Stakeholder identification-based data requirements specification approach for city-level dynamic digital twin

Jiayi Yan[1], Qiuchen Lu[1], Nan Li[2], Michael Pitt[1]
[1]The Bartlett School of Sustainable Construction, University College London, UK
[2]Department of Construction Management, Tsinghua University, China
j.yan.21@ucl.ac.uk (Lead author email address)

Abstract. The concept of city-level digital twins (DT) has been proposed by many researchers and practitioners as a key to realising smarter, sustainable and more resilient cities. The current pilot implementations of city-level DT have been designed and developed for scenarios such as land cadastral management, energy management, water management, urban infrastructure facility and asset management etc. However, while bringing the DT concept to implementation, the lack of data requirements has become a challenge for the data collection in the DT development stage and further data management in the DT operation stage. Especially, the organisational aspect (i.e., stakeholders) has been overlooked. This study proposes a methodology to establish data requirements for city-level DT development based on identified stakeholder social networks. By analysing the stakeholder networks from network, actor, and tie levels, we innovatively propose the data requirements that can help with the DT development process and DTs' application. Consequently, both the technical and organisational aspects of DT are addressed at the city level, which will ultimately accelerate the digital innovation process for cities to be smarter and more resilient.

1 Introduction

In recent years, the advancement of digital twin (DT) at city level has been proposed to improve city operations' smartness, sustainability, and resilience because DTs can potentially provide decision-making support driven by heterogenous data (Shahat et al., 2021). Many cities have developed DTs out of different application requirements, such as the city-level water distribution network DT of the city of Valencia (Spain), the city-level DT demonstrator for facility and asset management for West Cambridge (UK), the national level DT for a holistic visualisation and management of buildings and infrastructure in Singapore (Schrotter and Hürzeler, 2020, Conejos Fuertes et al., 2020, Lu et al., 2020, Kshetri, 2021).

However, from the concept to practice, the challenges brought by heterogeneous data management have gradually aroused both researchers' and practitioners' attention. Compared to building-level DTs, city-level DTs have more complex virtual environments, which may include diverse geometric sources with different data formats, georeferences, nomenclature etc. Besides, to achieve more comprehensive applications, more heterogenous non-geometric data from isolated information systems with inconsistent data attributes, data volumes and speed should also be collected and integrated, which intricates the data management situation (Yan et al., 2022). For instance, in the West Cambridge DT case study in the UK, (Lu et al., 2020) discussed that the key challenges revealed from the study were data management-related, including data integration, heterogeneity of source data systems, data synchronisation, and data quality. Given that the development and application of DTs are all data-intensive processes, it is crucial to define the data requirements that can ensure the success of DTs. Without proper data requirements, the data collection may not be intentional, and the data quality cannot be ensured; then, the management and application of the data will be jeopardised for good. However, existing studies on data requirements for city-level DT development were very rare.

For the development and application of city-level DTs, there are more than the technical issues to focus on. The organisational issues that influence the digital innovation should also be emphasised based on lessons learned from existing DT implementations (Nochta et al., 2021, Agrawal et al., 2022), while have not been well-addressed. For example, the issues include coordination among multiple (specified and unspecified) stakeholders, cross-disciplinary roles' cooperation (e.g., computer scientists and AEC engineers) (Broo et al., 2022), regional governance and conflicts between the traditional management method and the digital innovation application. Inevitably, the abovementioned issues partially indicate the importance to involve people to prompt the development of city-level DTs as people are responsible for items such as stakeholder requirements provision (Lim et al., 2010) and data provision (Becerik-Gerber et al., 2012). In this case, the method of social network analysis, which identifies all involved stakeholders and their connections, can be used to figure out the overlooked stakeholders and their requirements, the influence on data management and how to promote the DT development and application within the organisation.

Given the research background, this study intends to propose a methodology to establish data requirements for city-level DT development based on identified stakeholder social networks analysis. This research focuses on DTs using (or recreating) data of buildings and infrastructure of certain regions to achieve comprehensive urban infrastructure facility and asset management.

2 Literature review

2 1 Data requirements used in city-level DTs

In existing studies about city-level DT development, most of the studies illustrated the data sources depending on the scenarios or the applications needed for the city-level DTs. For example, (Bujari et al., 2021) demonstrated the data sources in a DT for urban facility management (UFM), including vehicular, presence, topography data, UFM data, and public utility. The data sources were described with contents, geographic granularity, temporal granularity, and data format (Bujari et al., 2021). There were other studies named more specifically the model layers or data sources (Seto et al., 2020, Ferré-Bigorra et al., 2022, Li et al., 2020, Broo et al., 2022). However, they can only be used as references for similar projects to learn from (Broo et al., 2022), rather than established data requirements that can be adopted for DT development. Although the study described the data sources that city-level DTs could contain theoretically, it was limited providing more thorough data requirements in practice. To address the data requirements for city-level DT use, emprical studies have been conducted. For example, (Wong and Ellul, 2018) conducted a questionnaire survey with Likert items about user requirements to examine the usefulness of different data types for a national 3D mapping product in the UK, such as ownership and cadastral data, underground utility geometry, address with 3D location etc. The results from exploratory factor analysis showed that users were more interested in additional information on non-building features rather than additional detail to building geometry. The research addressed the importance of both geometric and non-geometric data, but it only provided the empirical study results without establishing the data requirements for DT development use.

In addition, information requirements adopted from BIM-based standards and research provided foundations for city-level DT data requirements to build on. For example, according to ISO 19650 series, information requirements specify for what, when, how and for whom we should produce data used for facility and asset management during project commissioning (Sacks et al., 2020). Hence, (Sacks et al., 2020) combined BIM-based information requirements and technology, lean construction thinking, and AI to define the requirements for a holistic DT mode of design and construction. In this study, the key information components include Project Intent Information (PII), Project Status Information (PSI), and raw monitoring data etc. (Sacks et al., 2020), which can be further referenced and extended for city-level DT data requirements. (Cavka et al., 2017) developed the owner requirements for BIM-enabled facility and asset management including requirement categories, specific items targeting multiple application areas, and detailed required information that needed to be collected. Moreover, (Becerik-Gerber et al., 2012) studied the application areas and data requirements for BIM-based facility management by conducting persona and expert interviews and online questionnaires. In detail, the data requirements proposed geometric (i.e., BIM models) and non-geometric data structures required in facility management and addressed the specific multi-stakeholders' functional requirements, data provision responsibilities the project's life cycle stages.

In general, literature is relatively limited discussing the data requirements employed in implementations, while existing studies provided an important basis for developing city-level DT data requirements in terms of methods (e.g., questionnaire survey, interview) and information compositions (e.g., data sources, formats, provision responsibilities). Also, the existing studies addressed the data requirements issue more for implementation purposes and capability (i.e., technical) aspects , where the importance of stakeholder involvement (i.e., organisational aspect) has not been fully considered.

2.2 Stakeholder involvement for city-level DTs and related studies

Although there have no existing studies working on stakeholder involvement in city-level DT development, the importance of it has been discussed. For example, (Broo et al., 2022) concluded lessons learned from the organisational perspective based on a smart infrastructure DT practice that the early involvement of stakeholders was beneficial to improve the DT development and application in terms of improving data fluency, clarifying required functionalities and capabilities etc. (Lu et al., 2020) illustrated the relationships of stakeholders and their contributions to the DT in the West Cambridge case study, which indicated the necessity of stakeholder collaboration during the DT development life cycle. (Becerik-Gerber et al., 2012) addressed the importance of the owner role and data provision responsibilities of roles in the AEC industry in the data requirements for BIM-based facility management. Therefore, it is reasonable and necessary to focus on the organisational aspect of stakeholder involvement for data requirements in the city-level DT development.

Reviewing the stakeholder identification issue from the cross-disciplinary fields, there have been studies that could potentially contribute to the city-level DT development. For example, (Crane and Ruebottom, 2011) proposed the stakeholder and social identity group cross-mapping framework from the managerial decision-making perspective to have a comprehensive stakeholder inclusion in business management. Besides, social network analysis, which investigates social structures through the use of networks and graph theory, is widely considered for stakeholder analysis within organisations and projects. For example, (Chung and Crawford, 2016) proposed using network-level, actor-level, and tie-level analysis based on the established social network for project management. (Lim et al., 2010) summarised stakeholder identification methods in categories of semistructured, checklist-based, interviews, and search, and figured out that the methods overlooked the bi-directional or single-directional links of stakeholders and the stakeholder prioritisation issues. Further, (Lim and Finkelstein, 2011) proposed a stakeholder identification approach based on social network analysis to specify and prioritise stakeholders and use it for eliciting functional requirements for large-scale software engineering projects. The abovementioned approach might be potential for city-level DT development in terms of stakeholder identification and data requirements establishment, while there is no existing study focusing on this area.

3 Research methodology

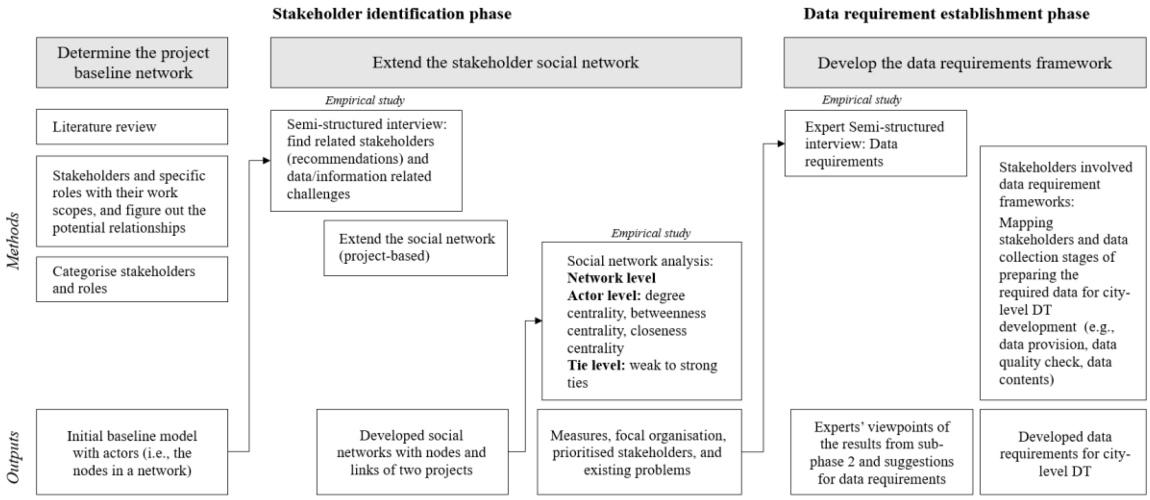

Figure 1 Methodology to develop data requirements for city-level DTs

3.1 Stakeholder identification phase

There are two phases in the proposed methodology (Figure 1). The first phase is to identify the stakeholder and establish the social network for city-level DT development, which contains two sub-phases. Sub-phase 1 is to determine the stakeholder baseline model (Sharp et al., 1999). Literature review of the existing city-level DT studies is conducted to analyse the important stakeholders involved in the DT development and figure out the relationships among them. Then, for the purpose to establish the network, clear definitions should be specified regarding what the node and link represent respectively in the network. Hence, the output from sub-phase 1 is an initial stakeholder baseline model which is going to be used in sub-phase 2.

Then, sub-phase 2 is an iterative process with both empirical methods (i.e., semi-structured interviews) and data analysis, which aims to extend the baseline network to the stakeholder social networks. By using the initial stakeholder network from sub-phase 1, the semi-structured interview of 8 persona (i.e., important roles in a project such as a project manager, software engineer) is designed to ask about the important stakeholders they work with (i.e., stakeholder recommendation) and the data requirements-related challenges they confront with during the DT development. The interviewees are found from two large-scale DT projects that have been developing the city-level and enterprise-level DTs (respectively) over two years.

Based on the interview outcomes, the extended (project-based) stakeholder networks are developed. Then, two levels of social network analysis are conducted, which are network-level analysis, actor-level and tie-level. The network-level analysis demonstrates the importance of the structure of communication networks and its impact on communication flow and performance (Chung and Crawford, 2016). Actor-level analysis concerns the location of the actor (i.e., the node) with respect to others within the network, which includes three measures of degree centrality, betweenness centrality, and closeness centrality (Chung and Crawford, 2016). The tie-level analysis indicates the relationships between the actors and range in quality from weak to strong (Chung and Crawford, 2016, Granovetter, 1973), which allows assessment of how influential or close or how strong or weak a connection is of one stakeholder to others. Based on the actor and tie-level analysis, the outcomes are expected to describe the current stakeholder network "patterns" (e.g., focal organisation, prioritised stakeholders, neglected stakeholders). Besides, key contents about the data collection, information, and ideas circulation within the stakeholder network are concluded.

3.2 Data requirement establishment phase

This phase is to propose a data requirement framework based on analysed outcomes from Phase 1. To achieve the objective, first, semi-structured interviews of 6 experts (with working experiences from 10-45 years in the AEC/FM, computer science, manufacturing fields) are organised to ask about the analysed outcomes. The interview topics include two parts:

- Stakeholder-related questions: regarding the analysed results of the focal organisation, prioritised stakeholders, neglected stakeholders, whether they are indeed the current situation commonly? How would they influence DT development?
- Data requirements-related questions: based on the experts' knowledge and expertise, what are their viewpoints about the data collection, information, and ideas circulation to develop DTs? How would the existing problems be addressed by stakeholders? And what are the key aspects to address in an ideal data requirements for DTs?

Then, by analysing the expert interviews results and synthesising with the stakeholder network results from Phase 1, the preliminary data requirements framework is proposed to help with DT development.

4 Stakeholder social network and data requirements

4.1 Baseline model

In sub-phase 1 of the stakeholder identification phase, several studies that indicated the involved stakeholders are listed in Table 1, which gives a view of key stakeholders that should be engaged in the DT development. However, it is limited that only the stakeholder or roles are provided in the existing studies without specific descriptions of the relationships (i.e., the links) among the stakeholders or roles. And more detailed information of the stakeholders/roles hierarchy was not sufficient. Only the study of (Lu et al., 2020) addressed that there were information supports (providing data), technical supports, and enumerating requirements within the stakeholder/roles. Accordingly, in the proposed baseline network, we are aware of the potential relationships, but do not assume any links among the stakeholder/roles in the first place. Instead, we categorise the stakeholders/roles and assign them as "actors" for sub-phase 2 use (shown in Figure 2).

Table 1 Identified stakeholders in existing city-level DT studies

City-level DT cases/research	Stakeholders/Roles	Reference
West Cambridge DT demonstrator for facility and asset management	university facility management team (facility manager (West Cambridge site), archive manager (West Cambridge site), technician (West Cambridge site), facility manager (the IfM building), technician (the IfM building)), academic team (team supervisor, researchers, technician), a consulting company (project director, technical support expert), modelling and data collection company (roles for collecting different data sources)	(Lu et al., 2020)
DT of the City of Zurich for Urban Planning	public administration, citizens, urban planners, designers, game users	(Schrotter and Hürzeler, 2020)
Smart Twin Cities for urban operations	scientists, officials, citizens, companies, developers	(Soe, 2017)
Precinct Information Modelling (PIM) integrating BIM and GIS	estate management (EM) departments, companies, councils, institutions, researchers, residents	(Li et al., 2020)
Smart city DT for city energy management	building managers, energy companies, city managers	(Austin et al., 2020)
Stakeholder-based modelling changing research in semantic 3D models	public (government agencies, non-governmental organisations and individual citizens), constructive (constructors and architects), data (data producers, administrators and publishers), innovative (scientists and developers) and application stakeholders (urban planners, visualisers and analysts).	(Nguyen and Kolbe, 2021)

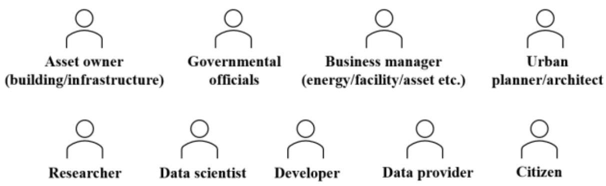

Figure 2 Specified actors in the baseline model

4.2 Stakeholder social network

Moving to the sub-phase 2, according to the specified actors in the baseline network, semi-structured interviews were conducted to ask questions about their role descriptions and recommendations (i.e., main tasks, daily communication with certain stakeholders/roles) in the network during the DT development and discussed the information and data requirements related challenges. Hence, stakeholder networks indicating the organisational structures of two DT projects were established (Figure 3).

For network-level analysis, there were two preliminary findings. First, in order to develop DTs, it is common to have two focal organisations, which are the owner organisation that propose to develop the DT and the provider organisation that assist the whole development process. This forms a business model that the current DT development applies. Next, the key information communicated within the network is mainly two parts, which are the requirements of the DT application from the owner to the provider, and the data requirements from the provider ties to the owner (which are often neglected in practices).

At the actor-level, by calculating the three measures for each network, the results are shown in Table 2 and Table 3. Based on the results, firstly, it indicates the project manager (provider side) in Project 1 has the highest degree, betweenness, and closeness centrality; and the technology consulting director (provider side) has the highest degree, betweenness, and closeness centrality and business analyst (provider side) has the very near degree and closeness centrality with the technology consulting director. This indicates that these positions have the most intensive information flow, communication activities, and communication convenience of DT application requirements and data requirements. Comparatively, the personnel of engineers has lower measures of centralities in general.

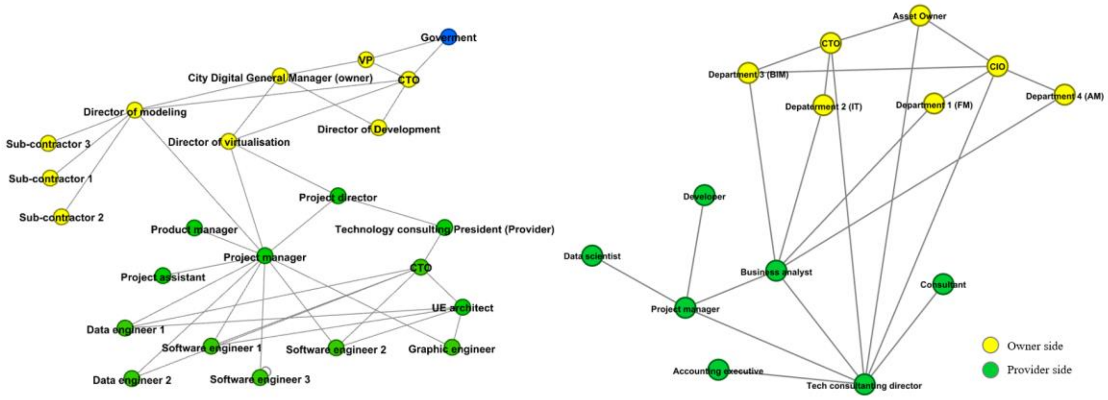

Figure 3 (a) The organisational structure of Project 1, a city-level DT for a Chinese area aiming to collect high-level of geometric data and linked non-geometric data for city governance (e.g., emergency, business development, human mobility etc.). (b) The organisational structure of Project 2, a city-level DT for a large enterprise in the US that owns building and infrastructure assets in a city, aiming to optimise the facility and asset management process.

Table 2 Actor-level analysis for Project 1

Actor	**Degree**	**Closeness Centrality**	**Betweenness Centrality**
Project manager	11	0.611	149.878
Director of modelling	6	0.537	87.472
CTO	6	0.355	9.200
CTO	5	0.423	38.833
UE architect	5	0.344	4.000
Director of virtualisation	4	0.489	38.028
City Digital General Manager (owner)	4	0.415	19.833
Project director	3	0.458	15.256
Software engineer 1	3	0.423	7.011
Software engineer 2	3	0.423	7.011
Data engineer 1	3	0.423	7.011

Table 3 Actor-level analysis for Project 2

Actor	**Degree**	**Closeness Centrality**	**Betweenness Centrality**
Tech consulting director	7	0.684	34.869
Business analyst	6	0.650	23.071
CIO	5	0.542	9.000
CTO	4	0.500	4.929
Project manager	4	0.591	23.000
Department 3 (BIM)	3	0.481	1.869
Asset Owner	3	0.520	0.810
Department 2 (IT)	2	0.448	0.667
Department 1 (FM)	2	0.448	0.393
Department 4 (AM)	2	0.448	0.393
Data scientist	1	0.382	0.000

VP	3	0.314	1.250	Developer	1	0.382	0.000
Software engineer 3	3	0.386	0.000	Consultant	1	0.419	0.000
Graphic engineer	2	0.407	3.700	Accounting executive	1	0.419	0.000
Data engineer 2	2	0.415	3.311				
Technology consulting President (Provider)	2	0.361	1.956				
Director of Development	2	0.310	0.250				
Government	2	0.310	0.000				
Product manager	1	0.386	0.000				
Project assistant	1	0.386	0.000				
Sub-contractor 1	1	0.355	0.000				
Sub-contractor 2	1	0.355	0.000				
Sub-contractor 3	1	0.355	0.000				

At the tie-level, there are weak ties exist in the organisational structures of the two projects. For example, in Project 1, the personnel managed by the director of modelling (owner side) has weak ties with engineers that develop the DT (provider side) because they do not know each other directly. They can only be potentially linked by the director of modelling and project manager. This personnel is the direct stakeholders in processing the data or the potential end-users of the DTs, which might have requirements of the DT application and data requirements. According to the highly cited the ‘strength of weak ties’ theory postulated by (Granovetter, 1973), the existing weak ties in the stakeholder networks can forbid novel ideas and information (i.e., the requirements) from diffusion to some extent.

According to the generated results of the three levels of analysis, semi-structured expert interviews were conducted. Specifically, the interview topics include (1) the focal organisations and the specified information diffused within the network for city-level DT development, (2) certain stakeholders with high centralities of information, (3) the ‘weak tie’ phenomenon existing during the DT development, (4) and the prospective data requirements for city-level DT.

4.3 Data requirements for city-level DTs

Based on the semi-structured interview results, in this study, we propose the preliminary findings for city-level DT development data requirements in Figure 4. Generally, it is figured out that the data requirements are generated based on stakeholder requirements. It is important to realise the requirements from all DT-related stakeholders in the whole organisational structure should be involved, and the requirements need to be understood by all stakeholders to enable the DT development feasibility and application effectiveness. Based on stakeholder requirements, the data requirements not only need to indicate what data to collect, it is crucial to ensure the data quality by establishing the data inventory and checking the collected data so that the developed DT can be useful in practice. Especially the high-quality and consistent non-geometric data is very important for the DT to actually connect to the real world. Besides, the importance of the provider stakeholders’ early involvement (especially the data-related roles) cannot be neglected to guarantee the collected data meets the stakeholder requirements accordingly.

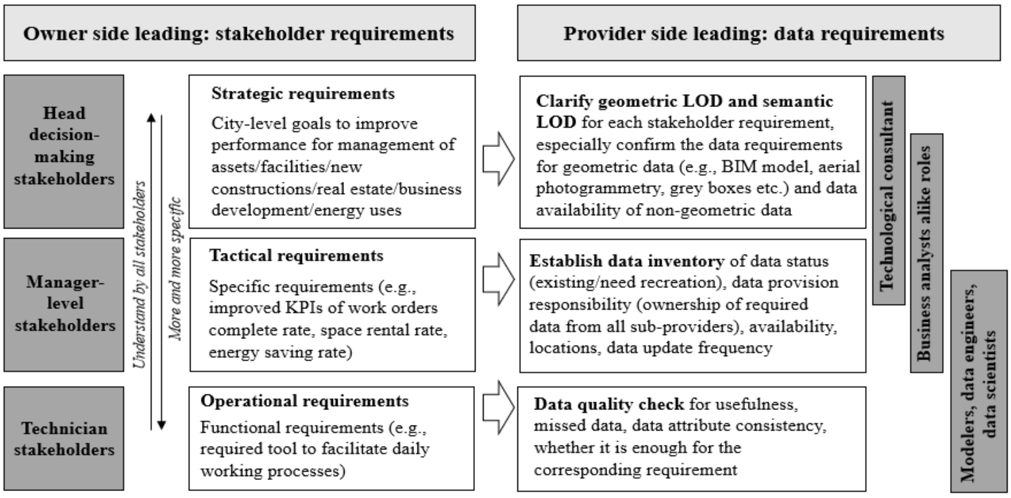

Figure 4 Preliminary findings for city-level DT development data requirements

5 Conclusion

Bringing city-level DTs from concept to practice, data management is a big challenge, where the organisational aspect of stakeholder involvement cannot be overlooked to ensure the successful development of the DT. This study firstly proposes the method including social network analysis to identify and involve stakeholders to establish data requirements that can instruct the data collection for city-level DT development and the DT application. The results of this study theoritically implies the important stakeholders and their relationships and how the the data requirements are driven by the stakeholders for the seek of city-level DT development; from the practical perspective, it can be used to guide the DT design and development more effectively. However, more details about the data requirements should be provided to prove the efficiency and effectiveness. In future work, stakeholder networks of more city-level DT projects in practice globally will be established and the data requirements will be further developed in terms of the named data needs in the preliminary findings.

Acknowledgement

The research that contributed to this paper was funded by the UCL/Beijing Zhiutech Co.Ltd Knowledge Transfer Partnership (Reference No. WT 5497677).

Reference

AGRAWAL, A., FISCHER, M. & SINGH, V. 2022. Digital Twin: From Concept to Practice. *Journal of Management in Engineering,* 38**,** 06022001.

AUSTIN, M., DELGOSHAEI, P., COELHO, M. & HEIDARINEJAD, M. 2020. Architecting smart city digital twins: Combined semantic model and machine learning approach. *Journal of Management in Engineering,* 36**,** 04020026.

BECERIK-GERBER, B., JAZIZADEH, F., LI, N. & CALIS, G. 2012. Application Areas and Data Requirements for BIM-Enabled Facilities Management. *J CONSTR ENG M,* 138**,** 431-442.

BROO, D. G., BRAVO-HARO, M. & SCHOOLING, J. 2022. Design and implementation of a smart infrastructure digital twin. *Automation in Construction,* 136**,** 104171.

BUJARI, A., CALVIO, A., FOSCHINI, L., SABBIONI, A. & CORRADI, A. 2021. A Digital Twin Decision Support System for the Urban Facility Management Process. *Sensors,* 21**,** 8460.

CAVKA, H. B., STAUB-FRENCH, S. & POIRIER, E. A. 2017. Developing owner information requirements for BIM-enabled project delivery and asset management. *Automation in construction,* 83**,** 169-183.

CHUNG, K. S. K. & CRAWFORD, L. 2016. The role of social networks theory and methodology for project stakeholder management. *Procedia-Social and Behavioral Sciences,* 226**,** 372-380.

CONEJOS FUERTES, P., MARTÍNEZ ALZAMORA, F., HERVÁS CAROT, M. & ALONSO CAMPOS, J. 2020. Building and exploiting a Digital Twin for the management of drinking water distribution networks. *Urban Water Journal,* 17**,** 704-713.

CRANE, A. & RUEBOTTOM, T. 2011. Stakeholder theory and social identity: Rethinking stakeholder identification. *Journal of business ethics,* 102**,** 77-87.

FERRÉ-BIGORRA, J., CASALS, M. & GANGOLELLS, M. 2022. The adoption of urban digital twins. *Cities,* 131**,** 103905.

GRANOVETTER, M. S. 1973. The strength of weak ties. *American journal of sociology,* 78**,** 1360-1380.

KSHETRI, N. 2021. The Economics of Digital Twins. *Computer,* 54**,** 86-90.

LI, W., ZLATANOVA, S., DIAKITE, A. A., ALEKSANDROV, M. & YAN, J. 2020. Towards integrating heterogeneous data: a spatial DBMS solution from a CRC-LCL project in Australia. *ISPRS International Journal of Geo-Information,* 9**,** 63.

LIM, S. L. & FINKELSTEIN, A. 2011. StakeRare: using social networks and collaborative filtering for large-scale requirements elicitation. *IEEE transactions on software engineering,* 38**,** 707-735.

LIM, S. L., QUERCIA, D. & FINKELSTEIN, A. StakeNet: using social networks to analyse the stakeholders of large-scale software projects. Proceedings of the 32Nd ACM/IEEE International Conference on Software Engineering-Volume 1, 2010. 295-304.

LU, Q., PARLIKAD, A. K., WOODALL, P., DON RANASINGHE, G., XIE, X., LIANG, Z., KONSTANTINOU, E., HEATON, J. & SCHOOLING, J. 2020. Developing a digital twin at building and city levels: Case study of West Cambridge campus. *Journal of Management in Engineering,* 36**,** 05020004.

NGUYEN, S. H. & KOLBE, T. H. 2021. Modelling Changes, Stakeholders and Their Relations in Semantic 3d City Models. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 8**,** 137-144.

NOCHTA, T., WAN, L., SCHOOLING, J. M. & PARLIKAD, A. K. 2021. A socio-technical perspective on urban analytics: The case of city-scale digital twins. *Journal of Urban Technology,* 28**,** 263-287.

SACKS, R., BRILAKIS, I., PIKAS, E., XIE, H. S. & GIROLAMI, M. 2020. Construction with digital twin information systems. *Data-Centric Engineering,* 1.

SCHROTTER, G. & HÜRZELER, C. 2020. The digital twin of the city of Zurich for urban planning. *PFG–Journal of Photogrammetry, Remote Sensing and Geoinformation Science,* 88**,** 99-112.

SETO, T., SEKIMOTO, Y., ASAHI, K. & ENDO, T. Constructing a digital city on a web-3D platform: simultaneous and consistent generation of metadata and tile data from a multi-source raw dataset. Proceedings of the 3rd ACM SIGSPATIAL International Workshop on Advances in Resilient and Intelligent Cities, 2020. 1-9.

SHAHAT, E., HYUN, C. T. & YEOM, C. 2021. City digital twin potentials: A review and research agenda. *Sustainability,* 13**,** 3386.

SHARP, H., FINKELSTEIN, A. & GALAL, G. Stakeholder identification in the requirements engineering process. Proceedings. Tenth International Workshop on Database and Expert Systems Applications. DEXA 99, 1999. Ieee, 387-391.

SOE, R.-M. Smart twin cities via urban operating system. Proceedings of the 10th International Conference on Theory and Practice of Electronic Governance, 2017. 391-400.

WONG, K. & ELLUL, C. 2018. User requirements gathering for a national 3D mapping product in the United Kingdom. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives,* 4**,** 89-96.

YAN, J., LU, Q., FANG, Z., LI, N., CHEN, L. & PITT, M. From building to city level dynamic digital Twin: a review from data management perspective. IOP Conference Series: Earth and Environmental Science, 2022. IOP Publishing, 092033.