# QUALITY DIMENSIONS FOR DIGITAL TWIN MATURITY IN THE CONTEXT OF DUTCH PUBLIC SPATIAL PLANNING

KOEN SMIT,[1] ROB PETERS,[2] CHAIM DE GELDER,[1]
JOHAN VERSENDAAL[1]

[1] HU University of Applied Sciences Utrecht, Digital Ethics, Ultrecht, Netherland
koen.smit@hu.nl, chaim.degelder@hu.nl, johan.versendaal@hu.nl
[2] Province of Utrecht, Ultrecht, Netherland
rob.peters@provincie-utrecht.nl

Digital Twin (DT) technology is being increasingly adopted by local and regional governmental organizations in the Netherlands to support spatial planning decision-making, balancing contradicting policy ambitions. These DT solutions are becoming more complex as more perspectives, based on sophisticated calculations, are added to one integrated view of the problem space. To be able to validate the quality of these DT solutions, quality dimensions are to be established. This study focuses on identifying quality dimensions for DT solutions, including legal and policy perspectives, and safeguarding public value; thereby transcending the technical focus that most contributions on quality dimensions for DTs have in the current body of knowledge. Based on empirical data collection and analysis, 15 quality dimensions were identified. Future research should focus on further operationalizing these dimensions, allowing for measuring DT solution quality on a maturity scale.

**Keywords:**
digital twin, maturity model, quality dimensions, dutch spatial planning, public values

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## 1 Introduction

DT technology is gaining attention in academia and industry, particularly in the manufacturing and asset management domains (Uhlenkamp et al., 2022), as well as in healthcare (Fuller et al., 2020) and government (Peters et al., 2022). While there is no consensus on a standardized definition of a DT, most research views it as a cyber-physical system that shares the concepts of a physical entity, a virtual model, and connections between both (Liu et al., 2022). This study adheres to the definition of a DT as "a set of linked operation data artefacts and (simulation) models, which are of suitable granularity for their intended purpose and stakeholders and evolve throughout the product life-cycle" (Boschert & Rosen, 2016). However, this definition does not fully comply with a true DT that should support bi-directional communication (Fuller et al., 2020; Liu et al., 2022).

The government sector is using DT solutions more frequently to facilitate stakeholder discussions on operational asset management and permit processing for citizens during the spatial planning process (Marcucci et al., 2020; Peters et al., 2022; Wan et al., 2019). However, the growing use of DT solutions raises concerns about their design, development, implementation, and impact on society, as well as their role in the democratic-legislative arena (Peters et al., 2022). Therefore, it is important to consider public values, particularly in the context of the ongoing climate discussion.

An increasing number of municipalities, provinces, and national governmental agencies in the Netherlands are experimenting with DT solutions to support spatial planning. However, these experiments are mostly isolated, and governmental organizations aim to collaborate to increase the effectiveness of their DT solutions by exchanging relevant DT models, such as heat stress, flood risk, nitrogen emissions, biodiversity, or land/zoning usage (CROW, 2022). This collaboration reduces redundant creation of DT models by scarce Subject Matter Experts (SMEs) who are proficient in both spatial planning and data management and science. Uniformity is also required for larger-scale benchmarking using monitors such as emission, air quality, or water quality monitors to measure policy effects.

Governmental organizations aim to increase the effectiveness of DT solutions by combining different DT models for variant analysis, simulation, and effect monitoring. Each DT model represents one or more measurable indicators related to specific policy ambitions, which may conflict with each other, such as noise level DT models relating to both mobility and quality of life (Deng et al., 2021; Ketzler et al., 2020; Schrotter & Hürzeler, 2020). Balancing these indicators in 3D spatial planning can better support scenario building and decision-making compared to printed 2D maps. The quality of DT models that curate policy ambitions into validated visualizations is the focus of this paper. To ensure the integrity of the digitalization process of policy ambitions, the Province of Utrecht is looking for ways to establish the quality of DT models made by colleagues from other Dutch governmental agencies and third parties involved in building real-estate projects.

To the knowledge of the authors no work on quality dimensions for DT models from an integrated perspective, i.e., integrating technical, legal, and public values, exists in the current body of scientific and practical knowledge. Also, it is important to include the cultural and contextual aspects in constructing quality dimensions for DT models, that, to the knowledge of the authors, has not been done before. Therefore, provided a Dutch context, our research question in this paper is as follows: '*What quality dimensions for establishing DT maturity level for spatial planning are deemed important in the context of the Dutch governmental domain and the preservation of public values?*' Because there is not much research on this topic yet, we intend to collect data for answering from observations of professionals in practice, operationalizing an empirical point-of-view.

The remainder of this paper is structured as follows. In section two, the background and related work are presented. This is followed by our research method in section three. Then, the results of our analysis are presented in section four. Next, section five discusses the limitations of this study with future research directions, which is followed by the conclusions in section six.

## 2 Background and Related Work

Dutch governmental agencies responsible for spatial planning, such as provinces and municipalities, use steering mechanisms to execute law and regulations for implementations and policies for localization in specific areas of planning. The related cyclic process is often referred to as the policy lifecycle (CROW, 2022) and comprises four phases, being: 1) Policy development, 2) Policy execution, 3) Policy enforcement, and 4) Policy monitoring. The policy development phase comprises the creation of spatial planning ambitions as well as more detailed spatial plans based on measurable parameters and calculation of effects. It is important to note that DT solutions are increasingly being used in this phase to assist in determining a proper trade-off between policy ambitions represented by indicators to create spatial plans for a given area in a Dutch city or region (Future Insight, 2023; Gemeente Rotterdam, 2023; Vereniging van Nederlandse Gemeenten, 2022; Witsenburg, 2020). The second phase focuses on the implementation of the policies, e.g., so that concrete ambitions and goals are applied to planning areas in city programmes. During the third phase, governmental services are provided such as online permit checkers for civilians and organisations that need to comply with these ambitions and specific goals. This third phase also entails the enforcement of policies concerning the actual physical situation where the Dutch government has the responsibility to ensure that individuals or organizations act according to the implemented policies, e.g., do not cut down protected tree species or extend buildings without official permits. Lastly, the fourth phase focuses on monitoring the extent to which policy goals and ambitions are achieved, which is an important fundament for the continuous improvement of the policies implemented. For this study, we are looking for relevant quality dimensions that assist Dutch governmental organizations in determining the quality of their DT models throughout the whole policy lifecycle. Yet, DT models are, at this moment in time, generally used in the first phase; Policy development, by civil decision-makers from Dutch provinces and municipalities such as Amsterdam, Rotterdam, Utrecht & Amersfoort.

A recent study that was performed on a large number of contributions with a broad focus on available DT Maturity Models (DTMMs) (77) revealed 31 dimensions across seven categories, albeit with a focus on production and logistics, see figure 6 in the work of (Uhlenkamp et al., 2022). We look at DTMMs as they are a good starting point and might contain relevant quality dimensions for DT models. In the context of this study, we refer to digital twin maturity levels as a hierarchical framework that describes the degree of advancement and integration of a digital twin into a system or process (Madni et al., 2019; Shahzad et al., 2022; Uhlenkamp et al., 2022). The analysis presented by Uhlenkamp et al., (2022) is recent, thorough and is entirely covering the technical perspective of a DTMM, e.g., levels of cognition, model maintenance, and computing capabilities, while largely lacking the consideration of explicit legal, policy, and preserving public values and the FAIR translation of indicators into the DTs. Results from our own narrative style literature review (Paré et al., 2015) reveal a similar direction, where contributions on DTMMs seem to predominantly focus on the technical capabilities of a DT and its underlying DT models, e.g., in the work of (Enders & Hoßbach, 2019; Fuller et al., 2020; Lim et al., 2020; Rasheed et al., 2020). Also, one should take into account that many DTMMs available in the current body of knowledge are designed to be either specifically tailored for a domain, e.g., manufacturing, healthcare or aerospace or designed to be universally applicable (also referred to as cross-domain), see table 3 in the work of (Uhlenkamp et al., 2022).

From a legal and policy point of view, it is important that the DT model is validated and holds when a decision made by spatial planners using a DT solution is disputed by individuals or organizations in court or permit processes. Challenges concerning this decision-making process are revealed to be numerous (Peters et al., 2021, 2022) and given the importance of legally-grounded technology (Peters et al., 2022), which represents important public values such as transparency, safety or fairness, the legal aspect should be taken into consideration when determining the value of DT model integration.

For the successful implementation of DT solutions, acceptance by stakeholders in the context the DT is applied is deemed "extremely critical" (Rasheed et al., 2020). This involves trust from the spatial planners, decision-makers, legal advisors as well as the individuals impacted by the decisions made based on the DT models in the DT solution. Trust in the DT solution is the umbrella term here, but it comprises a combination of many public values (Voas et al., 2021) represented by the DT solution, which also differs per stakeholder group. Because of this pluriformity, it is not sensible to explore all of these integrally in this study, at least not at this stage. As the maturity of the research domain is low, this stage should focus on identifying constructs and their relations (Edmondson & McManus, 2007). Therefore, we focus on exploring the concept of public value for policymakers and decision-makers in a legal and policy arena where disputes about climate goals, housing and SDGs are becoming increasingly severe and digital means are becoming part of the political arena. Public values are those providing normative consensus about 1) the rights, benefits, and prerogatives to which citizens should (and should not) be entitled, 2) the obligations of citizens to society, the state and one another; and 3) the principles on which governments and policies should be based (Bozeman, 2007). As can be derived from the above definition, the normative consensus on the mentioned aspects in itself represent values relevant for individuals, e.g., privacy, equality, democracy, integrity, and honesty. A set of validated principles commonly used in the combination of ICT, the governmental domain and the use of DT solutions is FAIR. The FAIR framework is an abbreviation for 1) Findability, 2) Accessibility, 3) Interoperability and 4) Reusability (GoFAIR.org, 2016). It is used as a framework by different Dutch governmental agencies guiding the use of technology, thus also covering the use of DT solutions. Because of this we utilize the FAIR framework as a central framework to identify relevant public values to determine DT model quality, and with this its maturity.

## 3 Research Method

The main aim of this study is to identify quality dimensions for determining DT maturity in the Dutch governmental domain. The maturity of research in this area is considered low, particularly for DT maturity research focusing on non-technical capabilities. Therefore, an exploratory and inductive approach is chosen (Edmondson & McManus, 2007) to extract relevant quality dimensions from practice, as an increasing number of Dutch provinces and municipalities are using DT models in the policy development phase.

### 3.1 Data Collection

We focused on exploring the opinions of SMEs concerning two aspects: 1) which quality dimensions are relevant in establishing DT maturity? And 2) what criteria are relevant in the context of the quality dimensions identified? For this study, secondary data was used, originating from the end of 2020 until the end of 2022. In total, thirteen SME sessions with an average duration of 1,5 hours were included in the dataset, which were all in Dutch. In these digital sessions, Dutch SMEs discussed DT cases that were developed and applied in the Netherlands, predominantly in the context of the Dutch government. The SMEs were mostly employed at Dutch governmental agencies, though the expert sessions also hosted several other interested participants such as researchers, semi-governmental experts and commercial DT model suppliers. In total, 15 hours of video footage was collected.

The sessions were organized in a presentation style setting in which two to four presenters digitally presented to a crowd after which Q&A was organized and discussion about the DT model ensued. In total, an average of 45 participants were present during each of the sessions. Not all participants could interact with the speakers given the large number of participants and limited time for each expert session, however. In addition to the expert sessions, two documents were coded. These official documents were produced with and by the provincial council of Utrecht together with other SMEs focused on how to further develop their DT models to support spatial planning.

### 3.2 Data Analysis

The data was analyzed using a thematic coding approach. Three coding cycles similar to Strauss and Corbin's (1990) process of 1) open coding, 2) axial coding, and 3) selective coding was used. The first round, open coding, involved analyzing significant participant statements. In this process, we tried to identify what Boyatzis (1998) refers to as "codable observations". Thus, we coded the data by identifying statements (both written and in audio) that discussed quality dimensions for DT models. For example, codable observations were: "*Most suppliers of Digital Twin platforms and models are built and offered in a closed sourcing agreement.*", and "*Depending on the policy phase the model supports, you need static or dynamic data.*" Synonyms as well as redundant codes were all registered to ensure completeness. This process was conducted in several steps of which the first step was to ensure high intercoder reliability among the three research team members. Three researchers coded the first expert session separately from each other during the first step. This resulted in a similarity of 0.759 using the Krippendorfs Alpha coefficient, which is acceptable given the fact that the study is explorative (Lombard et al., 2004; Yeaton & Wortman, 1993). Because of this, two coders proceeded with distributing the data and coding them separately from each other. Additionally, the two coders compared one more random expert session from the data together to compare the results to see whether coder reliability was maintained, which was the case.

Subsequently, we conducted axial coding. In this round, we categorized the open coding results so that quality dimensions can be identified. For example, we coded the following five codes under the quality dimension **Visualisation capabilities**: *"Visualisation of real-time data is better when done in symbols because textual information is* *rather slow."*, *"Visualisation of fictive settings must be possible next to realistic visualisation because of the closeness for the affected user."*, *"Visualisation in a virtual reality"*, *"One must deliberately choose which data to visualise and which data to omit depending on each stakeholder involved"*, and *"Changing between 2-D and 3-D map layers"*. This process was conducted by two researchers and resulted in 20 Digital Twin Quality Dimensions (DTQDs).

Lastly, we conducted selective coding to normalize the identified categories as well as to re-assess codes that could not be attributed to any of the existing DTMMs, in which approximately 50 codes could be assigned given the discussion involving the context in which a statement has been made. The normalization was discussed between the two researchers involved in the coding during rounds one and two. This process resulted in the recategorization of five DTQDs into existing ones. For example, the quality dimension 'Level of detail capabilities' has been merged with the quality dimension 'Visualisation capabilities' because, when analysing the context of the statements and semantics of the codes we learned that it concerns a visualisation criterion and does not warrant a separate quality dimension. In total, 103 codes were deemed not suitable enough to be included as supporting existing or new DTQDs after three rounds of thematic coding. The results of this stepwise process are presented in the next section.

## 4 Results

Based on our analysis we identified 15 DT quality dimensions, which are further detailed in this section. The dimensions are sorted by the number of codes identified. Furthermore, we clustered the dimensions using 1) Technical, 2) Governance, or 3) legal labels. Figure 1 provides a visual summary of the identified DTQDs.

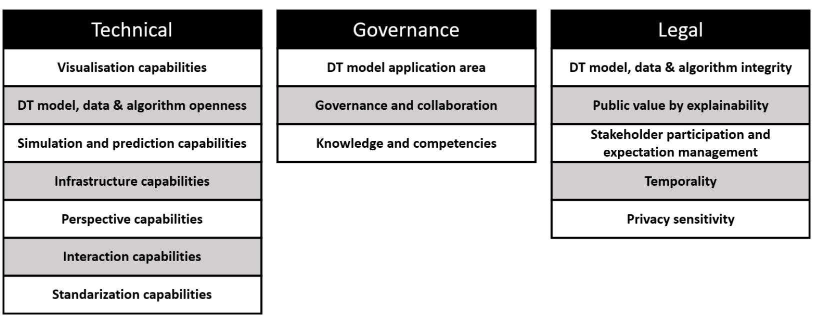


**Figure 1: Identified DTQDs**

Governance - DT model application area(s) and goal(s) (220 codes)
The model in a DT for a certain area in a city or region consists of policy themes. The DT model itself serves the goal of balancing the policy themes and ambitions and covers a perspective, based on one or multiple data sources, that constitute indicators and their mutual interaction in business rules and the foundation for these rules, which must be made explicit. Examples of thematic indicators are air quality, road infrastructure, soil structure, elevation level, water storage, biodiversity, light emission, energy usage, social participation, public transport mobility, economic building function, etc.

**Technical - Visualisation capabilities (149 codes)**

Because DT models enable the visualisation of multiple integrated perspectives, knowledge elicitation and communication become more effective and efficient. SMEs state that, although not always required given the type of data, 3-D visualisation helps manage complexity for all stakeholders. Part of that complexity is the inherent capability of adjacency, where sound affects health, given a specific distance between source and housing quarters, for example. Many calculations among different indicators are set as regulations and permit requirements. Also, being able to work with different levels of detail is deemed important. Effective visualisation when integrating data in one view includes appropriate colouring, layers, dashboards and graphs. Also, augmented and virtual reality technology are mentioned as contributors towards the quality of visualisation by SMEs. An example of this is where 3-D above and below-ground data is integrated into one view using different colour markings for types of infrastructure. Using this visualisation has lowered the error margin for building accidents by 3-5%.

**Technical – DT model, data, algorithm openness capabilities (141 codes)**

Often mentioned by SMEs is that DT models and data should be openly maintained and shared. This increases transparency towards and auditability by stakeholders. Openness is a multi-faceted concept that could relate to the data being publicly available, availability of the calculation algorithm, open sensors to facilitate citizen science, re-use of data and DT models, etc. Other important criteria mentioned were, in a technical sense, the quality of the data and how data could be safely shared. Also, SMEs want to be able to modify and further develop third-party DT models themselves after implementing them. For example, SMEs stated that most DT models currently being released are closed source, not enabling proper collaboration, which is deemed inefficient especially because Dutch governmental organizations should collaborate to achieve targets and policy ambitions at higher administration levels (i.e., ministries) as well as to meet with public expectations.

**Technical - Simulation and prediction capabilities (120 codes)**

One of the core additions to the spatial planning policy lifecycle using DTs is its ability to simulate scenarios and predict outcomes. SMEs state that civil servants rely on simulating effects, probability calculations, stress testing, impact-assessment, etc. It is also important for them to be able to work with KPIs and thresholds so that the effectiveness of the simulation of the scenario can be established. Underlying the simulation and prediction is the promise of increasingly more effective and efficient utilization of artificial intelligence. An example mentioned is the ability to predict water damage in a city when riverbanks are flooded during storms, where mobility, demographics and weather data are included in the predictions.

**Technical - Infrastructure capabilities (104 codes)**

Using (a combination of) DT model(s) with large datasets in a 3-D environment requires proper infrastructure. SMEs urge that the DT platform and its infrastructure should support large sensor networks and APIs to interface web-based services and datasets used in the DT models. The amount of processing power of a DT model is also mentioned as an important criterion by SMEs because current DT models do not seem to scale appropriately. There is often a trade-off between the level of detail and the size of the area covered in the DT. The larger the size, the harder it becomes to maintain the same level of detail for that area. Also, depending on which policy lifecycle phase must be supported by the DT model, either static or dynamic data must be used. The update frequency of data is high when policies are monitored using automated sensor networks creating a near real-time datastream, requiring different resources compared to one-time-only imports of historical data. An example of an infrastructure choice is about how to provide the DT model to stakeholders, either web-based or in a client-server (local) configuration. This choice impacts the required infrastructure capabilities for governmental bodies.

**Technical - Perspective integration capabilities (100 codes)**

A (3D) DT platform offers the possibility to combine multiple perspectives in one overview. SMEs state that spatial planning complexity becomes more transparent once multiple layers of data are combined, on a technical level. This in turn improves their ability to consider different indicators as well as to decrease error margins created by misalignment between planning and execution. For example, by combining noise, green and mobility data, one can use an assessment framework to balance a decrease in quality of life for occupants living near busy roads, keeping city segments accessible for public transport, maintaining biodiversity, and reducing heat-stress in the city, amongst other policy ambitions. SMEs stress that combining physical and social data, amongst others, is very important for efficient and effective spatial planning policy design.

**Legal - DT model/data legal integrity (93 codes)**

Using DT technology to support policy lifecycle management in spatial planning requires the DT model and data to be reliable and validated. SMEs stress that the DT model and its underlying data must have the legal power to hold up in court, or else it cannot be used effectively in spatial planning. Legal foundation is also multi-faceted because one could refer to the sensors used, the dataset itself or the algorithm used to represent an indicator, e.g., nitrogen pollution. For example, some SMEs stated that DT models published by scientific national knowledge institutes are preferred over, e.g., commercial third-party organizations or from citizen science, while others pose that such data is just as sound.

**Legal – public value by explainability (65 codes)**

Each DT model inherently represents a combination of ambitions with indicators. SMEs stated that these indicators should be made explicit so that the users of the DT model can use the DT model in a way that these indicators are all considered in an assessment framework that is used to ground spatial planning decisions. For example, SMEs find that the DT models and underlying ambitions and indicators considered should be explicitly communicated and made explainable when presenting spatial planning policy decisions. Such an approach also forces third-party/commercial DT model developers to be transparent about indicators served by their DT models as well as to take public values into account by design.

**Governance – Governance and collaboration (63 codes)**

Governance proved to be multi-faceted, however, is deemed an important cornerstone for SMEs. It is important that, when collaborating with other organizations, governmental bodies explicitly manage ownership of DT platforms, DT models and data. Also, because of the call for standardization, the governance around the standardised components must be clear. Furthermore, governmental bodies aim to collaborate in a quadruple helix setting, which adds to the complexity of governance around DT models. For example, when a standardised federative national DT platform would enforce a standardised approach, it must be clear what local autonomy the governmental bodies have in building their own DT models.

**Technical - Interaction capabilities (59 codes)**

In addition to the visualisation capabilities of a DT model, SMEs also stressed the importance of interaction capabilities. Because multiple perspectives are combined, SMES find it useful to interact with the data so that layers of data can be enabled or disabled. Changing levels of detail by zooming or selecting specific areas on maps are examples of how interaction helps stakeholders utilize the data to support scenario building and simulations. SMEs also mentioned augmented and virtual reality, e.g., with a hololens, as ways to more realistically interact with the DT model. Other examples of using these technologies are walking, driving or flying through the DT.

**Legal - Stakeholder participation and expectation management (56 codes)**

Different stakeholders are involved during the policy lifecycle. SMEs state the importance of explicitly taking into account when each type of stakeholder is involved and to what extent. For example, involving citizens during the policy design phase provides them with the opportunity to influence the design of their neighbourhood, while it could also be the case that citizens are merely informed about the plans using the DT at a stage in which they could not influence the design at all. The way participation is perceived is also based on a few other criteria such as the level of detail, the fictiveness of the visualisation, and what data is presented.

**Technical - Standardization capabilities (34 codes)**

One dimension that is similar yet distinct from the openness of a DT model is that of standardisation. SMEs stated that for them to be able to effectively collaborate, DT models and data should be interchangeable as well as their platforms be interoperable as much as possible. SMEs expressed their needs toward a national standard or principles, e.g., using an Object Type Library, reference architecture, and definition libraries. Using a more standardized approach enables importing DT models, standard building blocks, and more plug-and-play working using DT platforms. For example, because of the current lack of standardisation, DT models between most Dutch cities are not interchangeable, hampering collaboration between them.

**Governance - Knowledge and competencies (16 codes)**

When DT models are introduced, their integration within the DT platform and interpretation of the data must be secured. SMEs declared that to be able to do so, people must have the right competencies. Also, knowledge about the DT platform and models must be retained by the governmental bodies using the DT for spatial planning, as employees leaving organizations causes a knowledge drain. To guarantee proper competency development and knowledge management, SMEs think it is important to collaborate with universities, domain standardisation agencies, and other partners. Additionally, decision-makers must be trained in using DT technology for spatial planning purposes in a value-sensitive way.

**Legal – Temporal capabilities (13 codes)**

Again, using a DT model for spatial planning decision-making requires it to be recognized as a legal foundation. However, decision-making processes commonly take a long time and data changes over time as well, which requires the DT platform and model to support proper archival capabilities. The moment a decision is made by stakeholders, its context, data, and algorithm used should be saved so that it can be reproduced when governmental bodies are requested to explain the decision in a later stage of the policy lifecycle. For example, SMEs want to be able to explain to citizens what circumstances (and data) were relevant at the time when the decision was made. This is especially relevant given the increasing level of monitoring of policy effects as part of the legal obligations of governments. There is a need for semantic consistency between policy ambitions and policy effects.

**Legal - Privacy sensitivity (9 codes)**

A combination of different datasets could lead to undesirable traceability towards individuals. SMEs stated that this could harm the privacy of individuals, especially when the data is accessible to the public. This risk is higher when data from the social domain is included in the model. An example would be where demographic health data is used to signify differences between streets, which could also be used to trace personal information towards a specific household or individual.

## 5 Discussion and future research

The findings in this study have to be seen in light of some limitations. The first limitation concerns the depth of our empirical exploration of quality dimensions of DT models intending to construct a DTMM. While we established a list of dimensions with possible criteria for each dimension, based on the current data we cannot quantify a level of maturity on these dimensions, yet. Future research should further operationalize our findings and derive possible dependencies between them. The same holds for dependencies across the quality dimensions, which is an important aspect when constructing MMs (Mettler et al., 2010). The second limitation concerns the data that is used to arrive at the DTQDs presented in this paper. We used secondary data as our primary data source. This presents a disadvantage over data primarily collected for this study, because of its potential lack of focus during the SME sessions as well as that coverage of all relevant DTQDs cannot be guaranteed. While theoretically, this is correct, our data analysis revealed that saturation was reached rather quickly when coding towards DTQDs in round two, meaning that most of the independent discussion amongst SMEs limited itself towards the concepts discussed in this paper. Another advantage of this approach is that it prevents some bias types. Future research should therefore include a larger scale direct approach in which SMEs are questioned about the DTQDs and their importance to determine the weight of the DTQDs at a later stage of development.

Concerning our coding approach, some limitations could affect the validity of the DTQDs presented in this paper. In total three research team members engaged in coding, of which two primarily coded the data. Future research should focus on increasing the number of independent coders. On multiple occasions, we identified a large consensus amongst the audience on certain statements, which we could not explicitly code due to the online setting of the meetings. Therefore we argue that our codes could have more empirical value than the absolute number of counts in our dataset implies. Whether this is the case should be further explored in future research.

## 6 Conclusion

To conclude this paper we revisit our research question: 'What quality dimensions for establishing DT maturity level for spatial planning are deemed important in the context of the Dutch governmental domain and the preservation of public values?' Based on a thorough analysis of secondary data featuring rich debate amongst SMEs in the context of the Dutch government we were able to derive 15 DTQDs along with possible criteria that constitute maturity. There are similarities between our findings and the results presented in the study presented in (Uhlenkamp et al., 2022). These similarities are predominantly focused on the technical dimensions of maturity, while the dimension of human-machine interaction is also present, though described at a high level of abstraction. Interestingly, the legal aspect as discussed in our data is not or barely mentioned in other studies related to DTQDs and should be further explored and operationalized in future research.

From a theoretical perspective, this study presents new knowledge about the empirical point-of-view that SMEs have in the Dutch context. It also adds to the knowledge about how the maturity of DT models can be measured as, to the knowledge of the authors, most contributions fully or predominantly focus on technical aspects of maturity. This study identified explicit empiric evidence concerning, e.g., the legal integrity of DT models, participation capabilities, and explicitation of policy ambitions. The legal integrity dimension points to two areas for further research. On the one hand, it is observed that effect monitoring gradually becomes a new standard in legislation, which in turn generates a push for consistency between policy design and policy output in the democratic arena. Citizens demand that politicians achieve what they have promised, and DT solutions seem to provide the means. On the other hand, we observe a merger between article or text-based legislation regarding those policy goals and the object-based area of application (effect). Further substantiation could support the theory that DT technologies enable such a merger between unstructured text-based administration and more object-oriented spatial data infrastructures as we already have observed with Inspire and Natura 2000 (Peters et al., 2009; Peters, 2016). This Merger implies a different approach towards legal processes from document versioning towards agile software development, This, in turn, requires a completely different approach or culture towards legislation. From a practical perspective, this study contributes towards Dutch governmental bodies about where to measure DT model quality on. Revealing the spectrum of DT model quality enables government agencies as well as SMEs responsible for integrating DT models in DT platforms to start and guide the discussion with regards to their approach of collaborating with others on integrating increasingly larger (combinations of) DT models underlying the policy lifecycle and spatial planning decision-making process.

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