Hybrid Aerial Sensor Data as Basis for a Geospatial Digital Twin

Uwe Bacher

Hexagon Geosystems, Geospatial Content Solutions, Germany, uwe.bacher@hexagon.com

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ABSTRACT:

More and more cities declare themselves to be a smart city or plan to be the same. Smart cities require a solid data source as basis for all further actions and the urban digital twin is the basis on which all information is collected and analysed. The urban digital twin is much more than just a 3D city model, but often this together with GIS data is the starting point for the urban digital twin. The basis of the urban digital twin is formed by geospatial data in the form of the geospatial digital twin. The digital twin hereby acts as a kind of hub into which all relevant and available information is included and analysed. To generate a geospatial digital twin aerial sensors that collect multiple data simultaneously, hybrid sensors, are perfectly suited for this task. In aerial data acquisition a new era started with the introduction of the first real hybrid sensor systems, like the Leica CityMapper-2. Hybrid in this context means the combination of an (oblique) camera system with a topographic LiDAR into an integrated aerial mapping system. By combining these complimentary sub-systems into one system the weaknesses of the one system could be compensated by using the alternative data source. An example is the mapping of low-light urban canyons, where image-based systems mostly produce unreliable results. For an LiDAR sensor the geometrical reconstruction of these areas is straight forward and leads to accurate results. The paper gives a detailed overview over the development and technical characteristics of hybrid sensor systems. The process of data acquisition is discussed and strategies for hybrid urban mapping are proposed. Furthermore, the paper provides insights into the advantage of LiDAR data for the 3D Mesh generation for urban modelling and on the possibilities to generate new products from the combination of the single products with the help of GeoAI. Finally, the use and some use cases of the hybrid sensor data and the derived products in the context of the urban digital twin is discussed and with the infinite loop of data, analysis, and action it is shown, that all data from the urban digital twin can only be a snapshot at a given point in time and the data recording and analysis is a permanent loop.

1. INTRODUCTION

The concept of a digital twins was originally introduced for the manufacturing industry for product lifecycle management. From there the idea of a digital realisation of the real world speeded out into a wide variety of industries, e.g., the building/construction industry as part of a BIM realisation or the automotive industry. In recent year the need of a digital twin for urban planning and management was reinforced by the emergence of smart cities. In this context the geospatial digital twin or sometimes also called the base digital twin plays a central role for the description of spatial relationships within an urban environment.

The geospatial digital twin of a city provides the framework into which other information with an attached position are integrated. By definition, a digital twin is a representation of the real world at a given point in time. This implies that in addition to all sensor data also the base data, like the geospatial data, is updated in (near) real-time. For geospatial data, like the city model, this is not practically possible. It is more important to have this base layer in the best possible quality and reflecting as many as possible different aspects in all 3 spatial dimensions. Nevertheless, update cycles for the geospatial base data should be kept in a reasonable interval. The demand for more precise data with better resolution and more diverse data products increases. This results in an ever-increasing demand for efficient acquisition methods.

Additionally, the data should be suitable for all kinds of analysis and so additional semantical information that comes with or can be derived from the data itself will be one of the success criteria. Acquiring the data required with traditional sensors systems would need a high quantity of flying hours, what is often difficult due to airspace regulations, weather conditions or availability of the right equipment; expensive and (due to CO_2 emissions) ecologically questionable. By combining the single sensors like nadir and oblique image sensors and LiDAR into hybrid systems for a simultaneous capture of all required information, the results become more reliable and the cost and environmental impact are reduced.

2. GEOSPATIAL DIGITAL TWIN

In the manufacturing industry digital twins are a well-established tool to accompany the entire product life cycle from design over manufacturing into service and maintenance. In the geospatial domain the concept of digital twins was first applied within the construction industry and dealt as basis for building information modelling (BIM). A BIM system focuses usually on a building or construction site with a usually rather small extend and the connected digital twin starts already in the design phase of the project with the digital construction and realization of the building.

Extending this concept from single buildings into an entire city directly leads to an urban or regional digital twin. The basis of a smart city, again, is the digital twin of the city. Nevertheless, there is a big difference to the digital twins used in the manufacturing or BIM context, namely that it is not constructed on the computer, but the basic data must be recorded using mapping and surveying methods and then converted into appropriate models.

But what is a digital twin of a city? Simply put, it is a reflection of the real world, with all the streets, squares, trees and houses, but also with all other facilities that make a city what it really is, such as parks, street lighting, public transport or playgrounds.

Figure 1: From 3D City Model to an Urban Digital Twin

Up to this point, however, one could easily say that this is not new; urban planners have been using this information in their GIS systems for decades, both in 2D and increasingly in 3D. In order to get from a "simple" GIS to a digital twin, it takes more than static (and therefore always outdated) information, only through the integration of real-time data can a GIS become a digital twin of a city (Chaturvedi, 2021). By using sensor data like weather data, air pollution measurements or GPS positions from public transport, the digital representation of a city becomes more and more a digital representation of the real city. Most of this information is already available throughout the city as it is measured by thousands of sensors distributed in the city. The big challenge here is to bring all this sensor information together and use it meaningful within a central platform. In the practical realization the digital twin will deal as the central hub to connect all data streams and bring the different information sources together (**Figure 2**).

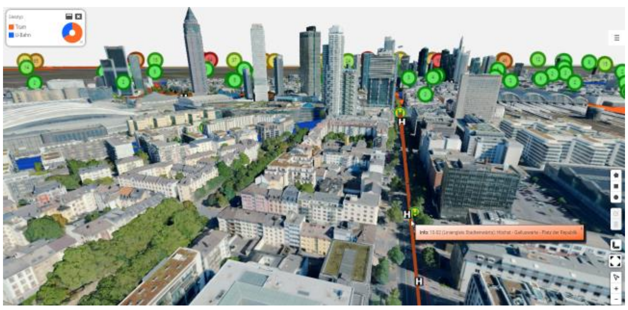

Figure 2: 3D Mesh, downtown Frankfurt, from CityMapper-2 hybrid sensor data. with transportation information

Here the information sources from different, formerly independent, authorities are connected into one large data pool with the goal to make faster and better decisions due to better information and often with the help of AI supported analysis to realize an urban digital twin and make a city a smart city. This helps decision maker to predict and plan the future using all information from the past and present (**Figure 3**).

Figure 3: Prediction of the future from the past

3. HYBRID AERIAL SENSOR DATA

3.1 Evolution of Photogrammetry – Photogrammetry 4.0

For a very long-time aerial data acquisition to produce geospatial content, such as ortho images, elevation models or base mapping, was purely done using aerial camera systems. All started with analogue cameras and pure analogue workflows – Photogrammetry 1.0 (for more details see also Fritsch, 2018). With the introduction of the first computer supported analytical plotters the Photogrammetry 2.0 was born. The next step in the evolution of photogrammetry, Photogrammetry 3.0, was the digitization of the process. In the beginning the film was scanned and processed in digital photogrammetric workstations, with the introduction of the first digital aerial image sensors in 2000 also the process of image acquisition became fully digital. Also, the introduction of the first operational airborne laser scanner systems falls into this period. The latest level in the evolution of photogrammetry is, in analogy to the industrial revolution 4.0, the integrated Photogrammetry 4.0. According to Fritsch, 2018 the integrated photogrammetry should be embedded in various workflows and products to deliver and explain 3D geometries, generate added value, and simply meet the challenges of society such as autonomous driving, app development and use. With the invention of the first hybrid aerial sensor, this integrated approach was realized on the sensor side. In combination with an integrated hybrid workflow from data ingest to the generation of value-added products, like semantic 3D vector models, this workflow was realized by Hexagon.

3.2 History of hybrid Sensors

For a very long-time aerial data acquisition to produce geospatial content, such as ortho images, elevation models or base mapping, was purely done using aerial camera systems. With the development in the laser technology together with the introduction of global navigation systems and performant IMUs the first airborne laser scanner systems were introduced in the mid ‘90s of the last century. This led to the formation of two camps around airborne data acquisition – the image-based data acquisition on the one side and the LiDAR focused on the other side. Both claimed themselves somehow to be superior over the other. But with an objective view into this, it always was obvious that both are wrong and right or with other words it was like comparing apples with pears.

Both systems have their Pros and Cons, from image data for example it is only possible to map what you see, and for the generation of 3D content, see means here that each object needs to be seen in at least two images taken from different positions. LiDAR on the other side generates only 3D points without any relation between the single points and without additional image data these points are often hard to classify or interpret (Lemmens, 2020).

As much as the differences between the two groups led into typical products derived from the sensor data, from the image data usually large orthophoto mosaics are generated and from LiDAR data typically DTM/DSM data is derived, both have their strengths that in combination are able to help produce a superior data product.
Considering the Pros of image based and LiDAR systems it shows that they are complementary, which consequently led to the first hybrid systems. In the early beginning this meant that the LiDAR systems had an additional nadir camara as piggyback sensor or for aircrafts with two holes a LiDAR and an aerial camera were used simultaneously. Then, with the help of large efforts in miniaturization, the first integrated hybrid sensor was released in 2016 by Leica Geosystems, named Leica CityMapper. It combined 3 types of sensor systems, a nadir camera system, an oblique camera system and a topographic LiDAR system in one pod. In this setup the subsystems are

combined in a way that they have adapted fields of view and performance parameters on the one side and make use of the same integrated GNSS/IMU system on the other side. This first integrated hybrid sensor was just the start of this new hybrid era (Toschi et al., 2019, Toschi et al., 2018).

Regardless the differences between the different hybrid systems, they all have one feature in common – they all are combinations of first-class sub-systems, so that none of them is inferior to the other.

3.3 Hybrid Sensor Characteristics

Summarizing the above, a real hybrid sensor needs to fulfil the following:

- all sub-systems are integrated in one platform (one pod)
- all sub-systems use the same GNSS/IMU system

Hybrid sensor technology can, and most probably will, be used not only for urban mapping, but also for large scale aerial data acquisition in the near future. However, this means that the setup of the overall system needs to be tuned into the one or the other direction. For urban mapping the focus is the 3D city mapping with products like city models, 3D Mesh models, TrueOrtho, and DSM/DTM point clouds. This means that obscured areas (due to building lean or narrow roads) are not wanted. To achieve this camera systems with a large field of view (FOV) (more than about 30 deg) are not suitable or produce a lot of redundant data. For city modelling it is usually also necessary to use an oblique viewing angle (between 35 deg and 45 deg) to capture facades, that are directly needed for the texturing of the building or 3D Mesh models. For large area mapping the focus is usually different and one of the key success criteria is a larger field of view of the camera and LiDAR system for efficient mapping. Building lean is less important for these applications and can, if necessary, be minimized with additional flight lines in dedicated areas. Also, the oblique views are less important in this case. A proposed configuration for urban and large-scale mapping can be found in Table 1.

	Urban Mapping	**Large-Scale Mapping**
GSD:	3 - 10 cm	> 15 cm
Nadir:	Yes, RGBN	yes, RGBN
Oblique:	yes, RGB	no
FOV:	20 - 30 deg	> 40 deg
LiDAR:	yes, min. 15 pts/m²	yes, 8 - 15 pts/m²

Table 1: Proposed parameters for urban and large-scale mapping sensors

3.4 Hybrid sensor for urban mapping

Following the above mentioned, the Leica CityMapper-2 is the only real hybrid sensor system for aerial data acquisition on the market. Consequently, the focus of this paper is on characteristics and performance of the Leica CityMapper-2 as an example of hybrid sensors for urban mapping to generate an urban digital twin.

The CityMapper-2 is consequently designed to fulfill the needs for urban mapping as described above. The sensor system consists of an integrated nadir and oblique camera system with a Hyperion 2+ LiDAR in a single pod. The system is supplemented by an integrated GNSS/IMU system and the required storage capacity to deal with the large data volumes recorded during a typical mission.

At urban mapping projects it is usually the case that one needs to deal within areas with strongly varying lighting conditions. This means that the cameras are subject to very high demands on dynamic range and low-light performance. To realize this, a camera system with a forward motion compensation (FMC) is recommended to be able to fly with a high speed even under lower lightning conditions as shown in the Figure 4.

Figure 4: Leica MFC150 with FMC off/on - showing the benefit of FMC for long exposure at low sun angle (1/200 sec at 120 kn)

The principle of oblique viewing angels for the modelling of vertical surfaces is widely used in 3D city modelling. To use the advantage of an oblique viewing angle together with an active LiDAR system results in a LiDAR system with a conical scan pattern as shown in Figure 5. With this, vertical structures are well represented in the resulting point cloud in all viewing directions (Figure 6). This is of high importance for urban mapping as vertical structures, like the building walls, are penetrated in a constant manner and invariant from the viewing direction. This provides in the further processing chain towards 3D models a geometrical accurate and complete skeleton of all buildings. With the help of dense image matching the skeleton of the building facades can be completed with all the details.

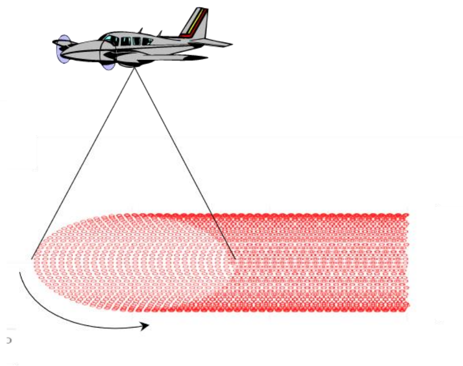

Figure 5: Conical LiDAR scan pattern

3.5 Product generation from hybrid sensor data

In the context of this paper, Hybrid Sensors consist at least of an image sensor and a LiDAR that are integrated into a single pod with a single GNSS/IMU system that is used for all sub-systems. Furthermore, all data are stored on a single media and processed on a common workflow. In general, this may lead to quite a large variety of different image systems, like oblique, nadir, large frame or combinations of these configurations. For the acquisition of 3D content in the context of smart cities or urban mapping, a combination of nadir, oblique and LiDAR covers best the different needs for the generation of the data products required for these purposes.

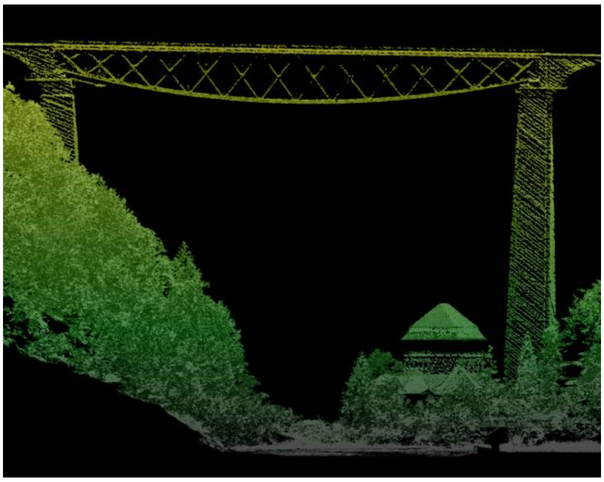

Figure 6: Profile view of a LiDAR point cloud from a Leica TerrainMapper-2, with a conical scan pattern. The result shows the enhanced details on vertical surfaces and even on the structures under the bridge deck.

As it was stated earlier, the state-of-the-art hybrid sensors consist of sub-systems that, in themselves, are suitable for dedicated data acquisition. Thus, it can be said, that the data captured with these systems can be used to generate all the traditional photogrammetric products, like orthophoto or DTM/DSM. In addition it is possible to generate a variety of different 3D products like, 3D mesh, LOD1/2/(3) building models or classified point clouds and true ortho images. Using the combination of the data from different sub-systems the 3D modelling becomes more reliable and of higher quality especially under difficult circumstances, like narrow road (urban) canyons or shadow areas.

In addition to the already mentions products, the use of hybrid sensor data unlocks a large field of additional data products that can be generated. The combination of LiDAR data together with 4-band image data opens the door to a wide range of applications in the context of vegetation analysis or urban forestry. Due to the temporal synchronization of the data acquisition progress, the combination of the different input datasets is the perfect source for machine learning applications. One good example here is the direct generation of clutter maps for the telecommunication planning purposes. Another important product that can be derived from the hybrid sensor data is the land cover information for a whole city.

With the challenges that climate change poses to modern cities, the classes of sealed areas and vegetation are of extreme importance. For both classes the combination of LiDAR data with 4-band image data is a perfect source. With the image data the classification can only be done for the land cover that is visible on the images, whereas the LiDAR provides an additional intensity information for all points. As LiDAR can penetrate vegetation and the intensity holds the reflectance information from the ground underneath the vegetation, e.g., the trees along an urban road, the impervious class can be modelled with much higher accuracy. For trees the information of ground and surface elevation adds the exact height of a tree into the dataset. This is more and more important for urban forestry and tree management (Figure 7).

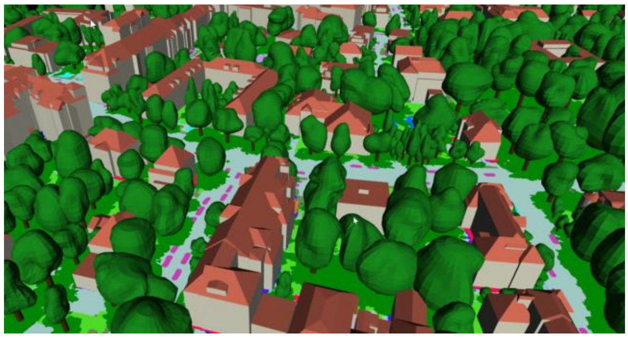

Figure 7: Land cover information combined with automatically derived LoD2 building models and 3D single tree information including position, height and diameter

All the before mentioned data products derived from a hybrid airborne sensor yield as input data to form a digital twin for an urban area or a whole region.

4. HYBRID DATA ACQUISITION

As described in the sections before, the single components of a hybrid sensor system alone have each several disadvantages or weaknesses. By combining these complementary subsystems into an integrated sensor, most of the less advantageous characteristics can be eliminated (see Table 2 &. Figure 9). As a result, the variety of data products is larger, and the quality and reliability of the resulting data is higher. One good example is the mapping of narrow streets with the adjacent buildings in an urban environment. In this section the planning and acquisition process for a hybrid aerial urban mapping mission is described in more detail.

4.1 Hybrid data acquisition for urban mapping

With an image-only approach, it is not possible to extract enough points on the ground in the required quality, because often a point is not visible in more than one image and due to shadows, the contrast is not suitable for image matching. Here LiDAR measurements are of big advantage as it need only "view" the reflection from the ground from a single point overhead. As it is an active system, the shadows also have no negative influence. Another example is the mapping of areas covered by vegetation. An image-based approach is only able to map what is visible from above and so the ground often is not visible, particularly when looking at one point on the forest floor from multiple locations in the air. A LiDAR system overcomes this as Laser pulses (i.e., the "footprint" of the pulse on the canopy) are able to pass through openings in the footprint to the lower vegetation levels and reflect ground and canopy surface (and often also the objects in-between).

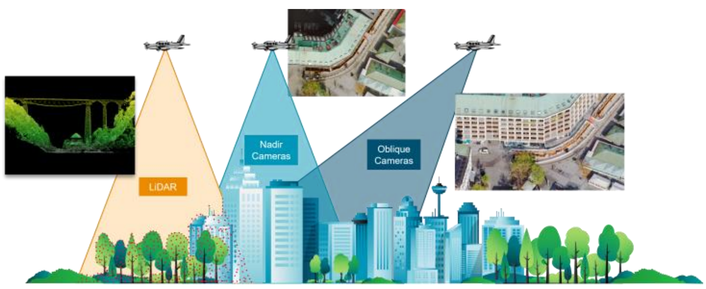

Figure 8: Hybrid data acquisition - Sensor sub-systems contribute to urban mapping

On the other side, a LiDAR-only system would have several deficits. For the generation of textured 3D models, image information is mandatory and can only be added from an image sensor. In this case, the oblique sensor is a great advantage, as it adds the views onto the facades. One last important point to mention is the spacing between single points. From image sensors the number of points per m² is much higher and usually in the range of the GSD, whereas for the LiDAR sensor the point spacing is larger (i.e., fewer points/m^2).

Taking the above into account the consequent step is towards hybrid data acquisition. Using a hybrid sensor system brings the advantages of both types of systems together. If there are no compromises in the quality of to the single sub-systems, there also will be no side effect on the usage of a real hybrid system. For further reading Mandelburger et. al, (2017), Glira, 2018 and Glira et al, (2019) elaborates some of the aspects in more detail.

Finally, there is value the fact that the hybrid sensor collects all data simultaneously, minimising temporal effects, such as vehicles in the LiDAR data set that are not in the image data and vice versa.

Image Data	LiDAR Data
High accuracy and resolution in X/Y plane	High accuracy in the Z component but low resolution in X/Y plane
Strong top-surface models	Multiple return capability for foliage penetration
4 spectral band (R, G, B and NIR)	1 additional spectral band (intensity @ 1064 nm)
2+ images needed for 3D reconstruction	Fills in details not visible to camera
Passive sensor (needs sunlight)	Active sensor (works well in shadows)

Table 2: Aerial image data versus LiDAR data - complementary benefits

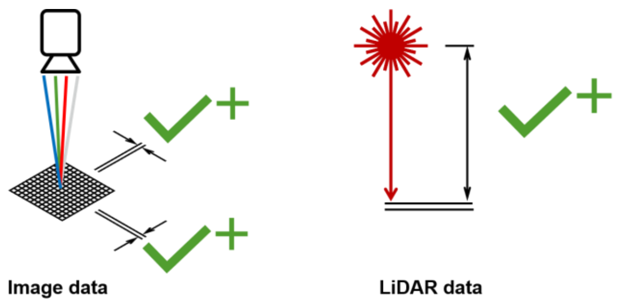

Figure 9: Aerial image data versus LiDAR data - complementary benefits

In addition to the sensor specific aspects, the flight planning and acquisition configuration is another important success parameter for the hybrid aerial data acquisition. To better understand this, first it is important to have a closer look into the products typically requested in urban mapping projects:

- Dense Point Cloud (DSM)
- True Ortho(mosaic)
- 3D-Mesh
- DTM
- LOD1/2, City Model

For the various products it is important that the initial data already match. For the DSM a combination of LiDAR points with a high accuracy in the elevation will be supported by the photogrammetric point cloud for the fine details. To realize this it is essential, that the overlap is chosen in a way that all areas are visible in at least two images. Therefore, a suitable forward overlap is necessary. For the TrueOrtho the DSM needs to have straight and sharp (building-) edges and for the nadir images it needs to be secured that no areas are occluded due to building lean effects. Hence, for the TrueOrtho the side-overlap in relation with the FOV of the camera and the maximum building height and distance in the project area needs to be chosen in a way that everything is visible in at least one image (see Figure 10). The basis for the 3D-Mesh is a combined dense point cloud containing both photogrammetric and LiDAR points for the geometrical modelling and the image data for texturing. For the LiDAR setup and the nadir images there are no additional requirements necessary, only for the oblique images it is important, that the facades are fully represented in the image data with an appropriate GSD. For DTM generation no additional requirements are necessary. For the LOD models the full coverage of the facades is mandatory if textured models are required.

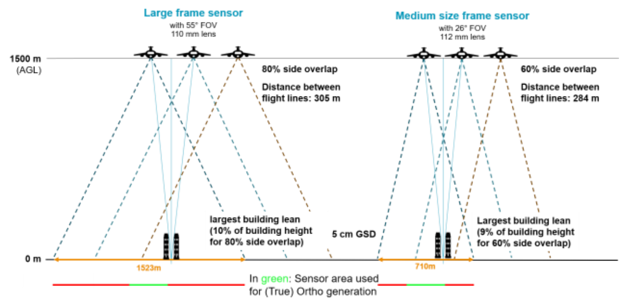

Figure 10: Building Lean vs. Side-Overlap, preferred configuration for TrueOrtho production

5. LIDAR IS THE GAME CHANGER

Some of the advantages of using LiDAR data in addition to image data for urban mapping were already stated. Looking into the generation of 3D Mesh models, the usage of LiDAR data helps to solve a number of issues that occur when working with images only even if flown with a very high overlap. The main reason for this lay in the photogrammetric image matching approach itself. To generate a 3D point it needs at least 2 images with adequate local texture representing the same point on the ground. As this is not always the case, some areas are not or not good enough represented in the photogrammetric point cloud.

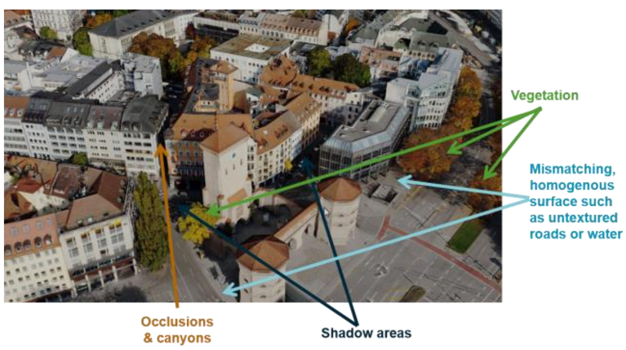

Figure 11: Advantage of LiDAR for 3D Mesh generation

Illustrated also in Figure 11 the 4 main problem areas for an image only approach for 3D mesh generation is demonstrated:

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Vegetation – the ground under vegetation cannot be modelled in an image only approach. LiDAR adds ground points and allows to represent the surface (tree crown) as well as trunk and ground.

Shadow areas – shadow areas or other areas with low lighting condition are difficult for matching algorithms to find corresponding points. This often leads to mismatches and so quite some noise in the resulting point cloud. LiDAR as an active system does not need any sunlight and only one measurement to generate a point in the shadow area with high accuracy.

Occlusions & Canyons – due to narrow road it will often not allow to get two images representing the same point on the ground to generate a 3D point with photogrammetric means. With LiDAR it is only necessary to bring one pulse to the ground to measure a 3D point with high accuracy.

Homogenous surfaces – due to the low variation in the grey-values it is often difficult to get proper matches on the ground with photogrammetric means. This also applies for repetitive structures and led often to mismatches and noise in the resulting point cloud. Again, LiDAR is not affected by this and can easily generate measurements on these surfaces.

Some examples illustrating the differences between an image only and an image + LiDAR approach are shown in Figure 12 and Figure 13. In Figure 12 the advantage in narrow roads (1), backyards (2) or for the modelling of facades (3). Figure 13 illustrates the advantage of LiDAR for homogenous surfaces (in shadows) and on the transition between road and buildings. In general, it can be shown that LiDAR adds an additional level of robustness into the 3D mesh modelling.

6. FROM DATA TO INFORMATION WITH GEOAI

More important than the data products generated from a hybrid sensor, like orthoimages or LiDAR point clouds is the information derived from these datasets itself and in combination with other input sources (e.g., sensor data or physical models). Since the input data is spatially and temporally synchronized it is the perfect source for a GeoAI. GeoAI or Geospatial Artificial Intelligence in this context is the integration of geospatial analysis with AI technics like machine learning (e.g., deep learning) to extract knowledge from spatial big data.

Figure 12: Comparison of 3D Mesh from image only (top) and image + LiDAR (below) approach. 3D mesh generated by Melown technologies from CityMapper-2 data, 5 cm GSD

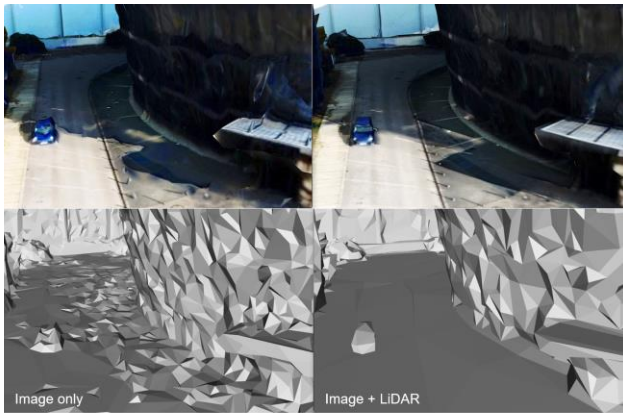

Figure 13: Comparison of 3D Mesh from image only (left) and image + LiDAR (right) approach. 3D mesh generated by Melown technologies from CityMapper-2 data, 5 cm GSD

The possible applications that can put the hybrid data into value are almost unlimited. The examples range from the extraction of single features like trees or buildings to a multiclass land cover classification to the analysis of complex simulations using physical models. These layers of information become even more valuable the more vintages you have available. From the time series the change in the development can be tracked and extrapolations into the future can be made. This helps to get a better understanding of the dynamics of change and to discover wrong developments in an early stage.

An example for the information extracted from the input data is a land use/land cover map. In this easy example this could directly lead to the information of the percentage of impervious surfaces in the digital urban twin. Having the same information layer from more different years the change in the sealed surfaces can be tracked. The example in Figure 14 shows a dashboard visualizing changes in the imperious areas for the calculation of local water fees.

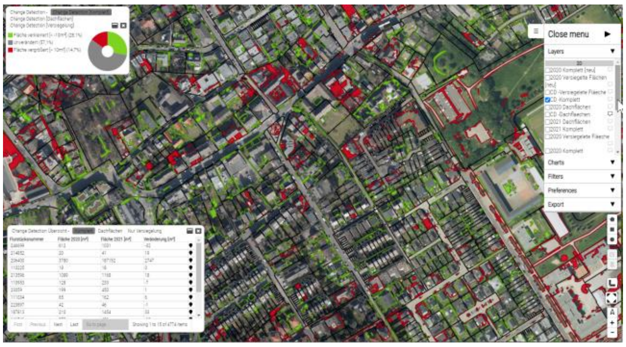

Figure 14: Hexagon M.App Enterprise to derive and visualize changes in impervious areas based on hybrid sensor data and GeoAI analysis.

6.1 Information for Decision Makers

For decision makers it is of high importance, that information is focused onto the right topic and presented in an intuitive way. Here the digital twin deals as the backbone of the analysis with a common database. For the decision making the information is prepared and presented in a clear way using easy to use dashboards focused on a certain topic on the frontend, e.g., urban tree management. Using the same data source, the digital twin, it is important to mention, that dashboards for different application areas or decision makers all have the same highly consistent source data. This prepares the road for a smooth way for easier collaboration between different stakeholders.

6.2 The Infinite Loop of Data, Analysis and Action

Life is not static, but the situation is constantly changing. The dynamics of relevant changes differs, so is traffic highly dynamic, whereas weather changes slower and the dynamics in changes in infrastructure and land use are comparably slow. But no matter how quickly individual aspects change, the process of analysis and information provision is a permanent cycle. The central component of this infinite loop of data, analysis and action, the GeoAI, learns from the past and predicts with the help of the latest input data what could happen in the future (Figure 15).

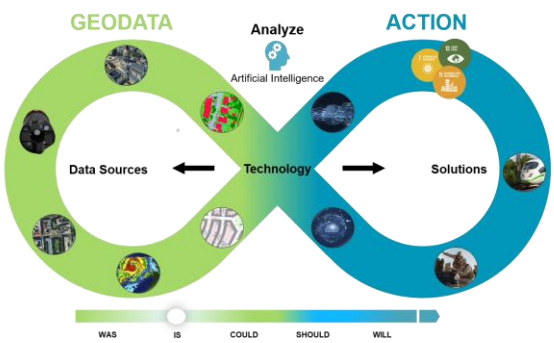

Figure 15: The infinite loop of data, analysis, and action for a (urban) digital twin

Within this loop, the geospatial digital twin, generated from hybrid sensor data deals as a central component providing information on spatial relationships for the analysis. The urban digital twin is using this central component and adds all other available information as input source for analysis. The result from the analysis is information that helps the decision makers to take their action. Triggered by the applied changes some parameters change what requires a new run of the analysis.

The action side of the infinite loops needs to be as easy and fast to understand as possible. The decision makers are responsible to manage a certain aspect of a smart city, but are not specialists of all the input data, so the interface needs to be clear and easy to understand with a focus on a certain question. This holds true for all different topics, always with the same datasets and information used, to make sure that inconsistencies are avoided.

7. CONCLUSION

The paper shows the advantage of hybrid sensor data for arial data acquisition in the context of a geospatial digital twin. A geospatial digital twin hereby acts as the base layer of an urban digital twin and provides the spatial context for all other spatial data. Of course, like everything else in an urban space, this basic structure of the digital twin is subject to change. For this reason, this base layer must also be updated regularly. On the one hand, these updates keep the basis of the digital twin up to date and thus represent reality as well as possible. On the other hand, the time series obtained in this way allows changes to be identified and based on this knowledge, to be predicted for the future.

The regular acquisition of base data for an urban digital twin always requires a not inconsiderable amount of effort and should therefore be carried out as efficiently as possible. Hybrid sensors which, in addition to image data in nadir and oblique view, also record LiDAR data simultaneously, are ideal for this. The simultaneous capturing of image and LiDAR data leads to consistent and better data products and opens the door to a wide range of new data products. With the help of GeoAI information can be derived from the raw data and additional data sources. Information for different stakeholders is all derived from the same, consistent source. This opens the door for closer cooperation within smart city or region administration.

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