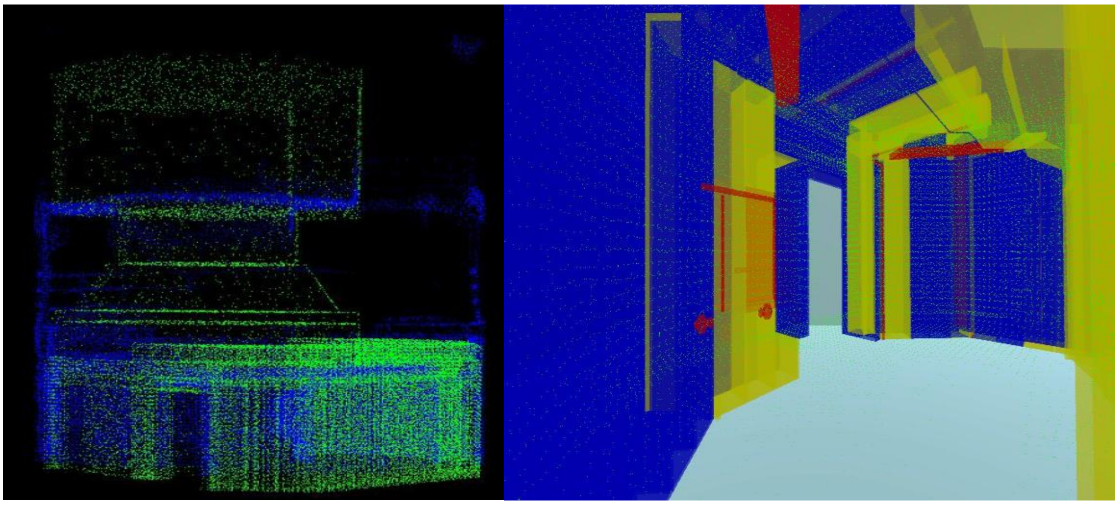
RESEARCH REPORT



Digital Twins - Safer-TONUS task report

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VTT

beyond the obvious

Preface

This report concisely describes the work done in the Safer-TONUS research project Work Package 1 Task 2 (T1.2): Digital twin supporting licensee–regulator dialogue in the first project year 2023. Task 2 (T1.2) is focusing on investigating the potential of novel digital tools in the context of use cases associated with nuclear power plant (NPP) operations. The goal is to investigate the potential from the perspective of different stakeholders, both the licensees and the regulator.

The work done in the task has consisted of two main parts, development of the change detection method and stakeholder interviews. Method development done in the project is the further refinement of a method enabling automatic comparison of the design data of the facility against the real operational environment geometry captured with the LiDAR device. The stakeholder interviews were conducted on three sessions with all together 10 experts from the participating organizations being interviewed.

This report provides an overview of the change detection method development, and summarizes the stakeholder interviews, serving as the main deliverable D1.2.2 of the Task T1.2.

This report is distributed to the following persons in the Safer-TONUS group for evaluation:

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1. Method: Building Construction Change Detection

1.1 Background

In this report, we present a systematized and automated building change detection method which including progress monitoring on construction sites, inspections, and the assessment of damage propagation. Changes are detected by identifying differences between two digital representations, that is 3D geometry from a BIM model and a scanned point cloud representing the current building state. The method could detect every occurrence of the following changes: component addition, component deletion, component modification and component attribute value update. This automated change detection is through an association and comparison between the Building Information Models (BIM) and a point cloud of the facility's current state. It can effectively identify the differences between them and locate redundant and missing elements of in a BIM model.

Building changes can be for example, furnishings; the walls, ceilings, floors, and doors; communications wiring, electrical wiring, plumbing, fire suppression, heating, ventilation, air-conditioning; exterior surfaces such as cladding and roofing.

There are many challenges to detect all these changes. Here we list a few. There is usually inconsistency between the building and its existing BIM model, because BIMs are generally not updated to reflect changes in the environment. The scanned point cloud data are large and noisy. The scanned point cloud representing the building's current state is incomplete (e. g, parts that are merely incompletely represented, specular surfaces, and occlusion). It causes ambiguity between building parts. Laser scanning in a building's interior is often challenging, especially in long corridors. Building interiors requires particularly reliable geometric evaluation with the metric accuracy and interpretation of statistically uncertain scanned point clouds.

1.2 Methods

Our method has two main steps: first the alignment of a scanned point cloud with the geometry of BIM model, then calculating the differences of the two representatives. Registration (or alignment) process (see Figure 1) transforms BIM model into 3D point cloud coordinate system. It is the most important step for change detection, and it decides the accuracy of the difference identification in the second stage.

Usually, BIM model geometry and 3D point cloud are in different coordinate system and with different scales, so we combine the global registration methods including Coherent Point Drift (CPD) algorithm for scaling and Probabilistic Point-Set Registration using Gaussian Filter with the local registration method Iterative closest point (ICP) for fine tuning. As the scanned 3D point cloud data are large, we represent point cloud with voxels in two levels from coarse to fine. The results from the coarse level serve as the initialization parameters to the second level registration.

Then we measure the nearest neighbor distances between the two well aligned 3D representations (see Figure 2). The change evaluation is decided by density estimation (see Figure 3), where a smaller distance indicates unchanged components, large distance means changes detected (removed or added), middle range distance means incompleteness (modified). This incompleteness might be that the captured point cloud was sparse, specular surfaces, or occlusion. Therefore, less geometric information available. The distance density threshold can be half distance of the maximum and minimum distances.

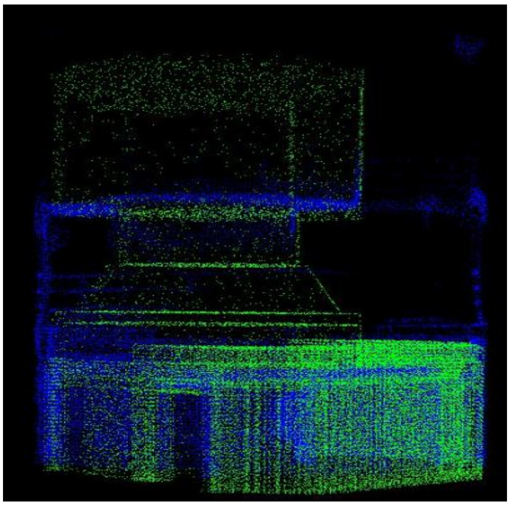


Figure 1. Aligned of BIM model and 3D point cloud (Lidar 3D point cloud in blue color, BIM model mesh in green color)

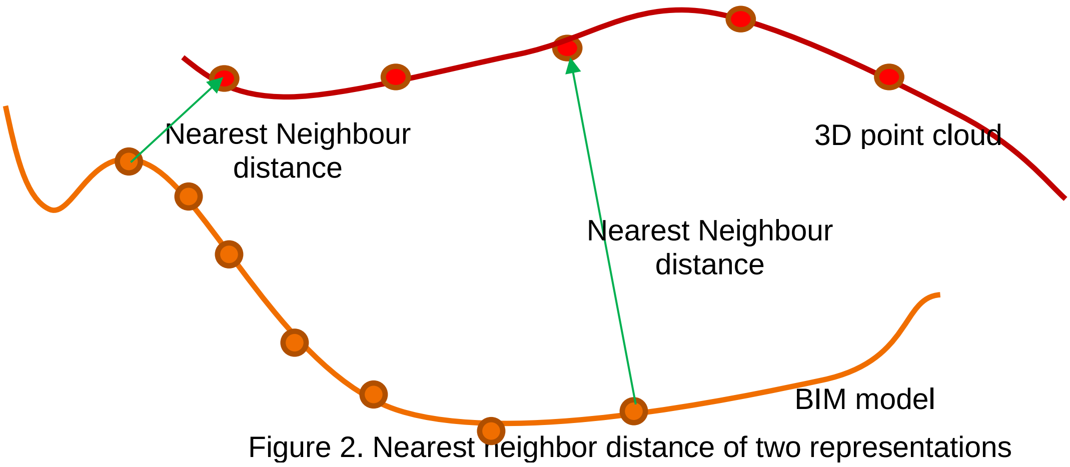


Figure 2. Nearest neighbor distance of two representations

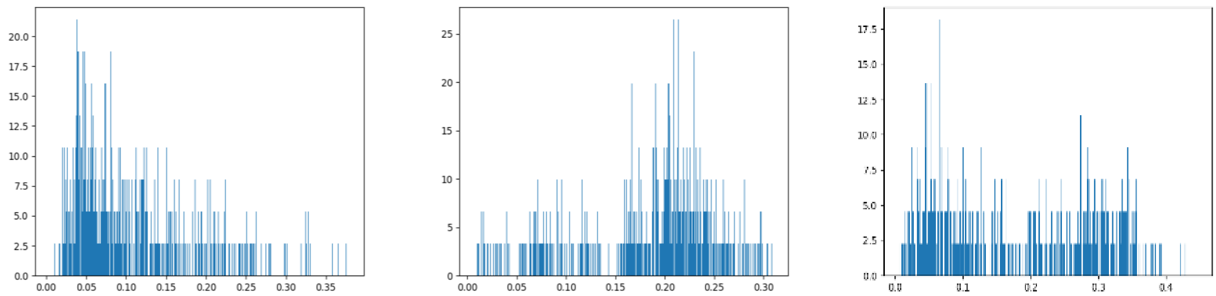


Figure 3. Density estimation (horizontal axis is the distance in meter, vertical axis is the count of distance). (a) not changes (b) changed (c) incomplete or clash

1.3 Experiment

In this experiment, we use python tools. The BIM model is in IFC format (see Figure 4 for the three of the build geometry structure). It iterates all geometry with semantic meanings (see Figure 4 left side). The alignment is sampling of the IFC object mesh geometry creating a point cloud (see Figure 1 BIM mesh sampled pint cloud green color). Lidar scanned point cloud was from nuclear reactor site and it was down sampled and cropped (see Figure 1 blue colored point cloud).

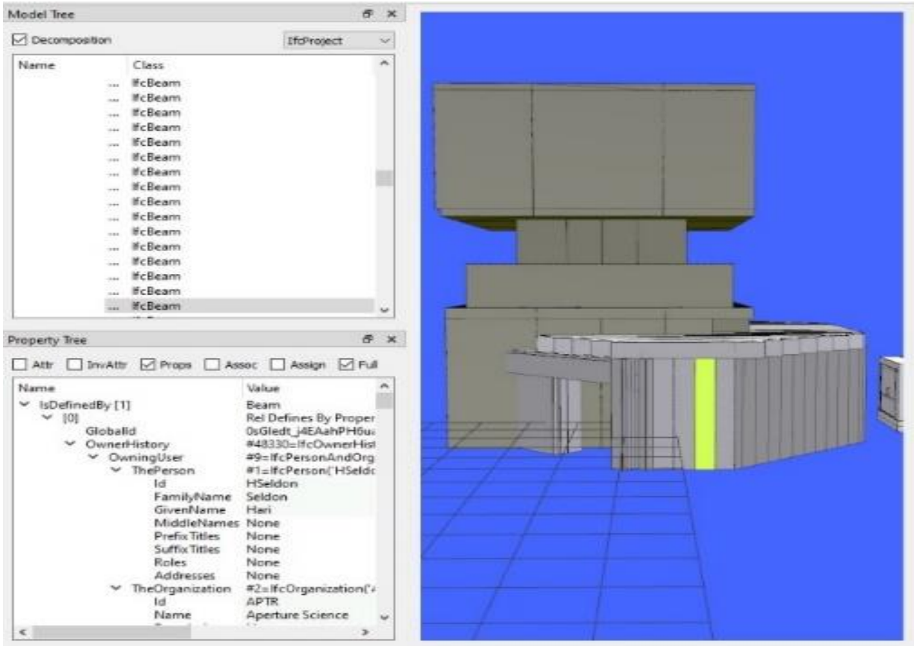
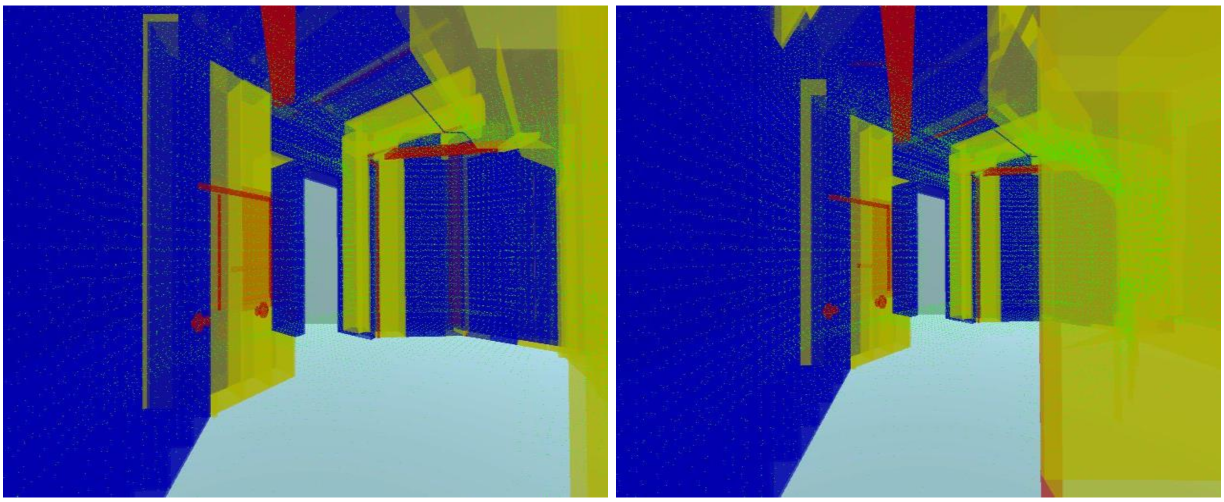


Figure 4. IFC tree of the nuclear reactor BIM model (green color highlighted element)

Figure 3 shows three example IFC element geometry which identified as not changed, changed and clashed or incomplete scanned points. It was a distance density histogram, where the x-axis represents the nearest neighbor distance, and the y-axis shows the count of the points.

We also made a live demo in unity. Figure 5 shows some screenshots from the unity scene, where components in red color indicate changed, components in yellow color means not changed, components in blue color assume modified or clashed.



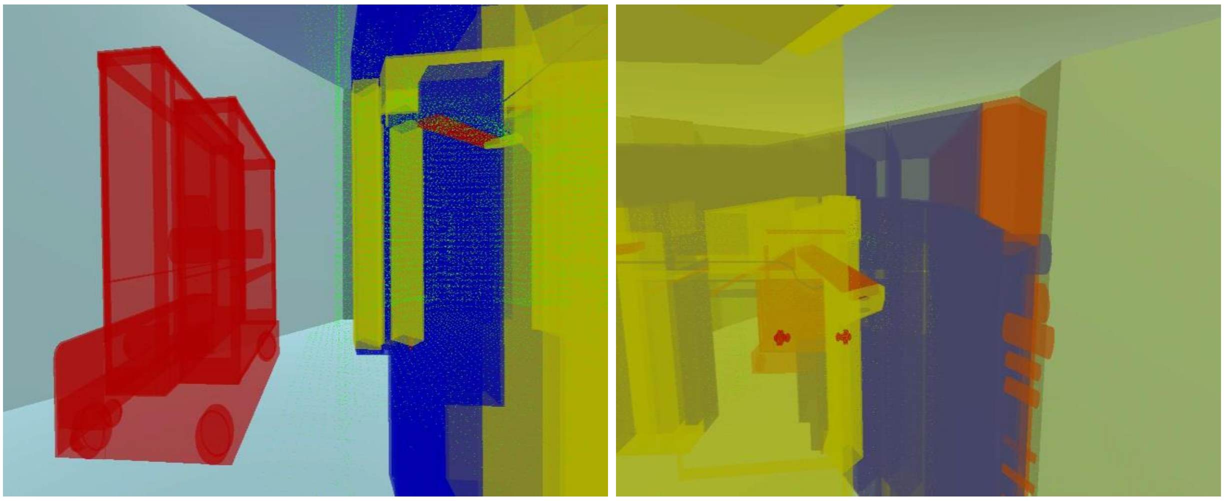


Figure 5. Unity visualization of the Changes detected (components in red color indicates changed, components in yellow color means not changed, components in blue color assumes modified).

1.4 Conclusions

The experiments on both a BIM model and the Lidar captured data demonstrated that the proposed approach could accurately detect the changes and locate the changed elements of the building in the BIM model. The algorithm of from coarse to fine level registration significantly reduced computation time and improved the alignment accuracy. The presented change discrimination method based nearest neighbor distance is robust even registration is less accurate.

Because building's interior is a quite challenging environment for the verification of detected changes. In the next stage we plan scenarios with varying indoor scanning geometry where incomplete (missing) point cloud can be automated filled in thus potentially improves the accuracy of change detection.

Safer-TONUS Stakeholder Interviews

1.5 Overview

In Safer-Tonus project Work Package 1 Task 2 (T1.2), the main goal is to investigate how digital twins, which in this case refer to the novel digital tools enabled by the use of virtual models and autonomous data collection from the operational environment, could be applied in the real NPP operational use cases. Investigation is conducted by introducing capabilities of the new technology and by interviewing stakeholders associated with the NPP operations.

In this chapter, the interviews conducted in the Safer-TONUS first project year are described. Goal of the interviews was to collect information and insights about the current use of the digital twin tools, potential future use cases, as well as factors hindering the application and adoption of the novel digital tools. Also steps towards application of novel digital tools was discussed in the interviews.

Novel digital tools were defined in this context as information systems comprising virtual models of the operational environment and spatial computing features for collecting sensor data from the operational environment and refining the collected sensor data into a situational awareness in the form of a dynamic digital twin.

1.6 Participants

Two participating organizations from the Safer-TONUS project were interviewed in three separate sessions. All together 10 persons from two organizations, TVO and STUK representing licensee and regulator of the NPP operation, were interviewed. Two of the interviews were conducted on-line through Microsoft Teams, and one interview was conducted face to face. All persons interviewed were experts working for the participating organizations.

1.7 Structure

Interviews were structured to first introduce the developed method and relevant results from previous projects to the persons interviewed to set the stage on the technical capabilities available, followed by a semi structured interview for collecting the ideas and insights from the participants on the potential and challenges associated with the new digital tools in the context of NPP operations.

Questions asked in the interviews were defined before the first interview, and the same question structure was used though all interviews. Questions were assembled under six main themes. Main themes were the following:

- Potential of the new digital twin tools
- Use cases for which new tools could be applied for
- Requirements for the tool
- Challenges and barriers for the application of the novel tools
- Impact of the novel tools to processes of the organization and required changes in the processes and company culture.
- How would a company see the novel tools to be developed further?

For each main theme, 1-3 detailed questions or topics to be discussed were defined.

1.8 Observations

In this chapter, some key answers from the interviewed persons are listed under the themes. Lists are assembled in simplified manner trying to catch the main points and not all answers are included. The listed answers are presented here just to give a deeper insight to the discussions and type of topics discussed.

1.8.1 Potential of the new digital twin tools

- Some methods along these lines already in use, for example 360 and LiDAR capture of the facilities already in use
- Also in some cases, some early experiments on using drones for visual data collection done
- In some cases, also 3D models of the facilities are available
- Potential definitely in inspections and training
- Value in increasing the situational awareness

1.8.2 Use cases for which new tools could be applied for

- Continuous environment condition observations, especially in the restricted areas
- Searching of radiation sources
- Visual inspection of detected fault situations
- Radiological mapping of the larger areas, for example storage areas
- Continuous and detailed radiological mapping of the areas for calculating and decreasing the exposure of the workers
- Use of environment scans in designing updates to the facility
- VR assisted training
- Observation of risk situations, for example during lifting operations

1.8.3 Requirements for the tool

- Radiation shielding should be considered for the autonomous platforms
- Reliability is of essence
- In practice, environments can be challenging to move around, lot of stairs, ladders and locked doors
- Wireless data communication is not allowed, data collection must take place fully autonomously

1.8.4 Challenges and barriers for the application of the novel tools

- Device contamination
- Increasing risks because of the new technology, all solutions should be already proven to be reliable and working properly in other domains
- Managing of the data amounts, point cloud captures are already consuming large amount of data storage

1.8.5 Impact of the novel tools to processes of the organization and required changes in the processes and company culture

- Training and education will be needed
- The added value of the new solution should be obvious to the adopting organization
- There always will be resistance to the new application of totally new solutions, and it should also be expected and allowed. Not everybody will adopt new things.

1.8.6 How would a company see the novel tools to be developed further?

- First tests should be performed in areas without contamination risks
- For testing in facility, bigger space could be considered to avoid need of moving in stairs and opening of doors, such as turbine hall
- There is willingness to find ways to enable testing and development of this kind of tools
- Testing and application of this kind of tools seen mainly as the responsibility of the NPP licensee
- Regulator is interested in following up on the development being of assistance in seeing how the solutions can be part of the communication

1.9 Conclusions

In the interview, great number of use cases were identified where the type of solutions introduced by VTT and currently under research could be applied. Also challenges and requirements for the tools were clarified, highlighting how NPP as an operational environment sets its own demands on the solution. Despite the challenges, there seems to be interest and willingness to participate in the development of this type of approaches further, and finding use cases where first prototyping could be tested even quite soon.

As such, the interviews provided valuable insight to the field, as well as good connections to carry on the discussions further. The observations from the interviews will be used to guide the digital twin related research further.

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