On the Use of Graphical Digital Twins for Urban Planning of Mobility Projects: a Case Study from a new District in Ålesund, Norway

Pierre Major[1], Ricardo da Silva Torres[2,3], Andreas Amundsen[4], Pernille Stadsnes[1], Egil Tennfjord Mikalsen[1]
[1]AugmentCity, Ålesund, Norway
[2]Wageningen University & Research, Wageningen, The Netherlands
[3]NTNU – Norwegian University of Science and Technology, Ålesund, Norway
[4]United Future Lab Norway, Ålesund, Norway

KEYWORDS

Digital Twin, Urban Planning, Planning Support System, Mobility.

ABSTRACT

Urban planning is a complex task often involving many stakeholders of varying levels of knowledge and expertise over periods stretching years. Many urban planning tools currently exist, especially for mobility planning. However, the use of such tools often relies on ad-hoc modelling of *"expensive"* domain experts, which hampers to incorporate new knowledge and insights into the planning process over time. Another issue refers to the lack of interactivity, i.e., stakeholders can not easily change configurations of simulations and visualize the impact of those changes. This paper presents and discusses the benefits of using a graphical digital twin to overcome such shortcomings. We demonstrate how a digital-twin-based approach improves the current planning practices from two perspectives. The first refers to automating the configuration and data integration in models, making the tool flexible and scalable to large-scale planning involving multiple cities on a national level and supporting automatic updates of employed models when input data is updated. The second refers to supporting interaction with the model through a user interface that allows stakeholders to perform actions, leading to insightful what-if scenarios and therefore better-informed decisions. We demonstrate the effectiveness of using graphical digital twins in a compelling real usage case study concerning urban mobility planning in Ålesund, Norway. Finally, this paper also outlines recommendations and further research opportunities in the area.

INTRODUCTION

While cities host currently 50% of the world's population, they consume more than 80% of the world energy and contribute to more than 60% of the greenhouse gases (GHG)[1]. Climate Change Mitigation (CCM) and Climate Change Adaptation (CCA) require profound societal changes, especially in terms of fostering greener mobility.

CCA and CCM demand a rapid response. However, urban mobility planning is a complex and time-consuming process, often involving the analysis of large volumes of data, processed through different tools, and involving interests and needs of several stakeholders (e.g., politicians, planners, citizens) [Fiore et al., 2019].

Urban planning often involves multi-disciplinary teams of experts with their own language and expertise [Brömmelstroet, 2010]. That situation may lead to vocabulary mismatches. Reports utilized in the decision-making processes have a high level of abstraction, being more convenient to a knowledgeable audience (e.g., urban planners, technical experts, and politicians). Domain experts tend to use jargon, metrics, and procedures, with difficult understanding for other stakeholders. Processing and analyzing such reports are also time-consuming tasks. There is also a lack of a common platform where insights from the various domain experts can be shared. Another issue refers to the fragmentation of plans, reflecting geographical and political particularities. The dynamic evolution of cities also poses additional challenges for the planning process. Often, this evolution is unevenly distributed in space and time, which may lead to tension both in planning and in realization phases.

Knowledge database, in the form of data collections, simulated analysis, and insight synthesis, comes very early in urban planning projects. Available data are often manually collected and manually fed into simulation models. Thus the model insights are static and are outdated when plans are matured, changed, or even when unforeseen events force behaviour change and durably transform mobility patterns, e.g., corona or energy crises. Furthermore, few pathways are explored during the analysis. The "business-as-usual" is compared against the evaluation of a discrete (in the mathematical sense) set of alternatives.

In short, the existing urban planning tools are not adequate for supporting effective decision-making.

[1]`https://bit.ly/unhabitatemissionreport`(As of Feb.2022)

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The employed procedures lack transparency, and there is a poor connection between the tools and the actual planning process [Brömmelstroet, 2010]. There is, therefore, a need for tools to "play with," aiming to generate strategies early on in the planning process; avoid using static representations in the dynamic planning cycles [Aspen and Amundsen, 2021]; and promote the early involvement of citizens, which may prevent conflicts and delays in later implementation phases.

Digital twin technologies have emerged as a promising alternative to address such challenges. Here, a digital twin is not seen as a control tool, but as a planning support system (PSS), i.e., as a tool that supports fast and better-informed decision-making towards sustainable city planning [Shahat et al., 2021], [Mylonas et al., 2021], [Ramu et al., 2022]. Digital twins have been used for anchoring the Sustainable Development Goals (SDGs) in concrete measures at the strategic and zoning plan level by supporting the analysis of different what-if scenarios and promoting active communication with other stakeholders, including citizens.

This paper presents and discusses the benefits of using a graphical digital twin to support urban mobility planning. We demonstrate that our digital-twin-based approach may improve the current practices in two ways:

1. Automating the configuration and data integration in models, providing i) scalability to multiple cities on a national level, and ii) automatic updates of the models when input data is updated.
2. Interaction with the model through a user-interface allowing stakeholders to perform actions, such as adding new infrastructure or changing capacity of a road segment.

BACKGROUND CONCEPTS AND RELATED WORK

Urban planning and Digital Twins

[Brömmelstroet, 2010] outlined relevant challenges and bottlenecks towards the implementation of an effective planning support system. Examples include the focus given on technical aspects, which lead to a lack of transparency and loose connections with the planning process.

Digital twins have emerged as a promising technology for addressing such challenges in planning activities. A digital twin can be defined as *"a dynamic and interactive virtual representation of a physical object or system, usually across multiple stages of its life-cycle. It uses real-world data, simulation or machine learning models, combined with data analysis, to enable understanding, learning, reasoning, and communication to stakeholders. Digital twins can be used to answer what-if questions and should be able to present the insights in an intuitive way."* [Stanford-Clark et al., 2019]. In this context, digital twins function as planning support systems, which could be utilized for land use and transportation planning.

The use of the term digital twin in an urban planning context has been used for a wide range of applications [Ketzler et al., 2020], [Deng et al., 2021], [Shahat et al., 2021], [Mylonas et al., 2021], [Ramu et al., 2022], including, for example, disaster simulation, land use analysis, and garbage management. Next, we discuss existing initiatives related to the use of digital twins for mobility analysis.

Digital Twins for Urban Mobility Analysis

Various forms of mobility analysis are essential input to planning on a regional and municipal level. In Norway, for example, on a regional level, these analyses are typically performed by consultants or the road authorities, which maintain a regional transportation model. A regional planning process can span years, and the models are typically run in the first part of the process for a limited set of scenarios. The results are static in the sense that they must be operated by experts, and there are limited possibilities for exploring different scenarios so that stakeholders can better understand the possibilities and limitations of the models. The planning process, on the other hand, is often dynamic: new data, expanding knowledge base, and other external factors may change strategies and goals.

Recent advances in establishing large scale traffic-models for cities based on open data-sets [Sánchez-Vaquerizo, 2022] and the availability of open-source models (e.g., MATSIM[2]) have fostered the development of digital twins for urban mobility modelling and assessment. One example is the work of [Chao et al., 2020], who investigated the benefits of state-of-the-art traffic visualization for the purpose of autonomous driving, not used for urban planning. [Major et al., 2021] also demonstrated the usefulness of graphical digital twin to visualize insights from different urban topics (e.g., mobility and energy) in a city. Their work, however, has not considered a dynamical scenario creation.

[Aspen and Amundsen, 2021] showed the usefulness of a systems' theory approach in instrumenting the SDGs into master plan planning strategies. In this paper, we investigate zoning plans and interventions at a lower level. [Metze, 2020] reviewed the literature over environmental visualisation. Many traits are similar to sustainable urban planning, such as cognitive tainted connotative interpretation of visual structures by stakeholders, i.e., the expert documentation is not always adapted to decision-makers and stakeholders from the civil society.

[2]`https://www.matsim.org/` (As of Feb. 2022).

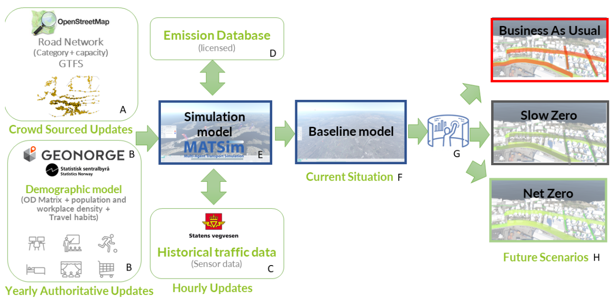

Fig. 1: Digital-twin-based mobility model assessment pipeline for interactive exploration of realistic what-if scenarios.

PROPOSED DIGITAL TWIN FOR MOBILITY ASSESSMENT

Digital-twin-based Mobility Model Assessment

Figure 1 illustrates the digital-twin-based mobility model assessment pipeline for interactive exploration of realistic what-if scenarios. The pipeline is generic, but, in this paper, its use is illustrated with data of Ålesund, Norway.

In the figure, we represent the main data sources, including the frequency of the data updates and information about which updates are automatic. The pipeline also includes a traffic simulation software that produces a *baseline model*. Finally, through a graphical interface, users interact with the model, performing analysis on different future scenarios. The whole mobility complexity is hidden from the users as all the parameters that can be generically entered for the whole country are pre-entered or automatically updated.

The architecture of the proposed digital twin is centered around the concept of an Origin-Destination (OD) matrix. An OD matrix can be seen as a list or matrix, which establishes the connection between the location where people work with the location where they live. These matrix values can be seen, therefore, as a proxy of the probability of traffic between two locations. The locations can be defined in terms of grid elements or geographical units. In addition, the travel habits, i.e., the probability of using a mode for a certain activity (detailed later in Fig. 4) is also a key concept in the mobility model implemented in the digital twin.

The key elements of the digital-twin pipeline are the following:

- The crowd-sourced open-source Open Street Map (OSM) (module represented with A in Figure 1) is imported to generate the network using road type, direction, and capacity. Crowd-sourcing implies that the network is constantly updated. Furthermore, the bus network information in the form of a General Transit Feed Specification (GTFS) time table are often openly published.
- Demographics data, such as the demographic and workforce densities and the OD Matrix are updated every year by the Norwegian Statistics Central Bureau (Figure 1 B). The travel habits surveys, which are updated and published every four years, are the default values for the simulation.
- Norwegian Roads Authority (SVV) hourly traffic measurements at key locations are dynamically updated daily, with traffic direction, and vehicle length and category (e.g., bike, car, trailer) – Figure 1 C. The data is automatically downloaded for the validation of the "current situation" scenario.
- The HBEFA database of emissions[3] is used to quantify the CO_2 emissions for each scenarios based on the modal distribution and the energy mix of the country (Figure 1 D).
- The agent-based mobility engine MATSIM (Figure 1 E), an open-source library with an active contributor base, is used to simulate the scenarios, such as the "current situation" or "baseline model." It also supports the creation of alternative pathways by changing some of its parameters.
- The "base model" is the result of the calibrated MATSIM model (Figure 1 F), validated with the traffic measurements from C. It serves as base for the model when users (e.g., urban planners) – Figure 1 G – play with different parameters.
- An infinity of what-if scenarios can be simulated. Here, three are selected (Figure 1 H): *"business-as-usual"* , which refers to population growth without changing the lifestyle and travel habits; *"Slow Zero"*, which relates to some change in habits towards a more sustainable living (e.g., living in denser areas); and *"Net-Zero"* paradigm shift, which refers to initiatives towards zero carbon emissions (e.g., closing motorways).

The proposed pipeline is flexible to support configuration automation of different mobility models. This eases the inclusion of new knowledge and plans and thus dramatically simplifies the identification of suitable mobility models considering different scenarios. Furthermore, the pipeline is generic and scalable to handle data of other regions (e.g., other Norwegian cities).

User Interface Functionality: Functional View

This section presents and discusses how the user can easily create new scenarios via the digital twin interface. Figure 2 shows a screenshot which summarizes the main available features: creating, choosing, duplicating, and deleting (if needed) scenarios. To create scenarios, one can "play" with the following parameters:

- Adding and editing network links in the networks, i.e. add new roads, bridges, and tunnels to the existing infrastructure and specifying speed limit, link

[3] `https://www.hbefa.net/e/index.html/` (As of Feb. 2022).

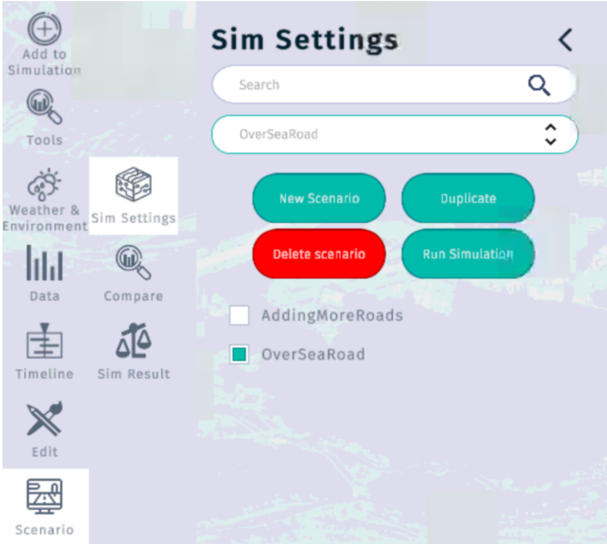

Fig. 2: Screenshot of the interface used for creating scenarios.

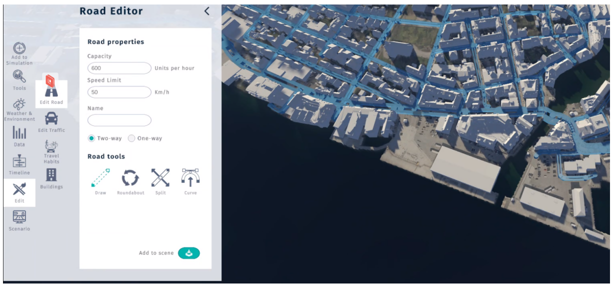

Fig. 3: Screenshot of the road editor interface.

capacity, and directionality, as illustrated in Figure 3. This can be utilized to support the creation of complex scenarios, such as closing a specific road for vehicle traffic.

- The flexibility to change the travel habits by activity type (e.g. work, school, service, shopping, care, etc.) is illustrated in Figure 4. This feature allows, for example, to simulate and visualise the effect of active mobility on congestion and on CO_2 emissions.
- Demographic and work force statistics can be altered on the $250m \times 250m$ grid unit level. This allows modelling scenarios where new residential or multi-purpose districts are created.
- Travel habits can be modified by activity to reflect anticipated societal behaviour change, see Figure 4.
- Some modifications are only possible in the background at the configuration file level, and are not yet part of the scenario building features. Examples include the GTFS public transport time table, which must be edited offline; and Modifications on the OD matrix.

Once a scenario is created, the simulation can be run to estimate the impact on traffic and emissions. The results can then be shown in the 3D graphical digital twin.

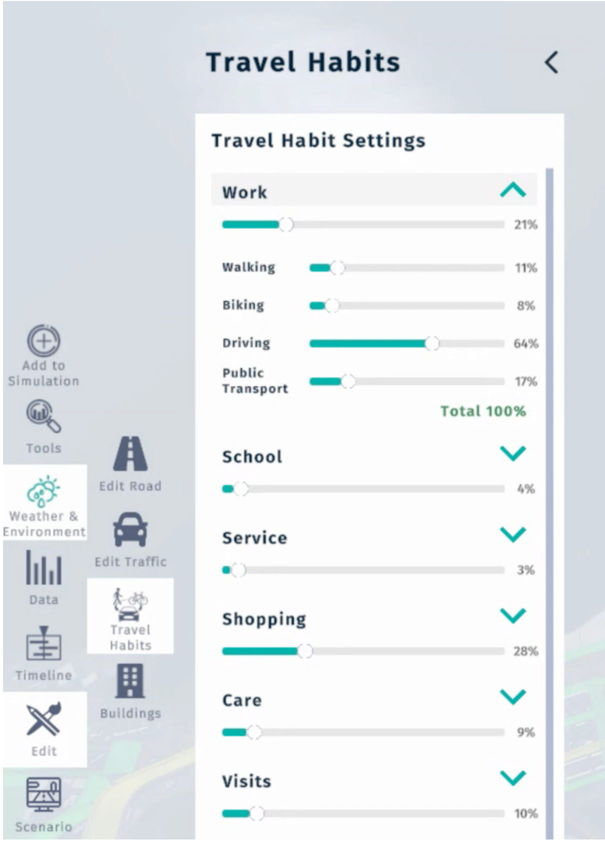

Fig. 4: Screenshot of the interface to collect inputs related to travel habits per activity. The travel habits are expanded for the "work" activity.

Additionally, specific features are provided to support the assessment of plans. For example, the tool allows to hide/show the buildings from cadastral register and import new BIM models in IFC or FBX formats.

USAGE SCENARIOS

To demonstrate the benefits of our digital-twin-based approach, we present usage scenarios related to the creation of a zoning plan in Ålesund, Norway.

Figure 5 illustrates four currently parallel projects in the city centre of Ålesund. Albeit they are confined to a bounding box of 600 m width, each of them has a different maturity, project timeline (start, concept, phases, stop), and political and citizen involvement phase or policy. Project (A) relates to the construction of a new road and a bridge.The goal is to allow crossing the sound westward/eastward. The new district (B), still partly in the conceptual phase, is affected by the bridge (A). There are also plans to transform the current cargo port and the bus and speedboat terminal into a modern multipurpose district. Project (C), currently in the detail phase, is the bus terminal relocation project[4]). This project does not take into account the speedboat terminal

[4] `https://bit.ly/zoningplan2018` (As of Feb. 2022).

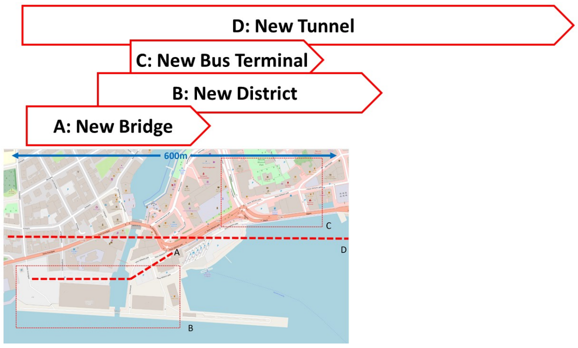

Fig. 5: Urban planning project portfolio.

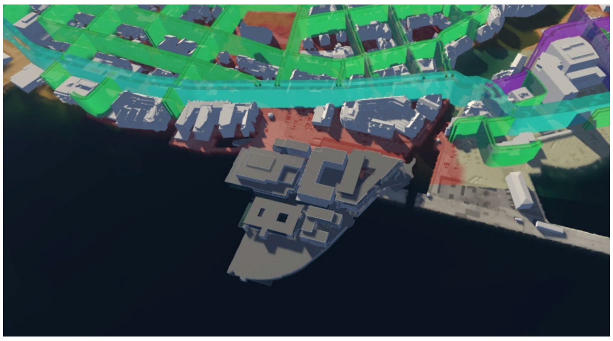

Fig. 6: Example of a case related to future districts in Ålesund, Norway. The figure illustrates removed hangars, added BIM of the new district, the road infrastructure, and information related to population density in the area.

that crosses the fjord. Finally, the new tunnel (D) under the city centre is expected to flatten the curve of peak traffic and revitalize the city centre by avoiding congestion.

Figure 6 illustrates how the visualisation helps stakeholders anchor their attention and contextualize the *future of city district* by removing BIM models (compare with Fig. 3), adding new BIM models, visualising the population density grid, and the road network.

Future built infrastructure can easily be modified to reflect alternative zoning plans[5]. Figure 7, for example, mirrors the network conditions of one such scenarios.

The mobility is only part of the big picture in urban planning and needs to be contextualized with other relevant insights. Figure 8 illustrates how the mobility model provides insights that can be superposed with other types of information, such as a heatmap representing the distance to schools dynamically calculated by open route service [6]. Regions highlighted in blue are associated with low-range values, while those in red related to higher values. The heatmap could be used, for example, to encode the distance to municipal and medical services, wildlife

[5] `https://bit.ly/brosundtunnel` (As of Feb. 2022).
[6] `https://openrouteservice.org/`, (As of Feb. 2022).

Fig. 7: Example of a case related to the inclusion of a new infrastructure. Two new links are added to the network: a bridge and a tunnel (highlighted in yellow).

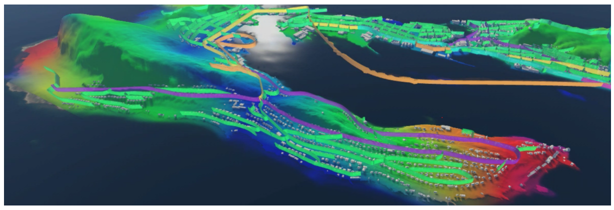

Fig. 8: Example of a case related to the assessment of the road network and distances to school.

impact assessment, and response time from emergency services. This exemplifies the kind of new knowledge that could be generated in later project phases. Using the same tool early on from the master plan to the zoning plan ensures continuous update of the insights regarding relevant variables considered in the planning process over time.

LESSONS LEARNED AND RECOMMENDATIONS

The developed digital twin has been validated in the context of the assessment of complex mobility scenarios. Obtained feedback from stakeholders has been positive towards the adoption of such technologies during the life cycle of mobility planning processes.

A key recommendation refers to the use of dynamic graphical digital twins to plan for automation of knowledge base using open source tools and open data sources. This may foster the continuous coordination of the insights and strategies between the master plan and their affiliated zoning plans throughout iteration and refinements, especially when the blueprints becomes more concrete.

CONCLUSIONS

This paper introduced ongoing research dedicated to the design, implementation, and validation of a digital-twin-based mobility assessment tool to support urban planning operations. The proposed digital twin synchronizes seamlessly the current physical world (city) and the digital twin in an urban mobility planning context, both through automation/integration from different sources and supporting for interaction from many stakeholders along the planning process.

This paper also demonstrates how the digital twin can be used to prototype mobility solutions both at the conceptual and detailed levels, allowing the creation and maturation of scenarios and plans along the urban planning project. Furthermore, the tool is scalable to other cities and regions (especially in Norway). Finally, it is connected to authoritative national databases, allowing not only the visualisation and analysis of past and present data, but also the validation of different models, considering newer calibrations and simulations of future scenarios.

Future work will address the challenges of how digital twins can be improved towards becoming more integrated into the planning process from master plan to zoning plan. Investigating how the tool can transform the planning process and how the process can be improved by the tool will be addressed in future work. Further research also concerns investigating how urban planners can use the tool as a co-creation platform across silos, including public/private organisations, municipal departments, in inter-municipal planning projects. Finally, to gain trust in the predictions, further research should focus on validation, accountability, and visualisation of parameter sensitivity.

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PIERRE MAJOR, currently as Head of Research for AugmentCity and OSC Ocean, he received his M.Sc. degree in Electrotechnique and Information Technology from the Swiss Federal Institute of Technology of Zürich (ETHZ) in 2005 and his Industrial Ph.D. on "data-driven models for fast virtual prototyping" at the Department of Ocean Operations and Civil Engineering, Norwegian University of Science and Technology (NTNU), Ålesund Norway, in 2021. His domains of interest are virtual prototyping of demanding offshore operations and graphical digital twins of systems such as cities or ships.

RICARDO DA SILVA TORRES is Professor in Data Science and Artificial Intelligence at Wageningen University and Research. Dr. Torres holds also a position as Professor in Visual Computing at the Norwegian University of Science and Technology (NTNU) since 2019. He used to hold a position as a Professor at the University of Campinas, Brazil (2005 - 2019). Dr. Torres received a B.Sc. in Computer Engineering from the University of Campinas, Brazil, in 2000 and his Ph.D. degree in Computer Science at the same university in 2004. Dr. Torres has been developing multidisciplinary eScience research projects involving Multimedia Analysis, Multimedia Retrieval, Machine Learning, Databases, Information Visualisation, and Digital Libraries. Dr. Torres is author/co-author of more than 200 articles in refereed journals and conferences and serves as a PC member for several international and national conferences. Currently, he has been serving as Associate Editor of Pattern Recognition Letters, Pattern Recognition, and IEEE Systems. He is a member of the IEEE.

ANDREAS AMUNDSEN is the digital twin coordinator for the municipality of Ålesund. He has previously worked as a research scientist with SINTEF, focusing on various aspects of software development within the offshore and maritime sector. He has also worked several years in the private sector as an IT consultant. He holds a M.Sc. degree from the Norwegian University of Science and Technology (NTNU).

EGIL TENNFJORD MIKALSEN Egil Tennfjord Mikalsen leads the technological vision and the engineering organisation of OSC AS as the Chief Technology Officer (CTO). Mikalsen connects technology, strategy, and business. Through his leadership and technical expertise he has developed the organisation and technology to deliver high end simulation and visualisation technologies in offshore, renewables and smart cities. Mikalsen also serves as a part of the leader group in OSC AS. Mikalsen has over 15 years experience in managing teams, developing complex systems and strategy.

PERNILLE STADSNES Pernille Stadsnes is Product Manager at AugmentCity AS, daugther company of OSC AS, leading the software and product development of digital twins for cities since 2019. Miss Stadsnes is also project manager for AugmentCity in research related projects. She received a B.Eng. In Ship Design from the Norwegian University of Science and Technology (NTNU) in 2015 and a M.Sc. In Systems Engineering and Industrial Economics from University of South Eastern Norway in 2019.