The role of 3D city models in PED development

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About SPARCS

Sustainable energy Positive & zero cARbon CommunitieS demonstrates and validates technically and socioeconomically viable and replicable, innovative solutions for rolling out smart, integrated positive energy systems for the transition to a citizen centred zero carbon & resource efficient economy. SPARCS facilitates the participation of buildings to the energy market enabling new services and a virtual power plant concept, creating VirtualPositiveEnergy communities as energy democratic playground (positive energy districts can exchange energy with energy entities located outside the district). Seven cities will demonstrate 100+ actions turning buildings, blocks, and districts into energy prosumers. Impacts span economic growth, improved quality of life, and environmental benefits towards the EC policy framework for climate and energy, the SET plan and UN Sustainable Development goals. SPARCS co-creation brings together citizens, companies, research organizations, city planning and decision making entities, transforming cities to carbon-free inclusive communities. Lighthouse cities Espoo (FI) and Leipzig (DE) implement large demonstrations. Fellow cities Reykjavik (IS), Maia (PT), Lviv (UA), Kifissia (EL) and Kladno (CZ) prepare replication with hands-on feasibility studies. SPARCS identifies bankable actions to accelerate market uptake, pioneers innovative, exploitable governance and business models boosting the transformation processes, joint procurement procedures and citizen engaging mechanisms in an overarching city planning instrument toward the bold City Vision 2050. SPARCS engages 30 partners from 8 EU Member States (FI, DE, PT, CY, EL, BE, CZ, IT) and 2 non-EU countries (UA, IS), representing key stakeholders within the value chain of urban challenges and smart, sustainable cities bringing together three distinct but also overlapping knowledge areas: (i) City Energy Systems, (ii) ICT and Interoperability, (iii) Business Innovation and Market Knowledge.

Partners

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1. INTRODUCTION

A digital three-dimensional (3D) city model describes the geometry and structure of an urban environment. Normally, a 3D city model is understood to combine non-geometric data with the 3D geometry of urban objects, such as roads, trees, terrain, and 3D building models. These models are typically built through 3D reconstruction and data integration, for example merging photogrammetry or laser scanning data with geographic information systems (GIS) data.

3D city models have become common geospatial data assets for cities that can be utilized in numerous fields. 3D city models can be used among others in tasks related to planning, visualization, and decision-making. Considering that urban metropolises are the lead contributors of greenhouse gas production, a rapid transition of urban areas towards energy efficiency and adaption to challenges created by climate change are greatly required. In this context, virtual 3D city models have shown huge potentials in the fields of city planning, environment and energy, from flood risk simulations to solar potential analyses. [1]

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2. RELEVANCE TO SPARCS

The SPARCS Work Plan for Espoo City (Deliverable 3.1) provides a breakdown of activities that will be completed as part of Action E10-1 and the Kera PED demonstration. The role of the 3D city model in Kera planning is explicitly stated as an activity.

Table 1: Excerpt from Deliverable D3.1 indicating the Action E10-1 breakdown.

Action E10-1	**City Planning for Positive Energy Blocks. Exploring the possibilities to utilize the continuously updated Espoo 3D City model as a support and tool in the development and planning of the new Kera area.**
Detailed plan	• Communicate with city architects and zoning personnel to understand and document the role of the 3D city model in Kera planning. • Map technical, economic and regulatory barriers in piloting innovative PED solutions. • Identify opportunities offered by energy community legislation and new cost-efficient renewable energy generation and distribution technologies • Assess new business models for generation, aggregation, storage and distribution. • Explore the benefits of using 3D city model in pursuing new opportunities and implementing PED solutions • Draft process to mainstream 3D city model support in PED development in Espoo.
Targeted outcome	Mainstreamed process to routinely integrate PED considerations in the early stages of city planning will reduce costs and improve the effectiveness of energy efficiency and distributed energy generation measures in new area development.
Roles and responsibilities	ESP: Main responsibility VTT: Support in identifying technologies relevant to PED development leveraging experiences from similar Lighthouse projects Siemens, Adven, PlugIt, Kone, stakeholders: Propose private sector solutions and new business models for public private partnerships in PEDs
Schedule	M18: 3D model in city architecture and zoning process documented M21: Barriers, opportunities and business models assessed M28: Assessment of 3D model feasibility in PED implementation finalized
KPIs	Qualitative assessment (Likert scale) of city planning tool Prospective On-site Energy Ratio and Annual Mismatch Ratio in Kera Prospective impact on energy expenditure for residents (€/year)
Financial scheme	This action does not require infrastructure investment. The city is actively engaged in projects to support renewable energy, circular economy and low-carbon mobility solutions, with specific budgets allocated to local pilots.

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3. The City Planning process

The land use planning in Finland is defined in the Land Use and Building Act. The regional land use planning is guided by the national land use guidelines issued by the Ministry of Environment. Each region in Finland is covered by a regional land use plan, which sets out the principles of land use and the community structure. The regional land use plan is drafted and approved by the Regional Council and represents a long-term plan and a guideline for the municipalities when drawing up and amending local master plans and local detailed plans.

The regional land use planning system is shown in Figure 1.

In 2020 the Regional Council accepted a new land use plan called the Helsinki-Uusimaa Land Use Plan 2050. It covers the entire Helsinki-Uusimaa region and all the important forms of land use with a time span until the year of 2050. The Helsinki-Uusimaa Land Use Plan 2050 contains a strategic structural plan, as well as regional land use plans. One of its main targets are to steer sustainable growth and regional balance and to face climate change and the sustainable use of nature and natural resources.

A general plan, or also called master plan, indicates the general principles of future land use in the city. The plan shows the location of and connections between different functions in the community, like residential areas, services, workplaces, and recreational areas.

The master plan is the frame for the local detailed plan, which shows regulated building sites and building volumes, and zones for different land use, like dwelling, workplaces, services, traffic, and recreational areas. The plan also contains detailed regulation of new buildings in the area.

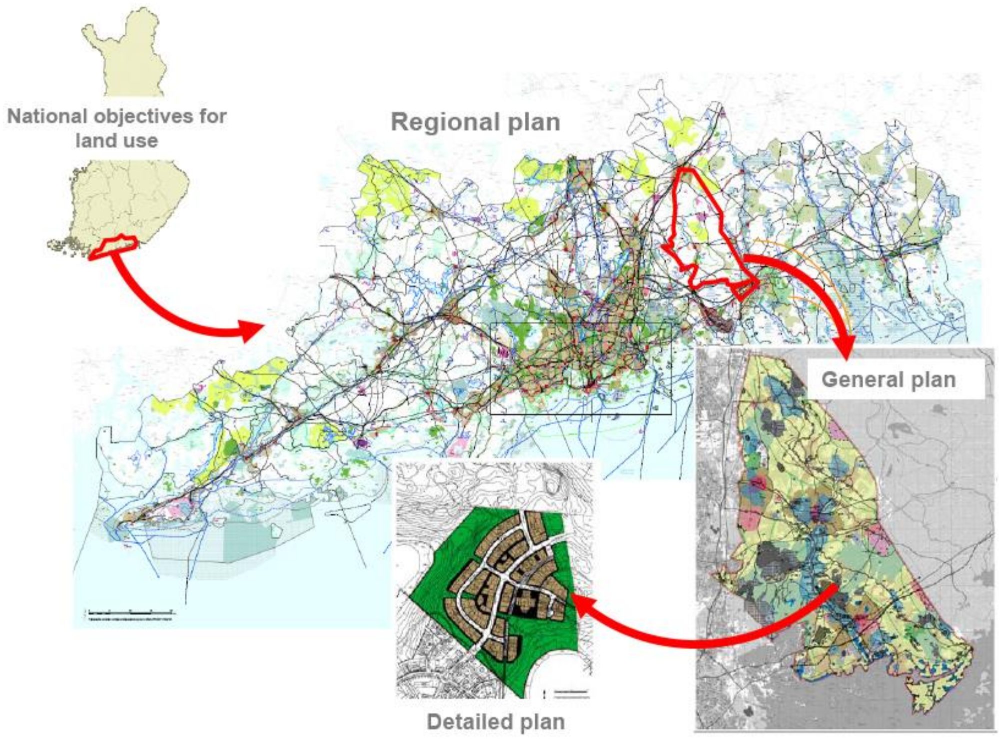

Figure 1: Regional land use planning system [2]

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The majority of Espoo is covered by legally effective master plans. The legally effective master plans are the master plan for the southern parts of Espoo (effective as from 2010), master plan I for the northern parts of Espoo (effective as from 1997) and master plan II for the northern parts of Espoo (effective as from 2001).

The current master plan for Espoo's northern parts, which entered into force in 1997, covers more than half of Espoo's land area, but is no longer able to respond to the challenges of the growing capital region and the changing city. A new master plan shall create the framework for the urban environment and well-being of future generations. Its goal is to steer long-term development while reconciling population growth, urbanisation, and carbon neutrality. The pending master plan is expected to be approved in spring 2021.

In general, the master planning process can be divided into 5 stages (see Figure 2).

Figure 2: Master planning process [3]

First, the City Board decides on the starting points and objectives for planning and a so-called participation and assessment plan (PAP) is drawn up for each individual plan. The PAP specifies how the preparation of the plan and decision-making will proceed and how participation, interaction (co-operation with residents) and impact assessment will be arranged. In the draft phase the City Planning Department creates reports and alternative draft plans. All draft plan preparation material is published for public review and during the review period, parties concerned may express their opinions about the presented material. Based on the feedback and further negotiations, the plan solution and its implementation are further specified. The plan proposal will be made available for review (30 days) in the same manner as the draft plan. If necessary, adjustments are made to the plan proposal. The City Planning Board processes the comments received on the plan proposal and sends the proposal to the City Board and then to the City Council for approval. After approval, the plan becomes effective when it has been announced in the newspapers the city uses for such purpose if no appeals have been made.

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4. Espoo's 3D City Model

The city model of Espoo is a constantly evolving 3D model, that follows the OGC CityGML 2.0 standard. [4, 5] CityGML (Geography Markup Language) is an open data model for the storage and exchange of virtual 3D city models. The aim of standardized models, such as the open data CityGML model, is to allow same data to be reused in different application fields. While CityGML represents the graphical appearance of city models, it also addresses the representation of the semantic and thematic properties, taxonomies and aggregations. CityGML not only includes a geometry model but also a thematic model, which employs the geometry model for different thematic fields. The thematic fields included in the CityGML scheme of the city of Espoo are shown in Figure 3. Engineering structures (such as bridges and tunnels) are currently not covered by the model.

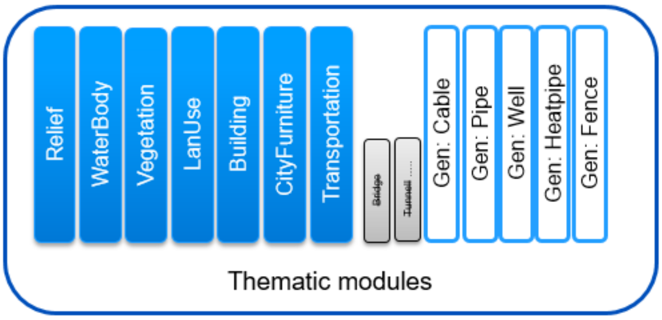

Figure 3: Thematic modules of CityGML scheme in City of Espoo

Additionally, Espoo uses generic objects to visualize mainly underground infrastructure, such as pipes, wells, and heat pipes. The level of detail (LOD) in CityGML specifies how detailed the object types are depicted. LOD 0 represents the lowest level of illustration and a high grade of generalization. LOD 3 models on the other hand, are detailed architectural models, which contain detailed wall and roof structures and allow mapping of high-resolution textures onto the structures. The LODs of different objects within the Espoo 3D city model are presented in *Table* 2.

Table 2: Object types at different levels of detail and their descriptions in Espoo's city model

FEATURE TYPE	LOD 0	LOD 1	LOD 2	LOD 3	TYPE	DESCRIPTION
Buildings	✓	✓	✓	✓	3D objects	completed buildings
Land Use	✓	✓	✓		area	properties
Plant Cover		✓	✓		area	parks (property of infrastructure)
Road	✓	✓	✓		area	streets (property of infrastructure)
Relief		✓	✓	✓	area	laser scan 2017 (grid)
Water Body	✓	✓	✓	✓	area	water areas from base map
City Furniture		✓	✓	✓	point	furnitures (property of infrastructure)
Vegetation		✓	✓	✓	point	vegetation (property of infrastructure)
Generics						
Cable	✓	✓	✓	✓	line-pipe	underground cables
Pipe	✓	✓	✓	✓	line-pipe	underground pipes (water-waist)
Heat pipe	✓	✓	✓	✓	line-pipe	underground pipes (heat)
Well	✓	✓	✓	✓	point	wells connected to underground pipes*
Fence	✓	✓	✓	✓	line	fences from base map

✓	Available on open data
✓	Open data covers geothermal wells only
✓	Not available on open data

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Information about the actual built environment of Espoo are presented in the city information model (CIM), which is maintained in Trimble Locus, a geographical information database. The model serves as an initial information model and enables more efficient planning and decision-making. The management process of the CIM and its information is illustrated in the figure below (see *Figure 4*). The model contains information of about 64 000 buildings, bridges, streets, city furniture, etc., and is updated by the city survey department.

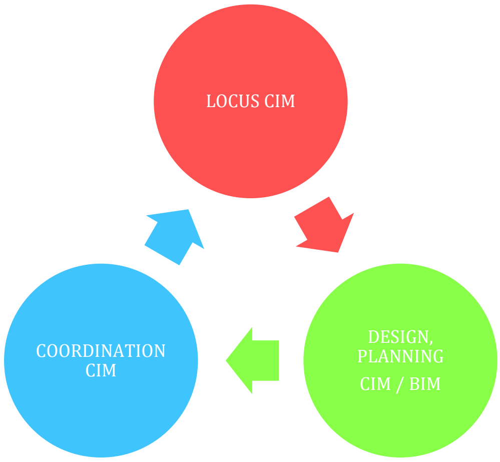

Figure 4: CIM workflow in Espoo [6]

Project models are handled either directly by the planner or – as it is usually the case - by the client and their consultant. Building information models (BIMs) for example are often used to ensure efficient management of information processes throughout the project's timespan (from concept phase to occupation). Later on, project models are brought into the coordination model as proposals. The urban planning centre is responsible for keeping the coordination model up to date. As a project makes progress towards legal status, the model's status is elevated into a more fixed status in the coordination model.

4.1 Strengths, weaknesses and opportunities of the 3D City Model

The strengths, weaknesses, opportunities, and threats of Espoo's 3D city model (and related to its development) were assessed by conducting a SWOT analysis.

The main strength of the current Espoo 3D city model is the rich and versatile information it contains. The model is not only up to date, but it also follows the OGC CityGML 2.0 standard. It is already a common tool in urban planning and the model's open data can be accessed freely by the public. Even though open data is freely available, there is yet no online platform through which citizens and users can experience and access the model in 3D format. Furthermore, the usage of the model and its data by other organizations is still low.

The number of opportunities identified illustrates the potential the 3D model and its future applications have. The rich and versatile information could not only be used by the city planning department, but instead also in different application fields. The 3D model could serve as a consultation tool for citizens (especially during the city planning process, but also later on for retrofitting or renovation purposes) and could be used to get citizens more engaged in the city

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planning process. The 3D city model could be further developed to offer an energy atlas of the city. Numerous simulations and scenarios could be created using the data from the 3D model.

When visualizing data in very detail, data privacy and anonymity must be considered thoughtfully. It should also be considered that the accuracy of source data can influence the overall quality of the model. The richer and bigger data model become the more computing power they require. This can also pose a threat to the user friendliness of the model.

Figure 5: Espoo's 3D model SWOT analysis

4.2 Competition overview and features

While there is no direct competitor to the city of Espoo in regard to the 3D city model, yet one could say that there is a competition between Finnish cities (for example in the race of becoming Finland's or even Europe's most sustainable city). Indeed, the city of Espoo is not the only Finnish city which is developing 3D city models. 3D city models of different Finnish cities are documented in the following paragraph.

Helsinki:

The city of Helsinki has developed two next generation 3D city models: a semantic city information model and a visually high-quality reality mesh model. The city information model allows users to perform a variety of analyses focusing among others on energy consumption, greenhouse gases or the environmental impacts of traffic. The reality mesh model can be utilised in various online services or as the basis for all kinds of design projects. Based on the city information model the city of Helsinki also published an Energy and Climate Atlas, which contains building-specific basic information, energy and repair data, as well as data on the consumption of water, district heating and electricity. Helsinki's city models are also freely available as open data from Helsinki Region Infoshare. [7]

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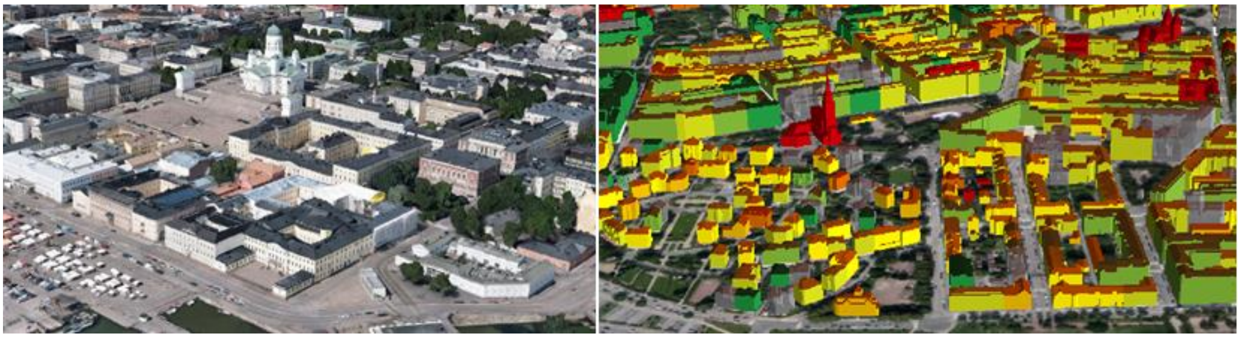

Figure 6: Capture from Helsinki's 3D city information model (left) and Helsinki's Energy and Climate Atlas (right)

Tampere:

The 3D model of Tampere is used as a tool for planning urban development, as well as communicating about it. The model has been built on the popular Unity gaming engine, which allows the utilisation of new technologies such as augmented or virtual reality to help with user inclusion. Various gamification methods are also used to support the new form of interaction. [8]

Figure 7: Capture from Tampere's 3D city model

In their article about 3D city modelling projects in Finland the authors (Julin A. et al., 2018) compared 3D city modelling activities and platforms within the six largest cities in Finland (see also *Table*). They concluded that the used platforms have a big variance. Within the 19 studied models, 13 different platforms were used. At that time, some of the software solutions applied in Finland were somewhat unique and have not seen wide adoption globally.

Even though Espoo was the first city in Europe to provide the continuously updated 3D city model to the public in form of an open data interface, the 3D model is still not publicly viewable. Other cities, such as Helsinki, have clearly outrun the activities in Espoo and become a forerunner by providing web-based viewing platforms and services such as the Energy Atlas.

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Table 3: A summary of 3D city modelling activities within the six largest cities in Finland [9]

City	Project	Used Platform(s)	Data Accessibility		Full City Data Coverage	Utilization of As-Planned Information
			Data Publicly Viewable	Data Publicly Downloadable		
Espoo	3D city model data	Locus	-	X	X	-
	Mission Leppävaara	CityPlanner	X	-	-	X
	Otaniemi lighting simulation	Unity	X	-	-	X
	Tapiola	Unity	X	-	-	X
Helsinki	Helsinki 3D+ information model	Cesium	X	X	X	-
	Helsinki 3D+ mesh model	Cesium	X	X	X	-
	3D city model data	Microstation	-	X	X	-
	Oulunkylä 2030	Unity	X	-	-	X
Oulu	3D city model data	Locus	-	X	X	-
	VirtualOulu	Unity, Unreal Engine	X	X	-	-
	Hiukkavaara 3D model	Unity	X	-	-	X
	SmartOulu	MAPGETS	X	-	X	X
Tampere	3D city model data	Novapoint, Quadri, AutoCAD, Viasys VDC	X	X	X	-
Turku	3D city model data	Locus	-	-	X	-
	3D model of Turku campus and science park area	Sova3D	X	X	-	-
Vantaa	3D city model data	Microstation	-	X	X	-
	Kivistö	Unity	X	-	-	X
	Minecraft	Minecraft	-	X	X	-
	Myyrmäki	Unity	X	-	-	X
Total	19	13	13	10	10	8

5. 3D CITY MODEL SUPPORT IN PED DEVELOPMENT

One important aspect when developing PEDs is the improvement of the energy performance of the already existing building stock. The three-dimensional illustration of the existing building stock can help to recognize potential buildings, that are e.g. in need of an energy renovation. Socio-demographic information, such as year of construction, building function, number of inhabitants, etc., may be available and they are essential for an urban energy analysis, often however, the available information is not sufficient to get an accurate energy characterization of the existing building stock. One challenge is, that data about the energy consumption of privately owned houses and buildings are not publicly available and the integration of such data in a public 3D model might be difficult due to data privacy reasons. Therefore, the trade-off between the privacy of consumption data and accurate energy analysis should be re-evaluated.

Instead of developing a 3D model on the building level, another option is to focus on the visualization and simulation of bigger building blocks or districts. This way the model might even reveal possibilities for collective investments or projects, without the need of revealing private data. The comparison between different neighbourhoods or districts might increase the awareness towards energy consumption, which potentially can lead to more energy-efficient behaviours.

According to R. Nouvel et.al [1] 3D city models have the potential to lead the energy transition even on a national level. In their study they concluded that 3D city models can enable the development of comprehensive urban energy strategies, by localizing energy saving potentials and defining refurbishment priorities.

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5.1 3D modelling in Kera

In SPARCS, Kera is the city planning demonstration site for Positive Energy Blocks, located in the Leppävaara district. The Kera area is a deprived industrial area developed in the 1970s and it will now be reallocated for mostly residential use. The development of Kera district is currently in city planning phase and its entire construction goes beyond the timeframe of the SPARCS project.

During city planning processes it is common to use 3D models to visualize the new plans and share them with stakeholders and the public. Often architecture companies are providing the models and visualizations for the cities. In the case of Kera, such visual reference plans were provided e.g. by the architecture office B&M Oy (see Figure 8). 3D models are also often used to simulate shading and visualize shading effects between neighboring buildings.

Figure 8: 3D reference plan of Kera's detailed plan by architecture office B&M Oy [10]

Kera as pilot site for the URBS-data project

Kera was selected as the pilot site for the URBS-data project ("Data integration and knowledge co-creation for smart urban development"), which began in autumn 2016 and finished in 2018. The aim of the URBS-data project was to renew the urban planning system in Finland. By supporting the accelerated development of digital business solutions and services, the main target of the project was data integration, knowledge co-production and the overall digitalization in the context of urban development. The consortium of the project composed the City of Espoo, Sitowise, A-Insinöörit, Tridify, Bonava, Aihio Arkkitehdit, ACRE, Business Finland and Aalto University. The project tried to address characteristic challenges of regional development projects by bringing large amounts of data and entities under control and present them in a clear and visually appealing form that can be examined by decision-makers, stakeholders, and residents. The principle of Big Room Planning played a central role in the URBS-data project. [11, 12, 13]

During the project a map-based survey ("Visions of Kera's central blocks") was created for Kera using Mapita. The map-based survey allowed respondent to use drawing tools to give their opinions on matters such as the construction phases in Kera.

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Furthermore, the Tridify Building Creation Tool was used to create 3D views of the Bonava residential block in Kera. The tool made it possible to change the 3D construction views of the block when changing e.g. selections for the gross floor area.

For the URBS-data project, Sitowise focused on developing its' Louhi service to serve the needs of infrastructure and construction projects. The Louhi service allows to visualize spatial data in a form that is easy for decision-makers and residents to interpret. In the project, Louhi was connected to the design processes to visualize the project data and manage information in spatial context. An example of the browser-based map service Louhi is shown in the figure below (Figure 9).

Figure 9: Kera visualized with Sitowise's Louhi map service [13]

A-insinöörit's Cityfier digital land use planning service was used to assess the impact of phasing on the increase in the value of blocks in Kera from 2020 to 2035. The Cityfier digital land use planning service uses open geolocation, city survey and house sale advertising data.

The URBS-data project succeeded in co-developing the use of data and in the development of data-driven collaboration. According to one of the partners involved, the project has strengthened the view of the need for collaborative digital tools in urban development processes. The outcome of the project was a Participative Planning Support System that compromises of four pillars: data management, process management, content management, and communication management.

Even though the URBS-data project is an excellent example of how digitalization tools can produce new tools for managing and coordinating increased data volumes, challenges remain since maintaining digital tools and models requires effort, development, and an allocated budget. The implementation of the project's outcomes and the integration of newly developed solutions into the city planning process is challenging as well. In the past, the city of Espoo has decided to discontinue the use of the Louhi service (which was developed during the URBS-data project) and now the city uses Trimble Solutions Oy's Trimble Locus service to manage and maintain information about the built environment.

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