A Conceptual Digital Twin for 5G Indoor Navigation

Vladeta Stojanovic, Hossein Shoushtari, Cigdem Askar, Annette Scheider, Caroline Schuldt, Nils Hellweg and Harald Sternberg - Department of Hydrography and Geodesy, HafenCity University Hamburg, Germany

The Eleventh International Conference on Mobile Services, Resources, and Users - MOBILITY 2021
May 30, 2021 to June 03, 2021 - Virtual Presentation

IARIA

HafenCity Universität Hamburg

Presenter Information - Vladeta Stojanovic

Vladeta Stojanovic is currently a researcher at HafenCity University Hamburg, working with the Department of Hydrography and Geodesy.

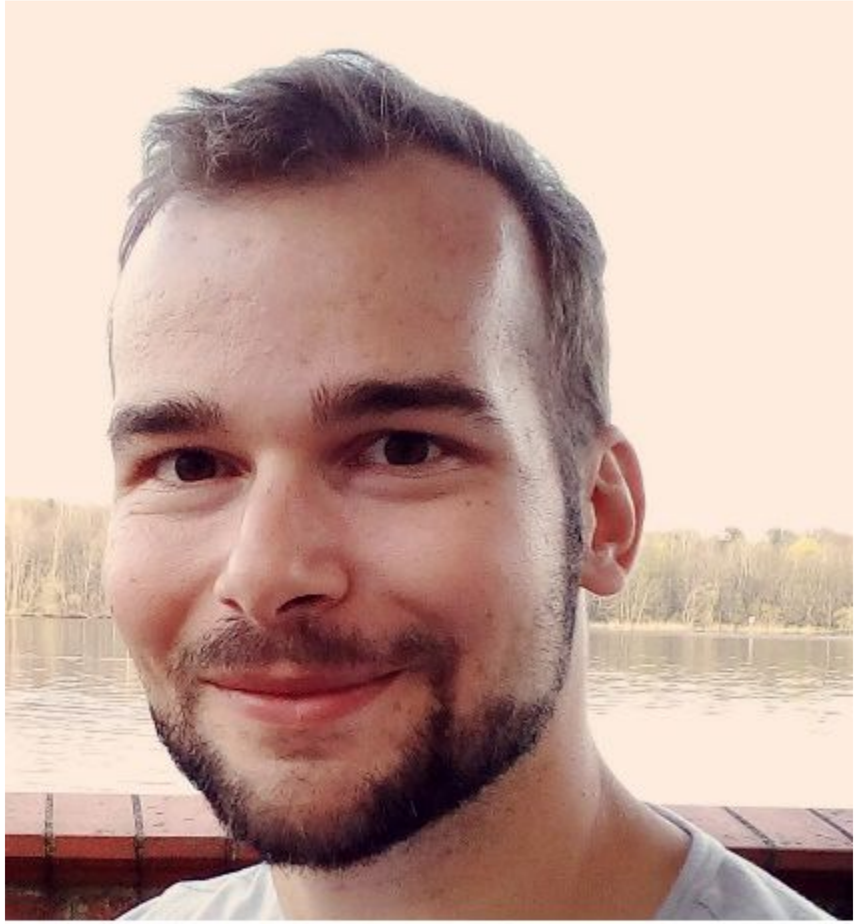
Vladeta does research in Interactive Visualization and Computer Graphics, with a focus on built environment visualization, digital twins of indoor environments, semantic enrichment of indoor 3D point clouds and sensor data analytics.

HCU: https://www.hcu-hamburg.de/master/geo/mitarbeiterin

LinkedIn:
https://www.linkedin.com/in/vladeta-stojanovic-17b94352/

ResearchGate:
https://www.researchgate.net/profile/Vladeta-Stojanovic

Education: B.Sc. (Hons) Computer Games Technology, M.Sc. Computer Science, Dr. rer. nat IT-Systems Engineering



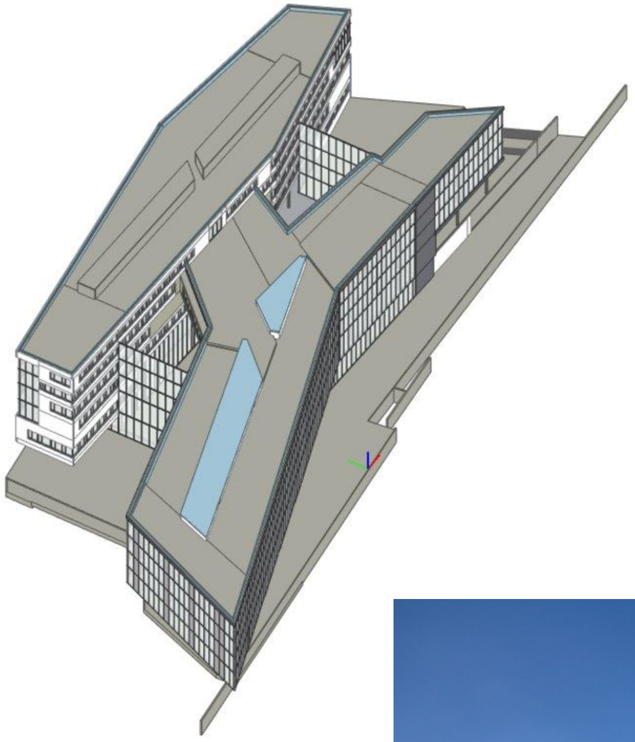
Introduction

- The focus of this research is on indoor navigation based on the ***Digital Twin (DT)*** paradigm.

- The use of a DT requires access to various data sources related to the specific lifecycle stage of the building.

- For Facility Management (FM) applications, historical and current data sources are needed in order to perform key analytics and generate results for furthering FM stakeholder engagement.

- Additionally, future states also need to be predicted (from 5G and sensor data).



The Digital Twin Paradigm

HafenCity Universität Hamburg

- The generation of up-to-date digital representations of buildings, specifically using BIM, is an expensive, time consuming and cumbersome process - largely tied to monolithic software systems.
- Combination of additional data sources e.g., IoT or existing digital documentation is often excluded.
- For use in Facility Management of current and future smart buildings, a centralized and automated approach for processing and analysis of data is required.
- A ***Digital Twin*** is a cyberphysical representation of a physical object (e.g., a building), that can be used to assess and forecast its former, current and future states based on analysis of related data.

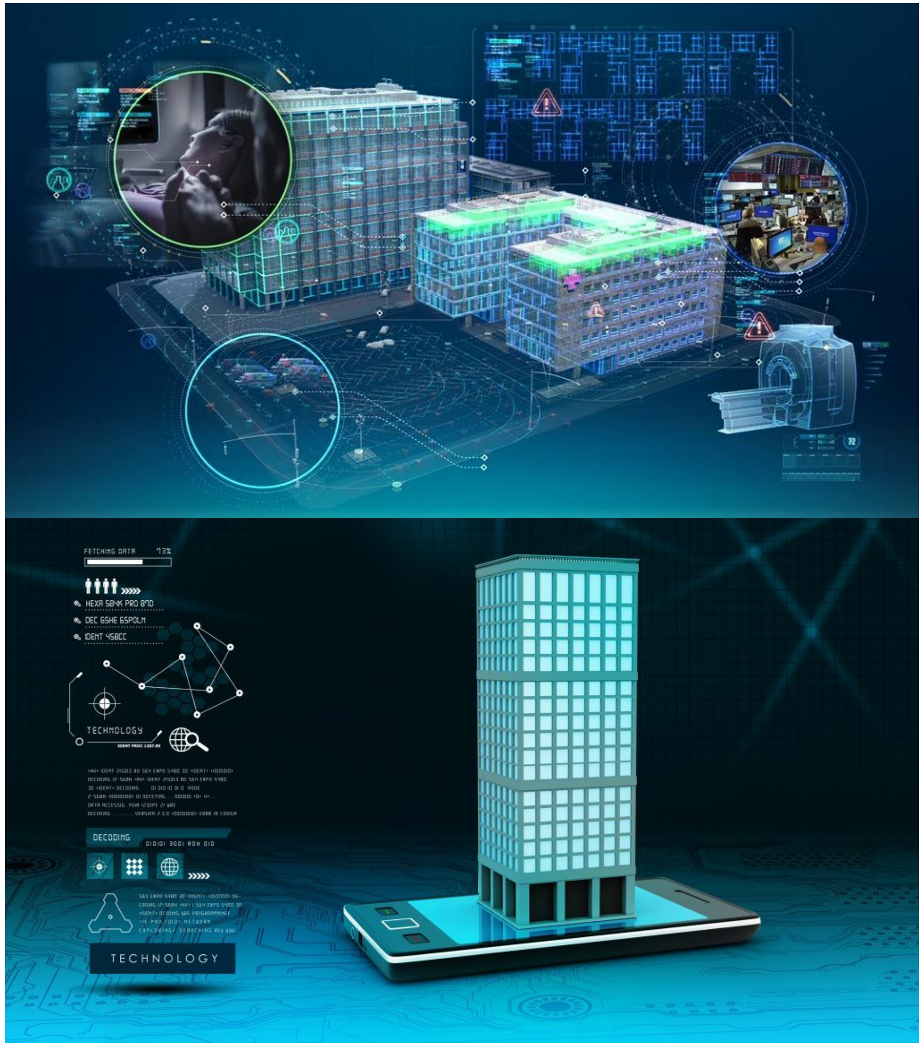
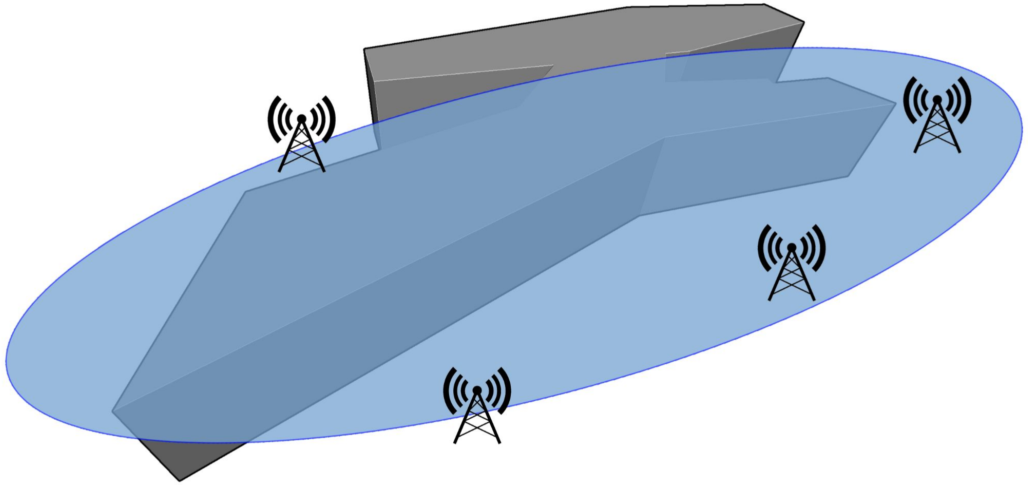


Image Sources: Autodesk/ General Electric

Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

Level 5 Indoor Navigation Project

- A 5G Non-Standalone (5G NSA) campus network and an additional experimental system will be realized at the main HafenCity University Hamburg building location between Q3 2021 and Q1 2022.
- Applications from the field of indoor navigation will be tested there and will serve research purposes.
- The planned campus network will consist of four outdoor antennas arranged around the main university building.
- For the planned outdoor and indoor network, the use of private frequencies in band B43/N78 (3.7–3.8 GHz) with a LTE anchor band is planned.
- The project will also set up a second experimental network, with frequencies in the range of 26 GHz–78 GHz to achieve even higher accuracy for the estimation of the position.
- Indoor units will also be provided on two floors of the building.



Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

Project Team

GIS + Laserscanning

Cigdem Askar

Head of Digitalization, HCU Presdient

Prof. Dr. Müller-Lietzkow

Project Planning + BIM

Nils Hellweg

Head of Geodesy, PI

Prof. Dr. Sternberg

Geodesy Research

Annette Scheider

Database

Caroline Schuldt

Positioning

Hossein Shoushtari

Project Assistant

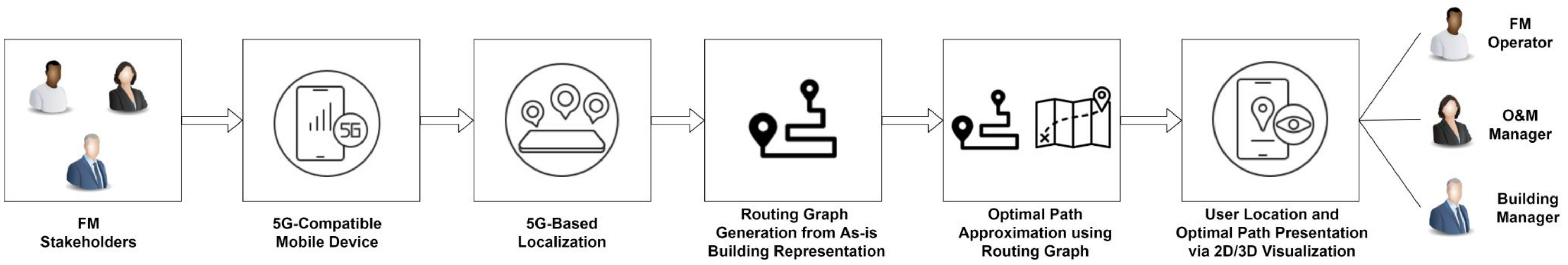
Elena Falcini

DT, BIM + AI

Vladeta Stojanovic

Problem Statement and Proposed Solution

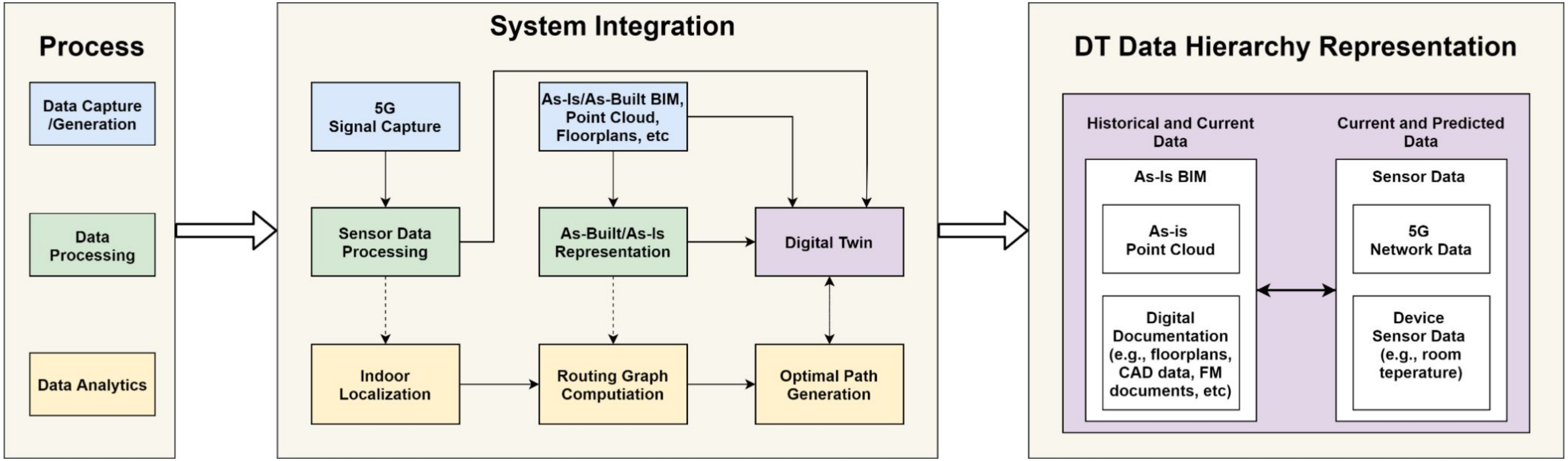
- Determining the optimal route to get between two points is often a bottleneck for FM tasks.
- Solving such a problem requires the approximation of the user's current location within a building as well as the approximate location of the destination point.
- One key approach to solving this problem is based using autonomous localization methods.
- The use of 5G infrastructure and technology could increase the accuracy of indoor navigation applications.



Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

Approach

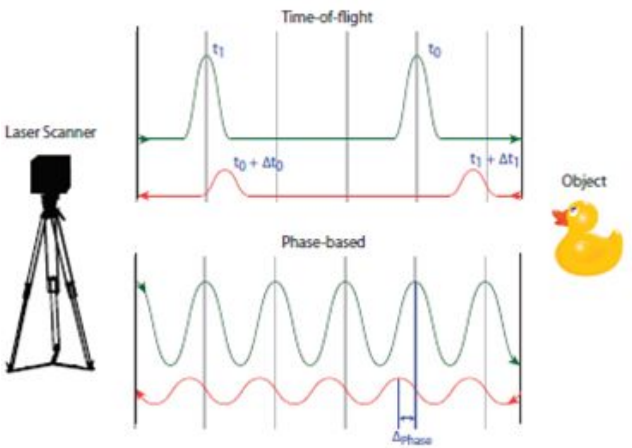
- The use of a service-oriented computation enables the design and deployment of complex software components and services.
- Such services are capable of meeting the requirements of accessing, storing and processing versatile data sources.
- Additional benefit of hardware decoupling is also present.
- SOS implementations can process and stream specific results related to FM activity to a variety of client devices.

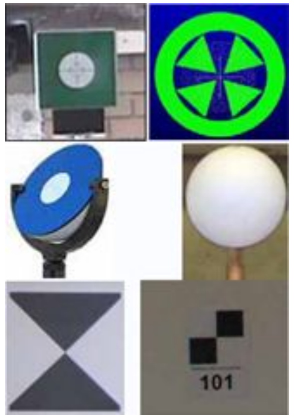


Stojanovic et al. “A Conceptual Digital Twin for 5G Indoor Navigation”. MOBILITY 2021

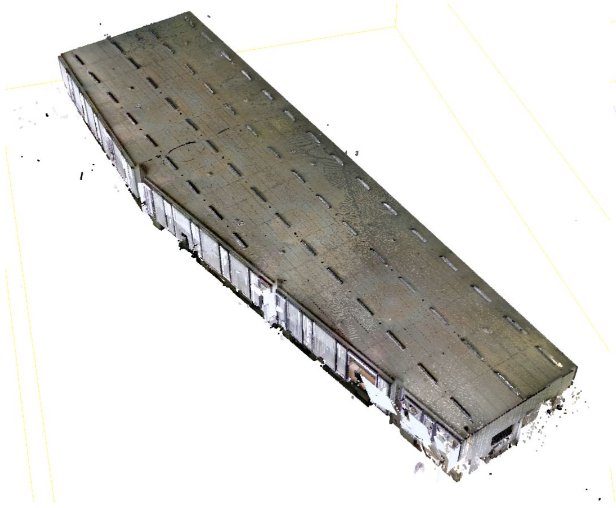
Capture of Indoor Environments

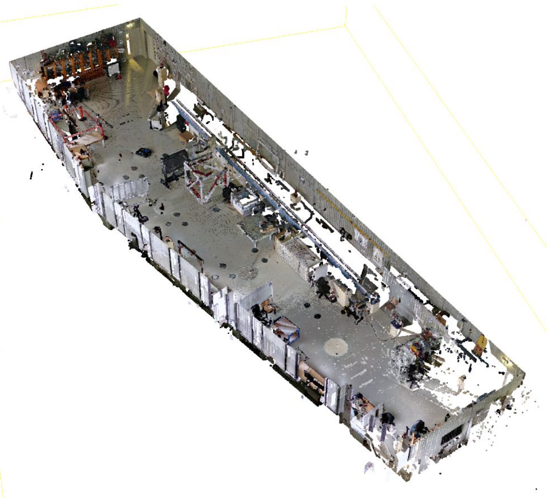
- Point clouds enable the capture and representation of the as-is state of the built environment.
- Terrestrial laser scanning (TLS) is a well-known technique in BIM surveying - captures the reality by using the reflection of laser light.
- Methods: time of flight, phase shift and triangulation
- Measurements:
  - Horizontal angle
  - Vertical angle
  - Distance
- Output:
  - 3D point cloud (XYZI + RGB)





Soudarissanane S. S., 2016, “The geometry of terrestrial laser scanning” ; Prof. Kersten, TLS Lecture Notes

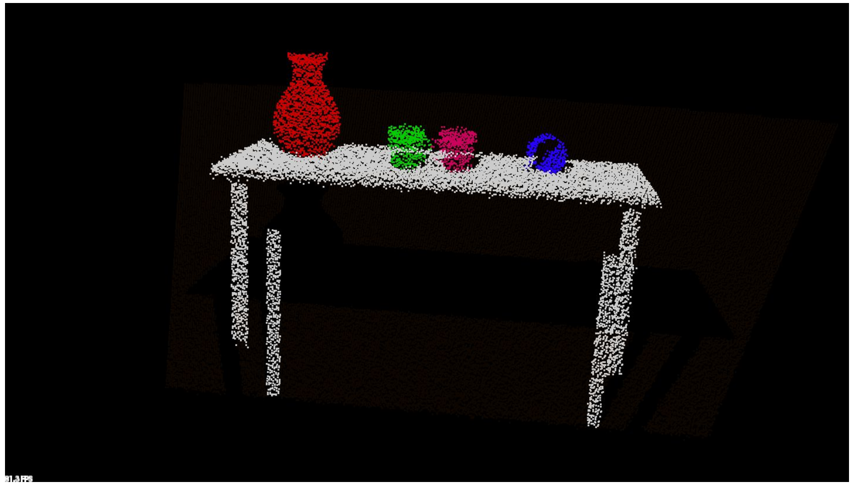


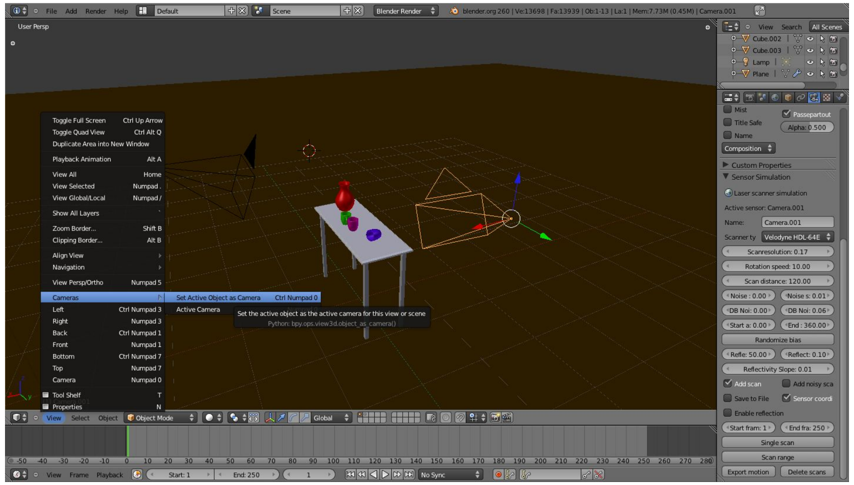


Stojanovic et al. “A Conceptual Digital Twin for 5G Indoor Navigation”. MOBILITY 2021

Simulation of Point Cloud Capture

- The simulation of LiDAR can also be implemented in software.
- If LiDAR equipment is not available or costly to use, the approach of synthetic point cloud generation can be applied.
- With this approach, a higher-level geometric representation (e.g., a 3D mesh), is used to simulate the process of point cloud scanning.
- Simulation of laser beams hitting a surface is accomplished by projecting rays into a 3D mesh and sampling the intersecting points.



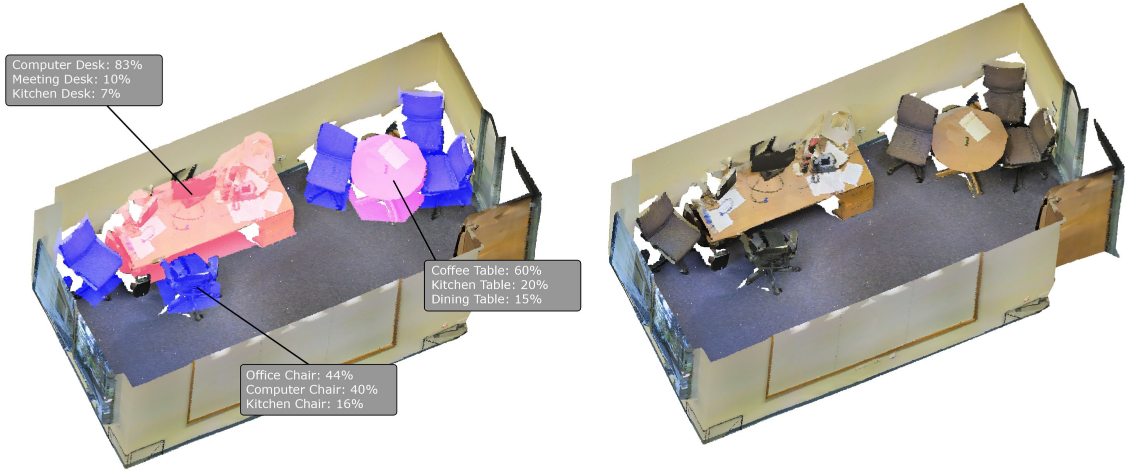


Blensor - https://www.blensor.org/pages/tutorials.html

Stojanovic et al. “A Conceptual Digital Twin for 5G Indoor Navigation”. MOBILITY 2021

Point Cloud Processing and Semantic Enrichment

- Raw point cloud data must be pre-processed prior to reconstruction and semantic-enrichment.
- Objective is to optimize complexity, while preserving key visual fidelity features.
- Point clouds do not contain any semantics default - therefore semantics need to be added manually or automatically.
- Automated methods rely on supervised deep-learning (e.g., use of 2D/3D CNNs) to add semantic labels to point clusters.
- Semantically-rich point clouds can then be used for generating higher-level representations e.g., *as-is* BIM data.



Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

Database Integration

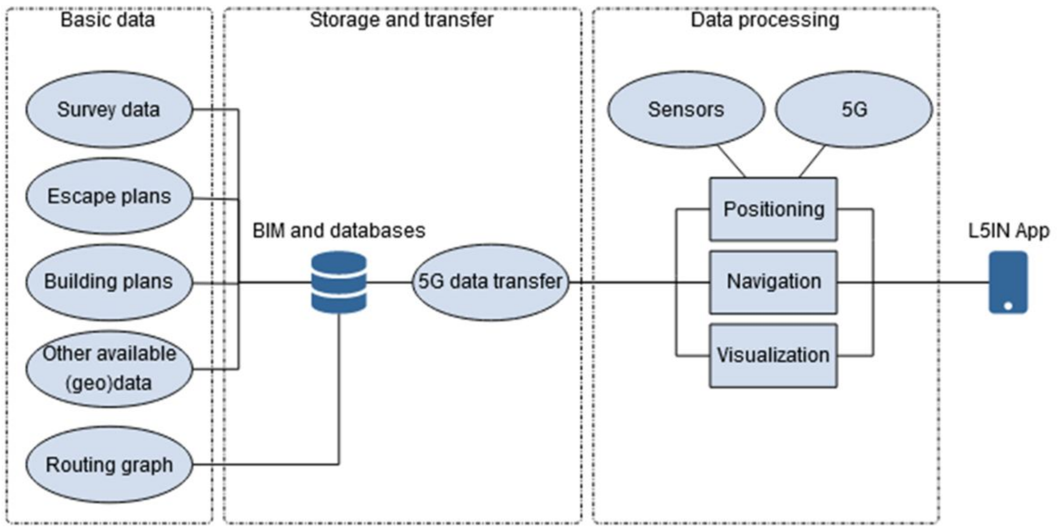
- A relational or non-relational DBMS can be used, with additional special spatial indexing operations.

- Use case: Quickly access point cloud, CAD or BIM representations of e.g., entire floors or specific rooms of a building, for processing and analysis.

- This also allows for the integration of point clouds with additional static (e.g., IFC models), and spatio-temporal data sources (e.g., sensor data).

- PostgreSQL DBMS is used as object-relational DBMS, along with its spatial database extension PostGIS.

- Such DBMS it provide support for georeferenced objects that enable spatial queries.



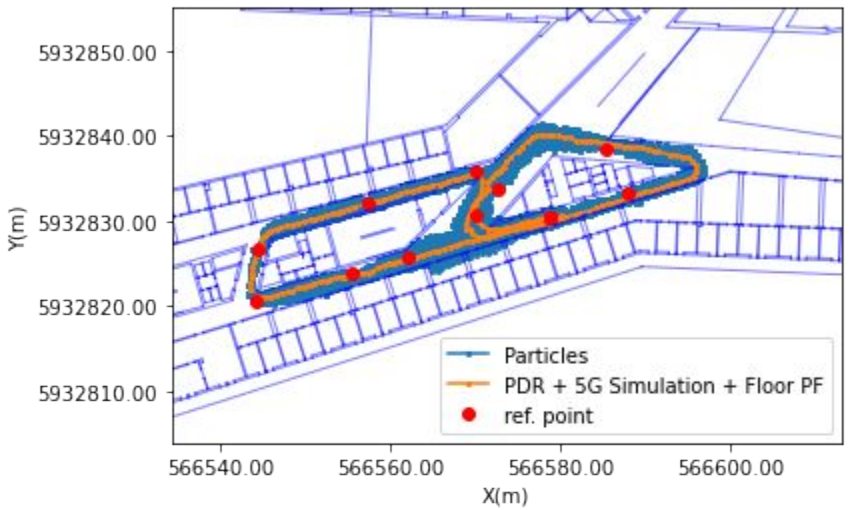
Schuldt C. et. al., 2021, "L5IN: Overview of an Indoor Navigation Pilot Project", Remote Sensing, MDPI

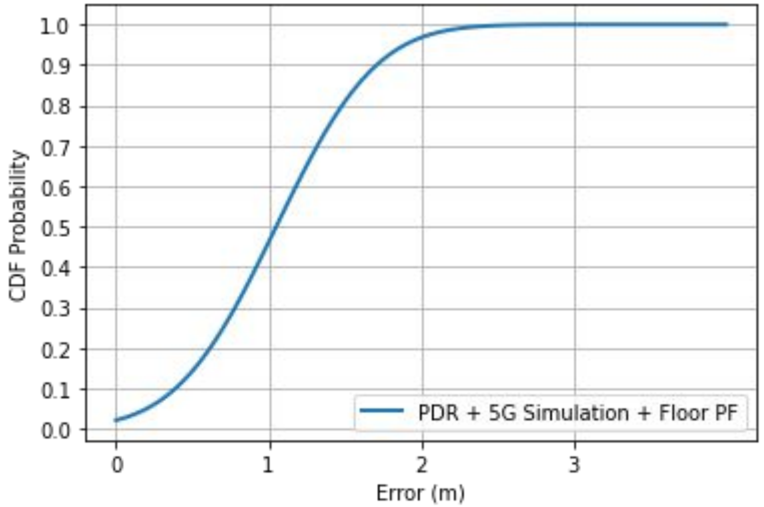
Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

Localization Methods within 5G Paradigm

HafenCity Universität Hamburg

- To approximate the user's initial location, different absolute positioning algorithms (e.g., triangulation, trilateration and multilateration), can be used to determine the approximate location of the user.
- User's current location can be estimated based on the fusion of the maps information, routing graphs, the absolute positions and the received sensor data readings.
- Use of state estimation algorithms is required for this (e.g., Monte Carlo Particle Filtering or Extended Kalman Filtering).
- Within the 5G paradigm, user's mobile devices can capture and process localization data, as well as provide additional sensor data output such as barometer readings.





Shoushtari H. et.al., 2021, Indoor Positioning Special Issue, MDPI Electronics journal

Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

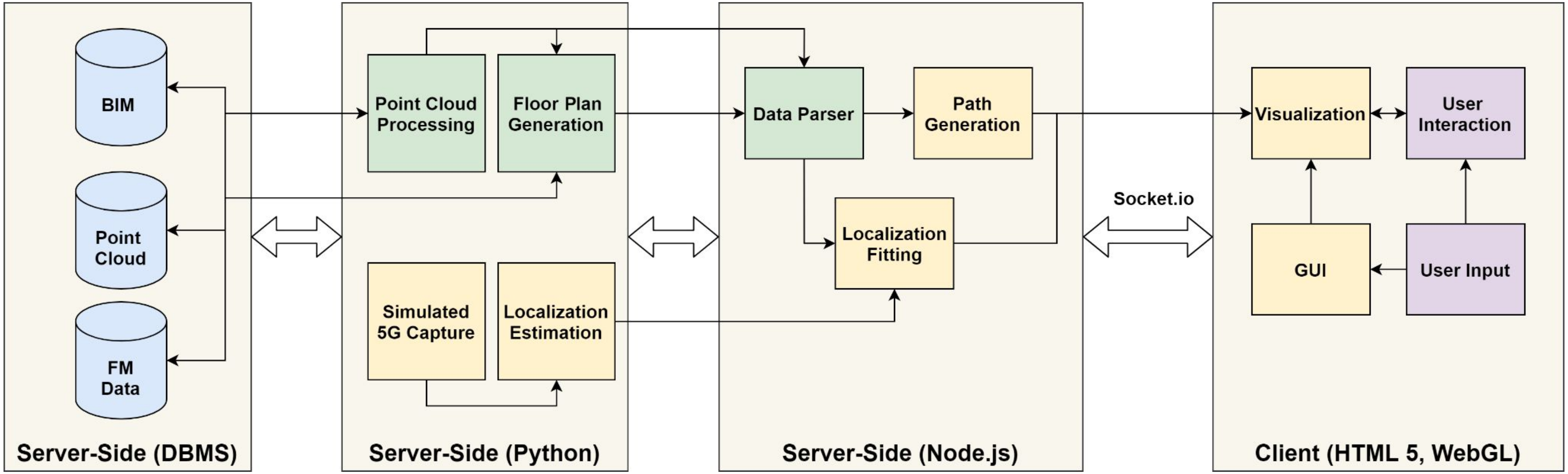
Representation and Interactive Visualization

- Visualization of key data sources is enabled using real-time 3D rendering.
- Can be implemented using existing game engines (e.g., Unity) or Web3D frameworks (e.g., Three.js)
- All related data e.g., point cloud, BIMs, CAD drawing, floor plans, etc, can be visualized individually or simultaneously.
- Viewing in 2D or 3D allows for inspection of areas of interest, and running on different client devices.
- Using an SOS implementation, key results can be computed on server and sent to client for visualization.
- The use of interactive visualization enables for enhanced decision making amongst FM stakeholders.

Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

Prototypical System Design and Implementation

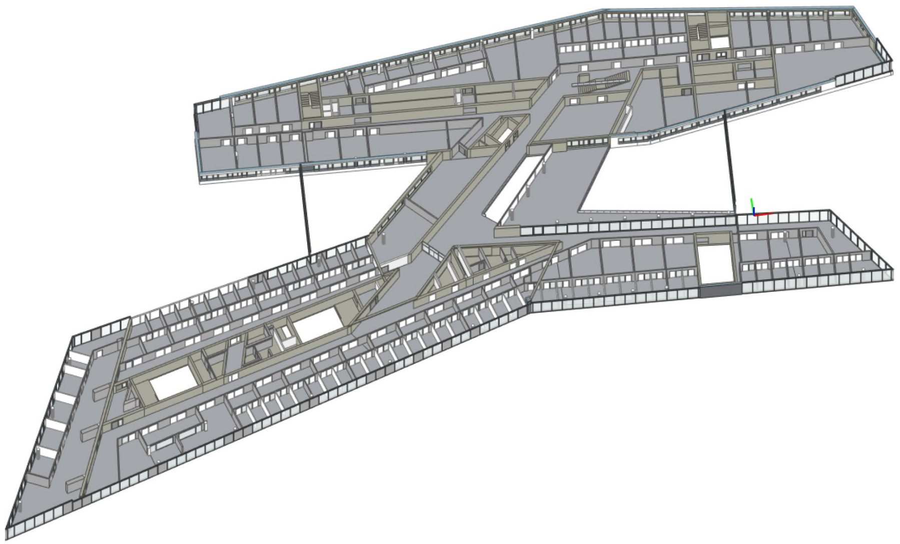
HafenCity Universität Hamburg

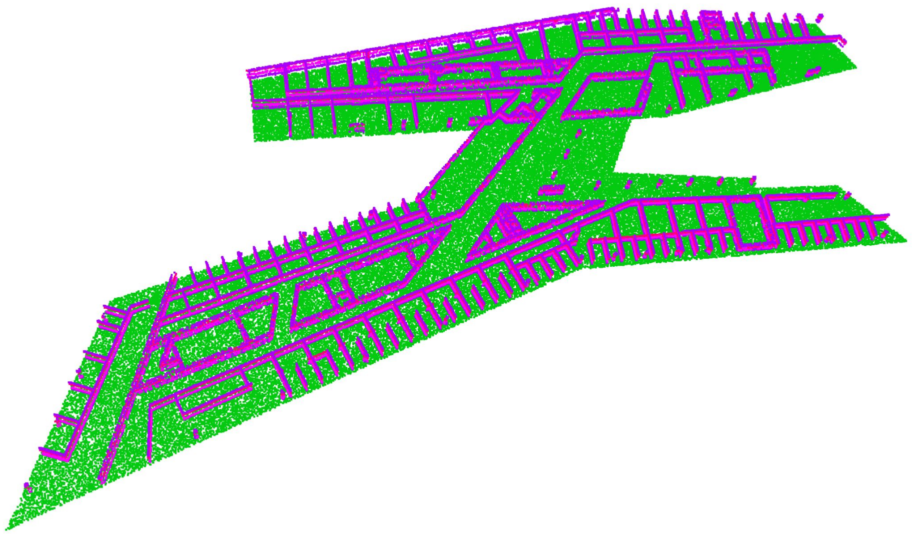


Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

Experimental Results - Point Cloud Processing

- The point cloud of the fourth floor area of the university building is generated using simulated laser scanning.
- We make use of the as-is BIM at LOD 300, from which we extract a triangulated mesh and sample points.
- Once generated, further processing is performed (e.g., sub-sampling, outlier point removal and segmentation).
- The result of these processes are point clusters representing key structural elements which can be used as floor plan layers.

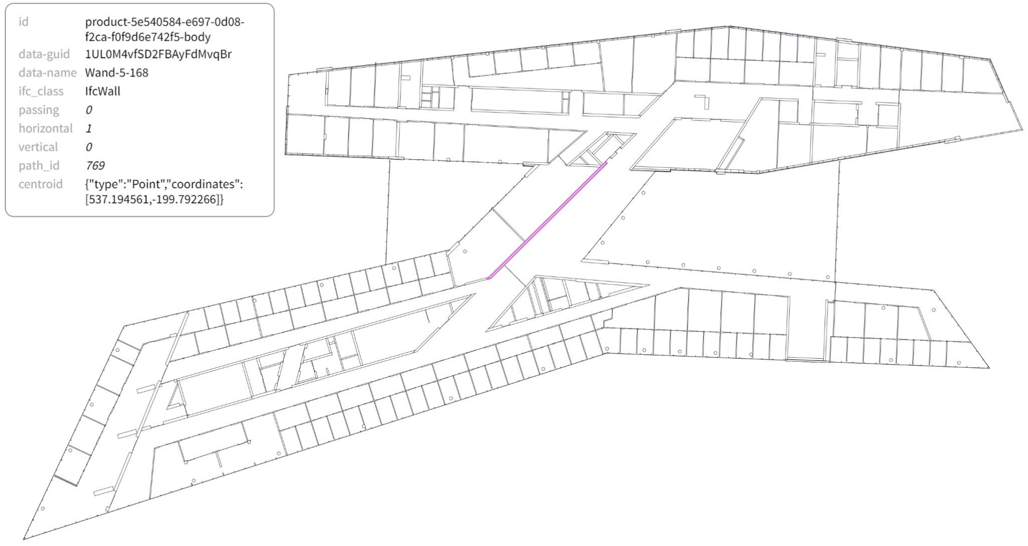


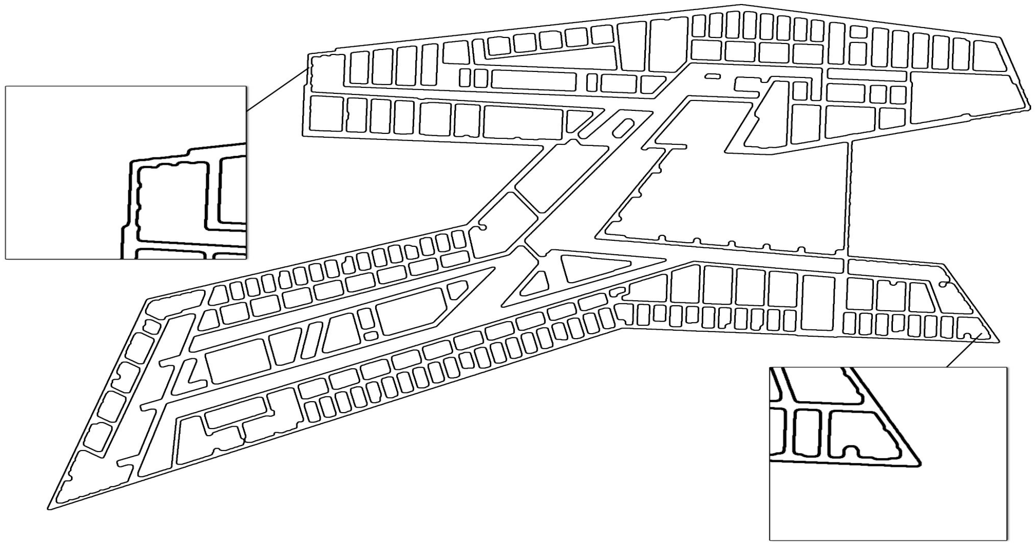


Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021

Experimental Results - Floorplan and Routing Graph Generation

- A key requirement of indoor navigation is the determination of navigable areas.
- A common name for data structures used to represent such navigable areas are ”routing graphs”.
- The use of routing graphs is therefore a requirement for pedestrian indoor navigation, especially for approximation of optimal paths.
- A 2D floor plan can be generated either from the existing as-is BIM, or from the as-is point cloud representation.
- By applying spatial analysis methods, the 2D floor plan can be used to approximate routing graphs.
- Once geo-referenced, the floor plan and the routing graph can be utilized by positioning algorithms to approximate the current location.

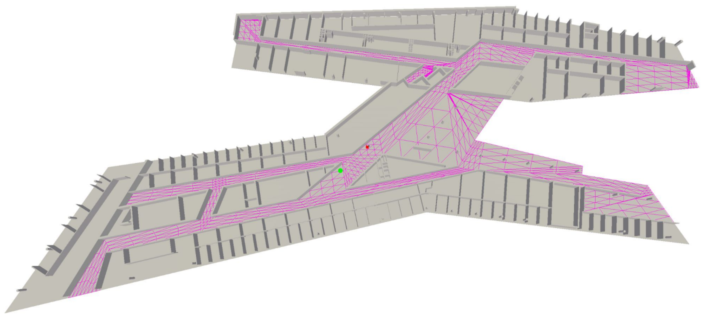


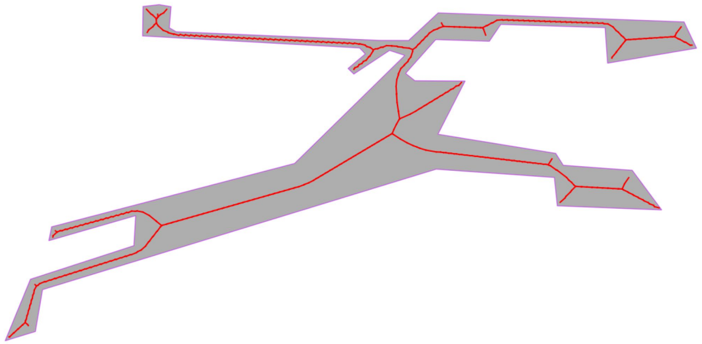


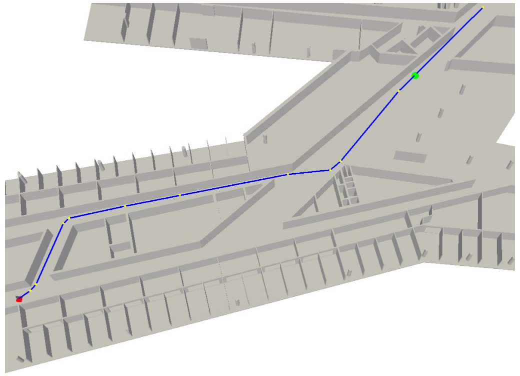
Stojanovic et al. “A Conceptual Digital Twin for 5G Indoor Navigation”. MOBILITY 2021

Experimental Results - Shortest Path Approximation

- The shortest path generation is performed using the generated routing graphs.
- For routing graph generation of 2D floor plans, we make use of a generalized Voronoi-based medial axis transform.
- For routing graph generation from the as-is BIM model, we use the triangulated mesh of the floor element boundary representation.
- For computation of the shortest paths using routing graphs, we make use of the A* shortest path algorithm.
- The generated shortest path computation allows the user to select and set starting and ending points, between which the shortest path will be computed.







Experimental Results - 5G Simulation and Localization

- Using the Simulated 5G Capture components, the antenna placement and three 5G positioning signals are simulated.
- This is calculated based on some reference points and given noise.
- In this way, one may simulate 5G-based coordinates with different precision.
- This is needed for fusion algorithms when such a simulated infrastructure-based positioning has a high range of noise.
- The number of desired antennas and positions can be set and by calling a calculation function, the predefined noises, frequencies and some measurement results can be computed.

posiition antenna_0:	566544.3851938975	5932861.893356447				
posiition antenna_1:	566645.2426318771	5932863.316240173				
posiition antenna_2:	566582.4586751128	5932845.739885898				
posiition antenna_3:	566636.4493381229	5932833.594533249				
posiition antenna_4:	566525.7057000671	5932823.464801805				
position number	x_position	y_position	dist_antenna_0	azimuth_antenna_0	RTT_antenna_0	dist_antenna_1
0	566599.7791847457	5932863.008387998	55.40521200619011	268.84684287140027	1.846840400206337e-07	45.46448941784358
1	566568.5187099848	5932861.343480687	24.139779661143052	271.30524329477737	8.046593220381017e-08	76.74927993483585
2	566597.4942251586	5932837.05046686	58.6322297421809	295.068851827887	1.9544076580726965e-07	54.49588233885269
3	566542.7864828033	5932820.144945236	41.779010469625135	2.1930095178892293	1.3926336823208378e-07	111.18013846707964

Stojanovic et al. “A Conceptual Digital Twin for 5G Indoor Navigation”. MOBILITY 2021

Conclusions and Outlook

- We have proposed our approach based on a concept of a Digital Twin.
- We have implemented key processing components to prove the feasibility of such an approach.
- The use of service-oriented software engineering allows for flexible implementation of key processing components, and delivery of results to various client configurations.
- We have identified the use of point clouds as a key source for as-is representation of indoor environments, alongside existing as-is/as-built BIM data.
- We approximated 2D floor plans from point clouds, and the generation of routing graphs from such floor plans as well as 3D mesh representations derived from existing as-is BIMs.
- We have designed a simulation for 5G-based coordinate estimation to overcome with the localization task.
- We have implemented and described state-of-the art approaches for routing graph and optimal path computation.
- The presented approach lays a solid foundation for future work focusing on developing a versatile indoor navigation software solution based on the DT and service-oriented computing paradigms.

Thank you for listening!

HafenCity Universität Hamburg

Level 5 Indoor Navigation Project
HafenCity University Hamburg

Vladeta Stojanovic - vladeta.stojanovic@hcu-hamburg.de

Hossein Shoushtari - hossein.shoushtari@hcu-hamburg.de

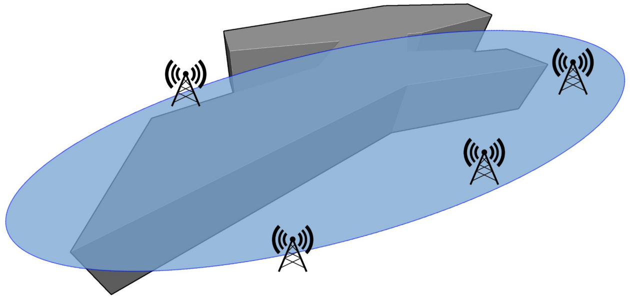
Cigdem Askar - cigdem.askar@hcu-hamburg.de

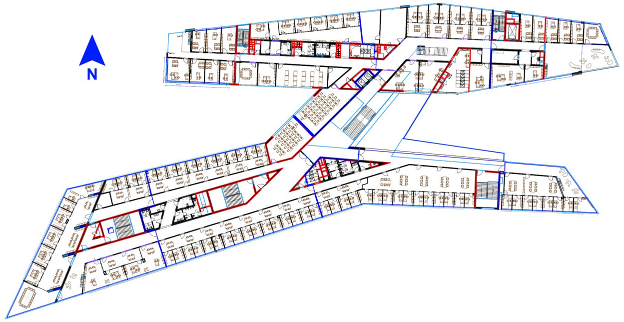
Annette Scheider - annette.scheider@hcu-hamburg.de

Caroline Schuldt - caroline.schuldt@hcu-hamburg.de

Nils Hellweg - nils.hellweg@hcu-hamburg.de

Harald Sternberg - harald.sternberg@hcu-hamburg.de





Stojanovic et al. "A Conceptual Digital Twin for 5G Indoor Navigation". MOBILITY 2021