Engineering For Social Change
A. Cooper et al. (Eds.)

doi:10.3233/ATDE240892

Transdisciplinary Perspectives on Navigating Digital Twin Adoption

James TOOTH[a,1], Nilufer TUPTUK[b] and Jeremy D. M. WATSON[a]
[a] *Department of Science, Technology, Engineering and Public Policy, UCL, UK*
[b] *Department of Security and Crime Science, UCL, UK*

Abstract. Digital Twins (DTws) can enhance simulation, modelling, design and decision-making capabilities across (and between) transdisciplinary teams of various engineering disciplines, throughout lifecycles of products or assets of interest. Yet, effective stakeholder collaboration may depend on interoperable models and data, which could be hampered by deviating user requirements or interpretations. Furthermore, security or resilience failures of certain DTws and the assets they represent, such as Critical National Infrastructure, can have severe implications for safety and privacy for users and the wider public. Given the multiplicity of DTws arising from these variations, collation of key sources of commonality, disagreement and uncertainty between stakeholders could support a more coordinated approach. Therefore, this research uses semi-structured interviews to understand the on-the-ground practical context of DTw adoption, gathering views of 23 participants from various disciplines across the public sector, industry and academia. These interviews discuss existing DTw approaches and identify areas for future investigation, relating to: 1) implementation, sectoral needs and user expectations; 2) future trends and emerging synergistic or antagonistic technologies; and 3) context and impacts of IP and liability concerns.

Keywords. Digital Twins, transdisciplinary engineering, semi-structured interviews, Industry 4.0, built environment

Introduction

Digital Twins (DTws) are often 4D virtual models of physical assets that use live data to represent, monitor, remotely respond to, and predict change in assets in real-time. Whilst DTws may have myriad potential applications to meet future business needs, there is no consensus on their definition or composition. Different opinions arise and evolve with time, innovations, and sectoral landscapes [1–3]. Cheaper, more advanced DTws have expansive engineering applications in manufacturing and construction, which are being integrated with other technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and Augmented Reality (AR) [4, 5]. Literature suggests DTws are mainly developed as technical innovations, yet are in fact sociotechnical systems that can bring value and insight to both engineering and non-engineering stakeholders [4, 6].

As DTws integrate with other technologies, new sociotechnical capabilities may arise. These advances could enable adaptable, connected DTws to model stakeholders' behaviours, and represent assets differently to align with diverse stakeholder goals [5].

[1] Corresponding Author, Email: james.tooth.21@ucl.ac.uk.

As such, sociotechnical challenges including privacy, transparency, security, trust, and human-computer interaction may need considering during DTw design to generate wider value. Furthermore, humans may need involving across DTw lifecycles to ensure good judgement and effective decision processes. Challenges in defining purposes of DTws and recruiting teams to involve may be solved by engaging a transdisciplinary range of stakeholders in DTw design [1, 6]. This study aims to understand how these stakeholders perceive DTw adoption, both now and in the future. An initial hypothesis was that responses might vary hugely, due to differences in stakeholders' awareness and priorities.

1. Methodology

This study uses semi-structured interviews to understand how stakeholders perceive challenges around implementing DTw. Table 1 lists generalised roles of 23 participants recruited from the public sector, academia and industry (P_{1-23}). 51 experts with relevant practical experience or contributions to the literature were approached, partly through snowball sampling (recommendations by previous participants). The 3 questions asked are addressed in sections 2.1, 2.2, 2.3. Areas of consensus and dispute were classified via thematic analysis, following the methodology of Braun and Clarke [7].

Table 1. Backgrounds of recruited participants

Public sector 8 participants	**Academia 7 participants**	**Industry 8 participants**
P_1 Civil service (transport)	P_2 Infrastructure engineering	P_3 Security consultancy
P_6 Engineering institution	P_3 Railway engineering	P_5 CTO/thought leader
P_8 Standards body	P_6 Digital design	P_{13} Automotive engineering
P_9 Civil service (security)	P_{10} Smart infrastructure	P_{14} Automotive engineering
P_{12} Civil service (business)	P_{11} City planning	P_{15} Thought leader
P_{19} Research council	P_{17} Infrastructure policy	P_{16} Solution architect
P_{20} Research council	P_{23} Cybersecurity	P_{18} Technology consultancy
P_{22} Policing		P_{21} Utilities security

2. Findings and discussion

The questions and findings of this study are summarised in Figure 1. Participants ($P_{3,4,8,17,18}$) noted DTws are a low maturity technology not yet established outside of research, lacking unanimous definitions, platforms or standards. Participants suggested that DTw innovation is time-consuming, requiring funding or technical advances, as well as stakeholder involvement, to experiment with DTw capabilities and limitations. P_3 noted that developing effective, secure DTws could strategically and reputationally benefit the UK, as other countries have yet to overcome these challenges.

2.1. QUESTION 1: What are the barriers to adopting Digital Twins?

$P_{1,5,7}$ mentioned DTws face challenges in both technological advances and human applications, which may be more complex (P_5). Hence a sociotechnical view might be needed to develop futureproofed, interoperable DTw ecosystems. In addition, $P_{11,19}$ noted that DTws currently focus on physical systems (e.g. engines and buildings), yet can also jointly or separately represent social systems (e.g. Metaverse, and models of economic or people flows). Securing buy-in from citizens can be crucial when DTws directly affect people or use public data. Also, $P_{1,7}$ warned that DTw models of human behaviour may need to factor in human deviation from protocol during emergencies. Participants agreed DTw adoption has barriers to overcome, which are grouped under themes: **what a DTw is**, **whether a DTw is valuable**, and **how to use a DTw appropriately**.

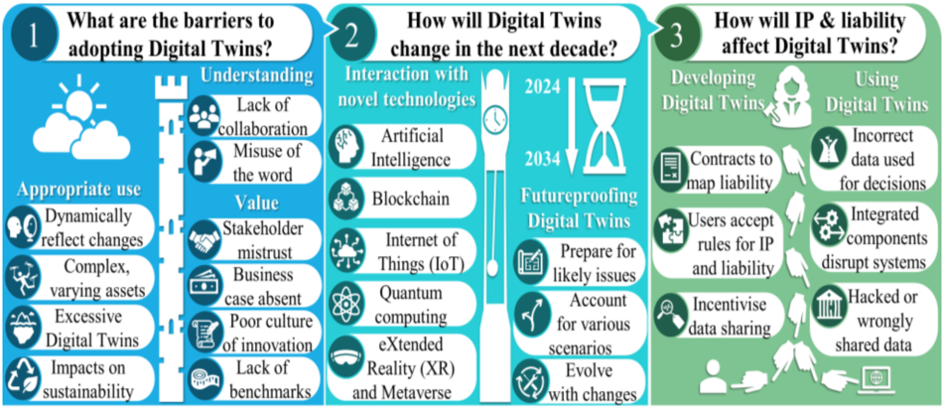

Figure 1. Summary of interview findings

2.1.1. THEME 1A: What a Digital Twin is

Participants highlighted the ambiguity of definitions, describing DTw as *"a term that's easy to misuse"* (P_3), *"means a million different things to different people"* (P_{18}), a *"buzzword"* (P_2), or *"a handy moniker that covers a multitude of things"* (P_{15}). P_{20} noted DTw is an established but contentious term rather than a buzzword, and deems contextual definitions acceptable as new DTws emerge. Specific definitions are out of scope of this work, which focusses on barriers due to mismarketing and a lack of collaboration.

Mismarketing: $P_{2,3,4,7,9,12}$ suggested the lack of consensus may largely be due to various DTw definitions that do not directly disagree, but: misdescribe propriety services (e.g. Finite Element Modelling (P_4), or a 3D scanned asset (P_9)) as a DTw or are overhyped by organisations speaking for reputational gain that have not developed a DTw. Mismarketing of tools as DTws (intentional or otherwise) that may not address customer needs can lead sceptical buyers unwilling to further invest in DTws, making it harder to sell value-generating DTws, and 'DTw' becomes a buzzword rather than a useful phrase (*"Twinwash"* according to P_9). P_3 remarked that *"organisations who claim they have* [implemented DTws] *may not have thought much about the term"* whilst P_7 was sceptical about anyone *"offering one-stop shop DTw solutions that claim it can sort out all digital needs, because each business is unique, with unique structures and products"*. This sociotechnical issue relates to user understanding and definitions.

Lack of collaboration: P_{12} recalled the phrase *"let's collaborate on the rules and compete on the game"* but remarked that *"people compete on the rules to begin with, but no one's playing the game"*. $P_{1,5,6,10,12,20}$ noted DTw owners may focus solely on their own system and business, and be uninterested in transparency. Thus, stakeholders might not widely understand benefits of collaborating, sharing data or making joint decisions. This creates barriers in convincing asset owners to share data or develop common DTw platforms, inhibiting change from siloed (isolated) individuals to standardised national or regional interactions via common practices, federated environments and shared reference data. Yet, $P_{19,20}$ suggest many companies lack interdisciplinary teams (not just multi-disciplinary (P_{19})) comprising diverse expertise (e.g. engineering, social science, ethics) that may be needed for the enigmatic process of creating resilient DTws. This social uncooperativeness leads to technical reduction in interoperability.

2.1.2. THEME 1B: Whether a Digital Twin is valuable

$P_{19,20}$ suggest DTw adoption has public perception issues, especially from excluded parts of society (no influence over DTw implementation, more cautious, or less technological knowledge), necessitating accessible DTws satisfying needs: *"*[DTws] *could be…theoretically valuable to everyone, but once you look at the addressable population, who is interested and can actually afford…a DTw, that number gets smaller… There needs to be a benefit associated with…having that data rather than just be interested or curious."* (P_{12}). The perceived value of DTws seems to be limited by a lack of trust, high investment barriers, non-innovative culture and a lack of benchmarks.

Untrusted DTws: $P_{1,3,4,5,7,8,13,16,19,20}$ listed various factors needed for people to trust and accept DTws, in order to minimise public pushback against DTws. These include security, safety, access, resilience, data integrity, transparency, accountability, quality protocols, sustainability (both carbon footprint and system longevity) and ethics. P_3 felt system assurance approaches need modernising to increase trust, remarking; *"Individual security mistakes may not be that bad, but a systematic absence of security will decrease trust in* [DTws]*… It's not security for security's sake but is also a way of increasing trust"*. P_8 suggested safety, security and ethics are all linked. Additionally, DTws could build trust via accessible data and easy-to-query models, to allow more thorough and simpler Freedom-of-Information requests (P_2). Similarly, low-code/no-code software could *"democratise"* DTws, by enabling users without coding expertise to rapidly adopt new or existing DTws (P_{14}). Trust appears to comprise both social and technical factors.

High investment barriers: $P_{1,3,4,14,15,16}$ noted DTws' perceived business cases do not justify costs. To change this, the wider innovation economy around DTws may need growing, by securing and aligning long-term investment with opportunities (what problems DTws address, who end-users are, what data can be shared, and how to scale up or change DTws over time), and better using overlooked data (due to e.g. quality concerns, inaccessibility to those who would benefit, and ignorance of organisations' data). Currently, it may be primarily larger enterprises investigating DTws, due to high investment and running costs (e.g. licenses, upkeep, maintenance, computing, storage). The optionality of using DTws, and infrequent adoption of precursor technologies (e.g. Building Information Modelling (BIM)) contribute to this trend. Investment challenges may be sociotechnical, comprising technical capabilities and social perception of value.

Non-innovative culture: Attitudes may prevent advancement *"from analogue to digital to fully digitalised business"* (P_7). $P_{5,7}$ suggested there is a lack of leadership and insufficient time or financial resources for DTw adoption, as it may not be seen to benefit profits. Recognising and adapting to the potential of DTws may be a social issue.

Lack of benchmarks: $P_{12,18}$ noted that establishing a critical mass of measurable, DTws (e.g. to monitor operational performance and optimise equipment (P_9), or to model university campuses and cities (P_{18})) could elevate trust. This in turn, improves business cases by validating cost-benefit ratios of applied DTws, which it was suggested is absent in current, largely theoretical literature. Additionally, P_9 noted *"good decisions need data. We've always had the ability to get information, it's just whether acquiring that is cost-prohibitive"* and suggested lower data costs yield bigger datasets and improve decisions. Improving measurements and persuading users to be first adopters may be sociotechnical.

2.1.3. THEME 1C: How to use a Digital Twin appropriately

$P_{1,2,6,7,8,20}$ mentioned that correctly used DTws could produce fit-for-purpose outputs that help teams to reach joint decisions (by denoting different strategic or on-the-ground priorities or perspectives), generate value (by answering business or policy issues) and support interoperability (by following sectoral best practices). Successful DTw use may face issues in sustainability, dynamically reflecting assets, complexity, and excessive use.

Sustainability: $P_{8,12,14,19}$ warned that DTws can be environmentally damaging, especially for larger interoperable systems, with heavy resource, carbon and water footprints to build or use a DTw and to generate or store big data (databases, systems, servers and cloud). They questioned whether DTws are worthwhile, compared to simpler data access approaches. Minimising unnecessary data generation or storage and using green data centres could render DTw use more sustainable. *"Sustainability is going to be a massive challenge. I don't just mean environmental sustainability, but also the cost of sustaining that system."* (P_{19}). Conversely DTws can be applied to improve sustainability, e.g. to reduce congestion in transport (P_{18}) or to optimise energy (P_{14}). This sociotechnical issue relates to social behaviours whilst achieving technical demands.

Need for dynamic asset reflection: *"The debate is all about how close can the model be to the real thing?"* (P_{11}). $P_{2,5,11,17,23}$ remarked that over-simplified or idealised DTw representations of reality could distort physical system behaviour and increase uncertainty in calculations. They suggested adjustable, high-quality DTw models changing with time to fully represent the complexity of assets and the physical environment (e.g. for a DTw to control traffic lights (P_1)) may be needed, particularly for unusual or innovative asset configurations or environments (e.g. climate modelling with limited physics understanding of some underlying environmental phenomena (P_{23})). $P_{2,3,12}$ noted DTws need to consider differences between designed assets (where duplicate components could be assumed to repeat) versus built assets (where individual component conditions need separately recording), as well as integrating historic data of real-world activities to improve DTw operational resilience. This limitation appears to be technical.

Complexity: $P_{3,4,6,10,11,13,14,15,21}$ outlined different components that may be integrated into DTws for data production and curation or to support decisions, predictions and changes (e.g. DTws in process industries and utilities distribution networks may need particularly granular data (P_{21})). Interoperable DTws may need to unbiasedly consume, manage, and integrate real-time, high-quality data from various sources (e.g. systems, environments, engines, other DTws of the same asset) with stable, secure *"hooks"* linking systems (P_{11}) and common visual output. P_7 suggested users could begin with simpler models that extract value quickly (e.g. running HVAC systems efficiently) and expand these later. P_3 felt data inconsistency could prevent integration of DTws across sectors, as most DTws are made for a specific purpose but struggle to interact with assets from other sectors; ideally anything happening in the real-world (regardless of sector) might want be actionable in a DTw. Similarly, $P_{5,16}$ noted data quality affects insights, quoting the saying *"garbage in, garbage out"*. These issues seem primarily technical.

Excessive DTw usage: *"DTws aren't just a technology, they're always deployed for a purpose"* (P_{10}). $P_{4,11,14,16,23}$ commented that DTws may not always need detailed models and assets communicating in both directions or to output full 3D visualisation in order to provide sufficient information about operating parameters and process data (e.g. manufacturing plants need operating parameters but are less interested in visualisation). P_8 warned DTws should only be used where they are worthwhile, *"otherwise we're just going to create a whole series of white elephants"*. $P_{22,23}$ noted that terabytes of data may need storing and processing. $P_{5,14,16,20}$ stated that considering User Experience (UX) may contribute to more interpretable, useable DTws that front-end users without technical backgrounds can interact with. Decisions on user capabilities may be sociotechnical.

2.2. QUESTION 2: How might Digital Twins change in the next decade?

P_5 cautioned against guessing the future, but suggested that scenario planning can predict impacts and that *"imagining the future we want and then working out what we have to do to make it true is really useful in the DTw space because then we can do things with intentionality…that's not happening at the moment…we might get to some desirable future* [randomly]*, but we're not knowing where we're trying to get to."* Collaborative cross-sector systems-thinking approaches could highlight changes in DTws and their requirements ($P_{6,7,15}$). Participants ideas about the next decade were grouped into themes of thinking about **future DTws**, and anticipating **DTw interactions with technologies**.

2.2.1. THEME 2A: Future Digital Twins

Hardware to generate and store DTw data may be cheaper and more available, potentially supporting more thorough representation of physical assets and rapid deployment of many small DTws ($P_{12,17,18}$). Widespread industrial and academic interest and investment in DTws could expand cost-effective use cases if current issues can be overcome; yet, conscious intervention may be needed for interoperable, reusable DTws, e.g. government support to facilitate (full or partial) DTw rollout. Furthermore, achieving different futures may also differ by other innovations co-evolving, so 'futureproofing' DTws may be optimistic ($P_{1,4,5,6,19,20}$) or DTws may already be futureproofed (P_{22}). Issues include preparing for likely changes, accounting for various scenarios and evolving with changes.

Preparing for likely future issues: $P_{1,14,17}$ suggested there may be greater focus on sustainably using DTws to adapt to climate change by reducing assets' energy, carbon and material consumption, with challenges in coping with higher DTw adoption and greater user demands and costs, potentially needing leaner, more adaptive, and connected DTws. P_5 warned *"one can imagine some pretty dire plausible futures which would impact how DTws are used. In a multipolar world, you can imagine the different poles wanting no connection with DTws in somebody else's world. So, there's going to be a limit to integration between DTws of different* [technical] *standards and ethical standards".* As DTws become more intertwined in our lives, there may be greater focus on 'Social DTws' to address broader, less-defined societal problems ($P_{1,11,13}$). This seems to be a sociotechnical challenge, depending on social attitudes to a technical issue.

Accounting for a range of scenarios: P_1 suggests a need for adaptable DTws that can predict and adapt to multiple scenarios. P_{10} suggested DTws can be applied at different scales (individual assets or cities), with roles supporting longer-term strategic policymaking. Furthermore, P_3 suggested futureproofing DTws involves managing information to anticipate lifecycle requirements: *"getting a DTw to last decades is far harder than demonstrating something that looks like a DTw… Futureproofing is about working out how we are going to ensure we've got information we need in 10 or 50 years' time…that is non-trivial, but once you work that out, you can start to work out how you mitigate risk".* For example, a decade-old predictive model of how people travel would not accurately represent post-covid reality (P_1). Extensible and configurable DTws that consider a wider range of future scenarios are more futureproofed ($P_{2,9}$) *"because the unknown unknowns will be the largest problem…we won't know what the issue will be* *so we just need to remain flexible and adaptable so that no one thing can break it"* (P_9). Federated DTws may need strategic intervention and guidance from governments and international bodies or *"there'll be lots of different individual DTws all working to their own standards and being quite useful, but not as useful as if we had done a bit of pre-thinking and worked out how to join them up. Joining up DTws will not get addressed by the market"* (P_5). The future may clearly depend on many sociotechnical developments.

Evolving with changes: *"As the needs of society change, the ability to replicate that digitally has to move with it... and DTws have got to be adaptable"* (P_{17}). DTws may become critical in the longer-term as users and society begin to rely on them ($P_{5,9,10}$). Yet, $P_{8,11,12}$ suggested futureproofing involves considering DTw quality and capabilities to preserve continuity, stability and resilience by retaining access to models and information about what decisions were made, when and why. Furthermore, DTws may need iterative testing in real applications, considering how they evolve and adapt to the behaviour of stakeholders of varying capabilities to directly change a DTw over time (e.g. operators, policymakers, designers). Since assets have longer lifespans than any technology. Adapting to such evolving challenges seems to be sociotechnical.

2.2.2. THEME 2B: Digital Twin interactions with future technologies

$P_{1,5,8,20}$ agreed a DTw is not a single technology, but an integrated amalgamation of existing and emerging ones. P_{17} suggested to *"design for the real physical asset and the DTw at the same time and keep those two in-step as technology changes"*. Some participants felt digital technologies may affect DTws positively (P_6), linking data inflows with modelling outflows (P_7). Conversely, P_8 warned that *"the danger always with these technologies is it becomes the answer"* and felt ethics needs considering for positive outcomes. Likewise, P_{18} advocated *"we don't need more emerging technologies"* and that DTws should use existing tools more effectively, whilst P_{22} suggested a need for centralised platforms (e.g. a 3D GIS). $P_{3,11}$ reflected that the information gleaned from a DTw is ultimately more important than data *per se*, and warned that some technologies distract from this. P_{19} suggested the pace of technology development exceeds the rate of technology adoption, noting that some innovation could be disruptive, but that interconnected systems always contain updating technology that affects the whole system. Furthermore, $P_{22,23}$ noted emerging technologies need to be practical, affordable and usable (e.g. photogrammetry for VR linked DTws (P_{23}), rather than e.g. holographic tables (P_{22})). Many technologies could intersect with DTws, including Artificial Intelligence (AI), blockchain, Internet of Things (IoT), quantum computing, and eXtended Reality (XR). Each of these may face principally technical considerations.

AI: AI was widely seen as increasingly important ($P_{1,2,3,4,5,7,8,12,15,17,19}$), to control DTws ($P_7$), and support automated data collection, modelling and analysis ($P_{1,5,19,22}$). Participants contested that AI is already established (P_{14}), will only help future DTws (P_8) or is *"overhyped"* and *"generally an unfortunate distraction"* (P_3). $P_{4,15}$ warned that AI will not improve data quality, as *"organisations using imperfect data to make fairly rubbish decisions...don't realise that AI will just do it faster"* (P_{15}), yet P_2 noted this need for good data would positively improve the broader DTw. $P_{1,12,16}$ suggested Generative AI such as Large Language Models (LLMs), could query 'big data' volumes and accelerate code development. $P_{1,8,10,14}$ noted Machine Learning (ML) may be more useful than LLMs to; support DTw models, handle continuous and real-world data, and make predictions and optimisations (e.g. to determine correlation or causation (P_{23}) or find leakages in a water system by factoring in usage patterns (P_{22})). P_{10} warned that *"for* *some things a black box making a decision would be completely unacceptable and unethical. So, AI components should inform human decision-makers, but shouldn't necessarily take decisions…we need to be careful about the level of autonomy that we give a system"*, meaning ML and AI driven analysis may need human involvement to reflect on critical decisions ($P_{10,20}$). Furthermore, Graph Database Technologies could allow AI systems to handle increased data that federated DTws need to process (P_{12}).

Blockchain: Blockchain could accessibly validate and permanently hold DTw data, to create trust and share sensitive data ($P_{1,3,5,7,8}$). P_4 suggested blockchain may be important for DTw governance and transparency in the public sector (e.g. to track asset changes, which could expose instances of government corruption), but that some private asset owners (e.g. homeowners) may have privacy concerns about monitoring. In contrast, P_9 suggested *"Blockchain is a technology looking for a problem it can be used to solve"*. P_5 noted alternatives exist, whilst P_{15} more tentatively defined privacy enhancing technologies that *"obfuscate but retain the granularity of information"*.

IoT: IoT devices can bring more live data to assets, data platforms, and models (particularly as sensors become cheaper, with greater accuracy and range) that could be quickly captured, transmitted and shared into DTws in large quantities via 5G or 6G communications, and interact with AI and be secured with blockchain ($P_{1,5,6,16,18,21,23}$).

Quantum computing: Quantum computing may only be ready or relevant for future DTws (P_{12}), or may not ever be pertinent for DTws (P_{19}). Alternatively, quantum computing could lead to more sophisticated, high-performance DTws that can live stream real-time data transfer and consumption, provide computational power to support realistic simulations, and accelerate other capabilities (the wider internet, generative AI, advanced robotics and biological technologies) ($P_{5,8,12,16,19,20}$).

XR: XR comprises Augmented Reality, Virtual Reality and Mixed Reality, and is used with 3D environments in DTws to allow remote access to assets (e.g. for training, simulation and decision-support). Yet, slow research progress and a lack of investment mean there are few other applications ($P_{1,5,13,14,15,16,22}$). Ultimately, DTws may or may not need to integrate into the metaverse ($P_{11,18,19}$).

2.3. QUESTION 3: How might IP and liability issues affect Digital Twins adoption?

Intellectual Property (IP) and liability issues were disparately considered fundamental ($P_{2,4,18,19,23}$), unimportant ($P_{3,8,9,14,21}$), or contextual ($P_{10,11,12,22}$), as they *"can involve different kinds of organisations. A DTw shared between two organisations not in competition with each other, without particular security risks and whose products or services are not life critical, have much lower concerns than for people delivering critical national infrastructure"* (P_{10}). $P_{4,9,11}$ warned that a major asset failure (e.g. bridge collapse or autonomous car crash) may be needed to establish legal precedent for liability or IP rights of DTws. Issues are grouped around **DTw implementation** and **DTw usage**.

2.3.1. THEME 3A: IP and liability issues from Digital Twin implementation

P_2 suggested DTws sit between stakeholders, and that liability obligations can clarify duties and explicitly record information that was tacit, unrecordable or was reluctantly recorded. DTw components may mostly follow conventional IP laws (P_{11}) in overcoming issues associated with resolving contracts, preserving innovation and data ownership.

Contract resolution: $P_{8,9,14}$ felt IP and liability can be built into contracts, and apply most to DTws for licensing third-party software, as identifying creators of individual resources may be simple. $P_{3,5,12,14}$ felt allocating acceptable liability to recipients and providers, and making DTw data and models available with the right caveats (data quality assessed with an agreed, open approach) is complex but not insurmountable, varying with license complexity (how many organisations are involved and own different parts of the DTw). $P_{5,8}$ suggested this may need deciding and standardising before contracts are created to speed up (commercial, legal and regulatory) requirements of IP and data sharing governance. Determining contract structure seems to be largely social.

Preserving innovation: Participants disagreed on how open DTw Intellectual Property (IP) should be. Concerns were raised that: DTw creators could use IP to restrict DTws of similar functionality (P_{13}), and without open-source DTws, large technology companies could obtain sectoral monopolies that hamper transparency and prevent access by smaller rivals (consequently, some public sector organisations might develop their own DTws from scratch to avoid IP challenges) (P_{12}). In addition, companies hesitate to put proprietary innovations into the public domain via an open DTw (P_2), as processes within a DTw could be reverse engineered (P_{21}). Collective benefit might be maximised by paying organisations to develop innovations for an open underlying DTw infrastructure (P_3). How DTw innovations are created and released may be sociotechnical.

Ownership and value: P_{10} noted that *"people think data has value in itself. But actually data only gets value once it's shared, so we need a new and broader approach to IP"*. $P_{1,10,11,12,17,18,20}$ noted (technical and business) liability concerns around how data is owned and commercially shared. $P_{3,15}$ recommended data sharing approaches be open between organisations and commonly understood, with some restrictions and rules for good service (e.g. defence or security (P_{12})). Industrial and academic stakeholders (with divergent attitudes and incentives) need to buy into sharing data and innovations (P_{20}).

2.3.2. THEME 3B: IP and liability issues from Digital Twin usage.

Lawyers and insurers may be involved in DTws to handle data for legal or insurance claims, and to address public liability risks. Yet, current insurance might not cover DTws, without custom insurance plans (e.g. for autonomous DTw-managed buildings (P_9)) ($P_{7,9,17,18}$). DTw use may need to consider issues of flawed decisions and system changes.

Flawed decisions: $P_{1,4,10,23}$ noted DTws may need validation, as physical assets may not perfectly replicate designs or simulated performance (e.g. a DTw of an asset in the North Sea with freezing temperatures and flowing water (P_{23})). Defining the value or sensitivity of obsolete or replica data may be hard, particularly if asset ownership is transferred (e.g. should former or current asset owners keep models up-to-date?), data has circulated through the DTw, or ML is used. $P_{1,8,9,13}$ noted incorrect decisions made raise issues over: liability for errors or actions taken from insights (the DTw, whoever set up federation, data providers or end-users?); determining bounds for acceptable use to minimise inappropriate liability (e.g. National Underground Asset Register not documenting an underground pipe (P_{10}), or a security DTw not finding a vulnerability (P_{22})). This may comprise sociotechnical responsibilities for humans and systems.

System changes: Integrated components in DTws can damage or disrupt the whole system (e.g. manufacturing machine halting a production line (P_{16})), with legal impacts (particularly for interoperable DTws) over: acceptable use to change or grant access to the DTw, and add or edit data; responsibilities for reliability, data history, and to notify owners of mistakes. These relate to social choices about technical decisions ($P_{2,8,10,11,16}$).

Privacy breaches: Liability may relate to data sharing culture ($P_{6,17}$). P_{18} noted that liability concerns can also arise from gathered datasets held in a DTw platform getting hacked or shared adversely. $P_{11,19}$ noted that internal organisational policies can restrict what data can be used or shared, particularly in the public sector. $P_{7,8,9,10,11,19,21,22}$ suggested compromised transparency and confidentiality of data might cause data ownership issues. This includes who can generate or use data in what contexts (e.g. bylaws may prevent Transport for London from tracking all users of the tube beyond tap-in and tap-out data (P_{11})), who determines appropriate use (e.g. DTws directly affecting people lives like flood management (P_{21})), if data combinations can deduce sensitive information (e.g. detecting house occupancy through energy use (P_9)) what personal information is stored (e.g. blurring faces (P_{22})), if IP belongs to data collectors or subjects, and how to enforce this: *"it's not even necessarily about IP, it's just basic data sharing agreements"* (P_{19}). Such issues may be largely social, with technical aspects.

3. Conclusion

The initial hypothesis of this study was that stakeholders' awareness and priorities diverge. By collating participant responses, there does seem to be broad consensus about the issues facing DTw implementation (which barriers affect DTw adoption in Q1, what technologies DTws need to interact with over the next decade in Q2, and risks to IP from DTws in Q3). However, participant viewpoints diverge on the specific solutions required (solutions to barriers in Q1, what the future will look like and the criticality of each technology in Q2, and whether IP and liability concerns will be resolved through time or require conscious action in Q3). Whilst outside the scope of this article, there is a need to compare participant responses against academic, sales and governmental literature to understand how participant experiences relate to and are documented by current research.

Amongst the ideas discussed, stakeholders may need to collaborate and reach agreement on purposeful, practical DTw adoption, taking into consideration the full asset lifecycle, from what a DTw is, straddling plans for future trends, all the way to addressing liability concerns. Future work could focus on preparing adaptable DTws capable of engaging with future technologies, specifically AI. Policy or regulatory interventions may also be necessary to mandate certain levels of accuracy and quality of specific decisions, supported by governance processes to ensure validation and verifiability.

References

[1] B.S. Barn, The Sociotechnical Digital Twin: On the Gap Between Social and Technical Feasibility,. In: *2022 IEEE 24th Conference on Business Informatics (CBI)*. pp. 11–20 2022.

[2] M. Segovia and J. Garcia-Alfaro, Design, Modeling and Implementation of Digital Twins, *Sensors*, Vol. 22, 2022, p. 5396.

[3] A. Sharma, E. Kosasih, J. Zhang, A. Brintrup, and A. Calinescu, Digital Twins: State of the art theory and practice, challenges, and open research questions, *Journal of Industrial Information Integration*, Vol. 30, 2022, p. 100383.

[4] M. Attaran and B.G. Celik, Digital Twin: Benefits, use cases, challenges, and opportunities, *Decision Analytics Journal*, Vol. 6, 2023, p. 100165.

[5] B.S. Barn, T. Clark, S. Barat, and V. Kulkarni, Towards the Essence of Specifying Sociotechnical Digital Twins,. In: *Proceedings of the 16th Innovations in Software Engineering Conference*. pp. 1–5. *Association for Computing Machinery*, New York, NY, USA 2023.

[6] S. West, O. Stoll, J. Meierhofer, and S. Züst, Digital Twin Providing New Opportunities for Value Co-Creation through Supporting Decision-Making, *Applied Sciences*, Vol. 11, 2021, p. 3750.

[7] V. Braun and V. Clarke, Using thematic analysis in psychology, *Qualitative Research in Psychology*, Vol. 3, 2006, pp. 77–101.