# LOCATION-ENABLED DIGITAL TWINS - UNDERSTANDING THE ROLE OF NMCAS IN A EUROPEAN CONTEXT

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**ABSTRACT:**

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. 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. For these emerging Digital Twins, location data such as that provided by National Mapping and Cadastral Agencies (NMCAs) has the potential to underpin Digital Twin modelling. It thus becomes important for NMCAs to better understand Digital Twins in order to determine whether current data offerings can meet this new demand and how best to support the various activities. As a first stage investigation under the auspices of EuroSDR, this paper explores challenges and opportunities for NMCAs and others working in the location sector, presenting the result of an international survey and workshop on these topics. We conclude that there is significant overlap with existing challenges within the geospatial community and those required to better support Digital Twins - e.g. interoperability and data management and governance. Additionally, the opportunity for a broader understanding and uptake of location data offered by Digital Twins should not be ignored.

## 1. INTRODUCTION

Digital Twins (DT) are realistic digital representations of physical things (Bolton et al. 2018). Exploring this definition in more detail (Sharp 2022):

> "A digital twin is a digital representation of an observable element with a means to enable a relationship between two elements; when added to controlling and human components to fulfil a function to form a cyberphysical system."

DT unlock value by enabling improved insights that support better decisions (Bolton et al. 2018). Split between manufacturing (49%) and other applications (Lamb 2019), what distinguishes a DT from a model is a direct link to a physical object (Wright and Davidson 2020, Evans, Savian et al. 2019). The Internet of Things (IoT) – physical objects that can communicate their status - and increased connectivity via Wi-Fi and 4G/5G telephony drives DTs. Big data from IoT motivates research in Artificial Intelligence (Alexopoulos, Nikolakis and Chryssolouris 2020) closing the DT loop. DT in the built environment can deliver better outcomes for the economy and society by (Sharp 2022):

- improving public sector efficiency
- driving up commercial effectiveness
- increasing productivity
- improving quality of life and public wellbeing

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The UN Committee of Experts on Global Geospatial Management notes that:[1] "everything that happens, happens somewhere over space and time," The physical objects in a DT are, in theory, mappable – i.e. can be linked to digital data that has a location component, to geospatial data that tells you where something is and when something happens. Such location data is potentially fundamental to enable, and form a framework for, the physical/digital linking of heterogeneous data within a DT.

Within the geospatial community, the concept of DT is not new - for example, we have long been able to create a two-way link between drivers' mobile devices (physical), calculation of traffic congestion (digital) and proposing a new route to avoid congestion (back to the physical), all in real time. However, although from the perspective of geospatial experts the location foundations of a DT may seem obvious, in reality there is as yet a lack of common understanding as to how location experts can best support and engage with DT initiatives.

This paper presents a first step to address this issue, reporting on the results of a survey and workshop to understand the current status, opportunities and challenges for location-enabled DT across Europe with the aim to bridge the gap between the DT as understood from formal definition and as potentially implemented in practice. The survey, conducted under the auspices of EuroSDR (see 3.2), addresses the question: 'What role should NMCA and the broader geospatial community play when engaging with current and future digital twin initiatives?'.

[1] https://www.un.org/en/development/desa/news/statistics/geospatial-information-3.html, Accessed: 23 April 2022

## 2. BACKGROUND

The concept of the use of a twin in engineering has its origins in NASA's Apollo space programme, which built two identical space vehicles so that the space vehicle on earth could mirror, simulate, and predict the conditions of the vehicle in space (Liu et al. 2021). While the term was mentioned earlier Hernández and Hernández (1997), it is widely acknowledged that the modern interpretation of the phrase 'Digital Twin' was first introduced as 'digital equivalent to a physical product' by Michael Grieves at University of Michigan in 2003 (Liu et al. 2021) in the context of manufacturing.

### 2.1 Applications of Digital Twins

Although the use of DTs seems to be flourishing in the smart manufacturing and industrial domain, their application in an urban context appears to be at a preliminary stage (Mylonas et al. 2021). Sharp (2022) cites examples including the coordination of street works, asset registration, scenario simulation, environmental management, traffic management, asset monitoring, carbon monitoring, resilience management and risk management. In the context of civil infrastructure Callcut et al. (2021) lists use cases that include anomaly detection, maintenance scheduling and predictive maintenance, emergency planning, city-level forecasting, across sectors including water, energy, rail, highways/autonomous vehicles, bridges and smart cities. Hetherington and West (2020) includes examples of applications to support retrofit of buildings. Focusing on the Smart City domain, Mylonas et al. (2021) add energy and building monitoring, urban planning, circular economy, traffic mobility and fleet management, risk mitigation and water management, pollution monitoring and healthcare.

### 2.2 Federated Digital Twins

While the DT examples listed in Section 2.1 are - at least at first glance - single domain, if the DT concept is to achieve the wider goals listed in Section 1 integration across multiple sectors and domains is fundamental. For example, Mylonas et al. (2021) note that a Smart City is a system of systems - and also mention the potential of DTs to boost the collaboration between Smart Cities. Sharp (2022) explore the concept in more detail - a DT can represent a discrete entity such as a train carriage but also connected systems - such as a tram service and will include the interfaces that enable human understanding of the twinned assets such as train timetables (Sharp 2022). At a more urban scale, Hetherington and West (2020) provide an example of regional resilience and response in case of events such as flooding, mapping out the vulnerabilities of multiple systems such as power and road infrastructure as well as to population information.

Taking this one step further, the UK's Centre for Digital Built Britain (CDBB) was established to promote and develop the concept of a National Digital Twin (NDT) (Bolton et al. 2018). The vision for the NDT is not that it should be one single DT of the entire built environment in the UK, but that it will be an interlinked system of DTs, a federated system[2] with data providing the anchor points and linking between the individual DTs (Bolton et al. 2018). Bolton et al. (2018) note that:

'"Not all digital twins will be connected, only where it delivers value to do so."'

[2] In this context, it is not anticipated that the federated system will be a series of identical twins

## 3. METHODOLOGY

### 3.1 Theoretical Background - Online Questionnaires

Questionnaires are applied in a wide variety of studies as a technique to collect both demographic data and user's opinions (Preece, Sharp and Rogers 2019). In contrast to interviews, they can be more rapidly distributed to a larger number of participants, increasing the data collection rate, and also giving the potential to reach those in other locations (ideal given the online nature of the EuroSDR event). The approach is also convenient - participants can complete the questionnaire survey whenever works for them, which may increase the response rate (Evans and Mathur 2005). The advantages of selecting a web-based questionnaire also the include speed and reach, ease, low-cost, flexibility and automation (Nayak and Narayan 2019).

An online questionnaire assumes that participants are interested in the topic and motivated to complete the questionnaire (Preece, Sharp and Rogers 2019). Given the asynchronous nature of the interaction - i.e. there is no opportunity for participants to ask for clarification - it is important that questions are clear, and that closed questions - offering a range of answers rather than asking for open text - are used (Preece, Sharp and Rogers 2019).

### 3.2 Context

Growing interest in the concept of Digital Twins led to this topic being identified - in 2021 - as an area of potential interest to the EuroSDR community. EuroSDR is a not-for-profit organisation linking National Mapping and Cadastral Agencies (NMCAs[3]) with Research Institutes and Universities and Industry Partners in Europe, for the purpose of applied research in spatial data provision, management and delivery[4].

In order to further determine the relevance of DT to the EuroSDR and wider geospatial communities, a two-day workshop was hosted (online) focussing on Digital Twins for National Mapping Agencies [5] held on the 21st and 28th January 2022. As a preliminary to this workshop, and mirroring previous work on the EuroSDR GeoBIM project (Ellul et al. 2020), (Noardo et al. 2019) a questionnaire was circulated to participants in advance of the workshop, as part of the registration process.

### 3.3 Defining the Questions

The aim of the workshop and questionnaire was to promote understanding of DT within the geospatial community, and to provide information for NMCA and other decision makers as to the importance of DT within their existing or future work plans. Building on Ellul et al. (2020) the questionnaire focussed on developing an understanding of the current state of play for DT amongst location practitioners, targeting NMCA and others in order to gain a perspective not only of the perception within the NMCAs but also across the geospatial community served by the NMCAs, i.e. the primary users of NMCA data.

[3] NMCAs are generally publicly owned organisations responsible for recording information relating to land parcels and buildings and - in some cases - the related rights, restrictions and responsibilities (Hämäläinen and Krigsholm 2022). They also have a key role in the provision of geospatial information and increasingly act as a geospatial information broker (Crompvoets and Broucker 2015)).

[4] http://eurosdr.net/commissions, Accessed 23rd April 2022

[5] `http://www.eurosdr.net/workshops/digital-twins-nmcas`

Topics covered in the questionnaire included: interest, expertise and implementation; relevant standards; opportunities; non-technical challenges; technical challenges; research and other initiatives[6].

Given the multiple definitions of Digital Twins (e.g. VanDer-Horn and Mahadevan (2021) identifies 46 definitions) and to generate an understanding of how respondents (with an interest in location data) understood the DT concept, an open question asking for a definition of a DT was also posed. During the workshop, participants were also asked to weight the importance of individual components of a Digital Twin (information flows, variable time scales, variable location/spatial scales, real time data, 3D data, location data, visualisation, analysis).

### 3.4 Recruitment

To generate both an 'internal to NMCA' and external perspective on DT, the target audience for the questionnaire was split into two groups: NMCA employees and others working with location data (which could include research, public sector, private sector and third sector). This allows potential differentiation of opportunities and challenges perceived within the NMCAs themselves and may also foster an understanding of the NMCA customer-base - i.e. the users of geospatial data. EuroSDR - the organisers of the workshop - has a Europe-wide focus and while it was anticipated that workshop participants may originate from outside Europe as the workshop was online, any responses provided from outside Europe are excluded for the purpose of the review presented in this initial paper.

The survey could be answered totally anonymously although participants were also informed that there was a potential to be identified indirectly e.g. if their response mentioned a job title and organisation or specific project.

### 3.5 Analysis of the Results

To identify whether there were similarities and differences between the perspectives of NMCA and other geospatial community members, all responses received were split into NMCA and other prior to processing. Mixed methods of quantitative and qualitative data processing were used to process the results. For the questions relating to expertise, interest/awareness, implementation, a count of each answer (from non-existent to very high) was taken.

For the more qualitative questions relating to opportunities, challenges (technical and non-technical) and standards the following steps were employed (adapted from Preece, Sharp and Rogers (2019)):

- Initial read-through to gain an overall impression of the data, and to identify any particularly surprising responses
- Themes (which are defined as something important about the data in relation to the overall goals of the study (Preece, Sharp and Rogers 2019) are created inductively (i.e. based on the themes emerging from the initial review, rather than any predefined themes).
- As needed (depending on the question) a third iteration of the data provides additional classifications - e.g. opportunities could be classified based on their broad type and/or to a listed application of DT.

[6] Given space restrictions in the paper it is not possible to reproduce all the questions. The questionnaire can be accessed here: `https://forms.gle/ooLuqMDURxRCYBVB9` Accessed 12th July 2022

## 4. RESULTS

### 4.1 Respondents

A total of 249 people signed up for the workshop. We received 73 responses to the pre-workshop questionnaire, sent out on sign up (i.e. approximately 30% of the registrants responded). 37 of the complete responses were from a NMCA staff, with 19 from an academic or research institution. Of the remainder, one person was a volunteer, twelve were from the private sector, one from a Local or Regional Government Organisation and two from a non-NMCA Central Government Organisation.

Of the 37 NMCA responses, three were from outside Europe (India, Rwanda and Nepal) and were excluded from the results. An additional three responses were incomplete. Thus a total of 12 countries - Estonia (1), Finland (2), France (4), Germany (3), Greece (2), Latvia(3), The Netherlands (4), Norway (3), Spain (1), Sweden (4), Switzerland (1), United Kingdom (3) are represented in the responses from the NMCA perspective.

A similar mix of countries was also identified for other sectors (which could broadly be grouped as users of geospatial information such as that generated by the NMCAs) - Belgium (4), Czechia (1), Finland (1), France (1), Germany(1), Ireland (1), Italy (2), The Netherlands (5), Slovenia (1), Spain (1) and Sweden (2), UK (1) with an additional one respondent listing multiple countries. To ensure that similar contexts were represented for the comparison between NMCA and other organisation types, all non-European responses (one from Canada, two from Japan, two from Nigeria, two from the Philippines, four from Singapore, two from the USA, two listing multiple countries outside Europe) were also removed (13 in total).

Following this, the total number of analysed responses was 31 NMCA responses from 12 countries and 22 other (15 academic or research, 5 private sector, one central government, one local or regional government) responses from 12 countries, with one multi-national representation.

### 4.2 Interest, Expertise and Implementation of Digital Twins

This question was posed as follows: 'To help us gain a clear picture of the levels of Digital Twin expertise (how much is known about the topic, could your group/department/organisation build a DT and/or advise others on this topic), interest (is there awareness, is there some activity currently or in the near future) and implementation (are you actually using DT)'. Figures 1 and 2 show the results.

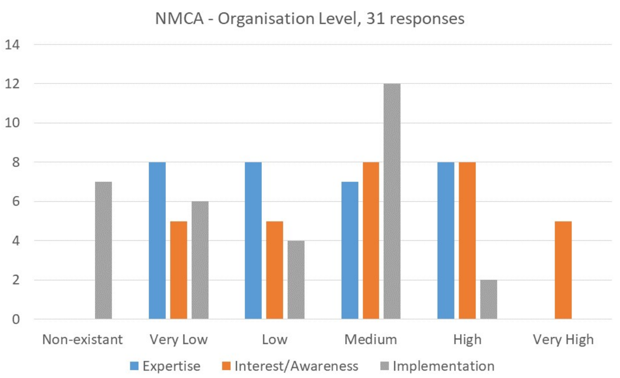


Figure 1: Levels of interest, expertise and implementation of Digital Twins - Organisational Level - NMCA Respondents

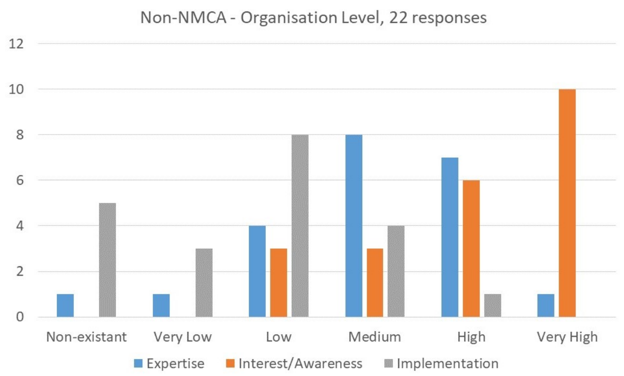


Figure 2: Levels of interest, expertise and implementation of Digital Twins - Organisation Level - Non-NMCA Respondents

Within the non-NMCA group, interest is generally very high and expertise on the topic is rated as broadly of medium level, with relatively low levels of actual implementation. For the NMCA group, expertise is also generally on the low side, but there is a generally medium level of implementation and expertise is relatively evenly distributed, although in this case no one has rated their expertise as very high.

### 4.3 Standards

Respondents were asked: 'Are there any Digital Twin-related standards that you are aware of? If so, please list them with as much detail as possible, providing links to any websites if you can and stating whether these are national or international. Type 'none' if there aren't any and 'no answer' if you are not able to answer this question.' Table 1 lists the standards mentioned by the respondents. A total of 18 NMCA and 18 non-NMCA respondents were either not able to provide a response or were not aware of any relevant standards.

| Standard | NMCA | non-NMCA |
|---|---|---|
| None (I am not aware of any relevant standards) | 8 | 5 |
| No answer (I am unable to answer this question) | 10 | 13 |
| CityGML | 5 | 2 |
| CityJSON | 2 | 3 |
| buildingSmart/IFC | 2 | 0 |

Table 1: Standards relevant to Digital Twins (note that some participants mentioned more than one standard)

**4.3.1 NMCA** Within the NMCA group, additional answers also included Linked Data, OGC (as a generic term), PWI JTCI-SC41-5 and JTCI-SC41-6 (Digital Twin and Internet of Things standards being developed by the International ElectroTechnical Commission [7] (with related ISO standards being ISO WD 30172, DT use cases and 30173, DT concepts and terminology). The UK Gemini principles (Bolton et al. 2018), the UK DT Information Management Framework (Hetherington and West 2020) and ISO TC/211 interoperability standards[8].

**4.3.2 Non-NMCA** In addition to the standards listed in Table 1, within the non-NMCA group, one participant mentioned that they are benchmarking ontologies including: BOT, geoSPARQL, SOSA, INSPIRE. Other standards mentioned by the non-NMCA participants included API Features, SensorThings, GeoJSON and BSI Flex 260. One participant noted that standards in their location were currently under development.

It was also noted by two non-NMCA participants that the standards listed do not totally fulfil the requirement for a DT. "these are not covering all the needed details for "real" digital twin" and "most standards relate to specific topics that might not be DT-specific".

### 4.4 Opportunities

Respondents were asked 'Please list any opportunities for your organisation with regard to Digital Twins. Give as much detail as possible. If you are not able to answer this question please type 'no answer'.'. A total of 41 responses were received.

**4.4.1 NMCA** Within the NMCA responses, nine were not able to give an answer. For the remainder, four responses can be categorised as 'promote the use of geospatial/NMCA data'. Seventeen respondents saw DT as an opportunity to provide data, with six not providing any further detail. However, 3D city models were mentioned eight times, four responses mentioned LiDAR, one mentioned orthophotos and one mentioned 4D data. Additional responses included 'increase data quality', 'conduct research' and 'contribute to European projects'.

**4.4.2 Non-NMCA** Responses from the non-NMCA group were more varied: while three respondents did not answer the question, eight mentioned research projects and two mentioned teaching. Seven respondents focussed on the opportunity to create real world applications of DT, with two mentioning opportunities for business development. Additionally, the non-NMCA group mentioned specific DT applications, including: city DT, engineering, urban administration, green houses, life sciences, natural sciences, traffic/transport, energy efficiency, project management, farms, water management, built environment, green infrastructure, telecommunications, mission planning, flight simulation,

### 4.5 Challenges - Non Technical

Figure 3 summarises the themes identified for this question.

**4.5.1 NMCA** From the NMCA perspective, **data**-related issues included legal permissions, General Data Protection Regulation issues (mentioned by two respondents); challenges with being ready for new dynamic data; the need to understand what data is required for DT; data ownership and data availability, as well as challenges that may also be technical: data availability, data interoperability and the need for up-to-date data. In terms of **lack of understanding** there was concern with regard to use cases in that potentially customers do not have the understanding required to make use of DT, and there are also issues relating to lack of internal support for developing DT within the NMCA itself. Related to this issue, it is perceived that there is a general lack of understanding of what a DT actually is, and how to get everyone involved on the same page, how to better understand requirements and communicate these to stakeholders and lack of general DT know how. The wide potential scope of DT applications may also cause problems, and there is currently a lack of example **Use Cases**. From the **financial** perspective, funding does not allow recruitment of specialist and experts, and funding may not be available to develop the required data or to generate a business model to support its collection and delivery. **Cultural** issues relate to the perception of DT as a

[7] `https://www.iec.ch/ords/f?p=103:38:515566808807571::::FSP_ORG_ID`, Accessed 23rd April 2022

[8] https://www.iso.org/committee/54904.html, Accessed 23rd April 2022

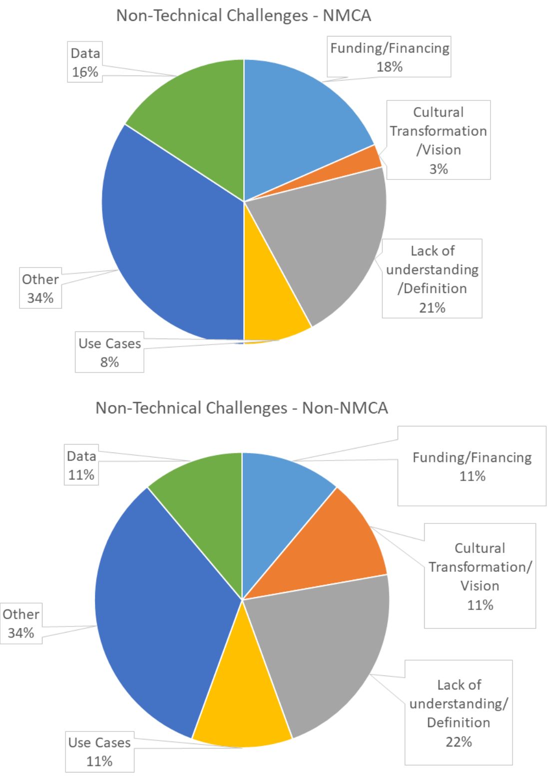


Figure 3: Non-Technical Challenges

socio-economic problem and that cultural issues are much more difficult to solve than technical issues.

**Other** answers were more broad: there is a low awareness or interest in DT, skills gaps exist, and there is a related need for capacity building; there is a perception of DT as just a new buzz word; there are challenges relating to the time spent to engage with new communities who say they 'have the solution' but don't ; the ecological footprint of DT may be significant;there is too much focus on the physical aspects of the built environment, at a cost of focus on 'non visible' aspects; DT are not priority within the organisation; there is a need to collaborate outside the NMCA - DT should not only be an NMCA responsibility; the need for a national level DT is unclear.

**4.5.2 Non-NMCA** From the Non-NMCA perspective, similarly to the NMCA group, **data** was highlighted in terms of data governance and how to determine what data to keep. **Lack of understanding** relates in particular to the overlap of terminology e.g. BIM, DT and also to the wide number of areas in which a DT can be applied. Expectation management was also highlighted. From the **Use Cases** perspective, finding end users/who need a DT and identifying what kind of services to develop for them is an issue. One respondent also suggested that we might need different classes of DT for different situations. **Financial** challenges were similar to those identified by the NMCA respondents: how to make the commercial model sustainable / how to finance a DT. **Cultural** transformation relates to how to coordinate DT activities.

**Other** responses included: how to ensure DT are used ethically, the need to think of the DT from a different perspective - i.e. the DT comes first, then the use cases rather than the other way around, and that location is pre-selected; a lack of links between different groups working on DT; the need to develop appropriate policies; the importance of identifying appropriate leadership; staffing issues and a general low priority of DT at the moment,

### 4.6 Challenges - Technical

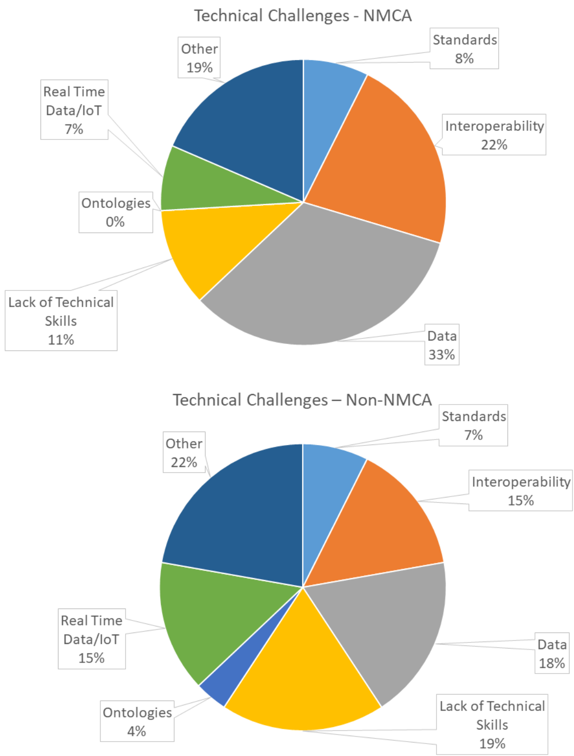


Figure 4: Technical Challenges

**4.6.1 NMCA** Exploring the responses in more detail (where this was provided), from the NMCA perspective **data** issues included data quality, lack of available 3D data. Lack of access to **real time data** was also mentioned. Technical **skills** gaps mentioned include lack of: 3D understanding, skills to work with real time data, skills needed to easily connect NMCA to other data sources; lack of skills to update the data. A need for the skills to manage the extensive data generated by DT was mentioned by two respondents. From a **standards** perspective two specific issues were mentioned - lack of interoperability between standards, and lack of specific standards for DT (or these not yet being mature enough), along with a need for simple data models for data fusion and evaluation. **Interoperability** challenges included legacy cartographic representations that are not fit for matching multiple data sources and links between management systems and the inputs/outputs of a DT.

**Other** challenges included how to design DT, how to integrate DT and other systems. Additionally, under the 'other' category respondents commented on non-technical issues - data ownership and licensing issues, collaboration with other data providers, the lack of a clear goal for DT.

**4.6.2 Non-NMCA** Generally similar responses were given by the non-NMCA group, with **data** related challenges including dealing with and with data versioning, as well as feature extraction from the data. Challenges dealing with **real time** live data such as that provided by the IoT were also mentioned. **Skills** gaps included lack of programming knowledge, lack of BIM understanding as many organisations are GIS focussed.

**Standards** issues related to challenges encountered when linking existing standards, as well as the fact that there isn't a single standard for DT. **Interoperability** challenges related to data update and versioning and **ontologies** were mentioned separately by one respondent, who noted in particular the need for specific ontologies to deal with DT solutions.

**Other** challenges included how to scale up solutions, how to visualise the data, the need to depend on existing software and solutions, and the transition to an 'analyze while you measure' approach. Again, non-technical challenges were mentioned within the 'other' category - in this case a lack of overview of the topic at organisational level, and a lack of available funding.

### 4.7 Initiatives and Research

| Project | Country | Scope |
|---|---|---|
| Digital Twin Cities, Centre, Chalmers University[9] | SE | National |
| Centre for Digtial Built Britain, University of Cambridge[10] | UK | National |
| UrbanAge Project, European Project on Cities and Healthy Aging[11] | EU | City |
| North See Digital Twin, DigiShape Data Science for Deltas Project [12] | NL | Coastal |
| 3CIM Project, Rainfall Modelling, Smart Built Environment Programme[13] | SE | National |
| Safety of Critical Water Treatment Infrastructure, Institute of Hydrodynamics[14] | CZ | National |
| National Digital Twin Infrastructure Consultation[15] | NL | National |

Table 2: Selection of Research Projects and Initiatives

Table 2 lists the key projects mentioned. The selection of responses presented here is focussed specifically on the projects where DT are explicitly mentioned. This means that projects mentioning e.g. energy monitoring in buildings, or smart cities, are not listed even though technically these are digital twins. These are city-wide or national in scope and cover both single-domain DT (e.g. rainfall) and 'twins of twins'.

### 4.8 Defining a Digital Twin

Table 3 shows the results from the thematic analysis of the responses provided in relation to defining a DT.

**4.8.1 NMCA** In addition to the main components listed in Table 3, NMCA respondents also mentioned cadastral systems, the ability to visualise the current state of a physical object, support for decision making, lowering costs and chances of failing. Visualisation was mentioned by four NMCA respondents and two respondents from the NMCA group mentioned an explicit link between digital and physical. Within the 'data' grouping, six NMCA respondents mentioned 3D specifically.

| Topic | NMCA | Non-NMCA |
|---|---|---|
| Number of Responses | 27 | 21 |
| Digital Model | 22 | 14 |
| Physical Environment | 22 | 11 |
| Data (including 3D or 4D) | 15 | 8 |
| Real Time Data | 9 | 4 |
| Simulation/Analysis | 7 | 1 |
| Applications | 5 | 2 |

Table 3: Defining a Digital Twin

Applications of DT mentioned by the NMCA group include: urban challenges such as segregation, flooding, pollution, traffic congestion, spreading of fire, disease spread but also less detailed including built environment, natural environment, cadastral systems, administrative data.

**4.8.2 Non-NMCA** Non-NMCA respondents additionally mentioned close and remote sensing, the representation of feelings within the DT. One respondent noted that DT is a "hype word for digital spatial data".

No respondents from the non-NMCA side mentioned visualisation. However, while only two respondents from the NMCA group mentioned an explicit link between digital and physical was mentioned by eight non-NMCA respondents. Five non-NMCA respondents mentioned 3D specifically. The non-NMCA group mentioned cities, land management and facilities management, smart spaces, land applications, remote monitoring of objects and environments within their definitions.

Building on the questionnaire responses, Figure 5 gives the results of the question asked during the workshop about the importance of various components within a DT. Location data, visualisation and two-way information flows have the highest priority. However, there is not a significant difference between the values for these components and the others, with the lowest value (2.9) related to the requirement to be able to manage variable time scales.

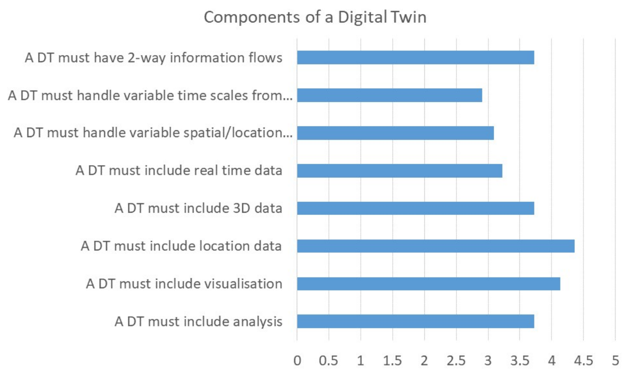


Figure 5: Importance of Digital Twin Components

## 5. DISCUSSION

The research presented in this paper addresses 'What role should NMCA and the broader geospatial community play when engaging with current and future digital twin initiatives?'. Based on the results, while a number of challenges exist - data interoperability, lack of standards, lack of technical skills, the need

[9] `https://dtcc.chalmers.se/`, Accessed 1st May 2022
[10] `https://www.cdbb.cam.ac.uk/`, Accessed 1st May 2022
[11] `https://www.urbanage.eu/digitaltwins`, Accessed 1st May 2022
[12] `https://www.digishape.nl/projecten/digitwin-noordzee`, Accessed 1st May 2022
[13] `https://www.smartbuilt.se/in-english/projects/open-call-8/3cim/`, Accessed 1st May 2022
[14] `https://www.ih.cas.cz/twin-skin-digital-twin-for-safety-of-critical-infrastructure-in-water-treatment-plants/`, Accessed 1st May 2022
[15] `https://www.geonovum.nl/over-geonovum/actueel/consultatie-digital-twin-fysieke-leefomgeving`, Accessed 1st May 2022


https://doi.org/10.5194/isprs-annals-X-4-W2-2022-53-2022 | © Author(s) 2022. CC BY 4.0 License.

for financing and for a clear definition of a DT - opportunities also abound. These include better use of 3D city models and wider uptake of data provided by an NMCA, as well as research and business development for non-NMCA respondents. The DT examples mentioned ranged from domain specific (e.g. rainfall, energy monitoring) to municipal and national DT that covers multiple topics, and while multiple definitions of a DT exist, many of these included similar components.

### 5.1 Defining a Location-Enabled Digital Twin

Respondents were asked 'The term Digital Twin means different things to different people - please provide a 1 or 2 sentence explanation of a Digital Twin in your own words'. In terms of the definitions of a DT, as could perhaps be expected most respondents mention digital and physical worlds. The definitions of a DT provided by the respondents closely match those in previous work - for example Callcut et al. (2021) provided existing definitions of a DT and ask users to agree with them; the main one selected by their respondents (53%) is "a realistic digital representation of physical assets, processes and systems". It is important to note that even though the requested definition was for a DT not a specifically 'Location-Enabled DT', location data was seen as a core component of a DT by many respondents. This is no doubt reflective of the group as a whole, given that the related event was organised by EuroSDR.

Within our survey few of the definitions mentioned specific use cases and where these were mentioned most of them were generic (e.g. environmental, urban) rather than specific applications, perhaps reflecting that a definition should not be domain specific. Although the sample size is not statistically significant, there is also a notable difference between the NMCA and Non-NMCA definitions, with the former having what might appear to be a broader focus, with more respondents including data, simulation and applications in their definition.

It is also worth noting that some respondents mentioned projects that do not explicitly call themselves Digital Twin projects - for example, the BIGG project[16] the Building Information Aggregation, Harmonization and Analytics platform specifically mentions data integration via the Internet of Things. Indeed, Mylonas et al. (2021) note that there will be a process of continued evolution of the DT concept as we develop a better understanding of it's potential, limitations and opportunities in the context of creating a city scale DT, and given this it is likely that a broader interpretation of the current definition of a DT will be required in order to ensure that, if it is beneficial to their progress and uptake, such projects can be identified as location-enabled DT even if they may not use the term.

### 5.2 Standards

Standards "offer consistency and allow markets to scale up" (Sharp 2022). However, they also take extensive effort to develop, particularly at international level (Sharp 2022). While existing standards such as CityGML were mentioned by respondents, there was general agreement that no one standard exists for DT. A number of respondents cited standards under development, but perhaps given the variety of definitions of a DT, and the range of domains covered, it may not be possible or desirable to develop a single standard in this context.

[16] `https://www.bigg-project.eu/#about`, Accessed 22nd April 2022

### 5.3 DT and the NMCA/Geospatial Community

In terms of opportunities, the NMCA group focus primarily on the potential uses of their data within a DT context. This contrasts with the non-NMCA group, who focus more directly on specific applications - e.g. urban engineering, life sciences, with applications mentioned being both urban and environmental, and at a variety of scales from local/single organisation to municipal and national. It is interesting to note that the applications listed in Section 2.1, along with those mentioned by respondents, reads like a list of geospatial applications, very familiar to those of us working in this domain.

Similarly the issues identified in Section 4.6 and Section 4.5 are not unique to a DT context but reflect the wider challenges faced by users of geospatial data. The findings also agree with previous research: (Mylonas et al. 2021), in the context of DT for Smart Cities, note that standardization, interoperability and data quality are the issues most frequently noted.

One key difference may emerge: to date, there has been relatively little attention paid within the wider geospatial community to applications involving real time, two-way links from digital to physical, although initiatives such as the OGC SensorThings API[17] show that there is increasing activity in this direction.

### 5.4 Further Work

**5.4.1 Reviewing the Questions** The overlap in responses between the responses to technical and non technical challenges indicates that the two issues cannot be clearly separated, and that addressing such challenges requires a combination of approaches. In future surveys the questions could be combined, although it could be argued that the technical and non-technical challenges would be addressed by different teams within an organisation. The answers to questions relating to existing DT projects and research are also very much dependant on the respondent's own knowledge of standards and initiatives and do not provide a full picture of DT activity across Europe. We also split the analysis of the responses into NMCA and other, but it can be anticipated that there will be significant differences in the latter group - e.g. between public and private sector organisations.

When asked to weight the importance of the various components in a DT, a prepopulated list of components was used, which may have led to the exclusion of components that respondents thought important. Additionally, a general 'analytics' term was used, whereas perhaps Machine Learning or Artificial Intelligence - often associated with DT - might have been separated out from more general location-based analytics. The open nature of some questions - while offering the opportunity to provide answers that are perhaps not foreseen by the researchers - also leads to a potential lack of consistency in the answers provided.

**5.4.2 Addressing the Challenges** Many, if not all, of the challenges identified by the respondents are already the subject of research within the geospatial community. Thus, future research on location-enabled DT is likely to converge, overlap and benefit from existing efforts. Defining a research agenda for location-enabled DT will help to focus efforts towards the highest priorities - for example, should efforts be focussed on

[17] `https://www.ogc.org/standards/sensorthings`, Accessed 1st May 2022

defining a DT, on creating a single standard, on enhancing interoperability between the existing standards? The weightings for each component provided during the workshop 5 may be useful to develop a definition and categorisation of a location-based DT, perhaps adding further components into the mix, such as the detailed challenges of data sharing and interoperability in terms of data protection, legal/liability and other issues. Data security was also not considered.

To further the synergy with existing efforts, research should include validation as to whether urban and national DT, underpinned by location data, should be treated totally differently e.g. to manufacturing DT or if there are sufficient commonalities to allow for combined research, and indeed for other DT communities to benefit from the extensive expertise that the geospatial community has with, for example, data interoperability.

**5.4.3 Skills and Competency** In terms of the research and education community forming a core part of EuroSDR, Plummer et al. (2021) have developed a skills and competency framework for information management in the context of DT, and this may be worth extending to encompass geospatial skills. Callcut et al. (2021) also note the need for management and leadership to further educate themselves on [DT] concepts, which could be achieved by offering Continuous Professional Development courses. Technology is only one part of a DT and challenges relating to stakeholders and communities involved should not be ignored (Mylonas et al. 2021).

## 6. CONCLUSIONS

The high number of registrants for the EuroSDR workshop highlights the general interest in this topic within both the NMCA and wider geospatial community. Given that DTs represent the physical world, it can be hypothesized that location/geospatial data are going to be fundamental to any urban or national DT, and this research shows that there is a strong overlap. This is furthered evidenced by existing NMCA work on 3D, spatial data infrastructures and national mapping data, which can all be seen as underpinnings for a DT. The opportunity offered by the growing general interest in DT outside the geospatial community should thus be seized. It is hoped that as well as further enhancing our existing work, the DT uptake within the wider community - and the pluri-disciplinarity that this will engender - will have the additional benefit of generating new markets for geospatial data and services, along with a broader understanding outside our community of the work carried out by geospatial experts.

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