PED-ID

Holistic assessment and innovative stakeholder involvement process
for identification of Positive-Energy-Districts

D2.1 – Annex: Identifying the Potential Role of Digital Twins in Supporting PEDs

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Acronyms table

Acronym	Definition
DTCC	Digital Twin Cities Centre
PED	Positive Energy District

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1 Introduction

This report presents the results from an interview study that evaluated the potential of Digital Twins to contribute to Positive Energy Districts (PEDs) with focus on early development stages, from selected stakeholders' point of view.

1.1 PED-ID Project

PED-ID is an innovation project that aims to accelerate the decarbonisation of the urban environment by promoting the implementation of Positive-Energy-Districts (PED). PEDs are districts in urban areas that manage their resources to achieve net-zero energy balance (more energy is produced than consumed) and reduce greenhouse gas emissions. This project provides decision-makers with improved information about methods, tools and guidance for PEDs at an early stage of development, proposing a knowledge-based participation process. Stakeholders will be able to actively use these methods in the data-driven participation process to consolidate their options and make decisions based on data. This process will be tested using real Living Labs of potential PED projects. With the help of this method, the decision on sites will be accelerated to reach the goal of 100 PED sites in Europe.

1.2 Aim & research questions

The aim of the study is to investigate if, and how, Digital Twins can contribute to improve identified challenges of Positive Energy Districts and to explore the potential to use Digital Twins to support stakeholders, their engagement, and prepare a specification for early-stage Digital Twins.

The following questions are explored:

- Which stakeholders in the industry require what kind of information?
- Which parameters are relevant to communicate visually in the early stages of PED development?
- What are the success factors, challenges, and critical points in PEDs and can Digital Twins contribute to overcome these challenges?
- What is the willingness of stakeholders to pay for Digital Twins in early stages?

1.3 Responsibilities and execution

This study was carried out under the guidance of Liane Thuvander (project leader for this specific study of the PED ID project) at Chalmers University of Technology, department of Architecture and Civil Engineering and in close cooperation with Keith Boxer from White Architects. This work is also part of the Digital Twin Cities Centre (https://dtcc.chalmers.se/) supported by Sweden's Innovation Agency Vinnova under Grant No. 2019-00041.

The empirical work was carried out by three students working at HandelsConsulting, with Sofia Kalles (project manager for the students' group at HandelsConsulting) together with Ebba Ankarås, and Tilda

Nilsson. HandelsConsulting conducted the interviews and the desk research and compiled the results into a power point presentation and a report. Liane Thuvander was responsible for the research design, she developed the interview guide, assisted with contacts for national and international stakeholders (potential interview persons), and transferred and modified the report from HandelsConsulting into the delivery *D2.1 Identifying the potential role of Digital Twins in supporting PEDs*.

1.4 Scope of this document

This document presents the results from an interview study and desk top research related to PEDs and Digital Twins in early stages:

- **Methods** – data collection procedures and background information about interviewees
- **Results and analysis** – main findings in relation to research questions
- **Conclusions and recommendations** – identification of key points

2 Method

An interview study of as relevant identified stakeholders has been conducted and combined with desk research, a minor literature review. In total, 15 qualitative interviews were conducted with experts in the building sector including property managers, architects, and technical consultants but also representatives from municipalities and funding organisations, see Table 1.

The respondents were identified via the PED ID projects, contacts of the researcher at Chalmers, and through internet research within the PED projects, for example, https://jpi-urbaneurope.eu/ped/, and relevant companies linked to the business.

The interviews were semi-structured and followed an interview guide, see Appendix. The questions covered background information about the interviewee, knowledge about Digital Twins, and needs and parameters relevant to be communicated (visually) in early stages of PED development

The interviews were performed via the online conference platforms Zoom and Google Meet and recorded via the platforms, in either video or audio format. From the recording, notes have been made and collected in an Excel document. The data were then analysed through discussions among the project members at HandelsConsulting.

Desk research has been conducted through Scopus and Google Scholar.

Table 1 Interview respondents. # = Respondent

#	Position	Company/ type of organisation	Date	Length	Role in PED	Location
R1	International projects	Innovation platform	23/3 - 2022	60 min	Communication of results, organize projects and stakeholders	Sweden
R2	Head of international research	Architect office	24/3 - 2022	41 min	Project leader of White's PED id research program	England
R3	Sustainability leader focused on energy	Municipality	16/3 - 2022	39 min	Coordinating Municipality's role in Uppsala Business Park	Sweden
R4	Co-owner, technical consultant, head of energy- and technology	Energy- and property technology consultancy	18/3 - 2022	51 min	None	Sweden
R5	CEO and co-founder	Digital Twin company	23/3 - 2022	43 min	None	Sweden
R6	Technical specialist regarding city development	Property owner	24/3 - 2022	54 min	Coordinates companies' involvement in Uppsala Business Park	Sweden
R7	Head of innovation and energy districts	Research and engineering office	25/3 - 2022	60 min	Technical expert and intermediate person pushing and planning the project	Austria

#	Position	Company/ type of organisation	Date	Length	Role in PED	Location
R8	Project manager/ Coordinator regarding trans PED	Research and demonstration platform	25/3 - 2022	60 min	Microgrid project connected to PED, trans PED and development of governance approach to PED	Sweden
R9	City planner involved in sustainable business planning	Municipality	29/3 - 2022	34 min	In a broad spectrum involved in the plan regarding Uppsala Business Park	Sweden
R1	Senior Research Officer	Funding Agency	16/3 - 2022	30 min	Financed and coordinated PED projects	Sweden
R11	Business developer manager	Consultancy with experience of Digital Twins	28/3 - 2022	21 min	Providing software for PED and finding partners to work on PED projects	Scotland
R12	Associate Partner, Urban Planner & Designer	Design studio – architects and urban planning	29/3 - 2022	35 min	Indirectly involved through Uppsala Business Park	Sweden
R13	Development Manager Ecological sustainability	Parent company of municipal housing companies	11/4 - 2022	60 min	Has applied for a PED project	Sweden
R1	Senior adviser, Program manager (international)	Funding Agency	13/4 - 2022	75 min	Yes	Sweden
R15	Operations consultant	Consultancy with experience of Digital Twins	21/4 - 2022	24 min	Yes	Scotland

At the time when the interviews were conducted, twelve out of fifteen respondents were involved in PEDs. One respondent will most likely be involved in PEDs in the future. Two respondents were not involved at all in PEDs but are instead involved in Digital Twins.

Concerning the awareness of Digital Twins, the assessment is that the respondents can be divided into three groups. One third of the respondents were familiar with the concept of Digital Twins, one third were acquainted, and one third were new to the concept of Digital Twins. Digital Twins are not a commonly used tool among the respondents. The perception of Digital Twins is less widespread on the market it might be a contributing factor to the difficulty of justifying the implementation of Digital Twins in PED; the limited use of Digital Twins may give reason to uncertainty and reduced legitimacy.

3 Results and analysis

This chapter presents the main results from the interviews combined with the result from the desktop research.

3.1 Potential use(s) of Digital Twins

Based on the interviews, the benefits of using Digital Twins can generally be divided into four topics: *planning; visualization; easier communication with external stakeholders; and simulation for different scenarios*.

The respondents see the potential uses of Digital Twins in PEDs to improve planning by being able to visualize different scenarios before building, which can lead to increased cost efficiency and the prevention of mistakes. For example, with the help of a digital twin a building will not build in an area where the use of energy is not efficient or sustainable (R1). Demonstration of different possible outcomes can also be communicated visually through Digital Twins in order to motivate e.g., legislators and other decision makers to change laws and decisions that make it difficult for PED projects. Respondents also saw a potential use to visualize and simulate what could happen in different situations regarding energy costs for example (R8).

Using Digital Twins for planning and visualization could save PED projects time and money. For example, one could see a response directly in the digital twin without testing it in reality. With a digital twin it is possible to find problems that you would not have discovered otherwise, or find untapped potentials in a PED (R4, R6).

Key points from the interviews:

- **Digital Twins can be used to achieve the desired energy balance**. By being able to model different scenarios, one can decide whether to make further investments or changes (R3, R13).
- **Digital Twins give an opportunity to see how legislation can influence** the possibility to achieve the greatest possible benefits within PED (R9).
- **Digital Twins can be a foundation or basis for planning**. Digital Twins can make it easier for different stakeholders to understand the PED and they can be used to analyse and simulate different scenarios depending on the situation; to see what happens with costs in different situations for example. Real-time information could also be used to get an advantage of Digital Twins (R8).
- **Digital Twins should be used as a visualization tool** to be able to visualize facts such as graphs, etc., but also as a tool to motivate stakeholders and to integrate PEDs in urban planning at different scales with relevant visualization. Architects could use Digital Twins visualizations for communication with external stakeholders because PEDs would be easy to view (R2, R4).

The literature review emphasizes advantages of Digital Twins which include reduction of errors, uncertainties, inefficiency, and expenses in any system or process. Simulations allow the investigation of a number of scenarios without any additional cost, and the design and analysis cycles shorten, which makes the whole process of prototyping or re-designing easier and faster. Once implemented, Digital Twins can be used in different stages of the product design process, from conceptualizing the idea of

the product to its testing. The ability of a digital PED twin is to capture the complex and dynamic relationships of different components in PEDs, which allows new levels of analysis of complex environments (Devine et al., 2021; Zhang et al., 2021).

Desktop research also indicated that Digital Twins could deliver the data-driven information needed to uncover significant energy, carbon, capital and operational savings. This while taking account of resource use, transport, social and economic factors. Bridging the gap between the real world and simulation, the Intelligent Communities Lifecycle (ICL) Digital Twin developed by IES enables the energy efficient design and continuous operational optimization of entire groups of buildings (IES, 2022).

3.2 Stakeholders

When asking which stakeholder to engage in the early stages of implementing Digital Twins in PED, most of the respondents mentioned property owners followed by owners of technical infrastructures and energy companies as the key stakeholder, see table 2. One of the respondents (R13) also added that in early stages, it would be crucial to include city planners in the implementation of a Digital Twin in PEDs.

Table 2 Stakeholders mentioned by respondents.

Stakeholder	Mentions by respondents
Property owners	10
Owners of technical infrastructure	7
Energy companies	6
Architects	5
Municipality, politicians	5
City planners	4
County administration (Länsstyrelsen, Sweden)	3

3.3 Driving forces and success factors for PEDs

When discussing the needs and parameters relevant to be visually communicated in early stages of PED development and specifically the driving forces and success factors, the respondents mentioned first of all views and insights in PEDs related to the climate and sustainability aspect. One crucial driving force of PEDs is zero carbon emissions - climate neutrality (R7, R13).

PEDs could manage the energy that is already available, which in turn can reduce dependence on external energy sources (such as from other countries) and reduce infrastructure costs and dependencies from other countries. Since cities burden the environment, PEDs could lead the way for a systemic thinking in cities (R8) when planning and managing cities energy as it would decrease the cities climate footprint.

The majority of the respondents believe that a success factor of PEDs is the collaboration between different stakeholders (national and international) who otherwise would not cooperate. It was also mentioned the available technology and smart steering is advantageous as it makes PEDs possible (R13).

Findings from the literature review suggest that sustainability is the central driving force for Digital Twins in the built environment (Smart Built Environment, 2021).

3.4 Challenges and critical points with PEDs

The respondents have different perspectives on what the challenges and critical points of a PED project could be, the answers did however lead to two key issues that all respondents found problematic. The first, the *lack of a ''process leader''* (R14); who is responsible for the coordination and the operational process throughout the project. The second, *unclearness of who will finance* the project from start to finish (including finance for tools such as a Digital Twin). There were also a number of other aspects that were pointed out to be problematic or challenging during a PED project:

- The different wills and interests of the various actors in the project can make it hard to make decisions for the area (R3, R6, R2).
- Difficulties in keeping stakeholders interested throughout the project (R5, R6, R12).
- At an early stage there can be issues in defining a concrete goal and purpose for the project (R6, R9).
- Unclarities regarding who ultimately is responsible for the PEDs delivery and creation (R2).
- Big cities are by themselves not able to produce as much energy as they would need to be energy positive (R3, R13, R15).
- Finding appropriate business models that are suitable for several stakeholders with different needs to partner with each other (R3, R6, R8).
- The technology required for a detailed PED (and Digital Twins) can itself require a lot of energy (transmitters, throttles, meters and such instruments that regulate buildings in real-time runs on electricity and energy) (R13).
- Managing the human behaviour within PEDs (R13).
- No incentives for energy companies (R15, R11).

Respondents point at that these challenges could possibly be overcome by having a proper guide or roadmap for PEDs.

An article found through desk research identified challenges for developing PEDs. The challenges identified in the article could be divided into seven topics that describe issues hindering a successful implementation of PEDs. The topics are interrelated to each other, and they all need to be fulfilled in order for success in PEDs. The seven topics are: incentive, governance, process, market, technology, social and context. Two ways to address these challenges are crystallized; 1) ''a common need for systematic understanding of the processes behind them'', 2) ''cross-disciplinary models and protocols to manage the complexity of developing PEDs'' (Krangsås et al., 2021).

Common denominators that were mentioned in the interviews are (in the parentheses relevant topic identified by Krangsås et al. (2021)):

- Collaboration issues between stakeholders (government).

- Need for drivers and motivators (incentives).
- Need for engagement (social).
- Difficulties in decision making (process).
- Needs of appropriate business models (market). In the interviews, this was discussed concerning mostly Digital Twins by R8, but can be concluded to include PEDs as well.
- Need to consider local differences (context). Year-round solution of PEDs was also mentioned in the interviews, as well as the need for a broader perspective of the effects of PEDs.

This shows that the data from the interviews are in line with the Krangsås et al. (2021) study. The literature claims that a collaborative governance model is imperative to connect different stakeholders and align their interests and priorities. It also mentions the necessity and importance of multi-stakeholder engagement. The establishment of a common vision and shared values among stakeholders is key to driving such a collaborative process (Bossi, 2020; Sareen, 2022).

3.5 Challenges in the early stages of PEDs

The challenges in the early stages of PEDs that were mentioned by the majority of the respondents are the lack of a main responsible coordinator or organization/company for the whole PED project. This leads to other problems in questions concerning who takes greater responsibility and initiatives, such as financial or operational decisions.

Another mentioned problem (R1) is the lack of detailed planning and predictions to prevent errors or uncertainties which leads to unnecessary expenses. The lack of precise information in early stages was also brought up (R11) in perspective of the importance of implementing PEDs as quickly as possible to new projects. The respondent meant that PEDs can be implemented in already functional buildings and projects, but the tools are then vastly limited.

3.6 Improvements of PEDs

When asking for improvements of PEDs, the main PED improvements mentioned by the respondents concerned firstly the need of a concrete guide or roadmap for the process to move faster, but also to extend the system limit to broaden the PED to Positive Energy Neighbourhoods/States and taking local aspects such as weather into consideration.

Respondents see that PEDs could improve in following ways:

- → Become less detailed to develop faster, because there is a problem that PEDs become too detailed; a larger perspective and demonstration on how PED benefits the world's environment and climate; not just in one area (R3, R8, R12).
- → PED projects take an extensive amount of time to develop due to the fact that there is no adequate road map (and no main owner/responsible). A concrete approach or guide would be needed for the process to be more effective (R7, R2, R2).
- → Be able to show results in a better way (R6).
- → Create greater engagement in stakeholders to prevent them from dropping out of the projects during the process (R5, R6, R12).

- Want to see a year-round solution with PED (concerning Sweden, since solar cells seem to not be primarily useful during the winter) (R3).
- Finding ways to include several energy systems in the surrounding area (R13).
- Extending the system limit to more climate aspects than just energy, in order to get environmentally/climate neutral districts (R13).
- Finding a good business model and agreements, making it easier and more cost effective to share energy between stakeholders (R13).
- Making a clear definition of what a PED is and what it needs to be able to qualify as such, making it impossible to claim an area to be a PED when it is not (R15).

Regarding the respondents' views on whether Digital Twins could be a helpful instrument in improving and working with PED, all respondents agreed that the Digital Twins could be useful but to different extents. Digital Twins can help to improve PEDs in visualizing complex data, demonstrate scenarios that would be difficult for humans to predict, and through that optimize planning over time, but also from day to day. R13 proposed to add Artificial Intelligence (AI) to a Digital Twin, so the AI itself could find and evaluate different scenarios for the PED.

Note: the question regarding the potential of Digital Twins is also connected to this question, such as questions on PEDs challenges and improvements.

3.7 Needs for a successful Digital Twin in PEDs

There needs to be certainty regarding who will create the Digital Twins as well as who will assist with providing data. The data not only must be accessible and legal to use, but the stakeholders must also be willing to share the information. Another concern is the responsibilities which come with a Digital Twin. Several respondents emphasized the importance of clarifying who should own the Digital Twin and be responsible for the maintenance and financing aspects.

R5 believed in developing the Digital Twin at an early stage, instead of spending way too much time on planning for it. “You can make changes and add dimensions as you go instead. I believe it would facilitate a successful implementation” (R5). R6 also drew attention to the importance of being able to demonstrate at an early stage what economic benefits a Digital Twin and PED means.

R13 says that access to the energy data is important, as well as the model’s capacity to understand effects and integrate the data in order for the Digital Twin to be a good tool for making decisions.

The literature review also highlighted the importance of data sharing between different stakeholders, other twins, and cities since implementation of open standards, open data, and open-source code is a key to success. Digital Twins develop their true value when data is shared openly between sectors and domains which requires overhead coordination and interest in collaboration (Zhang et al., 2021). As Digital Twin technology deals with the data, one concern is about privacy, confidentiality, transparency, and ownership of this data (Devine, 2021). A successful implementation of Digital Twins also relies on efficient data sharing and the availability of open and shared data (Zhang et al., 2021).

3.8 Relevance of Digital Twins in early stages of planning PEDs

When asked to what extent Digital Twins would be relevant for the interviewed stakeholders working in PEDs especially in early stages, the majority said it is not relevant to them at the moment but could see it as a good tool for making decisions. The main reason for this was because the stakeholders interviewed could not see the profit, or the difference between a Digital Twin and an advanced 3D model in the early stages of PEDs. The respondents working within the Digital Twin's business were convinced that Digital Twins would be relevant further on for different stakeholders, as soon they understand the value of it.

> *"The biggest benefits of having a Digital Twin will be first when the district is built. As long as the district does not exist, it is not really a copy of reality but more of an advanced 3D model." (R4, R5, working with Digital Twins)*

It is also difficult to justify at the moment Digital Twins because they have not yet been proven to be effective or profitable or are not seen to be used successfully by other stakeholders. This is a commonly mentioned problem in the interviews.

The literature review confirms the lack of clear understanding about the value a Digital Twin can bring to individuals, businesses, or industries. Developing a Digital Twin is a time-consuming and labour-intensive exercise, which makes it an expensive investment. Therefore, economic feasibility studies and business models of digital PED twins are necessary. Unfortunately, case studies of successful practices or business models implementing Digital Twins into company activities or realistic estimations on the costs involved in this implementation are lacking (Devine et al., 2021; Zhang et al., 2021).

3.9 Parameters relevant to be communicated visually in early stages

Which parameters are relevant to be communicated visually in early stages of PED development? The question is hard to answer to because different stakeholders need different parameters. There is a broad selection of different parameters possible to communicate to various stakeholders, thus a selection of respondents means that the information should be highly tailored to the different cases and interests of each group (R2, R11).

> *"The number of parameters is related to different types of projects and may vary depending on which industry is involved in the respective project." (R14)*

Respondents argued that a certain area and project might be more interested in energy sustainability, while others might be more interested in sustainability reached through a lower carbon output. The same respondents were also very positive to the illustrative aspects that Digital Twins provide, such as the 3D modelling and the dashboard feature.

Other respondents were more concerned about how the building would look with solar panels and different energy solutions (R9). Some of the respondents who were able to answer the question agreed on what energy systems would be used in the development of the building. They were focused on how the building would use insolation, reusable and storable energy (R7, R4).

Other answers provided by interviewed stakeholders (R8, R12), provided a different approach to the question at hand and meant that all information generally was useful. Particularly concerning the power aspects previously lifted but they expressed that the information needed to be accessible faster. Giving up some accuracy for a more general but faster interactive Digital Twin would be more advantageous than an accurate but slowly receptive Digital Twin.

R13, working with property management, says that data relating to mobility is an aspect that property owners wish to see. R13 also mentioned important data or template numbers that can help with seeing net numbers on how properties affect climate neutrality; how to build to be climate neutral, concerning size, placing and shape of buildings and how it affects being climate and energy neutral, where solar cells can be placed and such.

3.10 Willingness to pay for a Digital Twin

Who should pay for a Digital Twin? None of the respondents had a direct answer to the question, which illustrates the complexity of this matter. The common view was that every stakeholder who benefits from it, which the majority believed to be the property owners, should pay for it. R13 says that a Digital Twin is a tool for city planners in early stages of PEDs, therefore they should be a part in financing a Digital Twin.

The respondents' answers were slightly scattered, but to conclude, many felt that the involved stakeholders should pay for a Digital Twin, such as e.g., property owners. A suggestion from several respondents was that all stakeholders that have overall responsibility and common denominators should split the cost for a Digital Twin. The problem with this is that different stakeholders own different parts (one owns the properties, one the energy and so on), or they have different interests and therefore it is difficult to get them to cooperate. R8 provided a form of response to this problem: one needs to design business models for this in order to demonstrate profitability with a PED collaboration for all different actors. Another option is to have a coordinator from the early stages of PED who can "pass the Digital Twin along" to an operator, and on to the next suitable stakeholder or person (R7). Many respondents, again, emphasize the importance of having a mainly responsible coordinator for the entire PED project, and that the lack of a coordinator causes problems with responsibility and financing etc.

When asking the question "Would you be willing to pay for a Digital Twin in early stages?" the majority of the respondents did not feel comfortable answering the question, due to the uncertainty of what would be needed to create a Digital Twin, who would take the responsibility for it, and which advantages it would bring. R3 also had difficulties with understanding how a Digital Twin differs from regular 3D modelling. Many do not consider themselves the right actor to be responsible for payment. Others are hesitant, as they are not familiar with what a Digital Twin is and what the benefit is versus the benefits of a 3D modelling. The ambiguity about ownership and responsibility also makes it difficult.

R6 did see the visual and technical advantages with a Digital Twin but emphasized the importance of its contribution to economic profitability as well. If a Digital Twin could achieve further cost efficiency, for example by replacing consultants, property developers would be willing to pay for Digital Twins on the condition that they possess it.

R5 suggested the real estate business as potential investors in Digital Twins since they in general have the capital required. R4 agreed but highlighted the lack of knowledge and potential use of Digital Twins within the industry.

4 Conclusions and recommendations

4.1 Digital Twins' contribution to Positive Energy Districts

The potential uses of Digital Twins according to the respondents can be divided into four topics: 1) planning, 2) visualization (design included), 3) communication between stakeholders and 4) simulation of scenarios. Digital Twins could, if successfully implemented, prevent and reduce technical errors (for example, preventing building on top of fundamental pipe systems) and find possible future improvements in PEDs. This is accurate in early stages as well as in far gone, existing PEDs.

Examples of how Digital Twins can help to overcome identified challenges of PEDs:

- Digital Twins could be used to overcome the lack of detailed planning in early stages of PEDs, through visualization and simulation of possible future situations.
- Include and integrate several energy systems.
- A tool to motivate human behaviour to change for the benefit of the PEDs to be achieved, through showing the possible results of a changed behaviour visually.

4.2 Digital Twins successful in PEDs

Three major themes have been identified: business models and stakeholder cooperation, responsibilities and process leader, and accessible data.

4.2.1 Business models and stakeholder cooperation

The benefit of a Digital Twin in PEDs must be communicated, and it must be communicated so that all stakeholders involved can relate to the benefits. Business models and data that demonstrate how Digital Twins can contribute to further profitability and cost efficiency are required. Appropriate business models for a digital PED twin, showing the profitability for involved stakeholders both individually and in groups to make it easier for stakeholders to understand why it would be beneficial for them to cooperate with each other is needed. The business model also needs to include some sort of marketing for a digital PED twin.

For example, Digital Twins can help overcome these experienced PED problems linked to stakeholder cooperation:

- Clarify results and profitability. (Which again motivates stakeholders to engage and cooperate with each other.)
- Visualization could simplify sharing energy between stakeholders and areas, which leads to cost efficiency

Challenges concerning cooperation between stakeholders, such as motivation and engagement could be facilitated by a Digital Twin if the Digital Twin is designed to show results and communicate benefits that are accurate to the relevant stakeholders.

4.2.2 Responsibilities and process leader

Responsibility must be crystalized; who will assist the Digital Twin with data? Who will be responsible for the operation? Who will finance it and who will own it? The main challenge with PEDs mentioned by all respondents involved in PEDs, is the lack of a ''process leader'' - a responsible coordinator on an operational level throughout the project. Thus, the existence of a process leader constitutes a vital requirement for a successful implementation of a Digital Twin. In addition, qualitative communication regarding responsibilities, ownership and maintenance is crucial for a successful implementation.

4.2.3 Accessible data

Lastly, to maximize the benefits of Digital Twins, open data is required. This requires that several actors are willing to cooperate and also to share data. This links back to the need of business models (for PEDs as well) showing the profits of stakeholders cooperating. In addition, there are legal obstacles due to privacy reasons and cyber security.

4.3 Parameters

Relevant parameters to be communicated through a Digital Twin are highly tailored depending on the needs of different stakeholders. Parameters focused on construction and design concerning energy flow; how to build to achieve desired effect, was the main answer given by the respondents involved in technical infrastructure and city planning.

4.4 Who should pay for a Digital Twin?

Digital Twins are not a commonly used tool among the respondents as the benefits are not known. Therefore, the willingness to pay for a Digital Twin is limited.

The most common answer from the respondents regarding which stakeholder should take the majority of the cost for a Digital Twin is the property owner. The property owner is believed to have the biggest benefit of a Digital Twin throughout the whole project.

Several respondents were of the opinion that everyone who benefits from a Digital Twin should take part in paying for it. Which is difficult to implement without highly motivated stakeholders that are made to cooperate by a responsible party that handles the coordination and planning of the implementation of the Digital Twin.

So, this circles back to 1) the lack of a process leader/coordinator, 2) the lack of a business model for a digital PED twin.

In conclusion, the lack of a process leader, the lack of an appropriate business model to motivate the use of a Digital Twin, and the cooperation between stakeholders are the main factors, according to the respondents, that stand in the way for the stakeholders' willingness to pay and therefore a successful implementation of Digital Twins in PEDs.

4.5 Key findings and recommendations

The key findings of the study can be summarized as follow:

- PEDs main driving forces are related to sustainability.
- The biggest success with PED is that several actors, who would not normally cooperate, now do so. This can create synergies and contribute to sustainability.
- The biggest challenges with PED are:
  - The lack of a clear process leader.
  - To maintain the involvement of all actors.
  - The lack of future funding.
- Business models for Digital Twins are required in order for stakeholders to want to
  - engage
  - pay
  - cooperate with each other.
- The function of a process leader in PEDs is both missing and needed.
- A proper guide or roadmap for PEDs could help overcome the challenges with PEDs.
- Willingness to pay for a Digital Twin is weak, for several reasons:
  - Due to the lack of knowledge of the benefits and uses of a Digital Twin.
  - Difficulties understanding how Digital Twins and 3D-modeling differs.
  - The question of ownership, responsibility and funding is vague and uncertain

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6 Appendix: Interview guide

Name of interviewee:
Position in organisation/company:
Country:
Role in PED:
Which PED:
Date for interview:
Length of interview:
Interview setting – phone/zoom:

1. **Introduction**
    a. Do you consent to the interview being recorded? (Explain why we record.)
    b. Short introduction on the purpose of the interview

2. **Background**
    a. What is your name?
    b. Where do you work?
    c. What position do you have in your current organization?
    d. Do you currently work with PED?
    e. What is your role in PED? / What is your experience from working with PED?
        - In what phase? (Master plan, planning, design, construction, operation)
        - How much experience do you have in it?
    f. Do you know about ''master plan''; overview plan made in the early stages of PED?
    g. Have you worked within a master plan/overview planning of PED?

3. **Digital Twins**
    a. What do you know about digital twins? How familiar are you with the concept of Digital Twins? *(If knowledge is lacking, briefly explain what a digital twin is.)*
    b. Have you used it or seen someone else use it?
    c. What potential use(s) of digital twins do you see?
    d. What stakeholders should or could be engaged in the early stages of implementing DT in PED?

4. **PEDs - Needs and parameters relevant to be communicated (visually) in early stages of PED development**
    a. What do you see as PEDs driving forces?
    b. What is the success of PED?
    c. What are the challenges/critical points with PED?
    d. What are the challenges in the early stages of PED? (Planning, master plan)
    e. How do you think PEDs could improve?
    f. Could digital twins be used to help improve PEDs/working with PEDs?
        - i. If yes; how?
        - ii. if no; why not?
        - iii. in the early stages?
    g. What would be needed for digital twins to be successful in PEDs? (In the early stages, master plan, planning)
    h. To what extent would digital twins be relevant for you as a stakeholder working with PED, especially in early stages of planning PEDs?
    i. What information would you need from digital twins as a stakeholder in early stages of PED in order to be able to develop it?
    j. Which parameters are relevant to be communicated visually in early stages of PED development?
    k. Who in PED needs what information in order to use digital twins and on what scale?
    l. Who should pay for a digital twin?
    m. Would you be willing to pay for a Digital Twins in early stages?
    n. Do you have suggestions for other people I could interview about this topic?

PED-ID TEAM

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