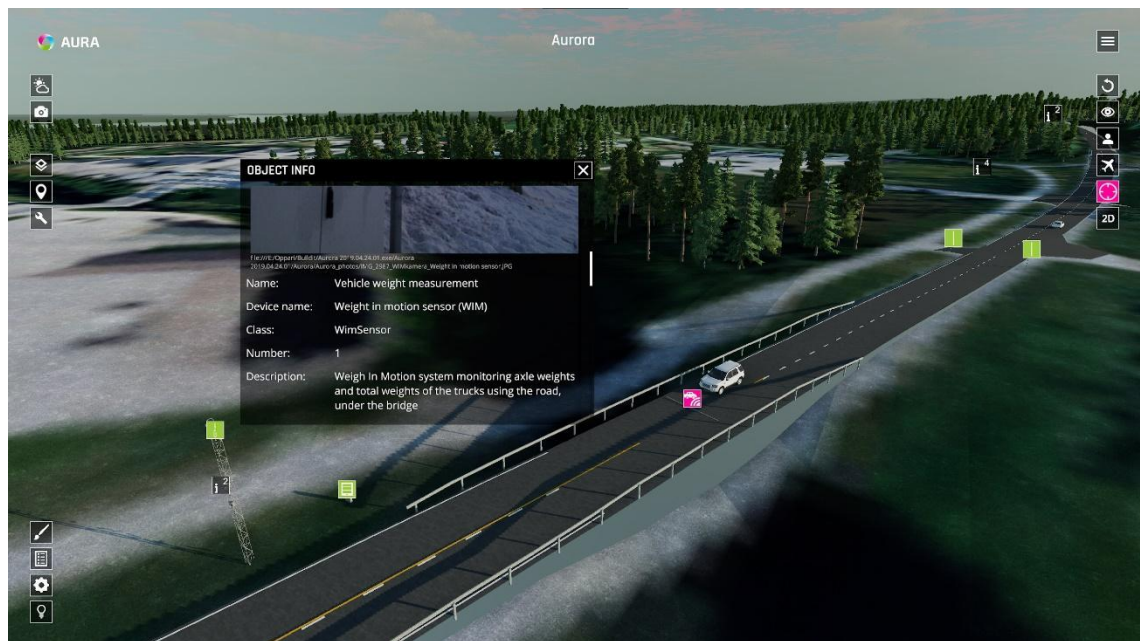
For smaller designs, such as parks, city blocks, or playgrounds, both Twinmotion and Enscape can be used for visualisation. However, larger areas can generate excessive data that is challenging to process. Twinmotion is good for high-quality image taking, panoramas, and 360° pictures from design data. It is also possible to simulate rain snow conditions easily. Both have their usage, but Twinmotion is more commonly used in the civil engineering design world while you can get from InfraWorks exported materials directly to work in Twinmotion even though it's more designed to work on smaller areas like buildings and interior design.

2.5.3 Unity and Unreal engine

For long-term projects requiring high-end visualisations and simulation tools, Unity by Unity Technologies and Unreal Engine by Epic Games are good choices. Currently, Unity is more widely adopted for civil engineering visualisations compared to Unreal Engine. Although the program's main function is to create games as game engines, they can be coded to serve purpose in civil engineering visualisations. The data obtained from design programs are needed to edit to work on game engine-based programs.

When using these game engines for civil engineering visualisations, extensive file conversion is often required to make them compatible with the engine. Civil engineering design programs don't usually directly export the files which game engines understand. Additionally, since civil engineering files use coordination data while game engines rely on a local origin-based system, reference points are needed to shift the data closer to the origin. Also, when the civil engineering files have coordination data while game engines have a local origo based system there are needed to use reference points to move the data to near the origo. Same issue happens in 3Ds Max by Autodesk if the 3D data is on the original coordinate.

Power of the game engines comes from the simulation and IoT as the collective network of connected devices and the technology that facilitates communication between devices and the cloud, as well as between the devices themselves (Kim et al. 2017), side. When developing the game engine to serve civil engineering the possibilities are endless. With IoT you can for example take GPS data of local buses and show it in digital twins in real time. Basically, anything that is measured with a sensor can be shown in the game engine build real time. Of course, developing this kind of simulation, there are required to have expert coders and developers to make it possible.



PICTURE 13. Example of IoT real time sensory data about passing car shown in Aurora digital twin project (Sitowise 2019).

Game engine-based visualisation tools are great for interactive visualisations. The visualisation can be created like a game, where you can move in the design area imported to the scene and move there freely. Also, there are straightforward workflows to create VR builds to get an even more immersive experience of the project area for investors and citizens in public meetings. Builds created with game engines can be an excellent tool for marketing projects, providing a valuable complement to traditional design presentations. The builds can be operated with a computer or with VR headset and controllers.

3 CASE EXAMPLES

With the principles of civil engineering visualisations and the software behind them now explained, we can move on to applying the theory in practice. In these two case examples, there will be explained how the visualisations were made, how the interactions with client and designers happened and how the citizens in the public meetings were reacting to these outcomes. These studies give practical understanding about the process of making visualisations and shows the complexity and collaboration needed to create the videos and pictures which are shown in the public meetings, newspapers and websites. In these cases, we delve into the process, exploring the decisions made and the challenges faced throughout the projects.

These case examples were selected for their unique starting points and distinct workflows, offering valuable insights into civil engineering visualisation. Both were completed during my time at Sitowise as visualisation expert.

The Mäkelänkatu case will showcase the workflow for virtual models, while the Hämeenpuisto project will highlight the use of visualisation programs. Together, these examples provide a comprehensive overview of different types of visualisation techniques.

The introduction will cover the simulation tools used in virtual models, along with commentary on the public event. The broader workflow for producing high-end visualisations will be illustrated, particularly through the Hämeenpuisto case, where multiple visualisation tools and programs were applied within a single project.

3.1 Mäkelänkatu street design

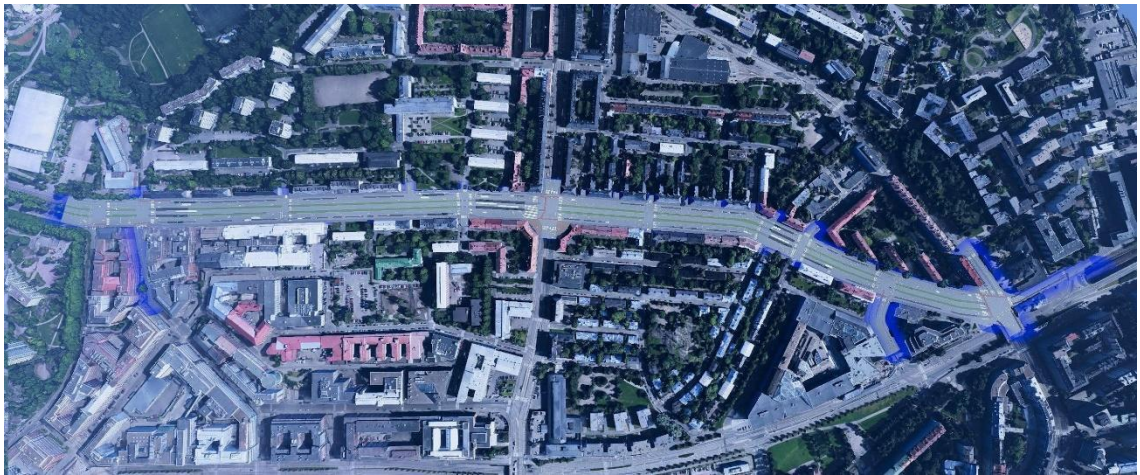
In this Mäkelänkatu case we are going to explore in detail how virtual models are used in civil engineering designs. There will be examples of the simulation tools in the virtual model and in the end describing how the public meeting about the design went with citizens living in the area. There is also a detailed description of

mesh model usage which gives the recognizable surroundings to the design's external area.

Mäkelänkatu is a street in Helsinki, Finland. Mäkelänkatu street design was created in 2018 at an existing location to improve its function and make the street more versatile. There were added bike lanes next to the driving lanes while in the middle there are two tram tracks. This street is quite busy during the workdays, so this design had interest for the public. Traffic on Mäkelänkatu was revamped during its renovation between Hämeentie and Kumpulantie. The plan included one-way cycle paths to improve cycling access and route continuity. Public transport was sped up, and safety enhanced by adjusting stops, pedestrian crossings, and intersections. Plans also accommodated a future light rail line. The street's aesthetics were improved, with trees added at tram stops and made those more accessible.

The renovation covered junctions with intersecting streets, updating street structures and underground utilities. Old sections of the tree-lined avenue were replaced, and tree growth conditions improved.

This was a bit different from virtual model projects that were done before while the design wasn't fully completed before the public meeting for the citizens about the initial design, so the street design was modelled by Blare Tech which was at the time Sitowise's Unity team. Usually, the AutoCAD files are exported layer by layer and modified for the Unity game engine but in this case the modelling was done in preliminary design and the 3D modelling was created by the Unity team.



PICTURE 14. Design area of the Mäkelänkatu inside the blue glow (Sitowise 2018).

The project included the delivery of Helsinki city's mesh model, which is a 3D triangulated surface model created using laser scanning from either a helicopter or a drone. The mesh model was then cut to create a hole to the mesh where the future design was going to be modelled. At the time there was in progress to laser scan a new and improved version of Helsinki city while technology improved. The different quality of the laser scanned mesh model can be seen in the presentation model. The new mesh was way more detailed and accurate than the old one.

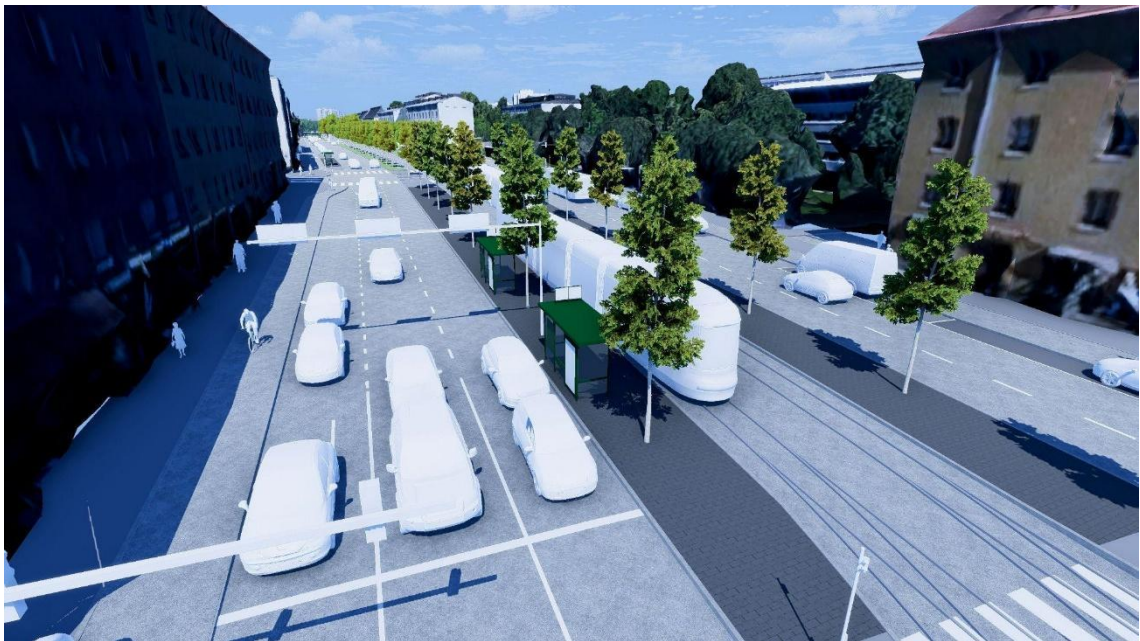


PICTURE 15. Difference of old mesh model on the left and the new on the right (Sitowise 2018).

These mesh models are important while they show the locals familiar buildings with the right textures and help to understand the design. Working with these mesh models can be challenging, as the triangulated models are quite large in file size, and isolating the design area is time-consuming. The triangles are irregularly distributed, lacking clean seams to easily trim the model edges. Care must be taken, as the textures can be affected by the removal of the mesh.

Mesh models are important in civil engineering visualisations because they give the context for the design area. Those also help the citizens living in the area to locate and see the difference of the new design when the surroundings are familiar. Big cities like Helsinki and Tampere have these mesh models for designers and visualisation experts to use in the projects.

The Mäkelänkatu project was also different while the city assets like cars, buses, street signs and pedestrians were textured white to make the design itself more in focus. Usually, the asset has their original HD textures which are imitating the real life colouring.



PICTURE 16. Unusual white assets on the Mäkelänkatu virtual model (Sitowise 2018).

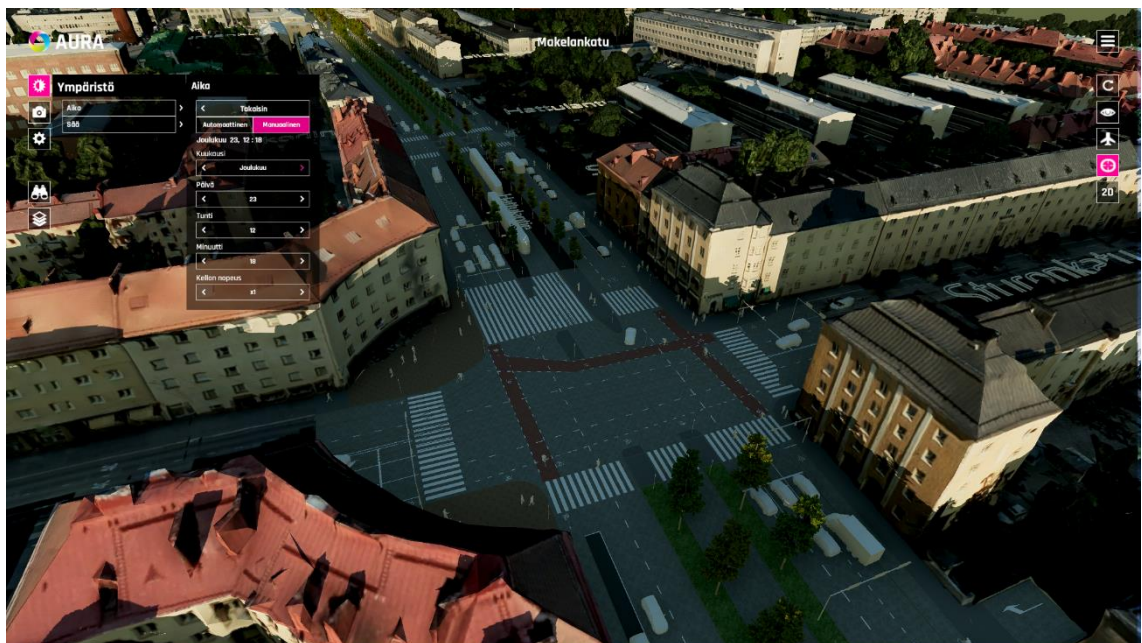
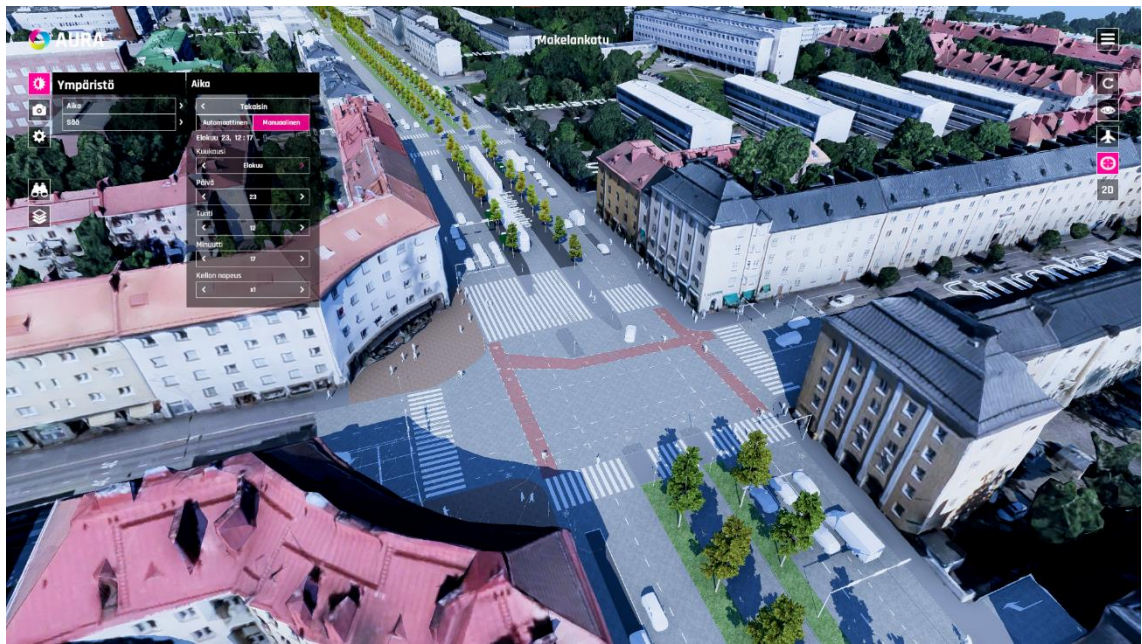
While the streets were modelled from the preliminary designing files, the actual virtual model itself was developed on its core functions before the project.

Sitowise has spent several years developing AURA, a Unity-based game engine product designed for civil engineering visualisations. As virtual models were created for clients, the simulation tools gained additional functionalities over time. In the Mäkelänkatu virtual model was a tool for viewpoints. This allowed the user to jump in the virtual model to the most predefined interesting places just with one click. This viewpoint tool was good for easy access in the most crucial parts of the design.



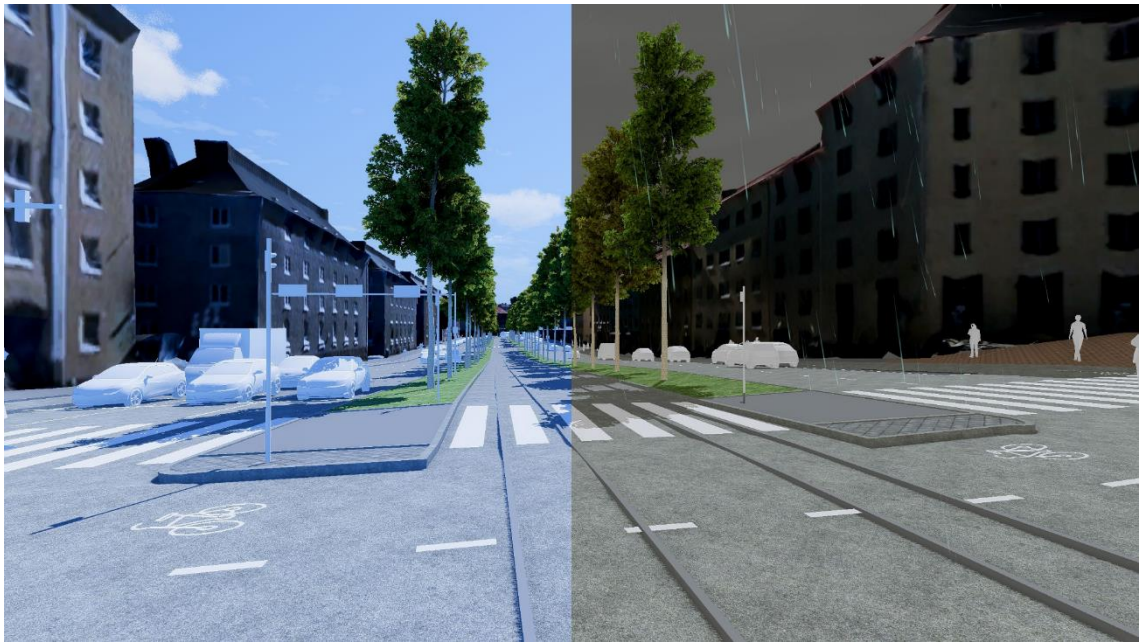
PICTURE 17. Showing Sturenkatu streets viewpoint tool in AURA (Sitowise 2018).

The 3D data is brought closer to Unity's origo point using a reference point. That means that there is, for example, a corner of a building and using that point to compare the point where it was in the original design program to where it was relocated for the Unity. This allows the materials to be relocated easily without losing their original position data. With the location data there was a possibility to develop tools for weather and time control. This tool is really useful in high northern countries like Finland where the light conditions vary a lot during the year and the time. The shadows are longer at different times of a year. With the time and weather tool it could be seen in the Mäkelänkatu build how the conditions vary during the year and a day.



PICTURE 18. Difference in light conditions from the same spot in August the top picture and December the down picture from AURA (Sitowise 2018).

The weather tool is also good for showing the different light situations and how the design looks in more realistic settings when there are clouds, fog, rain or snow. Although coding snow build-up in Unity remains challenging, it is more advanced in the Twinmotion visualisation program.



PICTURE 19. The Mäkelänkatu virtual model features cloudy weather, with a bright day on the left side and rain on the right (Sitowise 2018).

Although the virtual model is effective for detailed inspection, the use of layers is also beneficial. In Mäkelänkatu virtual model you could turn off and on different sets: street names, pedestrians, existing old trees, new planted trees, parked cars, vehicles on the road, the design area, buildings, the old surface mesh model and new modelled mesh model. Depending on the situations it is really handy to focus on specific details without the excessive data on the way so the simulation tool fits for many different purposes.

The Mäkelänkatu project had a public meeting where there was a presentation about the design solutions and a big about 2,5m long print of the 2D preliminary design. In the print citizens could put paper post notes on the print to write comments. There were also all the main civil engineer designers and project lead to answer any questions after the presentation about the design. From the civil engineering visualisation point of view there were presented the final AURA model to let the citizens use the simulation tool themselves or with guidance during the event. Before the public citizen event, 360° videos were created for virtual reality headsets, taking viewers on a flight path over the design area of the virtual model.

The event itself went really fast. There were many worried citizens who lived next to the design area and were happy to understand what was designed with the AURA model. Different parts of the model were shown to various people during the event, where stories were shared about living in the area, and feedback was given on the design. It was commented positively that the 3D model made more sense with the mesh model while the buildings looked the same in real life, although smaller in the virtual model. The 360 glasses were also a hit in the meeting. There was always someone wanting to see the design with the glasses, and many mentioned it to be their first time ever using VR glasses. The comments about the flight on the 360 were that the flight was too fast and gave some people a bit of motion sickness. Some people commented to get a bit scared of heights when the flight path started from street level and suddenly rose above the buildings. Aside from that, people were pleased with the new experience and appreciated the opportunity to engage with the design commentary. After the event the civil engineering designers continued the work in the next design phase with the valuable comments.

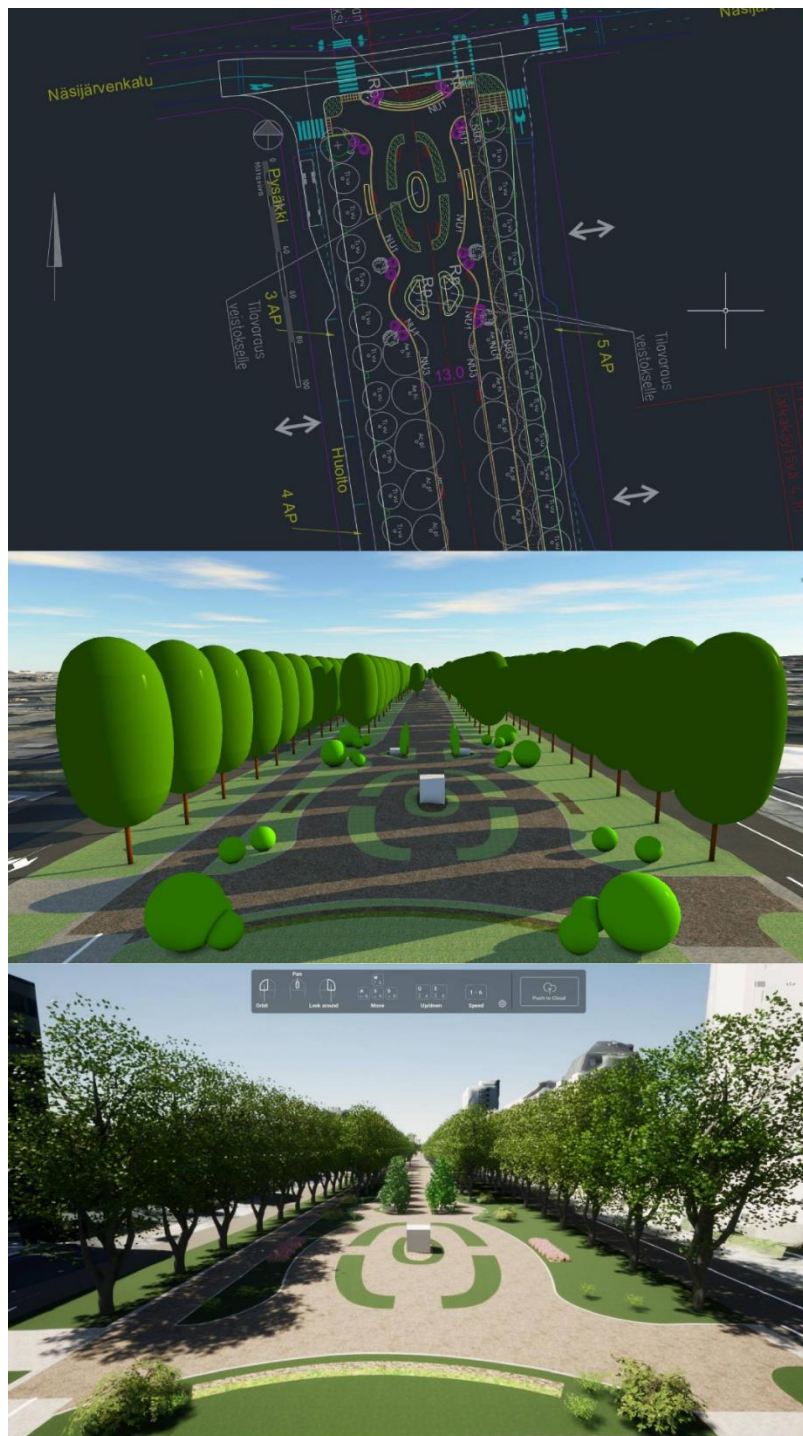
3.2 Hämeenpuisto visualisation

In the Hämeenpuisto visualisation case, the process of creating the visualisation using two key visualisation programmes will be explored in depth. This method is still a bit unusual while so far visualisations have been done with one program. In this Hämeenpuisto case was the first time to try to achieve higher visual outcome using InfraWorks as a base for visualisation data. Once all relevant data had been gathered from the civil engineering design files in InfraWorks, it was exported to Twinmotion. There, the textures were upgraded to high quality, and assets such as street objects were replaced with those from Twinmotion's catalogue and more realistic versions provided by the client. This case example demonstrates both preliminary phase tools and road and railway design tools simultaneously. It will illustrate how data from civil engineering tools is meticulously edited for visualisation tools, along with examples showcasing the workflow in detail. Engaging examples of specific situations within the workflow will also be presented.

Hämeenpuisto is a main park in Tampere city in Finland. The project requiring visualisations was in the preliminary design phase in 2023. The goal was to redesign the park with its crossings and park design. There were two designs: A version without bike road and B with bike road. In this thesis we will concentrate on the B version while it was the responsibility of the author to create the InfraWorks model, presentation model, videos and pictures.

The civil engineering designers created the design with collaboration of the client and while the variation designs were getting commented and finalised, I was creating models on Autodesk's InfraWorks program. Basically, when the AutoCAD or Civil 3D by Autodesk files were ready made by civil engineers, I opened them with Civil 3D to export parts of the design relevant for the visualisation model. Main goal is to get all the layers which are visible, so plumbing and underground details are not needed. A visualisation DWG was created as a drawing file in this design, incorporating key layers and elements for the visualisation within a single file in Civil 3D. The benefit of this is to get a trimmed version of the original DWG files like eliminating nonvisible layers. It is beneficial to have everything useful in one file rather than in several original ones. It helps to keep track of what exports are taken to the InfraWorks program. Downside of this approach is to update the DWG file every time there are changes in the original files which happens quite from time to time in this design phase. That's why several exports are done during the design process to make sure the materials are out the latest version.

The process is to export data to InfraWorks where all the data for visualisation is gathered and textures tweaked in right alignments to create a core of the design. Following this, all the data will be exported to Twinmotion, where the details will be finalised to create visualisation images and videos.



PICTURE 20. Same area shown of the Hämeenpuisto version B on Civil 3D as top picture, InfraWorks as middle picture and Twinmotion down picture on early design (Sitowise 2023).

In Finland, larger cities typically have mesh model cities available in their databases, which can be used for models, as demonstrated in the Mäkelänkatu case. The mesh models can be made by laser scanning with drones or helicopters or simplified IFC models. In Hämeenpuisto case the park was laser scanned on-site and the mesh with texture was cut out in 3D software to create

a hole in the mesh net on the part where the new design was created. The benefit of mesh models is that they allow users to easily visualise existing buildings and landforms, making it simpler to identify specific areas of a park. These scans are done periodically to ensure the up-to-date mesh.

In InfraWorks the design is exported bit by bit from the cities database data, designers DWG data. Simplifying the process when taking 3D data like a mesh model you need to make a SVG as a scalable vector graphics file, export of the DWG file. After that it is imported to InfraWorks as a terrain model. When using civil engineering data, which typically consists of 2D lines and polylines from civil engineering design programmes, areas such as roadway asphalt need to be edited into closed loops. This allows InfraWorks to interpret them as simple 3D data and texture information. The command inside the Civil 3D to export is MAPEXPORT. This is done with every data set with a different texture like cobblestone, grass or asphalt. In this part there is quite much manual work for the visualisation expert.

Civil engineering design data is useful because of its existing location data. With the precise location data in every design DWG file the updates on design doesn't create much workload while the parts exported goes in the right places. In every change in design the new exports need to be made and overwritten on the old one. This is one of the reasons for incorporating visualisations later in the process, as it minimises the risk of duplicating work. However, some degree of overlap occurs in every project.

In this project, all the city furniture was added as placeholder models in InfraWorks; simple objects like cubes and cylinders were used to represent benches and trash cans, which would be replaced in Twinmotion. In InfraWorks the model gets more 3D from the DWG file. In the InfraWorks the all upper layers from DWG are imported to the model like street markings, different types of roads like dirt, asphalt and cobblestone. All the cobblestones are assembled in the right directions in InfraWorks and put placeholder textures to the same areas. In Twinmotion those placeholders are selected by type and replaced all with the desired object with a lot of more detail in the models. In this project, other visualisation experts in version A created their own models to represent local

features, such as park shops and café buildings which were also added to the B version. Also from public databases there was taken city furniture used in the Tampere area.

In the Hämeenpuisto park there are a few sculptures which were added on the design variations. To achieve a realistic appearance, they were laser scanned using a phone app and delivered to us for use in the presentation models and Twinmotion. The results were looking realistic, and the scale was kept the same.



PICTURE 21. Scanned Minna Canth memorial statue in the Twinmotion model (Sitowise 2023).

Hämeenpuisto variations were shown a few times to the client during the process. Navigating through the Twinmotion model allows us to showcase various design solutions and gather valuable feedback from the client. This kind of realistic visualisation of the street design phase is critical to get quality comments from clients and make their job easier to follow the design solutions without needing to have a degree in civil engineering.

When the main street and park designs were on the Twinmotion with right assembled cobblestones and placeholder objects and textures were replaced by Twinmotions own more detailed versions the model was used to design the park design even further. It is a bit atypical to create civil engineering designs on Twinmotion while it usually is done 2D images exported from Civil 3D or AutoCAD. In these modelling and design sessions the park designer designed

the bench and more importantly bush locations and types. When the design was accepted, those locations were implemented to the original DWG files. The colours and plant types were easier to understand in 3D space than 2D. Typically, the process is reversed: the DWG file is updated first, followed by updates to the InfraWorks and Twinmotion models. This kind of work might be more popular in the future.

After several rounds of development, the final proposed versions of the park design began to take shape. In the Twinmotion model was then added more props like animated humans and cars to make the visualisation feel more alive. Adding these made the Twinmotion to work slower while the program started to crash often with the heavy data input. That made the further processing of the work slower. Twinmotion is designed for visualising smaller areas like buildings and areas directly next to a designed building. Hämeenpuisto is about a one-kilometre-long park so the Twinmotion was having struggles to open and progress the data, making the folder structure clearer and hiding not so crucial data during the work helped with these problems.

Although there were struggles, the results were dazzling. There were taken 12 visualisation pictures from each version and longer flying video from Twinmotion, where the whole length of the design was shown. Client side was pleased with the outcome and pictures of the design were seen in different newspapers in Finland.



PICTURE 22. Visualisation picture from the north side of the Hämeenpuisto park in Twinmotion (Sitowise 2023).

The author was truly honoured to be involved in this project. While it was challenging and hard work, I learned a lot of how to handle the used programs and could use my own visualisation knowledge to the fullest to ensure the end result to be visually high standard. Both A and B versions of the Hämeenpuisto visualisation designs were ultimately successful.

4 DISCUSSION

This thesis addressed several key questions regarding the processes involved in civil engineering visualisation:

First, it explored how understandable and realistic visualisations could be created for the general public, city officials, and clients. Given that the data produced by engineers is often highly technical and requires expertise in multiple fields to interpret, strategies for making this data accessible were examined.

Second, the thesis investigated how visualisations could be designed to facilitate meaningful conversations between civil engineers and the communities affected by these designs. The importance of clear communication and engagement in fostering collaboration was emphasised.

Lastly, the thesis considered what methods could effectively engage residents in the design process and enable their feedback on proposed projects. By enhancing understanding and encouraging participation, these methods aimed to promote community involvement in decision-making. These questions formed the foundation for understanding the role of visualisation in civil engineering and its potential to bridge gaps between technical data and community engagement.

To create meaningful interaction between citizen and civil engineering design team during the design phases, the visualisations are the key element. Without easy-to-understand visualisation pictures and videos it's hard to give accurate and felicitous feedback and comments without knowledge in civil engineering. Visualisations for the public meetings are worth the time and effort for meaningful conversation and are nowadays one of the established methods.

Although the cases differentiate significantly, they demonstrate that there are many paths to achieving clear and understandable results. As technology advances, workflows continually evolve, allowing for new types of materials to be exported for review. Virtual models and visualisation programs each have their own strengths and unique workflows. Depending on the project's nature, either or both can serve as effective visualisation tools.

With the case in Hämeenpuisto Twinmotion loading problems could be fixed in the future. Before that there is something the visualisation expert can do to help the program to handle the data with layer management and hiding temporary assets like animated people. The program is built for way smaller area visualisations than it was used in Hämeenpuisto visualisation. Although the final videos and images were high resolution, the associated costs and issues were quite significant. Although those were slowing the work down the work was completed and the client was pleased.

Virtual models and digital twins can be powerful tools for simulations. Although experience has taught that even when there are Unity builds done for the projects, those are still rarely used by clients or third parties. There is still reluctance to try new programs even though there can be manuals for them or shown how they work. People tend to use what they are used to. Even though the models are not so used as they could be, they give valuable information of the city's structure, show the data collected in easy-to-understand form and can be useful in simulation. For example, the virtual model created for Central Pasila in Helsinki by Sitowise was used for shadow simulation in park design. The designers utilised the light tool to assess how much sunlight different areas of the park received throughout the year, making it easier to decide which plants could be planted. That model was also used on the client side to show third parties how the infrastructure was going to change during the construction. There is still room to explore how to use these models in the best way. Usually they are used for marketing purposes, showing investors the design, showing the citizens the upcoming changes and showing the 3D data in a visual way.

While pictures and videos are still the main source of visualisations, the new technology has its own use. Like digital twins can help to maintain a city functions without going to the physical site.

In civil engineering visualisations are still evolving and there is not yet one program or method which could fit most of the cases. There is a need for a program that can convert 2D lines and polylines from AutoCAD and Civil 3D into 3D surfaces and objects for game engine-based visualisation tools like

Twinmotion and Unity, minimising the amount of manual work required in the process. The conversion is at the moment a trial-and-error phase and effort to have knowledge of every program between the work is excessive. Making the whole process simpler could save a lot of work hours and would give more access for people to use the visualisation tools while the learning curve could be easier. There are programs like Trimble Connect and Novapoint for civil engineering which create 3D data, but they are still not commonly used which makes the conversion to game engines a bit easier.

Although these visualisations were the result of collaborative efforts, the process could become much more streamlined in the future as technology continues to advance. As visualisation tools evolve, they may become more accessible to a wider range of experts, reducing the need for specialised knowledge across multiple software programs and conversion processes. In the future, creating high-quality visualisations might no longer require juggling various platforms, allowing experts to focus more on creativity and precision rather than technical constraints. This shift will open up opportunities for more professionals to contribute to the field, ultimately driving innovation and improving efficiency in civil engineering visualisation.

Additionally, as VR, AR, and MR technologies become cheaper and more powerful, they will become available to a wider range of consumers, further improving visualisation techniques. These technologies hold immense potential for the future of civil engineering visualisations, enabling more immersive and interactive experiences. Exploring VR, AR, and MR should be a priority for future developments, as they will continue to shape how civil engineering projects are visualised, communicated, and understood by both experts and the public.

Digital twins represent the future of civil engineering visualisation. Although still a relatively new and complex technology, their potential applications are vast and largely unexplored. They are being explored more and more in upcoming thesis works and as research in this area grows, the true power of digital twins will become more known. This continued development will drive innovation and transform the industry in ways we have yet to imagine.

5 FUTURE

While there are already various ways to create visualisations of civil engineering designs, the future might change everything. Every time there comes a new improved technology accessible it migrates to the design world over time especially in the visualisation side. Many companies in Finland experiment and make demos of new ways to visualise and mark the projects with actual design data rather than artistic interpretation of the design. People are more involved in Finland to comment and discuss the designs, especially bigger cities and the visualisations needed to serve them better and find new ways to open the discussion in a meaningful way.

When now the visualisations are heavy on human touch, editing the AI and machine learning might come popular in the future. AI algorithms can be trusted to enhance resource allocation, optimise project planning, predict delays, and streamline scheduling and ultimately improving project performance. Meanwhile, machine learning excels at processing vast datasets to identify trends, enabling more precise forecasting. Automation is also playing a pivotal role in the future of civil engineering. Autonomous drones are now being used to inspect and scan structures, significantly cutting down both time and effort in operations (BOSS Editorial 2024). ChatGPT is already creating complex pictures so maybe in the near future it can combine 3D models to a picture of the design area and implement it to the generated picture. Maybe in the future there will be no need for Photoshop from now and with the design pictures anymore.

While digital twins are quickly becoming essential tools in civil engineering their usage can be even more common in the future. These virtual models of physical infrastructure enable real-time monitoring, simulation, and maintenance of assets. As a result, maintenance strategies are optimised, risks are minimised, and decision-making improves. For example, a city's water supply network can be equipped with a digital twin to quickly detect leaks and enhance distribution efficiency, reducing downtime (BOSS Editorial 2024). Digital twins will come more integrated with IoT as the buildings, bridges, and roads actively communicate, providing real-time updates on their condition. By integrating data analytics and IoT sensors into structures, you can anticipate maintenance requirements,

monitor the health of assets, and extend their lifespan. This innovative approach not only boosts safety but also helps prevent costly failures and prolongs infrastructure durability.

VR and AR are invaluable tools for civil engineers, allowing construction projects to be visualised in immersive environments while MR might take more time to get more common as a tool. These technologies enhance collaboration, improve design precision, and contribute to operational excellence. VR also plays a crucial role in training, offering a risk-free space for staff to practise complex tasks, which results in more efficient designs, fewer errors, and smoother project execution. Also AR can provide cheaper and easier ways to educate and show the internal constructions at sites even more accurately.

Adopting these cutting-edge innovations in construction can lead to more sustainable, intelligent, and resilient infrastructure. By embracing these technologies, we can revolutionise the future of civil engineering together.

To stay at the forefront of visualisation, the rise of digital twins is particularly revealing. These virtual replicas of physical assets are increasingly being developed on a larger scale, offering real-time insights and optimising infrastructure management. Collaboration across fields—such as engineering, architecture, data science, and urban planning—further enhances their future potential, enabling more precise simulations and informed decision-making.

As digital twins evolve, more research and theses are exploring their applications and development, positioning them as the future tool for civil engineering visualisation. The process of integrating digital twins has already begun, and once current obstacles are overcome, their potential will be limitless. These tools will enhance security, streamline coordination, and bring cities to life in ways we have yet to fully imagine.

In the future, collaboration with citizens will also become more prominent, enabling even clearer, more inclusive urban planning and development. Digital twins will not only improve infrastructure but also create a platform for communities to engage with and shape their environments more directly.

As technology evolves, new visualisation methods will emerge, potentially simplifying the process and making it more straightforward and accessible. This progress will make digital twins and other tools easier to handle, allowing for even greater efficiency and broader adoption in civil engineering and urban development.

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