Digital Twin for Urban Spaces: an Application

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Abstract

A Digital Twin is a virtual representation of a real dynamic system that can simulate its current conditions, predict its future behavior, and log valuable information about its internal operation and interactions with other systems. A key feature is the capability of automatic bidirectional information flow between virtual and physical worlds. The objective of this work is to create a Living Lab for the demonstration of interacting urban Digital Twins under the United Nations' Sustainable Development Goals of sustainable cities and communities, health and wellbeing, and industry, innovation, and infrastructure. By using a network of sensing devices mounted on a vehicle, the proposed system is capable of processing real-life data through edge computing, modeling software and Machine Learning algorithms. With the processed information, a 3D virtual representation of urban spaces and the vehicle itself, the interactions between both subjects and the evolution of each is enabled. This approach of Digital Twin technology for urban spaces has significant value when it comes to analyzing a community's evolution, mobility, a vehicle's dynamic behavior, and its interaction with urban infrastructure. This work presents the proposed methodology for developing Digital Twin concepts for urban spaces and vehicles as well as their respective characteristic components.

Keywords
Digital twin, simulation, modeling, urban spaces, smart mobility.

1. Introduction
Digital Twins (DT) are an emergent technology which has seen a recent surge in case studies mostly centered on the development of DTs for smart cities, building information models and manufacturing applications. With case studies on smart cities and urban spaces, some applications of DTs revolve around the target of accurately modeling the evolution of urban spaces, living standards and the interaction of people with infrastructure, buildings, mobility, etc. Certain interest has risen with respect to having more insight on infrastructure, citizen feedback, and building information models. This insight is of great value towards city planning, disaster prevention and improving accessibility for everyone. The basic architecture of a DT as proposed by Campos-Ferreira et al. (2019) is composed of three aspects: the *physical world, digital world*, and the *connectivity* between both. Automatic bidirectional flow of information between physical and digital worlds is what allows a DT to accurately represent real-life conditions and evolve through time as well and to have an impact on the physical twin. For each aspect, there are several devices and methods that work together. For instance, the physical world requires a network of sensing devices that generate input for the DT, and a series of methods is necessary to ensure connectivity between worlds, etc.

United Nations´(UN) Sustainable Development Goals (SDGs) (United Nations, 2015) were considered to direct the objectives towards sustainable development, citizen wellbeing and smart mobility. The target SDGs are the following:

- **Goal 3** – To ensure healthy lives and promote well-being for all at all ages.
  - Through this SDG, a DT may allow the analysis of an urban space in terms of security and infrastructure to determine wellbeing and health within a specific area. This information could also be used as insight towards improving living standards (White et al. 2020).
- **Goal 9** – To build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

  - An accurate digital representation of an urban space, would enable analysis of infrastructure accessibility and commute times, etc. This together with citizen feedback may improve city planning and help understand city spaces perceptions.
- **Goal 11** – To make cities and human settlements inclusive, safe, resilient, and sustainable.
  - According to the UN, "as of 2020, 16% of the average global share of urban areas was allocated to streets and open public spaces. This is short of the 30% streets and 10-15% public open spaces target" and "as of 2019, only half of the world's urban population have convenient access to public transport. Convenient access means residing within 500 m walking distance of a bus stop/ low-capacity transport system and 1000 m of a railway or ferry terminal" (Department of Economic and Social Affairs, 2021).

Developing DTs for understanding the inner operations of a vehicle, its interaction with its surroundings and the evolution of an urban spaces may allow to study specific problems targeted by UN's SDGs such as the lack of access to open public spaces, the lack of convenient access to public transportation, the effect that vehicles have on an urban environment and in the future may even incorporate citizen feedback to add a level of insight of citizen perception. This type of data can enable data-led decision making for urban planning, infrastructure, smart mobility solutions, etc.

This work is innovative in the sense that in a recent literature review on databases such as MDPI, Science Direct and IEEE Xplore, it was found that no recent (from 2019 to present) publications have been made around DTs where vehicle twins have been developed in conjunction with urban spaces' twins and their interaction being analyzed. More on the literature review methodology will be explained in the Section 2. Although a lot of work has been put into the development of DTs for smart cities and urban planning, there is very little record on performance-focused DTs for vehicles and a study of their interaction with urban spaces. For this work to be successful, a set of state-of-the-art software tools and methods have been employed to design, model, and simulate the characteristics of the DT concept.

1.1 Objectives
The objective of this work is to create a Living Lab for the analysis of interactions and evolution of experimentable DT concepts of an urban space and that of a vehicle. In this sense, Living Lab (LL) by the Massachusetts Institute of Technology (MIT) as a research platform that leverages a space as a testbed for innovation and the co-production of sustainability knowledge (MIT Office of Sustainability). Considering UN's SDG's, the LL concept will enable a suitable digital platform for the Digital Twins to coexist, interact and evolute under the scope of sustainability studies. Marcucci et al. (2020), affirm that "a reliable model for planning should not only be capable of mimicking real-life experiments, so to reproduce past events, but also be able to predict the future, assuming different scenarios have different probabilities of actually materializing". In the sense of the DT for a vehicle, a set of simulators and Machine Learning (ML) algorithms is needed to develop a model that is capable not only of representing real-life conditions but also predicting future behavior. So, to accomplish the proposed objective and developing a reliable model for urban planning and analysis, cutting edge tools like ML algorithms, simulation technology, modeling, etc. will be developed.

2. Literature Review
A literature review refers to the research and synthesis of the state-of-the-art (SoA) of a particular subject in literature to understand the most recent concepts, methods, protocols, etc. In the case of DTs, as seen as an emergent technology, there is a wide variety of applications and situations where the concept can be implemented. In fact, as of today, there is no definitive or universally accepted definition of a DT given that its application on different areas may cause a difference in the structure of the DT, differences in the analysis and scope of the system or even a difference in the basic functionality or objective of the DT. This poses a problem for further development given that this lack of standards "impedes the widespread design, implementation and adoption of this technology" (Sharma et al., 2020). For example, when it comes to manufacturing applications, the DT concept may be focused on an accurate real-time representation of a production line and the dynamic interaction with providers, manufacturers, clients, etc. In the case of a DT-based smart city concept, the focus might be on having insight on the interactions and dynamic lifestyle of citizens through behavior simulations and surveying. In Section 3, the definition and basic components for this work's DT is explained.

It was important to make a literature review to define the scope and the desired maturity level for this specific work. In this sense, the methodology for systematic-like literature reviews (SLR) (Charles Sturt University, 2021) was employed. An SLR is one that seeks to "collate evidence that fits pre-specified eligibility criteria to answer a specific research question. They aim to minimize bias by using explicit, systematic methods documented in advance with a protocol" (Higgins and Thomas, 2021). The outlined steps for SLRs are the following:

1. Identifying answerable research questions
2. Developing a protocol
3. Conducting systematic publication searches
4. Selecting studies to include
5. A comprehensive revision
6. Extracting and synthesizing information
7. Writing and publishing the review

In accordance with the outlined steps for SLRs, the following research questions where proposed. *RQ* represents the main research question and *SQ1* represents a sub-question. Figure 1 presents the selection criteria for the studies included.

- RQ: What is the SoA of DT technology in implementation applications?
- SQ1: What are the challenges of implementing a DT-based system with current technology?

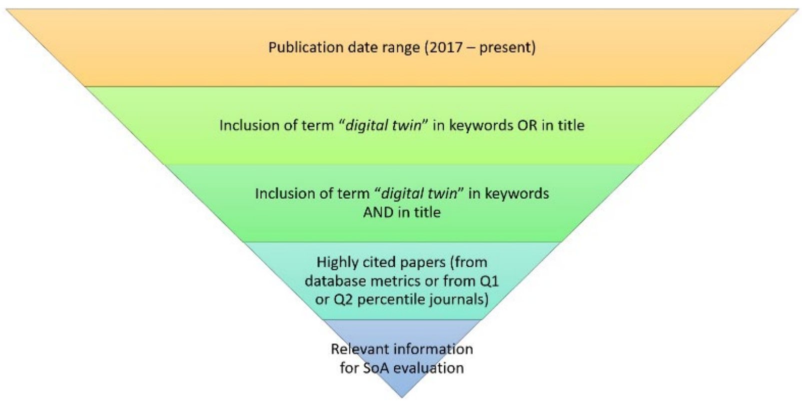

Figure 1: Selection criteria process for a publication comparative analysis and SoA evaluation.

The SLR process was valuable in determining the current technology readiness level (TRL) (European Comission, 2014) and societal readiness level (SRL) (Innovation Fund Denmark) of different DT studies worldwide.

The analyzed studies (110) where classified with regards to their readiness level. In accordance to the TRL index, the following phases were determined: research, proposal, simulation, implemntation and commercial application. It was found that most applications of the DT concepts lie in their simulation and implementation stages (6-7 TRL index) where the prototype has been developed and is in a testing phase. However, most studies do not formulate extensive solutions, potential societal impact, or identify potential stakeholders for their projects. Meaning there is little consideration of society's readiness level. Most of the analyzed studies lie in the lower three levels of the SRL index.

In terms of the classification of DTs, Juarez et al. (2021) propose three classes regarding integration levels:

- Digital Model: virtual representation of a physical subject with no automated flow of information from physical to virtual worlds.
- Digital Shadow: Virtual representation where there is a unidirectional flow of information usally from physical to virtual world.
- Digital Twin: Uses a bidirectional flow of information shceme to enable the management and monitoring of the object's life cycle.

Singh, et al. (2021) propose a three-level hierarchy classification: the basic level is the Unit Level where DTs represent single objects, materials, etc. In the System Level, physical twin could be a production process or a complex object's lifecycle and finally a System-of-systems (SoS) level where there is product of process life cycle management. Evans et al. also propose a maturity spectrum for DTs that is shown in Table 1. This maturity spectrum evaluation to this work is mentioned in Section 6.

Table 1: DT Maturity spectrum (Evans et al.).

Maturity element (logarithmic scale of complexity and connectedness)	Defining principle	Urban space outline usage
0	Reality capture (LIDAR, drones, photogrammetry, plans, etc.)	Existing as-built digitalization
1	2D maps/system or 3D model	Space coordination and model
2	Connect model to persistent (static) data, metadata and BIM stage 2	Asset management, life cycle monitoring, simulation experimentation
3	Enrich with real-time data	Real-time life cycle monitoring
4	Two-way data integration and interaction	Remote and immersive operations, control physical from the digital
5	Autonomous operations and maintenance	Complete self-governance with total oversight and transparency

Due to the characteristics of the DT, some concerns arise in terms of implementation challenges and limitations. For instance, the development of this concept depends on the development of enabling technologies such as IoT connectivity, ML and Big Data. Furthermore, common implementation limitations and challenges are: cost, complexity (due to a large number of interconnected devices and platforms), and an investment on staying up to date with the development of enabling technologies. Deloitte Tech Trends (2020) present the fact that developments in simulation and modeling tools, IoT device conectivity, expanded bandwidth and better computing architectures will enable DTs to become a predominant tool for companies and governments.

Some examples of DT implementation for urban spaces and smart city works include an implementation for civilian surveillance applications (Lee et al., 2020), a DT for the management of drinking water distribution networks in Spain (Conejos et al. 2020), an application for the evaluation of buildings' energy (Kaewunruen et al. 2018), collaborative city DTs (Pang et al., 2021) and even the life cycle management of buildings (Mannino et al., 2021). According to Salaj and Lindkvist (2020), DTs for urban facility management applications could be of great value when it comes to guaranteeing the connectivity between communities and existing buildings and infrastructure which is currently absent in urban planning. Benefits that include the ability of having insight on community's behavior (using demographic modelling), optimization of energy resources and improved infrastructure planning. All of which impact the proposed SDGs (3, 9 and 11). From this SLR research, it was determined that DT technology is on the rise with innovations and case studies being published very frequently. This concept can be applied to a variety of situations but by convering to a universal definitions, standard and characteristics of DT, it is possible to continue it development on a better defined framework. Some companies have started venturing into commercial DT applications, but the technology is still on early maturity stages. More development on enabling technologies and a better understanding and acceptance of DT will enable wider adoption.

3. Methodology

Located in the southern part of Monterrey, Mexico, Distrito Tec is an urban polygon of 452 acres, with the main purpose of achieving urban regeneration. With respect to the polygon's extension, this work will focus on modelling Tecnológico de Monterrey campus Monterrey's surrounding street, as is shown by the green line in Figure 2a.

The model representation will include three of the six layers contemplated for urban DTs (White et al. 2020) as seen in Figure 2b: terrain, buildings, and infrastructure. Mobility, digital and virtual layers will be added in future versions, when real time information from street sensors is enabled yielding data about mobility and people density in an area.

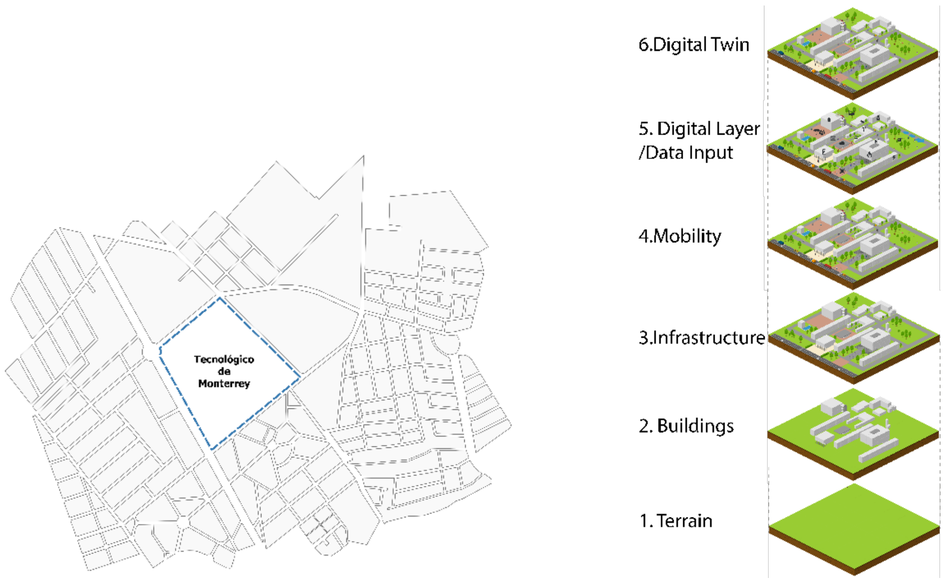

Figure 2. a) Distrito Tec area representation (left). b) Layers of DTs for urban spaces (right).

The urban DT will be modeled with points clouds (PCs) obtained from the Light Detection and Ranging (LIDAR) device. Collected PCs reflect the physical reality, so every point represents a part of the surface of objects in the field of view (FOV), therefore containing a value for its coordinate distance in x, y, and z axis. Accumulated PCs have been previously processed by a near distribution transform (NDT) and distinctive feature registration (DFR) algorithm that stitches together multiple LIDAR frame readings into a single accumulated PC map of a trajectory. More on the validation process of this algorithm in Section 5. Coordinates are then stored as CSV files and converted to LAS files (ArcGIS Pro, 2021). Using CloudCompare (An open-source 3D PC processing software), the coordinate attributes can be visualized, processed, and saved as a LAS file, enabling interoperability with ArcGIS (Esri's mapping software). ArcGIS allows classified points to be visualized according to American Society for Photogrammetry and Remote Sensing (ASPRS) classification codes which are listed on Figure 3.

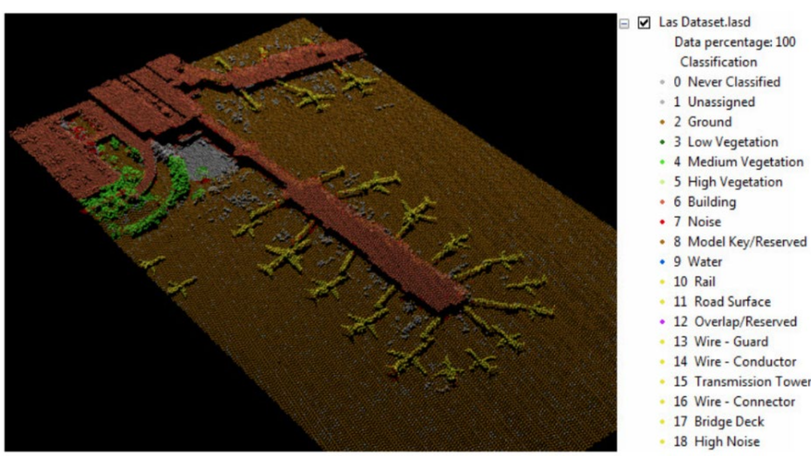

Figure 3: LAS 1.4 cluster classification code example.

The three layers are obtained by extracting elevation surfaces and producing as output the Digital Terrain Model (DTM), Digital Surface model (DSM) and Normalized Digital Surface Model (nDSM). Because the LIDAR device is mounted on a vehicle, it is not able to scan height in objects, so in this case, tall buildings or trees will not have their real heights. However, the software allows to add a height approximation. For a better height representation, there is a need of aerial LIDAR data or architectural plans information from buildings.

Footprints will be extracted through ArcGIS's geoprocessing tools, filtering points corresponding to building classification and running a process called "Last point statistics as raster" which uses a specific sampling value and creates an elevation layer that contains every value from the roof points. Finally, the raster layer is converted to a polygon layer and the footprint is regularized with more accurate right angles on its perimeter. Building's extrusion is possible but is generated as a 2.5D object due to the height attribute absence.

To model the mobility layer, YOLOv4 (Bochkovskiy et al. 2020) is used for object detection in the urban environment. It is an open-source ML algorithm that allows the use of COCO trained models to enable object detection from video footage. In this case, a Geotab device is mounted onto the vehicle and generates images of the vehicle's trajectory using a Google Maps application programming interface (API). In the future, a video camera will be mounted on the vehicle. Some objects that can be detected are people, bicycles, cars, motorbikes, traffic lights and stop signs. A JSON file will be generated to save the results which include the name of the object, its ID, its relative coordinates (central x and y, height, and width) and the algorithm's confidence level. This information is generated in real time.

The architecture for the DT concept and the data acquisition network on the vehicle is presented in Figure 4 where a DTs three main components are made evident. In the physical world, there is the physical twin (test vehicle: Mazda 3 2018 Hatchback) and the data acquisition network composed of several devices (LIDAR, Inertial Measurement Unit, COWTECH Device, GPS, Geotab). The data acquisition network will allow real sensed data to flow automatically from the physical twin to the virtual twin as input. The virtual world is made up of the virtual model multi-system real-time simulator and the mapping module (composed of the NDT and DFR algorithm for LIDAR processing and IMU processing algorithms). All the processing is made using Matlab and Simulink applications deployed onto the edge processor. The connectivity component is achieved by using representational state transfer (REST) API data streaming between the edge processor (NVIDIA Jetson Xavier NX) and a web server. The data streaming technique uses a database-type storage system that groups data into categories, which are sent as a package that is appended to the existing database. In this sense, an external user can view the live stream and make data-led decisions effectively targeting the bidirectional information flow characteristic of DTs.

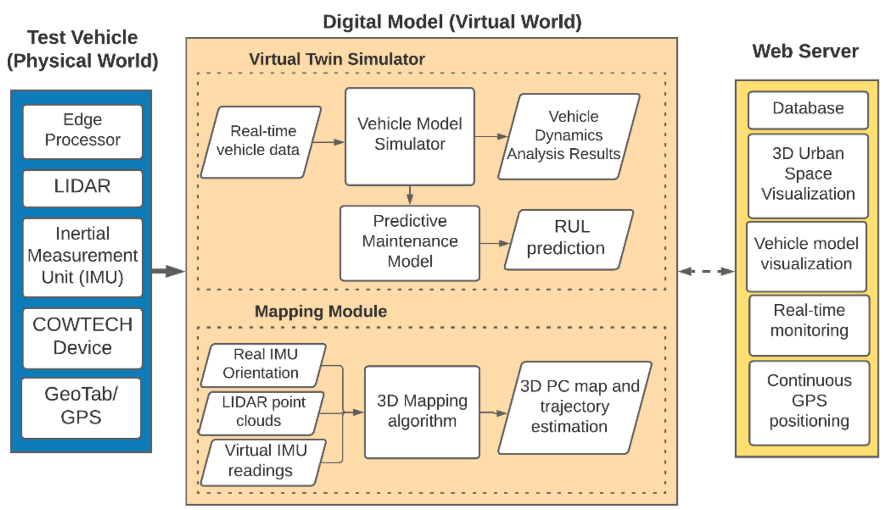

Figure 4: Current architecture for the vehicle DT concept.

4. Data Acquisition

For the data acquisition network, a set of devices are mounted onto the test vehicle itself such that, through the vehicle's performance and trajectory, the DT for the urban space is generated and populated. In this sense, the devices are mounted on an enclosure design to keep all components in attached to the vehicle to guarantee their safety. The enclosure is design to be magnetically attached to the roof of the vehicle in the geometric center of gravity. Connectivity to the car's electronic control unit (ECU) and its available signals is achieved by analyzing the controller area network (CAN) Bus signals. By using the COWTECH Device and the onboard diagnostics (OBD-II) port in the test vehicle, decoding the signal IDs (through the CAN protocol) from some sensors such as the throttle and brake pedals, steering wheel, tires, and engine is possible. These signals serve as input for the virtual model of the vehicle together with predefined technical specifications. For future versions of this system, the state of the physical vehicle will serve as calibration input to keep its DT as representative to real life as possible.

The IMU, LIDAR and Geotab/GPS devices will allow the car to collect information of its surroundings throughout a trajectory. In this case, the LIDAR is used to collect PC information and perform a trajectory estimation, the IMU is used to perform a trajectory estimation (which is fused with the LIDAR data to produce a more precise estimation using Kalman filtering), and the Geotab/GPS devices are used to gather information on the geolocalization of the vehicle (which is later processed with Google Maps API).

To process the information, the NVIDIA Jetson Xavier NX edge processor is also mounted on the same enclosure and is connected to all devices. Information flowing to the processor is sampled and used in the real-time virtual simulator. The processor is also currently being configured to enable its wireless connectivity with the web server. For the data stream, relevant vehicle dynamics information is going to be constantly updated in the web server (readily enabling real-time monitoring), and at the end of a session, the relevant information from the mapping module will be uploaded to said server to perform the visualization with the ArcGIS software. The end information from a single session is of great value for contextual analysis of the vehicle's performance, analysis of the urban space, and further studies of the dynamic interaction between the vehicle and the urban space. Examples of these further studies include mobility and traffic analysis, accessibility to public spaces and infrastructure, vehicle performance, and pedestrian density.

5. Results and Discussion

After having tuned the parameters of the LIDAR mapping module, an experimentation process was used to test the system under different conditions to evaluate and validate its performance. In this sense, an experimentation scenario was generated where the objective is to test the effect that the vehicle's speed has on the precision and accuracy of the 2D map and the estimated trajectory. Also, the effect of surrounding dynamic objects (moving vehicles, people, animals, etc.) is to be evaluated. For this scenario, a straight street (Avenida Fundadores) with little elevation was chosen. The experiment consists of driving at a constant speed three times. Then changing the speed (20 km/h, 40 km/h and 0-60-0 km/h) and evaluating if there is a difference in percent error with respect to the Google Maps trajectory distance estimation. Comparison of distance estimations is performed for each set of takes at the same speed and estimations at different speeds effectively evaluating both precision and accuracy. The results and evaluation of this experiment are shown in Section 5.1, Table 2.

To achieve more accurate error values, a stricter control of the travelled distance is necessary. For instance, ensuring that every take of the experiment consists of the same real distance. This will be achieved by using a Garmin device to calculate real distance and altitude and having start/stop marks on the road to ensure every take starts and ends in the same place. Also, additional testing is required to evaluate the LIDAR-IMU fusion algorithm.

From the complete 3D mapping system, one will be able obtain the dimensions that define the urban elements in each of their vertices and edges. This can then be visualized and analyzed through ArcGIS. Additionally, one will recognize the lengths of the streets that are being analyzed, as well as their total area and the volumes of the analyzed physical spaces. In the same way, urban features will be obtained such as the buildings' volumes, the land, and their areas, as well as the current infrastructure of the area. The later will be useful information to recognize a spectrum of mobility within the Distrito Tec polygon, thus creating social value and cultural characteristics of the population. This information fused with the object detection ML algorithm will enable in the future, the first 3 layers of an urban space DT and start to work in the fourth layer, putting the system closer to achieving the six layers.

5.1 Numerical and Statistical Results

The following table present the results of the LIDAR mapping module experimentation. In the row "Distance", the estimated trajectory distance by the system is presented. Table 2 shows that the average percent error for distance estimation is 1.80% (translates to an average error less than 5 m) which as a positive result that shows a level of high definition of the mapping module. The expectation for the experimentation of the LIDAR-IMU fusion algorithm is that this error will be reduced to approximately 1.00% (less than 2.75 m average error). Additionally, GPS coordinates may be added to the system in the future to further decrease the error and enable other functionalities to the system such as live GPS tracking of vehicles within the urban space DT (effectively achieving interaction between both DTs).

Table 2. LIDAR mapping module experimentation results.

	40 km/h				**20 km/h**				**0-60 km/h**	**Total**		
Category	1	2	3	Avg.	1	2	3	Avg.	1	Avg.	Variance	Standard Deviation
Distance [m]	315,73	286,08	248,95	283,59	237,17	264,43	254,51	252,04	260,21	266,73	594,64	24,39
Rise [m]	37,50	36,54	35,00	36,35	35,33	43,87	32,45	37,22	31,32	36,00	14,35	3,79
Predicted Dist. (Google Maps)	322,00	290,55	253,79		239,39	270,53	259,06		266,12			
% Error	1,95	1,54	1,91	1,80	0,93	2,25	1,76	1,65	2,22	**1,79**		
RMSE										**5,08**		

This initial experiment was also significant in the sense that it demonstrated that dynamic objects have very little to no effect on the precision of the system. This is mostly because the NDT-DFR algorithm only register distinctive and static features throughout LIDAR frame readings. This means, that the algorithm ignores dynamic object such as cars and people. With these results, one can also conclude that speed and acceleration have little effect on the precision of the system. This is more evident with the 0-60 km/h take which shows and increase of percent error. The expectation is that the LIDAR-IMU fusion algorithm will help reduce this effect attributed to fast movements of the sensor. This due to the fact the IMU gyroscope might reduce the drift effect in LIDAR data.

5.2 Graphical Results

After processing LIDAR data, the accumulated PC map is generated. Figure 5 portrays the result of one of the Scenario 1 data takes (left) and the Google Maps distance estimation (right). As mentioned earlier, for future experiments and more accurate results, a Garmin device will be used to set true values of distance and altitude. The result from the current mapping module is a 2D map and a 3D trajectory estimation, however, after being processed with ArcGIS, the system will yield HD 3D visualizations of urban spaces and more accurate vehicle trajectory estimations.

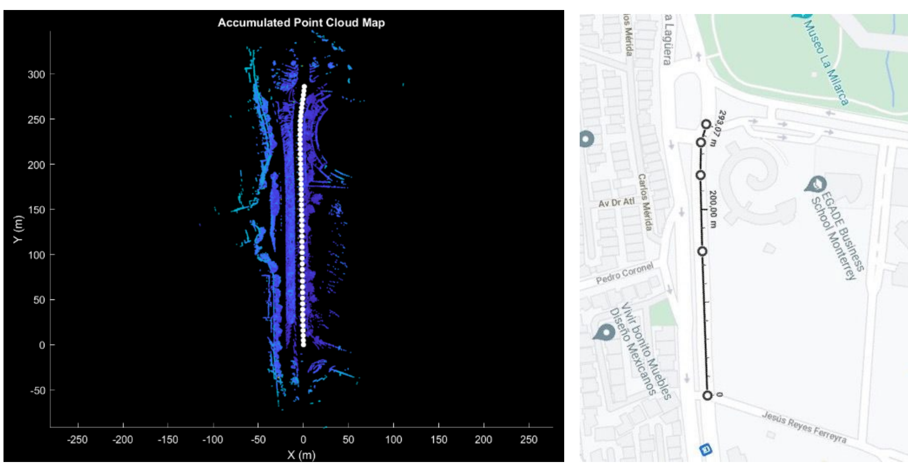

Figure 5: LIDAR mapping module result from an experiment in Avenida Fundadores (1.8% traveled distance error).

Apart from the experiment, the system was also tested with single takes (no experimental control) on more complex trajectories. Figure 6 is an example of a take where the vehicle travelled through a neighborhood with more elevation differences, speed bumps, sharp turns, and some dynamic objects (people).

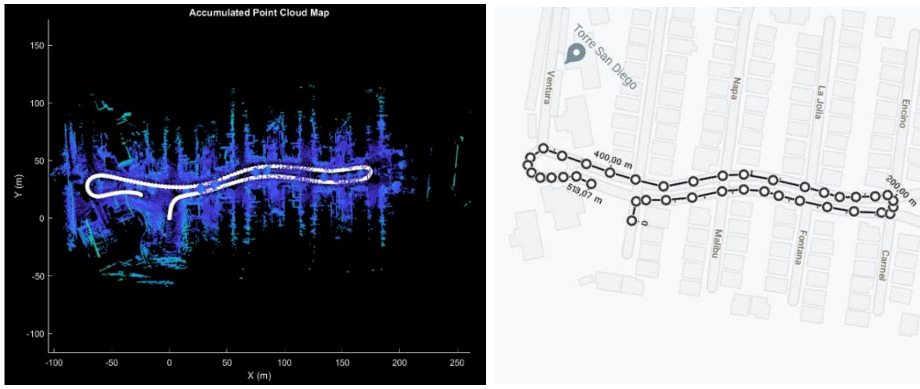

Figure 6: LIDAR mapping module result from take inside a neighborhood (Los Angeles, Monterrey).

In terms of the vehicle DT, the simulator was designed in Simulink. It is defined as a multi-system real-time data-driven simulator. This means that it includes sub models and sub systems that model various systems within the vehicle such as the engine, suspension system, chassis, tires, etc. The multi-system and hierarchical architecture of the simulator also enables more degrees of freedom (DoF) of the test vehicle model (MathWorks, 2021). In this case, the model has 14 DoF (6 DoF of the vehicle body, and 2 DoF for each wheel) and is optimized for vehicle dynamics analysis. Since most of the systems are modeled as grey boxes and some black boxes (Ran et al. 2019), once the physical vehicle and simulator automatic connectivity is achieved, testing will be needed to evaluate and validate the model's accuracy with respect to its physical twin.

The simulator is also data-driven since it uses several signals as input to ensure the most accurate representation of its physical twin. Signals such as steering wheel angle, throttle and brake pedal positions and tire pressures are inputs to the system. The connection with the vehicle's CAN Bus to extract said signals is still being developed, so the current simulator uses simulated signals to run. A real-time synchronization block was added to ensure that the simulation always runs in real-time. It uses the processor's kernel clock to ensure that a threshold of missed ticks is not reached.

Currently, the simulator monitors input signals and virtual sensor signals in accordance with the ISO 15037-1:2006 standard (International Organization for Standarization) which outlines the general conditions for measuring equipment, data processing and test reports during vehicle dynamics test methods. An example of said graphical results is shown in Figure 7. Other results that are generated by the simulator are the vehicle's engine performance and even combustion gasses analysis. These results will effectively target a sustainability analysis on the performance of the car, real-time monitoring, and air pollution studies for urban areas.

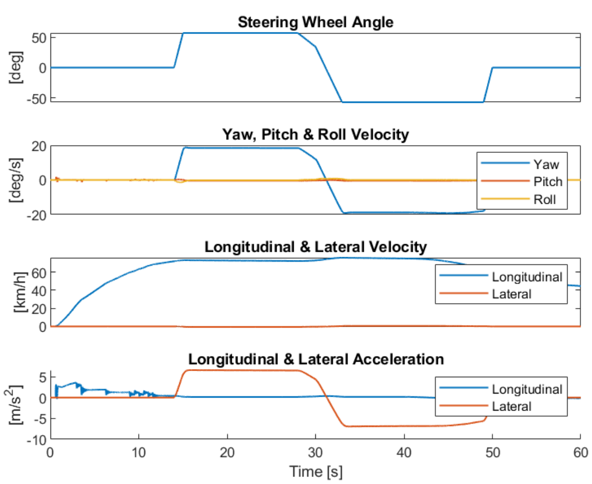

Figure 7. Graph results from vehicle DT model from simulated trajectory.

5.3 Validation

The validation process is very important when it comes to evaluating and validating systems or models that represent real objects or processes. In our case, since the digital models are desired to produce calculations and conclusions on the behavior of their physical twins, these need to be as accurate and precise as possible to present the most real information as possible. For our system experiments, the validation process is carried out by comparing absolute true values to those output by our design system. In the case of the mapping module, distances and altitude is evaluated through percent error and RMSE calculations.

When the system and individual models are complete, the use of other validation techniques are necessary. For our work, the Grieve's Tests of Virtuality (GTV) will be performed to evaluate the ability of our models to mirror their physical twins. These GTV consists of three tests: sensory visual, performance, and reflectivity (Juarez et al. 2021) where the behavior similarity of both physical and virtual worlds is evaluated.

- Sensory Visual Test: A tester subject demands a movement either from the DT or the physical twin and if the tester cannot differentiate among the real system and the DT, this test is approved.
- Performance Test: The tester demands an action from both twins and if it cannot differentiate the performance among both, this test is approved.
- Reflectivity Test: The tester demands information on the current state of the object, if there is no difference between the data from the physical and virtual twin, this test is approved.

5.4 Proposed Improvements

With respect to the accuracy of the 3D urban space visualization, more research is needed to determine the adequate set of tools need to generate the most accurate maps. Automated PC classification algorithms have a 90% accurate classification percentage that, when used with tools like geospatial deep learning (DL) models packages, can be increased. These DL packages have already been trained by Esri with high volumes of geospatial information and could extract building footprints, land cover classification and tree point classification.

LIDAR terrestrial sensing has limited ranging capacity in terms of a 3D space. As mentioned earlier, using this method, knowing the height for objects is not possible. Using drones for aerial LIDAR sensing is a good option to increase the level of detail (LOD) of the objects being registered, but specially of buildings, allowing to calculate the real height to objects, gather more data and create a better 3D representation. However, this data acquisition architecture will bring increased complexity and components to the system. Autodesk programs like Revit, Civil 3D or City Engine from ESRI, could enable a better LoD for buildings and infrastructure, allowing asset evaluation in several situations or simulations like energy consumption, flooding risk, zoning regulation, among others (Autodesk, 2020). These will be explored and assessed to determine their participation and interoperability with this project's system.

In terms of the vehicle's DT, the use of the CAN Bus has presented challenges when it comes to decoding signals. For instance, each vehicle manufacturer will operate under different IDs and CAN protocols, meaning signals will never be decoded or identified in the same way on different vehicles. This challenge becomes even greater if the system is desired to have widespread adoption. A proposed improvement is developing an external network of sensors to measure the desired signals instead of having to sniff the vehicle's private CAN Bus.

6. Conclusion

Urban spaces DTs, requires a lot of systems, layers' integration, and software interoperability, making it a design and management challenge. Working with statical data allows to understand how information could be processed for an increased LoD and integration level of modeled objects. One of the key improvements to enhance this DT system is utilizing real-time data from the different devices and processing them using edge processing techniques to obtain high quality and high-fidelity simulations and predictions. This will enable higher levels of maturity and integration. Before moving to automatic bidirectional information flow, individual system evaluation and validations processes need to be carried out to ensure maximum accuracy and precision. After this phase, the connection between all systems and platforms is the next challenge.

With the current results, the system may already be classified in a maturity level 1 according to the DT maturity spectrum index. However, once the system is complete and once it is validated, a level 2 and even level 3 of maturity will be achieved. The static information and real-time information will come from the sensing devices mounted on the vehicle. This will also demonstrate the interaction between an urban space DT and a vehicle DT concept. Furthermore, the current system may be classified as a SoS level hierarchy and an integration level of Digital Shadow. When the system is complete, the integration will be classified as a Digital Twin. A lot of work needs to be done with the interoperability and connectivity of platforms and devices. It is a special challenge when it comes to real-time data processing, and enabling technologies such as ML, Big Data, DL, IoT and edge processing have a great role.

The objective of creating the Living Lab for the demonstration of the interaction between DTs is still to be reached, but with the current developments and experiments of the system, a solid foundation is being set that will facilitate the further development of the system and the DT concept. This initial development of a vehicle's DT and initial steps for urban spaces is the first step of creating the LL. Working under UN's SDGs has also provided a more defined framework for our system objectives and focus and has allowed the team to work under the focus of sustainable innovations. The project transcends technological improvements but considers societal impact and future societal needs which adds great value to the core value of this work. This research has a direct contribution to vehicle DT concept development for performance management and urban space and smart community DT systems interoperability with sensing devices and other DTs.

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