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How can GI science advance the value of city-level and national Digital Twins?

AGILE Pre-Conference Workshop
June 13th 2022 - Delft, Netherlands

Bénédicte Bucher, Jantien Stoter, Claire Ellul,
Roland Billen, Bart De Lathouwer, Per-Ola Olsson

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Official Workshop Report

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1 Introduction

The basic concept of a Digital Twin (DT) is a realistic digital representation of a physical thing with two-way flow of information from the physical to the model and back: one way is a refinement of the digital representation, back is the triggering of real impacts on the depicted reality. This concept was introduced by the manufacturing community to improve product life-cycle. It has extended to the built environment and underpins areas ranging from urban administration to telecommunications. Location-enabled Digital Twins are investigated at city and national levels motivated by cost reduction, efficiency, decision-making and innovation, and particularly to contribute to local and national Net Zero initiatives [Ellul et al. 2022].

Within the geoscience community, DT concepts are not new; indeed, the location foundations of a DT may seem obvious. However - perhaps due to DT origins in manufacturing - there is as yet a lack of common understanding as to: (1). How geoscientists can best support, engage with and benefit from the increasing number of city-level and national DT initiatives, (2). What geoscientists can learn from the DT community.

To address these questions, EuroSDR organised a workshop “City-level and national Digital Twins” as an AGILE workshop on 13th of June in Delft. The documents that have been prepared for this workshop as well as the outcomes are reported in this EuroSDR publication. The workshop gathered twenty participants from diverse backgrounds in a mixed format of short presentations from researchers and industry experts, followed by two break-out sessions. This report summarises the workshop.

The first section of this report provides an overview of geoinformation science challenges for digital twins building upon past EuroSDR activities on Digital Twins such as the workshop “Digital Twins for national mapping and cadastral agencies and other governmental organisations” held on 21st and 28th of January 2022 (http://www.eurosdr.net/workshops/digital-twins-nmcas) and a workshop presenting the results of a questionnaire on the status of Digital Twins in Europe (http://www.eurosdr.net/workshops/follow-workshop-digital-twins) held on 25th of May 2022. The previous workshops highlighted the potential of digital twins to broaden the understanding of the role of National Mapping and Cadastral Agency data as an underpinning to many issues faced by society, but also noted key challenges relating to defining a digital twin and addressing interoperability issues. The second section focuses on key challenges for city-level and national Digital Twins, selected by each of the speakers at the workshop. The final section reports the findings of a breakout session that was designed to encourage more in-depth discussion between participants.

2 Geo Information Science Challenges for Digital Twins: an overview

Jantien Stoter

The locational aspects of national and city-level DTs is crucial, and therefore the science of GI has a lot to offer to the implementation of DTs representing our living environment. There are many GI-related challenges still to be tackled to fulfil the promises of nationwide and city-level DTs that will fundamentally address and solve global challenges. Below, a few of the most persisting and essential GI challenges for nationwide and city-level DTs are described.

2.1 A catch-all term with the risk to ignore (remaining) fundamental problems

DTs are considered to represent the current state of reality in 4D, to integrate data from different sources, to be able to run simulations and to investigate what-if-scenarios. Similar challenges have been studied in the past in the GI domain. However, the contexts in which they were studied were named differently before the concept of DT was introduced in the GI Science domain 6 or 7 years ago, i.e. SDI, GeoBIM, Smart Cities. Nonetheless there are still many challenges for the implementation of an all-encompassing GI concept beyond individual projects or organisations. For national and city-level DTs it is crucial to be able to exchange data without any restrictions across organisations, different domains and different software systems (which can be commercial), which is the essence of DTs. The risk of a catch-all term like DT is that research can focus on just a part of the DT (mostly technical) and ignore the fundamental issues which are harder and more complex, and therefore require a different skill set to the technical skills traditionally associated with digital skills, to study. There are indeed many examples of GI science publications on DT-research that are limited to only an isolated part of the problem. At the same time, research on the full implementation of DT at city or national levels is rare and long-standing, fundamental research challenges about collecting, sharing and integrating multi-temporal, multi-resolution heterogeneous data across organisations, scales and domains still remain. These GI challenges, more details below, still need attention.

2.2 Going beyond the concept of an exact mirror

The exact mirror concept of a DT representing reality works for a single product that can be isolated from its surroundings such as a car or a plane, but not for a complex, interconnected reality of our physical environment. GI modelling is always based on an abstraction of the world where selections and generalisations are applied to capture reality in geographical data. In practice different data views on the same reality exist, depending on the application for which the data was acquired and on how the data was acquired. For example, a building in a BIM model is a collection of many, very small, constructional elements, all modelled as volumes, while a building in 3D GIS is modelled as one object, at a much lower level of detail, while the boundaries representing walls and roofs are surfaces. The metaphor of one, overarching DT is thus not sufficient for DTs that represent our living environment. Different DTs exist depending on focus, scale and purpose. The question is therefore how to develop and implement a multi-view (multi-scale, multi-temporal) DT concept. We can learn from the research that has been done on the integration of geo-data and BIM data and on the development of open standards to support such a view (see Section 3.3. Standards for Digital Twins). In GeoBIM research the focus is also not on developing one integrated model that contains both data views on reality but on exchanging data from different domains in a meaningful way.

2.3 Temporal data

To enable the two-way flow of information from the physical to the virtual model and back, realtime data and continuous updating of the DT is required. For geo-data an update cycle of days or weeks is often already high and more frequent updates might not even be needed. Therefore, the question is how real-time is real-time and what temporal data do nationwide and citywide DTs need to solve global challenges such as climate adaptation and the energy transition. The research challenge also still exists of how to maintain and manage different versions of geodata to be able to (always) go back to a version of the data on which a specific decision was based or to be able to study trends of specific phenomena. An important issue in GI is also the definition of the timestamp for a change (to identify a specific version of a building). When does a building/road etc. actually exist? Or is there more than one time stamp? For example a building can go through several phases such as 'planning officially accepted', 'construction started', 'top reached', 'construction finished', 'residents moving in', 'postal address assigned' etc. Related to the abovementioned multi-view aspects of DTs, there is a challenge of how to synchronise various digital twin dataflows. It is already challenging to integrate data from different data flows at one moment in time. But these data models also evolve within their own workflows.

2.4 Simulation in city-level and national DTs

The ideal picture of a DT is a DT in which simulations can be done on the fly within the DT from which it can directly be seen what the impact of a specific intervention is on different aspects such as noise, air quality, mobility, energy etc. However, most of these types of simulations are embedded in highly specialised domains. They require mathematical models and sophisticated hardware and often work on specific data structures. Therefore, the DT-data for a specific moment in time needs to be processed and prepared for such simulation. In addition, some simulations can take quite some time (several days or even weeks). The challenge is how to use the same DT-basis for a wide variety of simulations that work on their own and how to feed back the simulation results which can be very heterogeneous into one integrated view? Moreover, we need time series from the past for these simulations. How do we design a DT technically (historization) to allow these time series to be available in the future (see also Section 2.3 Temporal data)? Another issue with simulations is the uncertainty bands that are inherent to modelling the complexity of our environment into simplified simulation models. How to expose such uncertainty to the users of DTs so that simulation results are interpreted in the correct way and appropriate decisions are made based on them.

2.5 Realism versus realistic

Visualising the current status of reality and possible future scenarios in a 3D environment is an important functionality of a DT. Often it is thought that the more real the DT looks the better. But realistic looking models are not per se realistic models of reality. These models can be outdated, contain errors and be equally (sometimes even less) accurate than less detailed models, while they are more expensive to acquire and to keep up to date. In addition, many simulations require thinning and generalisation of detailed geodata resulting in models at lower level of detail. The GI science challenge here is firstly how to specify and accommodate (create, manage, align) different levels of detail and different accuracy levels for the same reality for different needs. Another challenge is how to model data quality and how to prevent that the realism experience of DTs is more valued than the data quality (see Section 2.6 Data sharing and interoperability). An illustrative example from the GI domain is the smoothing of hooked contour lines that are generated from individual observation points. The smoothing makes the contour lines look more real, however they are farther away from the original observation points. Therefore, from a GI science point of view, the hooked lines are preferred in geodata analysis.

2.6 Data sharing and interoperability

Since the basic principle of a DT is to get an integrated, real-time view of reality, sharing data across organisations and domain silos is crucial and this is still a challenge. This becomes even more challenging if more data and simulation models need to be shared, integrated and synchronised. For this we need practice-proof standards that are not only applicable in our own GI domain, but are easy to use by non-GI experts. This will allow domain experts and practitioners to access and use DT-data for their application without investing time and effort in searching for data and preparing it for their specific use. Besides those standards that enable technical interoperability, agreements need to be made on many other aspects to openly share data according to the DT-principles: security (to avoid misuse of data), privacy (to protect personal data), accountability (who is responsible for updates and dissemination of the data?), reliability (who is responsible for errors in the data?), copyright (to protect the IP of data generated by companies), governance (to align data from different organisations), finances (who will finance the key locational data underlying national and city-level DTs? Are the benefits in balance with the investments?), ethicality (to assure that the data is used appropriately) etc. The importance of GI-research on those non-technical aspects is being acknowledged, but more research is needed to cover the data-sharing and interoperability challenge of DTs in all its needs, potentials and limitations.

2.7 Practice readiness of DTs

To understand the practice-readiness of DTs it is helpful to locate the current state of the implementation of nationwide and city level DTs on the hype cycle of Gartner (see Figure 1). This graph predicts how a certain technology evolves from a promising technology when it is introduced to an accepted and implemented product that actually solves real-life problems.

The introduction of the Digital Twin concept in the GI domain some 7 to 8 years ago has caused an innovation trigger for national and city-level DTs. As mentioned above, many (mainly technical) aspects of DTs have been studied since this introduction, in projects, specific software environments, pilots etc. These studies have shown the (mainly technical) potential of location Digital Twins which has led to high, and often inflated (not realistic) expectations. Therefore the concept of national and city-level DTs can be placed somewhere between the Innovation trigger and the Peak of Inflated Expectations. In some cases the concept can be placed between the Peak of Inflated Expectations and the Trough of Disillusionment, where implementations of DT concept in practice have raised awareness about both the technical and non-technical limitations of DTs in solving real-world problems. The real proof of the pudding is when implementing the DT concept to solve real-world problems not only for one area or one moment in time or within one project, but as a sustainable solution covering the issues mentioned above and within the budgets that are available for the implementation. A sustainable DT infrastructure requires investments in infrastructure, coordination within and between governments and sectors. How to align all these aspects to realise a DT-implementation in all its facets that does not only look promising, but is realistic to implement and actually helps to face global challenges also involving citizens.

More exemplars are required that convert results and insights from pilots into feasible DT implementations to understand how fundamental GI science challenges, as described in this section, can be addressed in order to implement the full concept of DTs in practice (i.e. as platform and infrastructure) to reach the Plateau of Productivity to solve real-world problems within available budgets and within organisational and institutional structures.

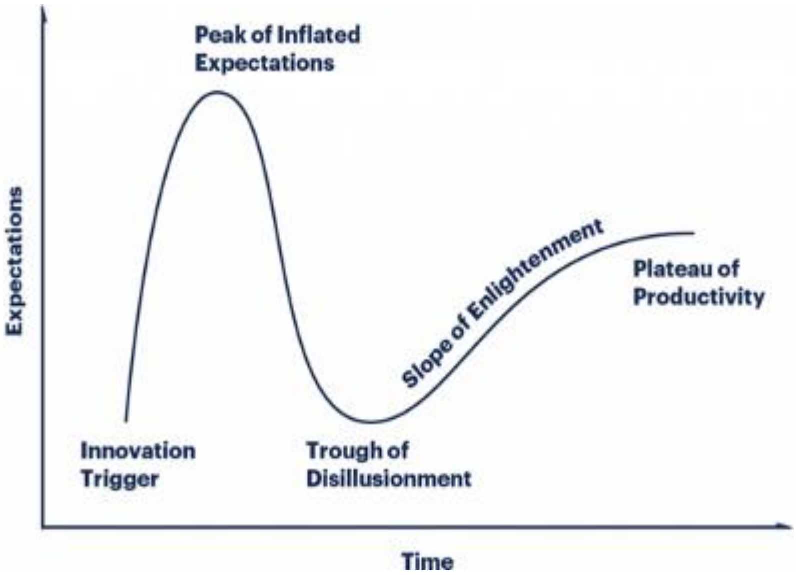

Figure 1: The hype cycle of Gartner[1].

3 Key Challenges

3.1 The (difficult) Digital Transformation of the Digital Twin (DT²)

Bart De Lathouwer

Digital Twins were introduced in 2002 by the community of manufacturing engineers for product life-cycle management. A digital twin is focused on a specific intended or actual product, system or process.

In an urban context, three types of reality must be considered: physical reality, social reality and digital reality. Paradigms already exist to study the links between these realities as illustrated on Figure 2. The Urban Digital Twin should be a triple and connect all these realities together.

Urban Digital Twins are made up of the sum of many (Urban) Digital Twins, in a distributed and decentralised fashion. Each of the twins have their own area of focus: either community, topic or physical area.

Today, still too much focus is on the traditional and smart city - whilst our lives are mostly affected by the changes in the Social and Digital Reality (social media is well known, but also AI, AR/VR, Web3 will have a large impact on our daily lives). From a legislative perspective, until recently, was between social and physical reality. The EU recently started to come with legislation (and guidance) for the digital reality.

[1] Image sourced from: Jeremykemp at English Wikipedia (see https://commons.wikimedia.org/wiki/File:Gartner_Hype_Cycle.svg)

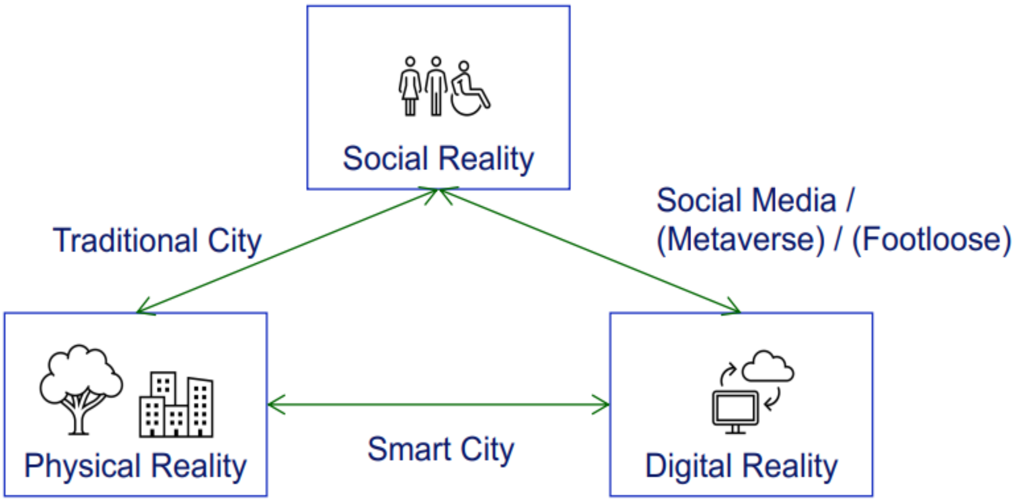

Figure 2: The Urban Digital Twin is a Triple © van der Heijden / deLathouwer.

An important milestone to achieving the Urban Digital Twin is to improve general awareness that digital is not solely an instrument but is part of the reality. This is an on-going process with debates regarding the ownership and governance of platforms that play a critical part in urban processes. National Mapping Agencies are needed to promote Open Urban Platforms that can be shared by public and private actors. Such Open Urban Platforms represent a more adapted solution than all private platforms or all public platforms.

National Mapping Agencies have managed (for many years) the foundational content for the digital representation of the physical reality, traditionally in 2D, but more and more in 3D to provide for the game-like experience that the user will be expecting (on accurate and recent data). Additionally, they also play a role in the ethical use of that digital representation in combination with the real-time feedback from the physical city (aka the smart city). Furthermore, the National Mapping Agencies are at the top of their technological game and are the guardians of an interoperable Digital Twin. NMAs have vast experience in achieving interoperability through the use of international Open Standards and are looked upon to provide technological leadership in their implementation.

The recent Digital Acts from the EU provide a first framework, to have the Urban Digital Twin (aka *citiverse*) according to European public values.

The Urban Digital Twin must be made and managed and benefitted from by both the private and public sector, academic community and especially the citizens themselves. We have seen what happens when the private sector directs social media (for almost exclusive commercial benefits, where the citizen is the product), and also where the public sector directs the urban triple (big brother like behaviour). An Urban Digital Twin, according to the European public values, benefits all; the NMAs sit on the board of the ethical committee that manages the multiple Urban Digital Twins.

3.2 Data Quality and Nationwide Digital Twins

Bénédicte Bucher

Quality management is crucial for legally mandated authorities to produce data that can ground trust and decision. Quality is defined by the International Standardisation Organisation as "the degree to which a set of inherent characteristics of an object fulfils requirements". There are inherent characteristics of geodata that are usually used as criteria to express application requirements across the many applications that use geodata. Hence, quality assessment implies producers who document inherent characteristics and users who translate application requirements through these characteristics. In that context, geodata quality has been addressed for decades by two complementary approaches:

1) the study of application-oriented requirements, also known as external quality, and
2) the identification of inherent characteristics which contribute to assess fitness for use, also known as intrinsic quality, and the documentation of these characteristics in metadata.

These complementary approaches can also be adopted to think about data quality in the context of nationwide Digital Twins. Hereafter are three messages related to data quality for nationwide DT that expands upon the literature on geodata quality and upon on-going discussions and experiences related to nation-wide digital twins within EuroSDR network.

Fitness for supporting ecological transition

Countries that engage in ambitious nationwide programs, for example the UK, The Netherlands, Sweden, Switzerland, Germany, France, share a similar usage of national Digital Twins. This frequently includes the need to equip their country with - taking the example of France - a solution for ecological transition. In the Swiss case there is a broader focus on the general welfare of the nation and the population. Such a solution is not machines telling us what to do with our country, our cities, our public spaces. Nation-wide Digital Twins are rather, as the Center for Digital Built Britain puts it, a solution to support our societies describing the future they want and deciding what impact they want to have towards this future. They should support debate, dialogue, decision, across disciplines, across stakeholders, across countries too.

To get some clues with regard to data requirements, we can look at what we are already doing with geodata to describe a desirable future, and to assist societies in having the right impact towards this future. The United Nations 2030 Agenda, with seventeen Sustainable Development Goals (SDGs), has engaged mapping agencies and statistical surveys worldwide to define the core geospatial information required to produce comparable enough indicators to monitor progress towards the 17 SDGs. Indicators should also support cross domain analysis, i.e. studying the interdependencies between the targets across the 17 goals and using data to better understand the world we are describing and the complexity of sustainability. This is why the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) experience is fruitful for learning quality criteria for nationwide digital twins. These quality criteria enable the capacity of the nation-wide DT to support:

- integration between different domains of data to embrace the complexity of our world,
- connection between multiple scales to reflect the different scales of decisions and of impacts (until the global scale of climate change),
- comparability across places, to support learning and benchmarking across these places.

Time consistency

The inherent characteristics of geodata used for analysing fitness for use in most applications are: specifications (when available), precision, accuracy, consistency, completeness. These characteristics usually are analysed through three dimensions: spatial referencing (planimetric and altimetric), time (update frequency), and theme (also called semantics). Among these, a key dimension for supporting ecological transition is time. The DT should support the user going back in time to grab hidden dynamics, like soil pollution by former industries. It should support the user going 10, 50 or 100 years in the future and exploring the different Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) scenarios for climate change. At a data level, it means interconnecting data from archives with current data and with simulation data, despite current silos.

(Let's get friends with) Metadata

Metadata are essential to document quality. Accessible metadata, like these on catalogue services, support rough quality assessment at the level of data product. Richer metadata that are relevant to support deeper quality assessment also exist, but they are not usable enough. These are published on web portals in the form of pdf documentation, usually in local language, and various ad hoc files to document production processes. They are not much usable outside a limited group of data specialists.

A key task is to bring more light on metadata, in order to improve their effective value. Metadata are so-to-say a boring topic left to a bunch of specialists. Improving their visibility and value requires establishing a stronger connection between data and metadata so that data users systematically become metadata users too, and possibly metadata producers themselves. A standard for data users to become metadata producers already exists: the Geospatial User Feedback (GUF) standard of the Open Geospatial Consortium (OGC). The GUF standard can be an opportunity to connect together the different experts who process data into nation-wide Digital Twins to consolidate their expertise related to data quality and usability.

3.3 Standards for Digital Twins

Per-Ola Olsson

This section discusses considerations when developing standards – which could also be called information models, or specifications – and gives a short summary of some experiences from a Swedish project where national specifications for 3D city models were developed with the aim to support digital twins.

To create digital twins it is important to have standards that facilitate storage and retrieval of data from different sources to be used within a wide range of applications. There are open standards for semantic 3D city models such as CityGML and CityJSON that can be used to facilitate the creation of digital twins. In the recently released CityGML version 3.0, modules have been added for better support of versioning and time-series data (such as data from sensors). Furthermore, the standards can be extended (e.g. CityGML Application Domain Extension; ADE) to support different applications or to create national profiles of the standard.

A main consideration when creating a standard for a digital twin is what to include.

One extreme approach would be to develop a standard that includes "everything" that is needed for a digital twin (Figure 3). That would result in a standard that is semantically very rich and it will probably be near to impossible to implement tools for the standard; there is already limited support to CityGML and ADEs. In addition, to maintain the data stored in e.g. a database to keep it up-to-date would be a major challenge since cities are dynamic with constant changes and flow of data.

Figure 3: Illustrating a semantically rich standard for 3D city models that includes everything.

Another extreme would be to exclude (almost) all semantics and only include geometries with metadata about data collection and accuracy and a unique ID in the standard (Figure 4). Instead the semantics could be stored in external databases and/or operational systems and linked to the objects in the digital twin via the unique IDs. That way the data could be stored and maintained closer to the source, e.g. at the traffic office or park management, but it would also require an efficient way of connecting to external sources and linking data.

Figure 4: Illustrating a semantically thin standard where objects in the 3D city model have unique IDs that are used to link to external databases and/or operational systems where data are stored.

One example of a national profile of CityGML, that in longer term will support the creation of digital twins, is the new Swedish specification for 3D city models called 3CIM [Uggla et al. 2023]. 3CIM was developed by the three largest cities (Stockholm, Gothenburg and Malmö) together with Lund University. In the project it was decided to develop a semantically thin specification and link the data in the city model to external sources and operating systems via external references in CityGML. The development of 3CIM was done in an iterative process: A version of the standard was developed in a series of workshops. Then test data was created and practical tests performed. The focus of the tests was simulations from an urban planning perspective (noise, daylight, flood) to see how well such simulations were supported by 3CIM. With a strong support of simulations, urban planners etc. can spend their time on analyses rather than searching for and converting data to required formats.

3.4 Geospatial Data Engineering for Digital Twins - A call to Action

Claire Ellul

Digital Twins are realistic digital representation of physical objects and are differentiated from traditional models by the live connection between the digital and the physical worlds, often enabled by sensors [Ellul et al. 2022]. They provide insights into the physical world for decision makers, for example via simulation, and can be used to directly alter the physical world without manual intervention. While they have their origins in manufacturing, they are increasingly being used within the built environment, by both public and private sectors. Increasingly city-wide and National Digital Twins are also being considered, to underpin local, municipal and central government decision making (ibid).

Data is a fundamental component of such Twins – and sources can include sensors (e.g. photogrammetry, lidar, remote sensing, but also traffic, transport tickets, air quality), 3D models (city models, Building Information Modelling), demographics and statistical data and much more. There is a many:many relationship between Digital Twins and data sources – i.e. data sources are reused again and again in multiple Twins.

A second key component of a Digital Twin is data science – the analytical component of the Twin that takes the incoming data and turns it into information for decision makers. Increasingly this involves machine learning and artificial intelligence.

However, there is a problem – a shortage of data scientists! This shortage is made much worse as around 50% of a data scientist's time is spent doing data engineering – finding, obtaining access to, formatting and structuring incoming data to a point where they can use it for analysis. More formally, data engineering is defined as – "the movement, manipulation and management of data" (Lewis Gavin).

Two changes are needed to make this vision a reality:

(1) Data engineering is not new – we've had spatial data infrastructures for many years now. However, very little attention is paid (or funding allocated) to this aspect of Digital Twins. To enable future Twins, **we need to prioritise and re-focus Digital Twin efforts away from AI and machine learning.**

(2) **We also need to take a 'geospatial first' approach to data engineering** – at the moment, searching for data is text based so you can't find related data for the same location easily, interoperability involves joining text fields rather than spatial joins which are often the only option, and we are not taking advantage of our expertise natural map-based aggregation ('generalisation') to build connected Digital Twins at regional and national scale.

Using a **geospatial data engineering approach** is particularly powerful given that most city and national data can be associated with a map location at some level of granularity (either directly or indirectly). Next steps involve further investigation into whether this concept will reduce the 50% time wasted and **free our data scientists to do data science**.

3.5 *Digital Twin Hype: Threat or Opportunity for PMAs?*

Prof. Roland Billen, Imane Jeddoub, Dr. Hadrien Macq

Very ambitious Digital Twins programs, as nation-wide Digital Twins, strongly impact organisations that produce, control or distribute geographic information. Currently, reference national geo-data somehow interconnects different ad hoc geo-data products, all particularly across urban areas where many ad hoc geo-data products co-exist. These products can be provided from different publicly mandated authorities (national, regional, city) and from private companies. In the past years, there were attempts to specify standardised real-time 3D models for DT with no satisfying articulation of publicly mandated authorities and private companies (Figure 5).

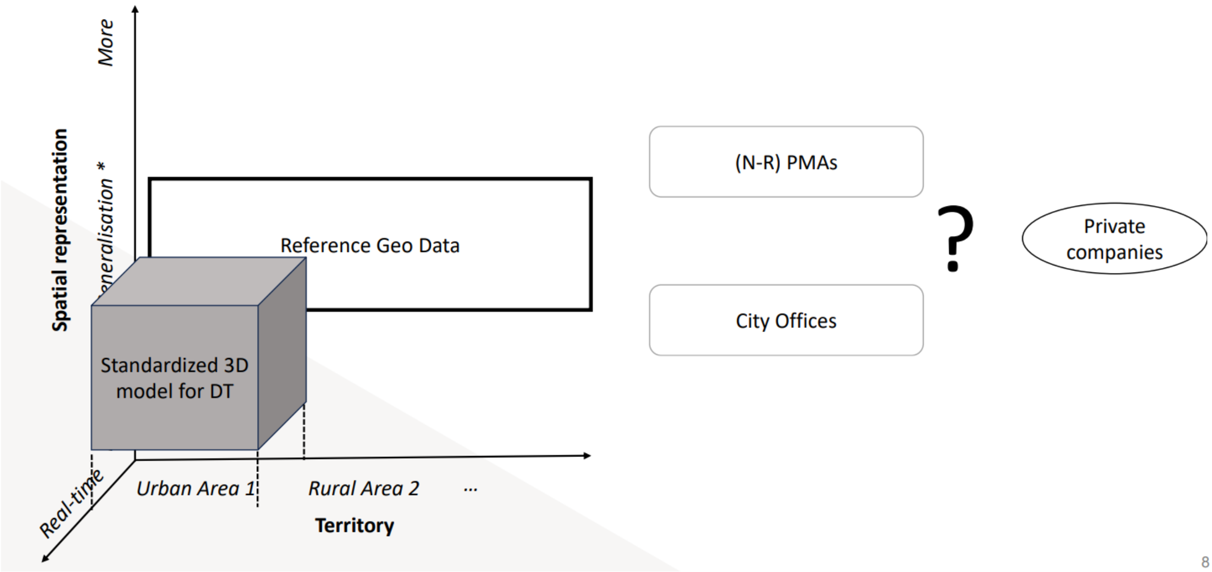

Figure 5: DT core 3D model's requirements © Billen.

Three main trends (Figure 6) can be identified and discussed considering their impacts.

(1) **"Keep it as usual"**: publicly mandated national and regional authorities adapt their production to fulfil DT requirements with no major change regarding articulation of publicly mandated authorities and private companies. Yet there is a risk not to meet applications.

(2) **"Promoting City Level"**: city DT are handled at the city level closer to the application and usage. The risk is to lack resources and competencies and consequently to lose public sovereignty and mastery on sensible data and processes.

(3) **"Reshaping Publicly Mandated Authorities (PMA) roles"**: to strengthen the articulation between publicly mandated authorities (national, regional, city). This is not a merely technical challenge but also a socio-technical challenge. Such an approach could keep a good balance with private partners and ensure public sovereignty and mastery of data and processes. However, it requires going against public operators' resistance to change and could raise political and governance issues. It could be the best schema to include Citizens in the whole process.

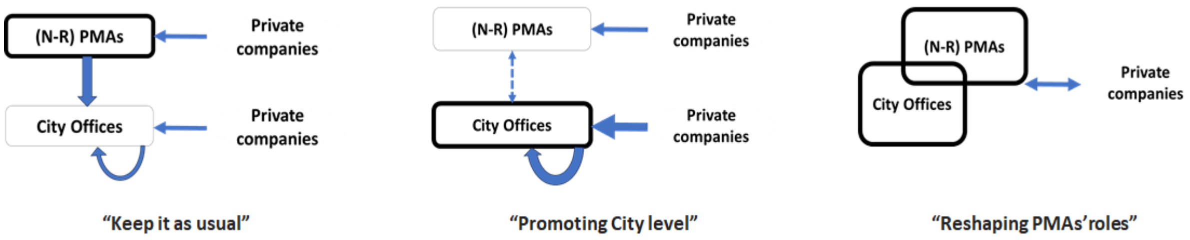

Figure 6: Data flow and Articulation between PMA and private companies in the three main approaches © Billen.

A partnership to investigate and prototype a digital twin of Liege was launched in 2022 between the City of Liège, the Liège University, the Liège Economic Redeployment Group (GRE-Liège) and Public Land Development Office (SPI, https://www.spi.be/). Different projects cover IT aspects of City DTs [Nys and Billen 2022] and acquisition of 3D semantic objects (SEM3D project - Digital Wallonia). The strategy is to achieve proof of concept to raise awareness among stakeholders as well as activate the various public partners. Interesting feedback from this partnership is the difficulty to prototype the third approach of reshaping PMA roles without firstly promoting the city level and addressing the governance issues.

4 Break out sessions

This section reports the findings of the workshop hands-on exercise, that builds on the aim of the workshop as a whole – i.e. to map GI Science activity to City and National Digital Twins activity, and find synergies and where GI Science can contribute to furthering Digital Twins.

The first part identifies key components for national Digital Twins. The second part identifies existing contributions and pending challenges for these key components.

4.1 Part 1: Distinguishing National DT Components

As there is no agreed definition of a national Digital Twin, the first part of the hands-on session involved asking participants to answer the following question:

> *Thinking specifically about city and national DT, what are the technical and non-technical components that make up a DT?*

This open question means that participants could both take advantage of their own knowledge, interests and expertise as GI Scientists and also build on what they learned during the two keynotes and the four mini-talks preceding this session; the topics of the mini-talks were selected to cover a wide range of aspects of Digital Twins to plant some seeds for this exercise.

Figure 7 shows a word cloud of the answers to this question. There were 99 separate responses in total, although one user typed 8 values into a single response. Additionally, some overlap is to be expected. as the results were visible on screen while participants were still typing answers.

Figure 7: Word Cloud of Answers to 'technical and non-technical components of a Digital Twin'.

These answers already allow us to identify different domains in GI Science that can contribute to city level and national DTs: 3D (3D models, virtual reality, 3D), SDI (governance, ownership, reference data, up to date data, interoperability, standards, data integration, system architecture, metadata, up to date data, workflow, management, public), Ethics (diversity & inclusion, public values, data ethics, citizen expectations), Users/application (users/target group, education, people, citizen expectations, privacy), Simulation/models.

Eight higher scoring components can be extracted from this survey, as shown numerically in Table 1. Similar terminology – '3D model', '3D data model', '3D city model' and '3D city models' was not grouped in the word cloud but has been grouped in the table.

Component	Number of Responses
3D city models	9
Standards	7
Data ethics	4
Simulation	4
Interoperability	3
Citizen expectations	3
Metadata	3
People	3

Table 1: High Scoring DT Components.

4.2 Part 2: Identifying Contributions and Pending Challenges for these Components

For the second part of the hands-on session, participants were asked to form groups and, taking the national DT components from the first part, identify where their research could contribute and what challenges or additional research was needed to enable this contribution.

A total of three groups were formed, with around 6 participants in each. Perhaps reflecting the range of interests, academic career stage and expertise in the room, one of the groups (group 1) focussed on specific Digital Twin applications, a second (group 2) on specific research activities and a third group (group 3) on mapping their activities to a subset of 3 components. Images of the groups' note sheets, along with transcriptions, can be found in Appendices 1, 2 and 3.

Group 1: Opportunities and challenge with regard to specific DT applications

This group consisted of a mix of representatives from industry with fewer academics/researchers in the group. Reflecting the wide range of expertise in the group, the answer to ***'How can GI Science Contribute'*** was therefore on the wider possibilities of contribution to specific Digital Twins from geospatial science, including hyper-local carbon modelling, aeronautical mapping and a Digital Twin of the atmosphere, Extended Reality (XR) modelling and a Digital Twin of a forest. Opportunities including modelling - e.g. of urban morphology, but were mostly focussed on the benefits of the end user of the Digital Twin, which included public engagement, making air travel safer, more comfortable and more economical, passenger engagement when in flight and simulating the future state of a forest. Higher level/more general benefits included the opportunity to show the relevance of the GI Science community to other disciplines/educate them in GI Science, as well as improved decision making, and the options for engagement with non-experts and the public.

In terms of **challenges**, the need for detailed data - including 3D - was identified along with a more general data management challenge. Privacy issues, data quality/currency and bias and lack of standards were also mentioned. Impact - what qualifies as a 'better decision' and the need for a better understanding of the end users of the Twin were discussed, and challenges to fund this research are also considered a barrier.

Group 2: Opportunities and challenges with regard to specific research activities

Group 2 was mainly composed of scientists, early career or senior, and consultants. Participants mapped their current research to one or more components from the word cloud. There was no attempt to be exhaustive but rather to speak from actual and current activities of the participants. Altogether seven components were addressed.

(1) Up-to-date data:

- Some contribution: research on continuous integration of data from multiple sources.
- Some pending challenges: define more precisely "up-to-date-ness".

(2) (Data) integration:

- Some contribution: research on automated data integration, research and activities on alignment of context specific models.
- Some pending challenges: to engage very specialised people to discuss together (either to compare the benefits of different technologies or to align their different specific models and make sure that terminology/language is aligned), to improve the actual usage of available data even if it implies integration workload -instead of producing new ones-.

(3) DT standards:

- Some contribution: to apply and evaluate standards, for subsoil for example, to design mediation solution to hide the complexity of standards.
- Some pending challenges: to maintain the extensibility of standards and ensure the openness.

(4) Citizens' expectations:

- Some pending challenges: developing inclusive solutions that are adapted to different contexts, incl. countries with no National Mapping Agency, that are adapted to different profiles and social groups.

(5) Education:

- Some contribution: bringing clarity to the DT domain, encouraging the use of these new terms with a critical perspective (this very workshop), use a representation of places (geodata incl. old maps, design and gaming tools) for education in geography, in climate change, in sustainable development, architecture and urban planning.
- Some pending challenges: the scalability and reaching consensus on the definition of DT with a larger group of people working on Education.

(6) People:

- Some contributions: engagement in Open Science where scientists are asked to connect with other disciplines, to connect with stakeholders.
- Some pending challenges: to elicit people's requirements for a national DT in their daily work and task as it can be disruptive.

(7) Metadata:

- Some contributions: to encourage users producing metadata through GUF statements, to make data products detailed documentation more legible and browsable to interpret the DT.
- Some pending challenges: to reach a critical mass of GUF producers, to engage the industry in the exploitation of metadata (incl. detailed product documentation).

Group 3: Linking City-level and national DT with GI Science topics

This group also considered the specific activities of the participants. These are: Semantic integration/visualisation of data, visualisation workflow and reproducibility, governance of open data, data ethics, costs & benefits analysis, privacy of mobility data, open data, data processing, digital twins for strategic planning.

They then defined 3 high level DT components and identified related contributions and challenges.

(1) Theory/research - *implementation gap and progression:*

- Some contributions: help with integrating tools, develop good business cases and case studies for municipalities.
- Some challenges: building trust, silos/collaboration between municipalities, developing a common language, secure funding, capacity building, create a sense of urgency, provide understanding to practitioners.

(2) Citizen expectations:

- Some contributions: visualisation, envisioning probable scenarios, real citizens engagement and empowerment, digital inclusion, explainable transparency, representative models.
- Some challenges: summarise expectations, manage expectations, build trust and be open about uncertainty, capacity building, inclusive samples, communicating in understandable manner for citizens.

(3) Data integration and interoperability:

- Some contributions: semantic integration and visualisation helps with having an idea of consequences, data community, data vault, citizen chose where to place their data, provide access to processed data.
- Some challenges: build trust, transparency, data ownership, level of aggregation, privacy and ethics.

5 Conclusion

This workshop was an opportunity to state the relevance of the concept of city-level and national Digital Twin as a distinct concept from the classical DT stemming from the manufacturing community. This concept emerges from the need to better use data to inform decisions related to territories in a fast-changing world facing climate change consequences. When detailing this concept and identifying its components, we state a strong connection between different subdomains of GI Science and this concept. There is also a need to engage with more disciplines beyond GI. This is needed to represent not only physical reality but also society as well as the digital world itself, to tackle the simulation capacity of such DT, to better communicate with citizens and practitioners. Last but not least, National Mapping Agencies have a part to play in this domain, as a reference actor to articulate different publicly mandated authorities and to articulate private sector platform with state platforms.

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Appendix 1 – Raw Data from Group 1

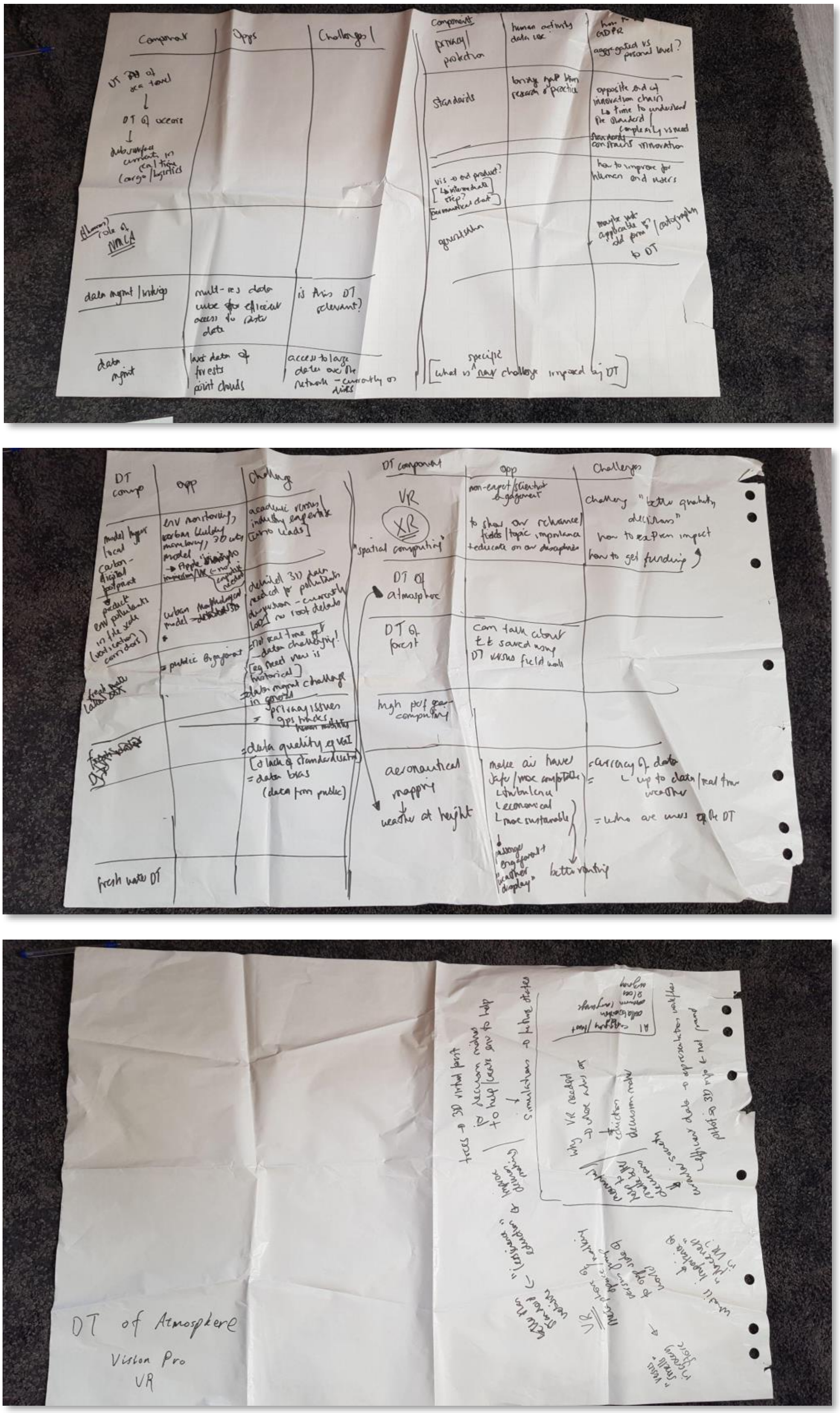

Figure 8: Raw Data from Group 1.

DT Application	**Opportunity / How Can Geospatial Science Contribute**	**Challenge**
Hyper local carbon modelling to predict environmental pollutants	- Environmental monitoring - Urban building monitoring - 3D city models - VR - Urban morphological modelling - Public engagement	- Academic versus industry expertise/who leads - Detailed 3D data needed for pollutant dispersion – however only LoD1 is available, no roof details - Not year real time – the data is challenging – e.g. google street view is historical - Data management challenge - Privacy issues of GPS tracks - Data quality and bias e.g. of VGI - Lack of standards
Aeronautical mapping – weather at height (DT of the atmosphere)	- Make air travel safer and more comfortable in terms of turbulence, economical costs, more sustainable, better routing - Passenger engagement via "weather display" through a flight	- Currency of data – need up to date/real time weather - Who are the users of the Digital Twin
Extended Reality modelling and "spatial computing"	- Non-expert /scientist engagement - To show our relevance / fields/ topic importance and educate on our disciplines - Better decision making - Reality – e.g. smells – versus the opportunity to virtually shop on the other side of the world	- Challenging "better quality decisions" – how to express impact - How to get funding for this research - Why is VR needed - What is "placeness" in a VR environment
DT of a forest	- 3D virtual forest for decision making - Simulations for future states of the forest - Saving money due to simulation rather than field visits	-

Table 2: Raw data from group 1 extracted in a table.

Appendix 2 - Raw Data from Group 2

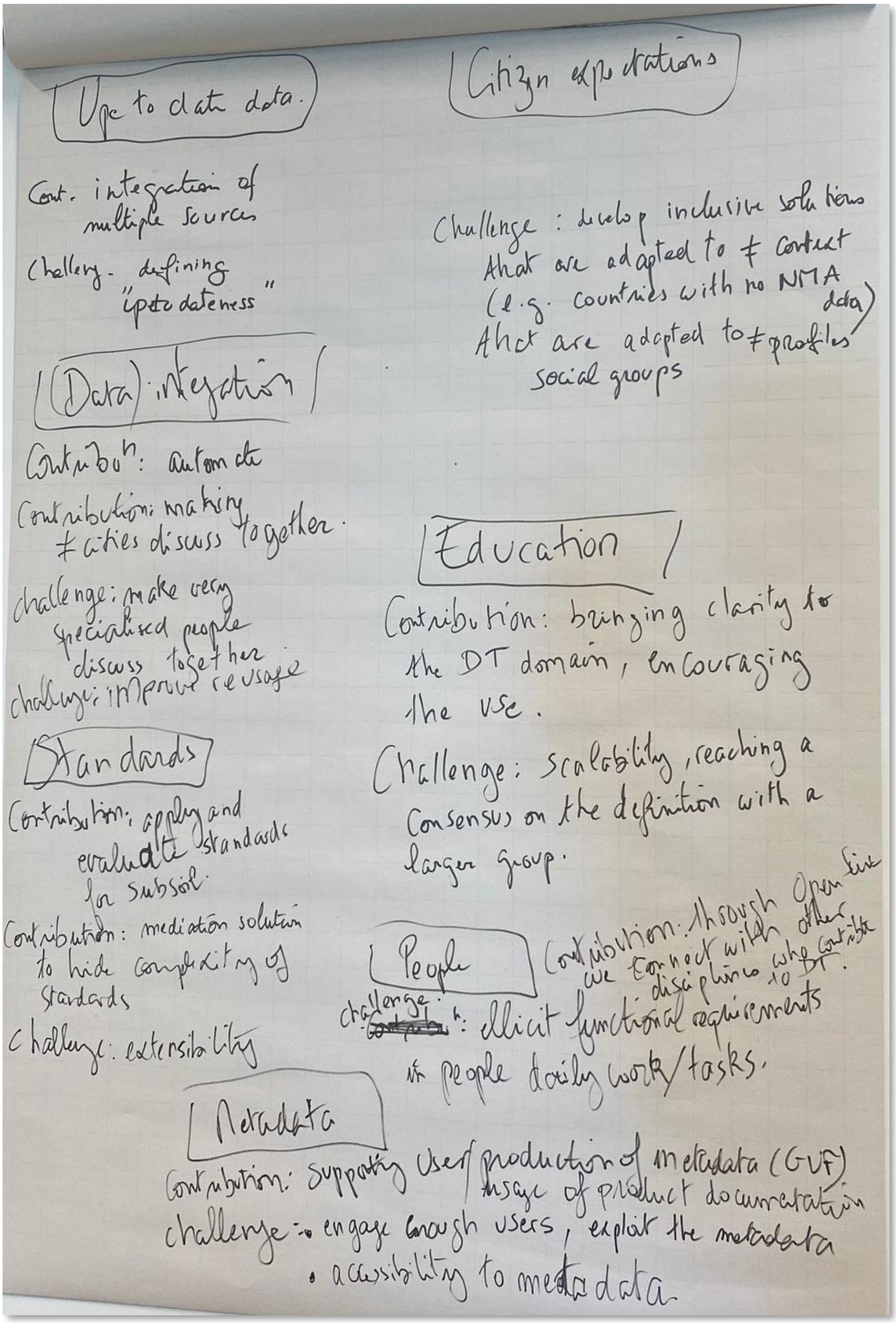

Figure 9: Raw Data from Group 2.

DT Requirement	Opportunity / How Can Geospatial Science Contribute	Challenge
Up to date data	- Continuous integration of multiple sources	- Defining “updatedness”
Data Integration	- Automation - Making different cities discuss together	- Making very specialise people discuss together
Standards	- Apply an evaluate standards e.g. for sub soil - Mediation solution to hide complexity of standards	- Extensibility
Citizen Expectation		- Develop inclusive solutions that are adapted to unequal contexts – e.g. countries with no NMA, different datasets or unequal profiles/social groups
Education	- Bringing clarity to the DT domain, encouraging the MSc	- Scalability, reaching a consensus on the definition with a larger group
People	- Open source to connect with other disciplines who contribute to DT	- Elicit functional requirements for people’s daily work/tasks
Metadata	- Supporting user production of metadata - Usage of product documentation	- Engage enough users - Exploit the metadata - Accessibility to metadata

Table 3: Raw data from group 2 extracted in a table.

Appendix 3 - Raw Data from Group 3

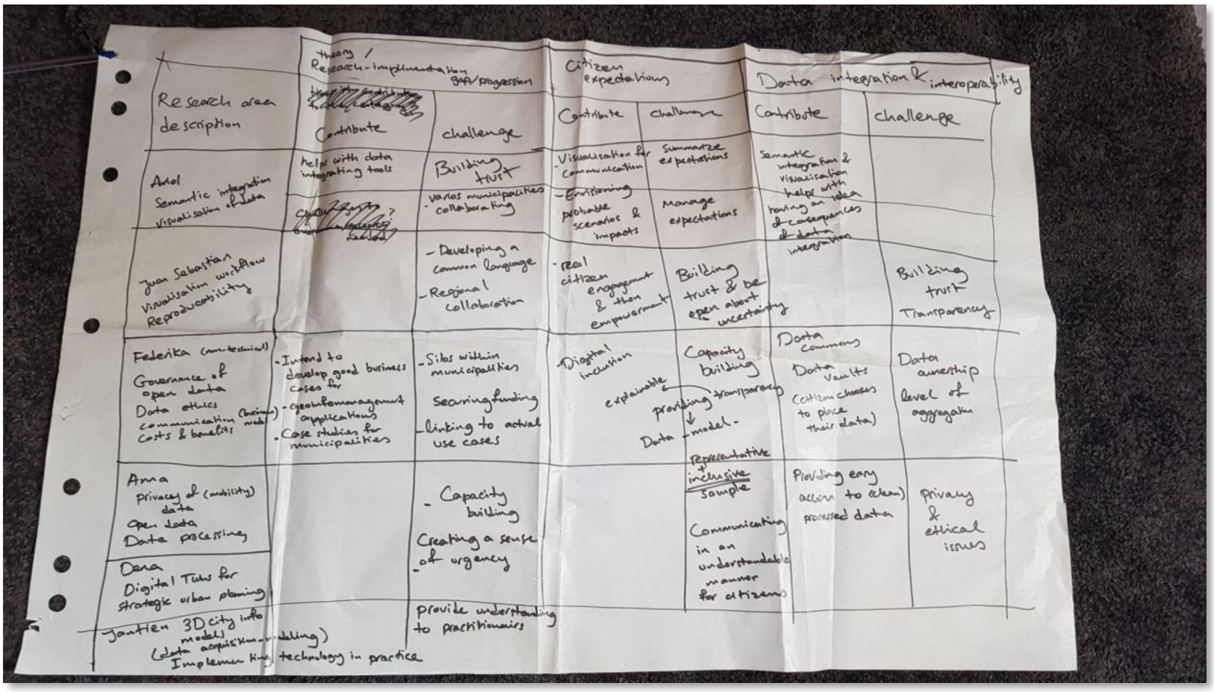

Figure 10: Raw Data from Group 3.

Specific activity of the participant	**Digital Twin High level component**	**How the activity contribute to the component**	**Challenge**
Semantic integration/visualisation of data	Theoretical Approaches	- Help with data integrating tools	- Building trust - Collaboration between municipalities
Visualisation workflow reproducibility		-	- Developing a common language - Regional collaboration

Specific activity of the participant	**Digital Twin High level component**	**How the activity contribute to the component**	**Challenge**
Governance of open data, data ethics, business models		- Develop good business cases for geoinformation management applications, - Case studies for municipalities	- Silos within municipalities - Securing funding - Linking to active use cases
Privacy of mobility data, open data, data processing		-	- Capacity building - Creating a sense of urgency
Digital Twins for strategic urban planning		-	- Provide understanding to practitioners
Semantic integration/visualisation of data	Data Integration and Interoperability	- Semantic integration and visualisation helps with having an idea of consequences and data integration	-
Visualisation workflow reproducibility		-	-
Governance of open data, data ethics, business models		-	- Building trust - Transparency
Privacy of mobility data, open data, data processing		- Data community - Data vaults - Citizen choses where to place their data	- Data ownership - Level of aggregation

Specific activity of the participant	**Digital Twin High level component**	**How the activity contribute to the component**	**Challenge**
Digital Twins for strategic urban planning		- Providing easy access to (clean) processed data	- Privacy and ethical issues
Semantic integration/visualisation of data	Citizen Expectations	- Visualisation form communication	- Summarise expectations
Visualisation workflow reproducibility		- Envisioning probable scenarios and impacts	- Manage expectations
Governance of open data, data ethics, business models		- - Real citizen engagement and then empowerment	- Building trust and being open about uncertainty
Privacy of mobility data, open data, data processing		- Digital inclusion - Explainable transparency - Representative data models	- Capacity Building - Providing transparency - Representative data models and inclusive samples
Digital Twins for strategic urban planning		-	- Communicating in an understandable manner for citizens

Table 4: Raw data from group 3 extracted in a table.