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BUILDING DIGITAL TWINS

MARKET PULL OR TECHNOLOGY PUSH?

The motivation for conducting this research came from the feeling that the development of digital twins for buildings had slowed down in recent years. We knew that many capable companies were working on the area, however, it felt that some of the momentum had been lost. This is only natural when you consider that digital twins are currently positioned in the trough of disillusionment in Garner's hype cycle - more about that later.

Our idea was to take a deep dive into the subject and to look at it in a new light. We felt that early studies had quite rightly focused on the vision of what digital twins could be. They mainly consisted of definitions and inspirational "wow effect" examples of what problems digital twins could solve. These examples were often close to science fiction and they needed to be, in order to generate interest in this emerging field from a wide range of problem solvers. If the technology behind the examples wasn't close to science fiction, then the ability to produce scaleable versions at a cost

that attracted the mass market certainly was. Our approach was to take a step back from what had been done before and to interview a wide range of stakeholders to find out what they wanted from digital twins.

The existing dialogue on digital twins for buildings has centered around building information models (BIM). The consensus is that BIMs contain a treasure trove of information and that they should be utilised after the design and construction phase. It's a classic technology push example "we have this amazing piece of technology, so let's use it". We wanted to take the opposite approach by initially focusing on the needs of the relevant stakeholders and by leaving the technology part until later. This report is a description of our journey following the market pull.

Dr. Ken Dooley, *Postdoctoral Researcher, Smart Buildings at Aalto University & Technology Director, Innovation and Development at Granlund*

> *Our approach was to take a step back from what had been done before and to interview a wide range of stakeholders to find out what they wanted from digital twins.*

FOREWORD:
NEXT STEPS FOR DIGITAL TWINS

Several companies across domains of the built environment have been discussing digital twins for quite some time. Technological advancements in cloud computing and building information modelling over the last two decades have opened new possibilities to manage data of built assets in a more efficient way, both within and between organizations collaborating in the construction or operation of buildings. But whenever the topic of conversation switches to "digital twins" instead of just BIM, it would seem that many business goals are still yet to be materialized into concrete results. Why?

One of the key reasons is that conversations have focused for far too long on trying to reach a shared wide understanding in the industry about what digital twins actually mean. Our research team began looking at many of the ongoing fragmentation issues within the built environment a couple of years ago and realized that digital twins were some sort of proxy or metaphor for whichever solution could solve those well-known problems: Data silos, model clashes, lack of model updates between building life-cycle phases, you name them. This was a sign that apart from the useful metaphor of "physical asset vs. digital replica", every stakeholder in the industry had a different meaning of digital twin.

During this same period of time, we have interviewed 40+ local experts working on different phases of the building life-cycle and tried to identify their common points of view about digital twins, which helped us to arrive at the definition which can be seen in the box on the right.

As we overcome the challenge of defining digital twins, we can observe another reason for their unrealized potential. Despite the abundance of inspirational examples of innovative tools and applications, which could help improve the efficiency of information exchange in the built environment, there is still a lack of scalable, wide-spread commercial digital twin solutions. We end up trapped in the "chicken-and-egg" loop that is fairly common in the context of emerging digital platforms: A digital twin solution needs the involvement of multiple actors to ensure a valid value proposition, but neither actor is willing to join until they have proof that the ecosystem is sufficiently populated.

There are various alternatives to break out of this loop. For instance, the public sector can take a leading role as a facilitator of digital twins, by providing the funding and service innovation opportunities. This has already occurred with recent publicly-funded research and industry collaboration projects, but further engagement from the private sector is needed. Another option is

that the public sector goes one step further in mandating the use of specific standards and practices for information exchange in the local built environment. However, that option most likely will lead to delays and an unclear timeline until we can see actual digital twins in an operational environment. Therefore, we believe the most suitable approach is to "roll up one's sleeves" and engage with other companies who have the required synergies to develop minimum viable product (MVP) digital twin solutions. It is fundamental to continue innovating with a hands-on approach of close collaboration between industry and academia, and we hope this market report provides useful insights to guide that process.

José Carlos Camposano, *Doctoral Candidate, Department of Software Engineering at LUT University*

"A digital twin is an integrated software solution that can manage and update both static and dynamic information of a building across its lifecycle phases, coupling the physical asset with its digital replica.

It usually offers a realistic visual representation of the physical asset, generated by enriching the geometric or graphical data with support from building automation systems (BAS), sensors, internet of things (IoT) components, and other feedback systems informing about the asset, its occupants or its environment.

Altogether, these heterogeneous sources provide value-adding data about the management, utilization and performance of the asset, in order to enable a view of its past (tracking changes), present (monitoring) and future (simulating and predicting) states."

INDUSTRY REALITIES

The digital replica of the building that is created and used during the design and construction phases are generally referred to as building information models or working drawings. Digital twins generally relate to the occupancy phase of a building, which takes place after design and construction. In order to envisage the future of digital twins, we must first discuss some of the realities and imperfections of the real estate and construction industry as it is today.

1   **Increasing expectations from customers and occupants mean that changes to buildings are becoming more frequent**

Office furniture and internal walls are constantly changing as employees expect their workplace to match their needs on any given day. This includes the need for spaces such as open office zone, quiet concentration working zone, vibrant coffee shop working zone, phone booths, collaboration rooms and different sized traditional meeting rooms. The same can be said for retail buildings where spaces are regularly reconfigured based on consumer trends and data from tracking the retail journeys of consumers.

"Workplace design shouldn't be thought of as a project. It is more like a continuous process or a journey."
Kati Barklund, *Senior Manager, Workplace Strategy at Tenant & Partner*

"In the past when you completed a workplace project it would stay the same with very small changes for several years but now changes are made all of the time in the workplace and it would be easier for the tenant companies to make the changes to the drawings themselves with help of digital tools."
Ray Lindberg, *Head of Project Management Nordics at CBRE*

2   **After the design and construction phase the building information models and floorplans are rarely updated when changes are made to the building**

The resources and the processes that are needed to update the digital replica are often not available after construction.

"It's a common situation that the drawings are not completely updated. We might have an updated version somewhere in the system but it's not updated everywhere."
Kimmo Hyttinen, *Group Property Manager at Citycon*

"The digital asset is like a car. You need to keep it maintained and serviced and full of fuel otherwise it won't work. Unfortunately, it is often not maintained as it's considered too hard to do or because it isn't anyone's job to maintain it."
Sam Cowley, *Architect & founder of Nordbim*

"Constructing something big is quite sexy but taking care of the everyday use of the building with minimizing cost. That's not so sexy."
Sami Korhonen, *Store Network Manager at Kesko*

"It's not a norm to make an as built model in 3D in most of the projects, its normally done on 2D drawings."
Riku Laiho, *Head of Virtual Design and Construction at NCC*

3. Information relating a building is easier to understand if it is presented on a graphical visual representation of that building

It is easier to relate to someone we have not met or to remember someone we have met when we see a picture of their face. This is why people add photographs to CVs and why social media is so successful. Similarly, when a piece of information relates to a unit, a floor, a building or a whole campus of buildings it is easier to understand when the area it relates to is shown alongside it. Also, different stakeholders in buildings need different user interfaces (UIs) and different types of content. For example, a technical person such as a facilities manager needs very different information than a customer in a shopping center.

"People really don't have the understanding of that kind of information when its not visual. You can always look at excel tables but you don't understand it the same way."
Antti Huhta, *Head of IT, Research and Digitalisation at Newsec*

"The BIM model could be the core database and could be a user interface too but you need to make room for the content. In those kind of use cases just hide the details. I don't see disc space for the database to be any problem for us. The detailed data can be there but not of I am looking for a meeting room."
Tomi Teikko, *Head and founder of Empathic Building at Haltian*

4. The occupants and customers in buildings are the most important stakeholders and simultaneously the most difficult to engage

Companies that consist mostly of knowledge workers are likely to focus more on productivity and employee experience rather than other areas of their operations as 90% of their operating costs are typically related to staff costs, including salaries and benefits[1]. Retail environments also focus heavily on customer experience in order to increase the amount each visitor spends. It is difficult to capture the attention of these stakeholder as they have very little motivation to learn how to use new digital tools. The other built environment stakeholders, who use digital tools in their daily work tasks will absorb the learning curve of a new tool as they need it to do their job. Occupants and customers don't have the same motivation and thus the tools should be easy to use and intuitive.

"Occupants say, why again is there a new application for us to learn how to use."
Esa Halmetoja, *Specialist - Maintenance Digitalisation at Senate Properties*

"Productivity as a concept is very multidimensional and its easier to look at the productivity killers. What are the elements that are creating unwanted productivity loss? Think of time. What are the things where you lose time when you shouldn't. Finding a space to work in is a great example."
Elisa Rönkä, *Head of Digital Market Development, Europe at Siemens*

"If you want to introduce an end user user interface its actually the same thing as human centric design in software. You need to select touchpoints, situations, apps and tools that end users need to use every day. Minimum once per day but ideally several times per day."
Tomi Teikko, *Head and founder of Empathic Building at Haltian*

5. The existing BIM open industry standards may need to be developed further and faster

Despite extensive work by industry bodies such as buildingSMART, the existing BIM open industry standards such as industry foundation classes (IFC) and construction operations building information exchange (COBie) need to be developed further. The lack of standardization is currently reducing the return on investment of using post-construction BIMs in the occupancy phase as a digital twin.

The treasure trove of data contained in the building information model is not organized in a standard way and thus accessing it is time consuming. Many standards do exist but there is no agreement on which one of those to choose and those that exist do not allow intricate solutions to be built on them. This is a problem when there are vast amounts of data and when there is still not a clear understanding of which data has value and which data does not.

"The industry should be able to switch to the mode where the architects act like coders. We need version control makes sure that you have a way to store the latest version of that model that a large team are building. We also need, standardization of how to present data. Currently architects have their own ways of where they put the information... we can't take two building models and let the computer make any kind of analysis of them."
Kimmo Ruotoistenmäki, *CEO and founder at Cozify*

WHY ALL THE HYPE?

Digital twins for buildings are complex pieces of technology. They are big, they are messy and they mean different things to different people. Complex is used here as a catch-all term. In essence, it means that they are difficult and expensive to create and difficult and expensive to maintain once they are up and running.

So why are we so interested in something that is such a puzzle and is still at least 3-5 years away from being a productive technology? The answer is that technology enablers like digital twins and data platforms are highly complex, but they have the potential to solve a vast number of problems. The bad news is that there is lots of work to do but the good news is that it should be worth it in the end.

Digital twins last appeared on the Gartner Hype Cycle for Emerging Technologies[2] (which can be seen in the right) in 2018 and there was definitely a hype and a buzz around digital twins back then. At that stage, the estimation was that these solutions would be productive in 5-10 years. Following that logic, then we still have at least 3-5 years before digital twins will be a profitable mass market technology.

In 2018, Gartner described digital twins as being at the "peak of inflated expectations" and predicted that these technologies would reside in the "trough of disillusionment" today. This is consistent with the feedback collected through our research interviews. The stakeholders who are waiting for digital twins to arrive, such as the property owners, investors and asset managers are more skeptical. These actors heard about digital twins for the first time a few years ago and they are frustrated and annoyed that the possible benefits have not materialized yet. On the other hand, different stakeholders such as the contractors, architects, engineers, facility managers and technology companies are still interested in the concept. Many of these companies are cooperating diligently to move digital twins along the curve towards the plateau of productivity.
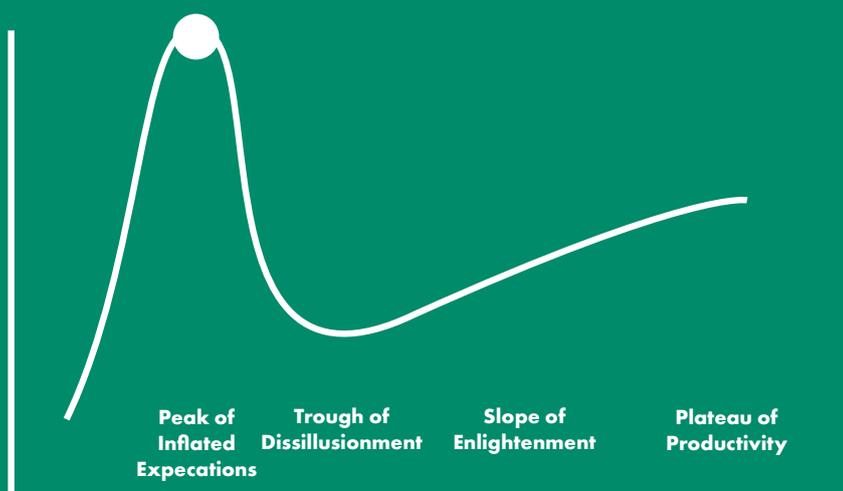
"The truly game changing aspect of a digital twin is that it has the capacity to bring together building information from a wide range of sources. That and the ability to build customised solutions that solve specific business problems, will not only deliver a 360° view of the building through one user interface, but also help optimise its performance through contextual presentation of data and automated analytics.

It may be obvious, but a digital twin can only be achieved with a solid strategy around information and data. Without a laser focus on business value, standards and high quality, interoperable data the digital twin will not succeed in neither the short or long term. This strategic focus needs to start at the outset of the process, at the design phase and should continue right through to operations in order to maintain an accurate, viable and valuable digital twin which will serve its purpose right up to the decommissioning lifecycle phase."

Claire Penny, *Global Digital Evangelist at Invicara*

Digital Twin (5-10 years)

Peak of Inflated Expecations　　**Trough of Dissillusionment**　　**Slope of Enlightenment**　　**Plateau of Productivity**

Gartner 2018

SERVICE DESIGN

Some of the digital twin buzz and hype has subsided since the peak of inflated expectations. One of the main motivations of this research is the feeling that the development of digital twins for buildings has slowed down in recent years and that some stakeholders no longer have faith in the concept. We wanted to bring them back to the centre of the development process, so that their needs are better represented.

Outside of the built environment industry, digital twins are predominately discussed with regard to the performance of high value objects like Formula 1 car engines or machines in a production facility. These components typically operate in an environment with a high cost of failure. The role of the digital twin is to ensure that the operations run smoothly and to support predictive maintenance. Therefore, it is not surprising that the most advanced built asset digital twins are of offshore oil rigs, where there is an enormous cost of failure.

Other built assets with high costs of failure are energy and telecommunications infrastructure and large production facilities. The vast majority of the buildings that make up our cities, such as workplaces, schools and service facilities do not incur high costs if they have to shut down for a day or two as a result of the heating or ventilation systems failing. In fact, as we have learned in 2020, most tasks in office buildings and schools can quickly move online when the need arises. Healthcare buildings may have the highest cost of failure in the urban built environment and thus they might be one of the first sectors to demand complex digital twins.

When you combine the traditional focus on operational performance with the fact that building information models are a free by-product of the design and construction process, then it follows reason that BIM has dominated the discussion on digital twins for buildings. However, the limitations to using BIM in the occupancy phase and the inherent low cost of failure of many of our built assets are some of the reasons why the adoption of complex digital twins has been slow.

Focus on the needs of a wide range of built environment stakeholders.

We wanted to look past the prevailing assumptions and to focus on the needs of a wide range of built environment stakeholders. We carried out 16 interviews that were approximately 60 minutes in duration and we collected business cases for each of the stakeholder categories. Once these interviews had been analysed, we contacted additional representatives to get a more detailed understanding of all the possible stakeholder groups. The categories of actors described throughout this report are listed below:

OWNERS
Developers and owners of buildings with spaces rented out to commercial tenants who manage a portion of the day to day operations of the buildings

INVESTORS
Fund managers of real estate investment funds who outsource the day to day operations of the buildings

RENOVATION TEAMS
Any stakeholder that works on renovations projects such as architects, contractors and engineers

ASSET MANAGERS
Third parties who oversee the day to day operations of a building on behalf of the owner or tenant

FACILITY MANAGERS
Specialized companies in charge of the technical operations and maintenance of a building on behalf of the owner or tenant

OTHER SERVICE PROVIDERS
Companies carrying out the non-technical operations of a building on behalf of the owner or tenant. This includes services such as cleaning, security, customer service, and catering

TECHNOLOGY VENDORS
Providers of equipment such as IoT, asset tracking, elevators, etc.

OCCUPANTS & CUSTOMERS
The end users of the buildings

FOUR SOLUTION CATEGORIES

Our research collected a variety of stakeholder problems that could be improved by digital twins and it quickly became clear that the wide range of problems could be solved by digital twins with different levels of complexity.

Based on these varying degrees of complexity, four different digital twin categories emerged, ranging from the most complex to the simplest as follows: The As-built digital twin, the Building Services digital twin, the Interactive Floorplan digital twin and the Business Intelligence Dashboard digital twin.

1

The **As-built** digital twin comprises all the different models from the design and construction phase. It includes models related to architecture, structural and mechanical, electrical, and public health. Mechanical, electrical, and public health is also called Building Services or MEP. The term as-built means that the design models have been updated to reflect any changes that occurred during construction, and also remain updated. This means that the models are up to date when the occupancy phase begins. The digital replica is shown in 3D and it contains all the static data from the design and construction phase. Dynamic data can then be linked to this core model to create a digital twin.
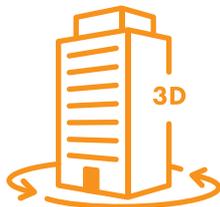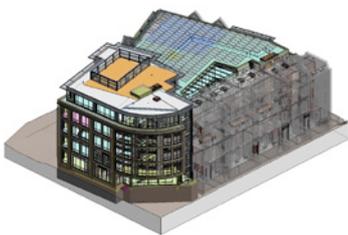
2

The **Building Services** version is a variation of the As-built digital twin that only includes the components of the models that are relevant to the long-term optimization of the buildings' technical systems. These are the mechanical, electrical, and public health models and some elements from the architecture model. The 3D models and associated static data are then enriched with dynamic data from the building management system, IoT devices or other sources (for example, room reservation systems) to create a digital twin.
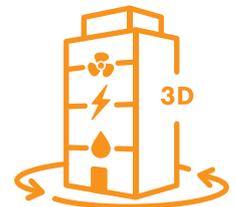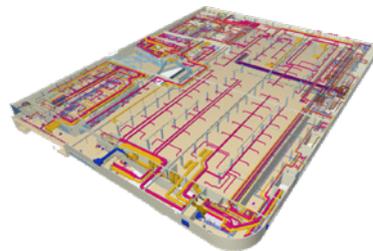
More Complex

3

The **Interactive Floorplan** digital twin consists of up to date 2D plan drawings or very simple 3D wireframe models of each floor in the building, which are enriched with static and dynamic data. It is a user interface on top of which a wide range of features can be added. For example, if the room names have been added to the interactive floorplan, then the user interface can show the name of the room when you click or hover over it.

4

The **Business Intelligence Dashboard** digital twin is a business intelligence dashboard with a 2D interactive floorplan or a map embedded within it. The key idea is that information becomes more intuitive when linked to the building that it relates to. For example, when a data point is selected, such as the details on a lease of a premises, then the floorplan or map should indicate the premises that the lease information relates to.

Less Complex

THE VALUE AND COMPLEXITY TIGHTROPE

At this stage in the development of digital twins for buildings, it is vital to find the balance between value creation and complexity. This is especially important, since the early inspirational "wow effect" examples did not achieve this balance. We need to counteract these examples, by showing that digital twins can provide a reasonable return on investment. To do this, we need to understand the full palette of problems that these technologies can solve. We also need to identify whose problems need to be addressed and if those actors are willing to pay for their problem to be solved.

At first glance, there are four different combinations of value and complexity, as shown in the image:

1 The **successful initial product** provides a low amount of value and is relatively simple. This may be the best starting point to accelerate the development path of digital twins in the coming years.

2 The **dream but unrealistic scenario** provides a high amount of value and is relatively simple. This is an unrealistic aim for digital twins of buildings, due to the use cases that require a medium to high degree of complexity.

3 The **unsuccessful product** provides a low amount of value and has a high degree of complexity. This scenario is the easiest trap to fall into, considering the historic trajectory of digital twin development, and must be avoided.

4 The **successful mature product** provides a high amount of value and has a high degree of complexity. This may be the long-term development target for digital twins, but it is still not clear what amount of the total value is created by the twins with high levels of complexity.

Realistically, we should be aiming for a digital twin that fits in the successful initial product or successful mature product quadrants.

"Solve one problem at a time and continue to take little steps in the right direction. Focus on one small but important part of the industry and try to solve that."

Esa Halmetoja, *Specialist Maintenance Digitalisation at Senate Properties*

"No you don't need the most complex version every time and yes you can solve simple problems with simple solutions. However, if you have a strategy that you are going to use the data for more than one or two use cases, then you should probably think about how to handle this thing when we have 10 or 15 or 500 different use cases. Then the usefulness of having a BIM model or any kind of digital twin database makes sense."

Kimmo Ruotoistenmäki, *CEO and founder at Cozify*
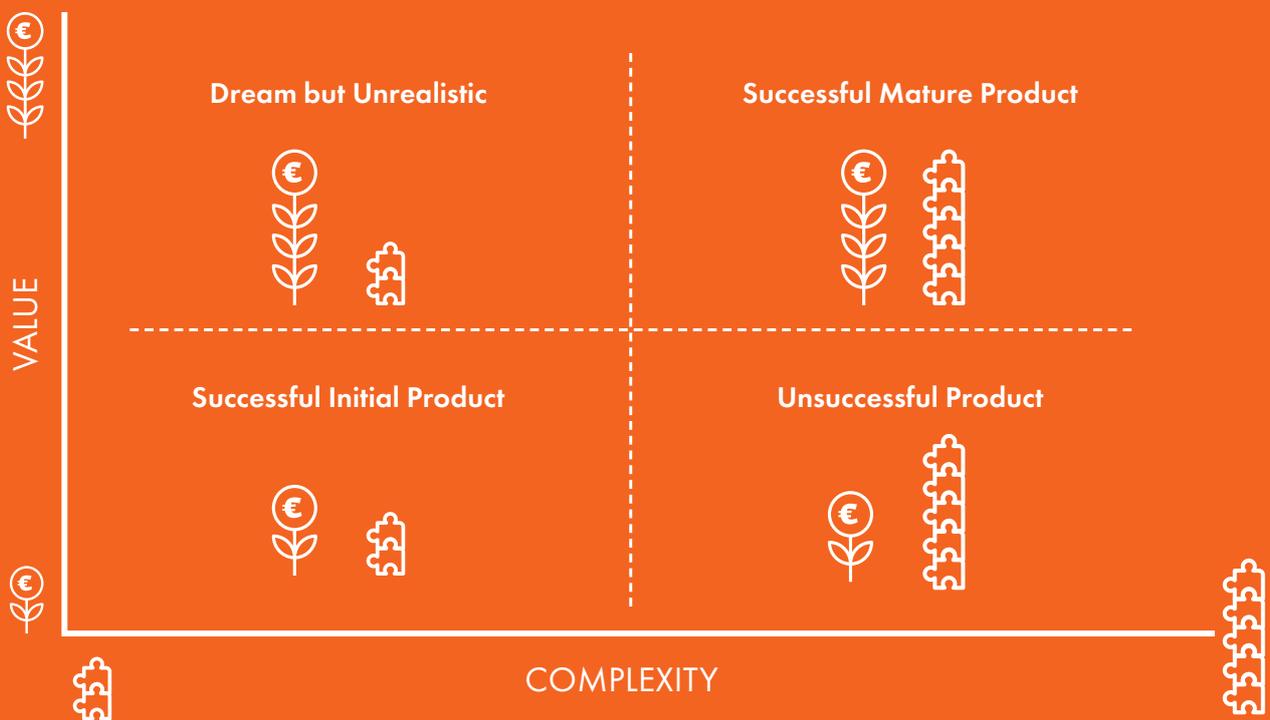
DEVELOPMENT PATHWAYS

How do we start on our journey to develop digital twins that find the balance between value and complexity? This question has rarely been asked before, because the starting point has typically been a building information model. If we put the adequate but imperfect building information models aside and start with stakeholder needs, then what route do we take? The following image shows two potential options, the iterative approach and the all-in approach.

The iterative approach takes small steps forward and considers the simplest business cases first. It aims to find sweet spot technologies, which create an amount of value that is in balance with the resources needed to set up and run the digital twin. The main advantage of this approach is that we learn as we progress, and we get to know the fine details of individual business cases while doing so. This approach also demands an organization that is agile and lean. Each version of the digital twin receives feedback from the relevant stakeholder groups, to understand if it meets their needs and how can it be improved. Following iterations add just enough complexity to support the next layer of stakeholder needs. The first sweet spot could be a smart workplace solution, such as Worksense by Rapal, Empathic Building by Haltian or Comfy by Siemens, or it could be a business intelligence dashboard digital twin. The iterative approach also enables companies to begin their journey with less resources. The early sweet spot solutions can be sold to generate revenue which can be used to grow the development team and fund the later solutions. The early sweet spot solutions also generate credibility for their developers as the stakeholder groups can assess them based on their previous success stories.

The alternative route is based on the premise that there are numerous high value business cases that can only be supported by complex digital twins, such as the Building Services and the As-built twins. The companies that choose the all-in route believe that the value derived from such business cases justifies the resources that are needed to set up and operate the digital twin. The setup costs can be reduced if the building already has a building information model from the design and construction phase. There is indeed valuable information contained in building information models and this is enhanced when linked to other dynamic systems, such as building management systems, energy meters, IoT devices, or other types of software like room reservation systems in offices. Faith in the high value business cases is vital, since this approach requires a high resource commitment over a number of years. The full potential of the all-in approach is explored in greater detail in the section on technology architecture.

Digital twins are not expected to be productive for 3-5 years. Therefore, taking an iterative approach is probably the safest option at this point in time. This statement was supported by the attendees of the virtual Granlund Smart Change seminar in October 2020, who were asked which is the best route to develop digital twins. From a total of 180 survey respondents, 87% recommended the iterative approach and 13% recommended the all-in approach.

AS WE CONTINUE OUR PATH TO DEVELOP DIGITAL TWINS, HOW SHOULD WE DO IT? (180 VOTES)

Should we create a solution that solves all of the possible problems for the life cycle of the building?

13 %

Should we start off with a simple version and continuously develop that over time, step by step?

87 %

The metaphor of the mountain is helpful to discuss and visualize the two approaches, but it may be misleading. It suggests that the development journey is one where complexity is continuously added until the highest level of complexity is achieved. In the setting of this report the highest level of complexity is the As-built digital twin. However, at this point we do not know if the complexity of the As-built digital twin will ever be necessary. It could be that most business cases can be supported by a simpler digital twin.

VALUE

Complex 3D
Digital Twin

Technology Sweetspots
Iterative approach
All-in approach

2024

Simple 2D
Digital Twin

2022

Smart
Workplace
Solution

2020
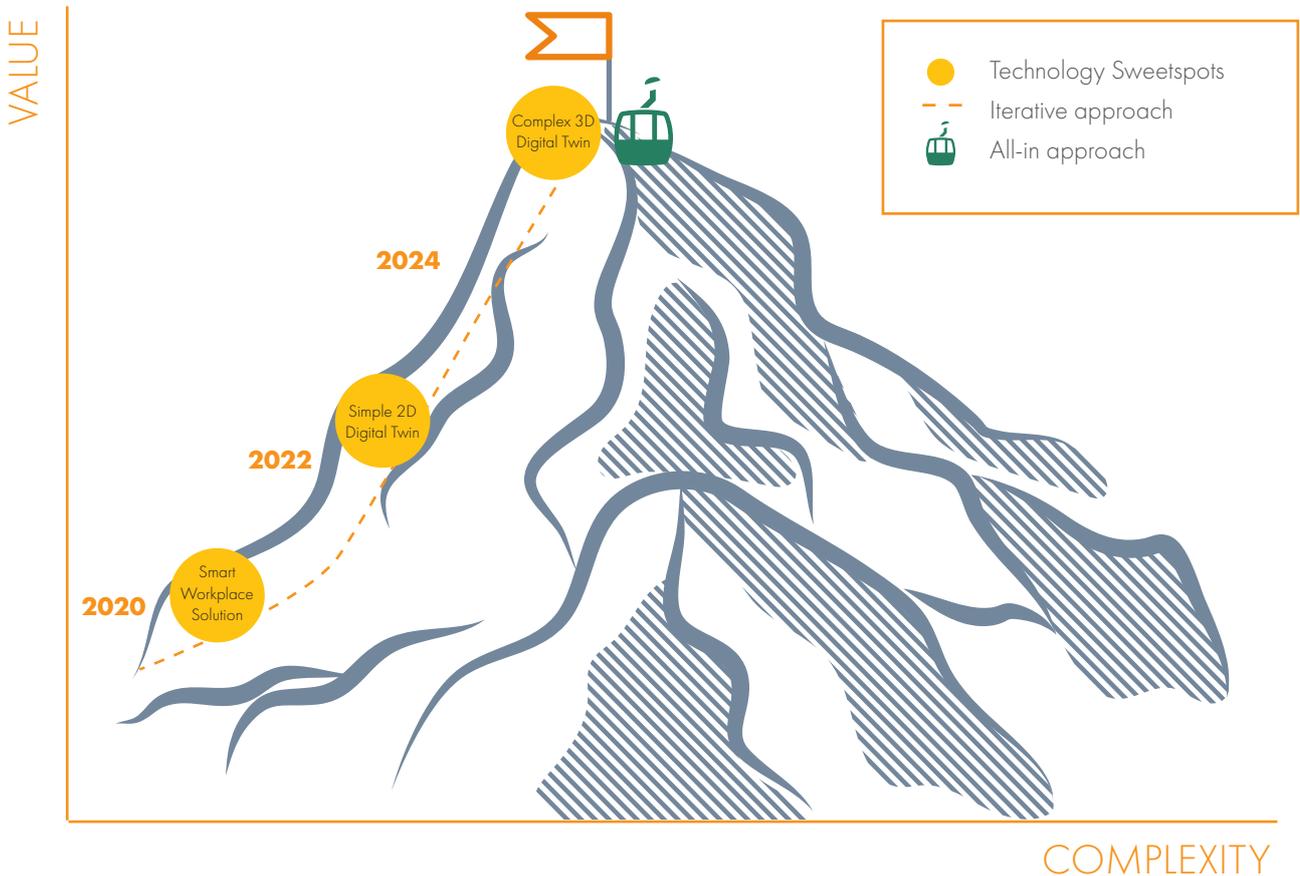
COMPLEXITY

REAL WORLD PROBLEMS

When writing this report, we have assumed that the stakeholder problems that can be supported by one kind of digital twin can also be supported by a digital twin with a higher degree of complexity. So, for example, any business case that can be supported by a Building Services digital twin can also be supported by an As-built digital twin. This can be thought of as being similar to backwards capability. In order to maintain the balance of value creation and complexity, the business cases presented in this report have been linked to the simplest digital twin that can adequately support them.

AS-BUILT DIGITAL TWINS
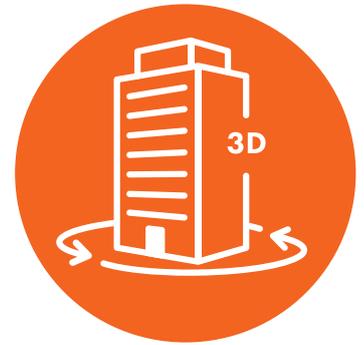
The following non-exhaustive list of business cases could be supported by an As-built digital twin:

Renovation projects: An As-built digital twin can help large scale renovation projects, by providing the same role that the original BIM provided during the design and construction phases.

Pricing of renovation projects: The bills of quantities and surface areas of the building can be analysed when making the bidding documents for renovation projects. The bills of quantities can be used to calculate the cost of replacing products and systems and the surface areas can be used to calculate the costs of materials and coverings of materials and coverings.

Technical Due Diligence projects: The condition of the building can be analysed using the digital twin, by showing the remaining service life of the products that make up the building.

Virtual tours: Detailed 3D models can be used to allow prospective owners or tenants to explore the building virtually.

Marketing material: Marketing videos and images can be made from the 3D As-built digital twin.

Customised design by customers: An As-built digital twin allows prospective owners or tenants to visualize design changes (e.g. new paint colours) during the fit-out phase.

Design automation: An As-built digital twin could also be used to automatically design the changes to building envelope and structural engineering that are needed during renovations.

"BIM data is valuable and should be utilized. The model in itself (ifc) doesn't have to be the UI, as it is just one input source."
Valentin Velinov, *Development Manager, BIM and Digital Services at Skanska*

"Owners have an increasing need for offering virtual tours to prospective tenants. With the help of digital tools the tenants can go through the building virtually and put their own vision of furniture in it. The need for these kind of tools will be greater due to Covid-19."
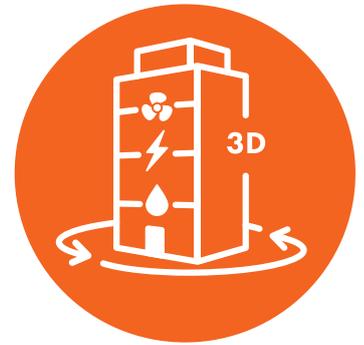**Mikaela Wrede,** *Associate Director at CBRE*

"We are building an F1 car, a digital twin, for someone that we have not yet met. Who is the operator and how will they use the digital twin? Those guys come to view 2 or 3 or 5 years later."
Riku Laiho, *Head of Virtual Design and Construction at NCC*

BUILDING SERVICES DIGITAL TWINS

The following non-exhaustive list of business cases could be supported by a Building Services digital twin:

Simulations: The twin should support simulations of the building to be run using the digital replica and the linked data. One example could be running a simulation to estimate the energy consumption of the next day in order to buy energy in advance. For example, a simulation of an office building could use the next days meeting room reservations and typical occupancy trends to predict occupancy rates for the simulation.

Energy optimisation: The twin should also enable energy efficiency audits to be continuously run on the building.

VR / AR guidance: The twin could be used to navigate the building with virtual reality or augmented reality when looking at the models in very fine detail.

Fault detection and diagnosis: The data can be used to generate alarms and the model geometry can be used to study the associated systems in detail. For example, if one room is particularly cold then the model can show which section of the heating or ventilation system serves that room and search for causes in that system.

Predictive maintenance: The data and the model geometry can be used to support predictive maintenance analysis. This could be related to having vibration sensors on the technical systems such as pumps or air handing units and monitoring which systems regularly have excessive vibration.

Design automation for building services: The twin could also be used to automatically design the changes to the building services systems that are needed during renovations. If a large meeting room is being split into two smaller meeting rooms then the design automation software can automatically redesign the mechanical, electrical, and public health systems to take the changes into account.

"Our staff are using mobile devices and most probably there are pdf drawings on the devices depending on what is available. If the BIM is in use then we are using that."

Tuomo Härkönen, *Vice President, Head of Digital Solutions at Caverion*

"A digital twin is more intuitive than facility management software in terms of inspecting and updating detailed information associated to building components or spaces. For example if a faulty faucet is replaced with a new product, product information in the digital twin must be also updated."

Valentin Velinov, *Development Manager, BIM and Digital Services at Skanska*

"The companies are outsourcing the maintenance to us and we must really know the buildings. Our guys need to know the buildings really well and if they need extra information then they check the documents."

Tuomo Härkönen, *Vice President, Head of Digital Solutions at Caverion*

INTERACTIVE FLOORPLAN DIGITAL TWINS
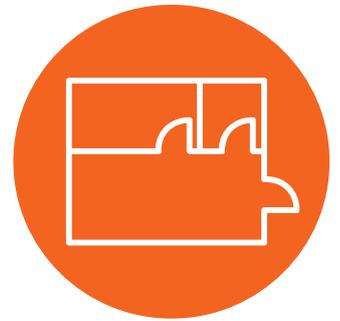
The non-exhaustive list of business cases described below could be supported by an interactive floorplan digital twin. A master floorplan that is used by many different business cases will ensure that the floorplan is kept up-to-date.

UI for interior designers: Interior designers always need an up-to-date floorplan when beginning a renovation project.

Visualising people flow: An up-to-date floorplan is important when displaying the results of people flow analysis.

UI for escape strategy: An up-to-date floorplan is needed for the escape strategy, e.g. in case of emergency, fire, or natural disasters.

UI to add comments during inspections: The results of annual inspections are easier to analyse when they have been added to an up-to-date floorplan.

Visualisation for performance analysis by managers: Performance data such as indoor conditions data is easier to analyse when they are displayed to an up-to-date floorplan.

Visualising equipment locations: Tracking assets and the locations of machines are easier to find when linked to up-to-date floorplans.

UI for remote maintenance: Similar to performance analysis by managers, performance data such as indoor conditions data is easier to analyse by maintenance teams when they are displayed on an updated floorplan.

Communication tool for remote & local maintenance teams: Remote maintenance teams can send staff who are working on-site to inspect a problem, such a room being much colder than it should be. In these cases, updated floorplans can be used to aid this communication.

UI for smart cleaning: Cleaning alerts are easier to answer efficiently if they are displayed on an up-to-date floorplan.

Visualisation of security alarms: Security alarms are easier to analyse when they are displayed on an updated floorplan. If multiple alarms are triggered, then the locations can help to decide if it is a real threat or a false alarm.

"For real estate, the first and the easiest digital twins case is to provide instant notifications for the end user. If you have lots of sensors in your building measuring temperature or CO_2 levels and if there is something going wrong based on your comfort targets, then a warning notification can be sent to the correct end user."

Mehmet Yalcinkaya, *Data Lake Software Engineer at Konecranes*

"As building owners most of our work is done with pdf drawings and floorplans."

Kimmo Hyttinen, *Group Property Manager at Citycon*

"We are mostly interested in existing buildings where we don't have a BIM model and where we will never have a BIM model, that's our challenge now."

Tuomo Härkönen, *Vice President, Head of Digital Solutions at Caverion*

UI for equipment providers: Online equipment such as IoT, light fittings, elevators etc. usually have a user interface to access and analyse the data that is generated. This data is easier to analyse when it is displayed to an up-to-date floorplan.

Visualisation of indoor conditions: Indoor conditions can be intuitively understood by end users when they are displayed to an up-to-date floorplan.

UI for reporting & tracking service requests: Feedback from end users such as service tickets, complaints, feedback on thermal comfort or anonymous reporting of workplace stress (such as vibemetrics) can be added to a up-to-date floorplan. This enables the accurate location of the problem to be reported and the floorplan can also be used to communicate the response timeline to the end users.

UI for space finding & booking: Up-to-date floorplans are important components of space finding and booking solutions for end users in office environments.

UI for indoor navigation: Up-to-date floorplans are an essential part of indoor navigation solutions.

Show the restaurant menu: The lunch menu for staff restaurant can often be difficult to locate. Sometimes it's on the intranet, sometimes it's on the webpage of the catering company and sometimes it's on the restaurant's social media pages. If the restaurant menu is added to the restaurant space in the user interface, then it can become a useful tool for occupants and visitors. It can also be used to check queueing times and ingredients for people with special diets.

Marketing material for selling or leasing: Up-to-date floorplans are also needed when selling buildings and when leasing out units.

"The most important things are the things that the end user uses everyday. Parking, showers, locker for your bike, how full the gym is."
Tomi Teikko, *Head and founder of Empathic Building at Haltian*

"We have been thinking about, not having to go to the site to check something. Could a cleaner or receptionist go with a mobile phone and show the on site situation? Then a remote expert could diagnose the problem."
Otto Juhala, *Account Manager at ISS*

"We have one cleaning on demand case where we have a floor plan on an ipad for cleaners. When the meeting rooms are used, the colour changes on the floor plan and the cleaner knows when they need to clean that room."
Antti Toivanen, *Head Of New Business at Lassila & Tikanoja*

"In my opinion, most of the time 2D images are easier to understand than 3D as a lot of maintenance personnel are not as used to computer graphics as 20 year old kids who play computer games. However 3D is needed for complex systems like pipelines which can't be shown on a 2D drawing."
Otto Juhala, *Account Manager at ISS*

BUSINESS INTELLIGENCE DASHBOARD DIGITAL TWINS

From our research, the Business Intelligence Dashboard digital twin primarily supports financial analyses. The following non-exhaustive list of business cases could be supported by this kind of twin:

UI for lease management: The lease information for each rental unit should be linked to up-to-date floorplans. This way when a lease is selected from the dashboard the location of the unit can be displayed.

Capex and Opex investments: The planned operational expenditure and capital expenditures could be shown for the selected buildings and linked to the location of the buildings on a map.

UI for financial performance analysis: Key financial performance indicators for different floors or buildings such as rental income, vacancy rates, and the size of the space, should be linked to up-to-date floorplans. This way, when the data is selected from the dashboard the location of the unit can be also displayed.

"Since the ownership layer is pretty thin in terms of resources, most asset management tasks are outsourced."
Jarkko Lehtonen, Portfolio Manager at United Bankers

"We lease out some parts of the premises. It would be great to have an up-to-date visual view of the use of premises by the different tenants."
Sami Korhonen, Store Network Manager at Kesko

"I think that digital twin will be the catalyst for digital transformation we have all been waiting for. In real estate management it is long overdue that we would finally get a visual user interface, that makes complex technical issues understandable and combines them with cash flow-affecting items, such as tenant or lease term information. This helps also the non-technical decision makers such as financial managers, to see the cause and effect for real estate investment actions to relevant KPI-issues, such as net income, leasability or asset value."
Susanna Sairanen, Group Manager at Granlund

"The latest report on Finnish open-ended alternative investment funds reveals that these funds own roughly EUR 8,2 billion worth of properties in Finland. The transparency of these funds are not where it should be, though."
Jarkko Lehtonen, Portfolio Manager at United Bankers

SWEET SPOT

Let's revisit the **successful initial product,** which was mentioned in the section on the value and complexity tightrope. If there will be four different digital twin categories in the future (As-built, Building Services, Interactive Floorplan, Business Intelligence Dashboard), then we can clearly see that there is a jump in complexity between the simple and the complex digital twins. To keep things simple for this discussion, we can crudely think of complex twins as those that require 3D models and simple twins as those that can be enabled with interactive 2D floorplans. The aim should be to go beyond minimum viable product or minimum loveable product, to develop a comprehensive solution that acts as an enabler and solves a vast number of problems.

One sweet spot solution is the digital twin that creates the maximum amount of value before this jump in complexity. Put another way, the maximum amount of value that can be created from interactive floorplans. At the core of the solution will be a master geometry model that is continuously updated. These updates represent the changes that occur during the lifecycle of the building. In this case the master geometry model would typically be an interactive floorplan. All of the business cases that are supported by both Interactive Floorplan twins and Business Intelligence Dashboard twins can then utilise this floorplan.

The 3D model can act as the master geometry model, from which the 2D interactive floorplan can also be extracted. However, updating a 3D model just to use it for 2D would add unnecessary complexity. It should be noted that in order to simplify the image on the right, each business case has been assigned to the most relevant stakeholder, although in reality many of the business cases are relevant to numerous stakeholders.

We can crudely think of complex twins as those that require 3D models and simple twins as those that can be enabled with interactive 2D floorplans.

Wheel diagram of building digital twin user interfaces:

- UI for lease management
- Visualisation for financial performance analysis
- UI for space finding & booking
- UI for indoor navigation
- UI for reporting & tracking service requests
- Visualisation of indoor conditions
- UI for equipment providers
- UI for smart cleaning
- Visualisation of security alarms
- Show the lunch menu
- Communication tool for remote & local maintenance teams
- Visualise equipment locations
- UI for remote maintenance
- UI to add comments during inspections
- Visualisation for performance analysis by managers
- Marketing material for selling or leasing
- UI for escape strategy
- Visualise people flow
- UI for interior designers

Legend:
- Renovation Teams
- Owners
- Asset Managers
- Facility Managers
- Other Service Providers
- Technology Vendors
- Occupants & Customers
- Investors
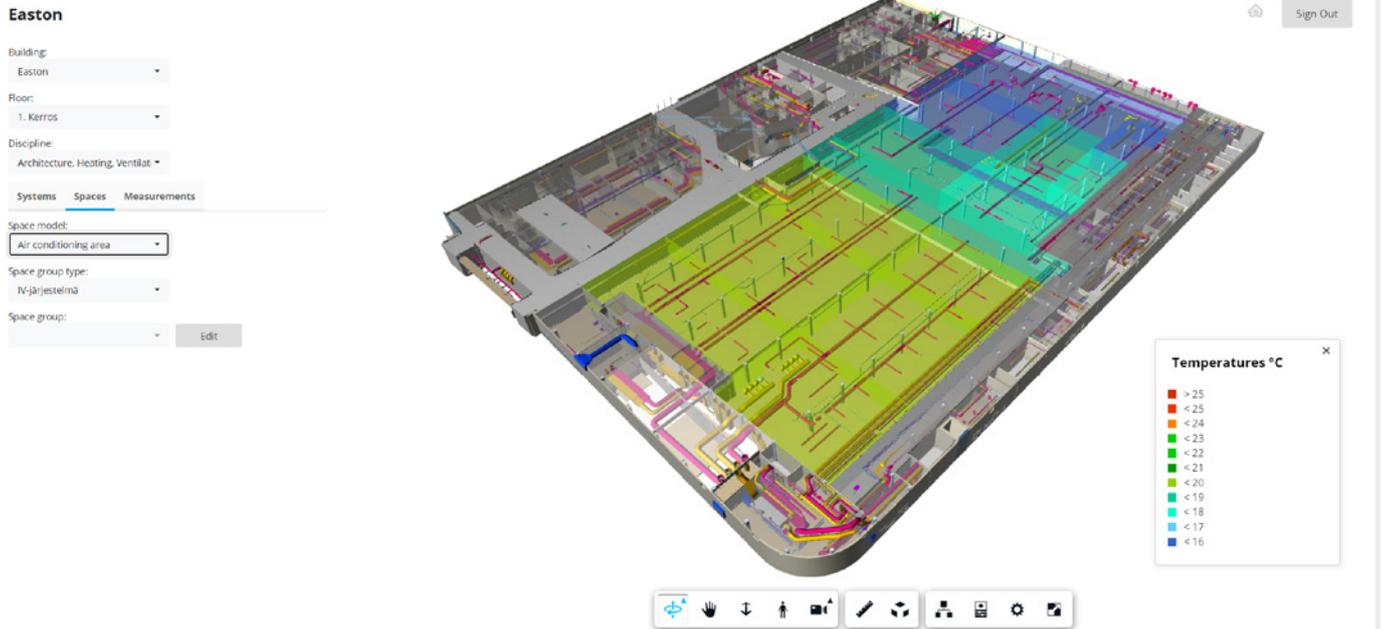
BUILDING SERVICES DIGITAL TWIN CASE STUDY:

EASTON SHOPPING CENTER AND KUOPIO UNIVERSITY HOSPITAL

The Granlund "Innovations and Development" department has been researching and experimenting with Digital Twin environments of building services models for several years. The first prototype was made in 2016 and was related to the indoor conditions of the Finnish National Museum. The software tools developed back then formed the foundation for our next digital twin prototypes which were from Easton shopping center and Kuopio University Hospital.

The digital twin environments consist of IFC models produced during the design phase, an Autodesk Forge graphics engine, and REST APIs to connect with external systems. The final digital twin solution is a webapp that doesn't require the installation of separate plug-ins.

The data contained in the BIMs has been standardized in order to make the IFC exports machine readable. This reduces the amount of manual work needed when converting the design models to digital twins and makes the whole solution more scaleable. It should be noted that we have deliberately chosen the IFC transfer format so that we do not have to depend on the individual characteristics of the different software vendors. With this in mind, we have followed the OpenBIM concept in our platform.

The digital twin is linked to dynamic data using documented REST APIs.

The digital twin is linked to dynamic data using documented REST APIs. The primary source of dynamic data for our examples has been building management systems (BMS). It was a Siemens system in Kuopio University Hospital and a Fidelix system in Easton shopping center. The data collected is related to the real-time conditions of the premises and this is linked to the technical systems and space objects in the IFC models. This makes it possible to visually analyse the real-time and historic data for any space and to relate the conditions to the related technical systems, such as the ventilation system, that serve that space.

The static data, that is the typical content of the IFC model, is linked to the digital twin solution. This data is related to the names of the MEP systems, the air volumes of the terminals, the pressure levels and the preset values of the controllers. In addition, the IFC model data is supplemented with the Granlund Designer software equipment database. This equipment database provides more detailed technical specifications for equipment that does not exist in the IFC models. The IFC data, the equipment database and the dynamic data are all visualised on the Forge graphical user interface. In practice, any data that can be easily and cost-effectively accessed, can be linked to the digital twin.

Granlund's strategy to experiment with prototypes and to turn these experiments into commercial software products has been particularly successful with regards to Digital Twins. Granlund Manager, which has been a maintenance management system for over 20 years, has commercialized these prototypes into a commercial application. This has made it possible to combine the daily routines of the property (service requests, maintenance procedures, equipment information...) with the Forge user interface.

AS-BUILT DIGITAL TWIN CASE STUDY:

HELSINKI OLYMPIC STADIUM

As-built is a broad and abstract concept, which is why it needs to be defined by the construction industry. Simply, it is a documentation and representation of how a building is constructed based on actual information. This is a product-driven perspective, where as-designed plans are refined and enriched into as-built documentation. Usually as-built digital twin approaches revolve around BIM, where the model's geometry is updated based on actual information gathered onsite and enriched which data sources as in Bill of Materials, quality documentation, service instructions, photos etc.

> *Our approach proved to be effective and the technology was reliable.*

Skanska Finland has widely adopted BIM modeling in its own production and Design and Build deliveries. All design fields are modelled, cross inspected and quality assured for any inconsistencies or data content deficiencies. From an as-built standpoint, one challenge is to gather all redline marking and update the BIM model accordingly. Technology may be of help, as we have experimented with the use of laser scanning and photogrammetry to compose an as-built model. Gathered point cloud and image data can be clash checked against the as-designed BIM model and intelligent software can detect deviations even up to 1 mm tolerances.

This approach was executed as a pilot in Skanska's renovation project of Helsinki Olympic Stadium. Our goal was to record and document geometry deviations from the design plans to the level of accuracy agreed with the customer with focus on cost-effectiveness. Our approach proved to be effective and the technology was reliable. Admittedly, composing an as-built digital twin must be approached as a justified investment. The level of detail is directly proportional to the work input needed.

INTERACTIVE FLOORPLAN DIGITAL TWIN:

WORKSENSE

Mobile space reservation and guidance systems are becoming available to all people as mobile applications and IoT solutions evolve at an unprecedented rate. New applications are needed in offices, malls, hospitals - wherever facilities and people meet.

Interactive floorplan is an application and service platform on which a digital space environment and user experience can be created. At the heart of the platform are intelligent floorplans that can be used indefinitely in a variety of applications that benefit space users.

Smart floorplans can be used in mobile apps, lobby screens, and other user interfaces available to space users. Deploying the platform is effortless: Floorplans can be converted to smart images as a service and updated with a new revision when changes are made to the premises.

Worksense - Employee's digital work environment - has been developed on the smart floorplans. The app runs in the employee's pocket on their mobile phone and allows employees to easily and quickly get information about the facilities they need and to reserve facilities and workstations for their use. Worksense networks through IoT with other intelligent real estate systems, such as presence and condition sensors located in an office environment.

The platform is also available to third parties.

The platform is also available to third parties to enhance and visualize the user experience of space use. The platform provides ready-made libraries and interfaces as well as a floorplan production service for implementing smart floorplans in your own application development project.
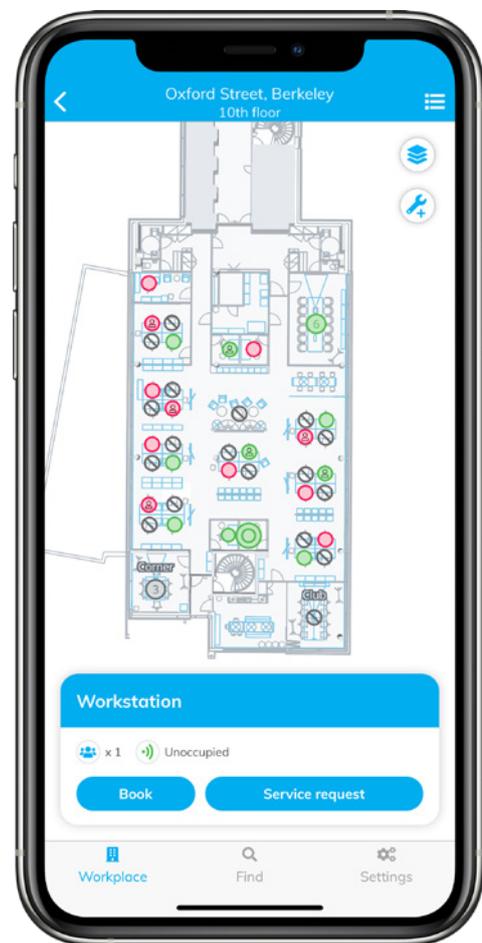
INTERACTIVE FLOORPLAN DIGITAL TWIN:
EMPATHIC BUILDING

Empathic Building is a human-centric digital service that enhances end-user experience and increases customer loyalty. Our purpose is to inspire and create the best possible employee experience and to give tools for employees to enhance collaboration and co-innovation. We enable a user-friendly way of visualising the building information in real-time and this eases the work days of thousands of employees globally.

The solution gathers data from sensors and visualises it via software for the use of the end users. The user interface is very similar to an interactive floorplan and it uses a very simple 3D wireframe to show the content. The content could be the name of the room or the amount of free tables in the restaurant. All this relevant and diverse data can also be analysed and reported for the leadership and facility management to support decision making. For example, Empathic Building generates space usage heatmaps and utilization reports for both desks and meeting rooms to help optimize and redesign the premises to support better employee experience.

The service also provides a feedback engine. It enables better facility and service planning and faster response

times. All interested parties can follow through the wide array of reports on how building utilization, user satisfaction and environmental factors affect each other and where the correlations reside. The work environment can, as a result,

> ## A human-centric digital service that enhances end-user experience.

be changed to suit the needs of the occupants better. The end-user satisfaction levels can even be used to measure the quality of the service provider instead of the classic model of "number of hours worked or tasks completed".

We are happy to be part of the work culture transformation. When we embrace the future where we inspire, give freedom and trust as well as boost open feedback culture, we can see the increase in employee experience and wellbeing.

INTERACTIVE FLOORPLAN DIGITAL TWIN:

# SMART CAMPUS PLATFORM & SMART OFFICE APP

Steerpath is a pioneer in providing location-based services which scale from individual offices to million square meter airports and campuses. In the heart of the Steerpath platform is an open, global digital twin engine. Open because everything about the digital twin has an API for extending and using the digital twin with 3rd party solutions and data. Global because all buildings are part of a global network of buildings, all data sharing the same coordinate system. This makes each building in the platform not just a digital twin but part of a larger smart city.

No data set, how rich and open it might be, is useful for the main benefactor of the data - human - unless the data can be visualised in a meaningful way. Steerpath has focused a great deal in creating a visualisation engine that enables global, 3D visualisation of the building information on any platform: mobile, desktop and big screens. There are both ready made services for end users such as smart office app for real time space availability visualisation and booking as well as embeddable views that can be used and customised for each use case such as building specific dashboards.

This makes each building in the platform not just a digital twin but part of a larger smart city.

We have seen that there are critical user groups that need to be included in the design of a smart solution. On top of the obvious facility management these are end users and business users. End users - the daily occupants of the building that can benefit from the smart building solutions which makes their daily operations smoother and help them to save time. Business users - with the end users smart building is suddenly much more than a maintenance tool. It serves daily operations and needs to have up-to-date information about the operational data of the building including but not limited to tenant names and types, space occupancy and reservation systems
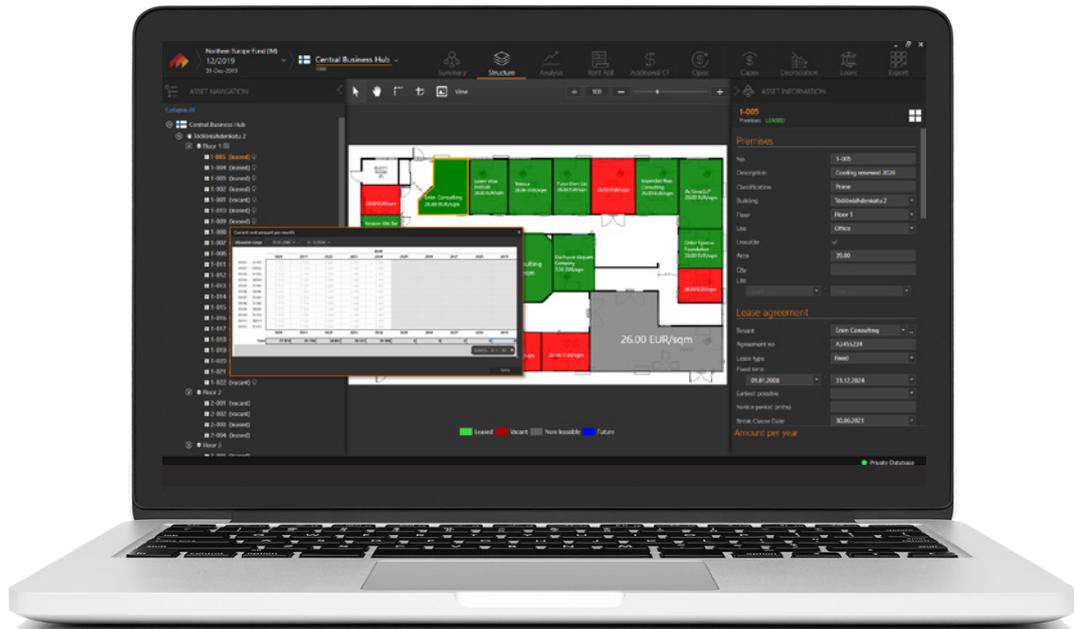
BUSINESS INTELLIGENCE DASHBOARD DIGITAL TWIN:

MODELTREE

ModelTree digitalizes real estate assets into virtual navigable objects. It is a financial modeling, analysis and reporting platform that helps commercial real estate investors and valuers to automate their daily financial modeling, reporting tasks and saving time.

ModelTree digitalizes real estate assets into interactive data objects and allows users to virtually navigate inside assets. Virtual navigation can start from the map where the user clicks the building and then virtually enters the building.

Inside a building, users can navigate themselves on any floor from the interactive stacking plan. The stacking plan itself visualizes each floor's leasing/tenant situation by indicative colours and calculates floor-level analytics such as vacancy rate and rent levels and other KPIs.

Inside a floor, the users see a visualization of the floor's leasing situation and performance. Each unit is visualized as a clickable shape. Interactive floorplan in ModelTree is designed to be rather simple, targeting ease of use rather than being a detailed CAD floorplan planner tool. Linking units to floorplan is allowed by drag-and-dropping them from rent roll onto floorplan image and

then adjusting the unit shape form and position. Linking units is as easy as drawing shapes on PowerPoint, yet it creates a powerful interactive floorplan very fast.

> *It digitalizes real estate assets into interactive data.*

ModelTree's main function is to act as a financial modelling/forecasting tool. Therefore, each unit and lease agreement's cash flow are tracked and forecasted to the future allowing user to get cash flow forecast for each unit, floor, building and asset as well as total portfolio. The ability to visualize building and floor level analytics in easy way is especially useful for the asset and leasing managers who need to understand and demonstrate the leasing or capex plans to the floor.

ModelTree is used by large and small real estate investors, property funds, banks and valuers to model, value and report about real estate investments.

BUSINESS INTELLIGENCE DASHBOARD DIGITAL TWIN:

ASSET & PORTFOLIO MANAGEMENT PLATFORM

Assetti has created an asset & portfolio management platform, a tool where one can aggregate and consolidate all the relevant data of a property asset. The application is very intuitive and easy to use. With just a few clicks, the user is able to navigate from a portfolio level down to a single lease and related unit, and navigate within and around the asset or portfolio.

Visualized KPIs (Key Performance Indicators) are making analysis and decision making easy. Assetti covers both the financial and rent roll performance of the asset as well as the data about the physical elements of a property - such as building, unit, lease and tenant. Those are viewed as factsheets within the application. This enables Assetti to work stand-alone, connected only to for example financial admin system in use, or in a wider context, connected to the Digital Building model (Digital twin).

Through an API, one can connect visual factsheets of Assetti into entities of the Twin - representing the physical elements of the property, such as Building, Plot or Unit. Through two-way synchronisation Digital Twin can work as the source of property data to Assetti.

This ensures seamless navigation and insight of the property from the technical and operations point of view, as well as from the financial point of view. With this knowledge, the user is able to understand not only the key drivers of operational performance, but also the asset's financial performance from the investment point of view. This makes seamless collaboration reality between different parties involved with the asset - from the investor's board looking at the big picture down to facility managers taking care of daily operations of a single property.

An intuitive and easy to use platform.

FINAL VISION

The next sections of the report set out our thoughts about the future vision for digital twins of buildings. The vision has been formulated by combining the experience gained while conducting this research with past conversations, discussions and reflections with other professionals.
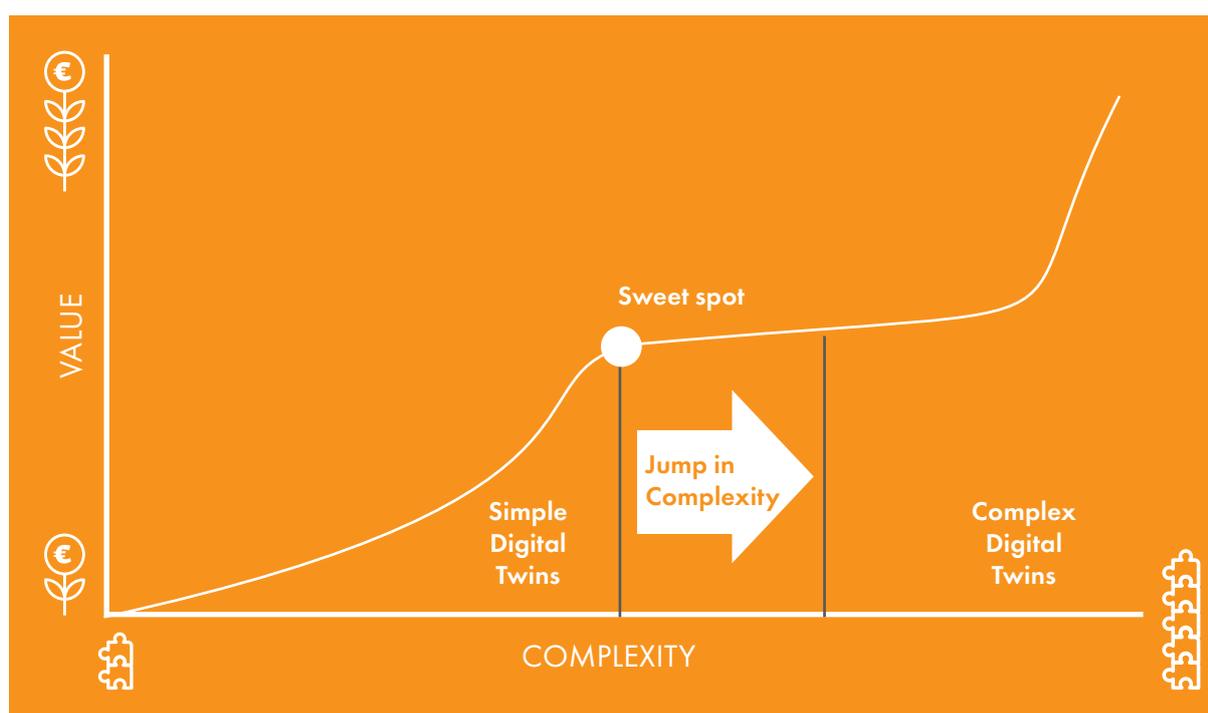
DISRUPTIVE INNOVATION

Since its introduction in 1995, the theory of disruptive innovation has commonly been linked to any kind of breakthrough that changes an industry's competitive landscape. However, it has frequently been misapplied[3]. In essence, an industry disruption occurs when a smaller company with fewer resources is able to successfully challenge the established industry players. A window of opportunity for disruption opens when the incumbents excessively focus on improving their products and services for their most demanding customers, until the point where their offering exceeds the needs of some customers and ignores the needs of others.

The established companies working on digital twins for buildings are capitalising on their knowledge of building information models and thus far they have mostly focused on complex digital twins. These companies are continuously aiming at digitizing more operations or enabling new services using the building information models that are the free by-product of the design and construction processes. This starting point positions them in the higher end of the market right from the beginning and their solutions support the highest value business cases for buildings. At first glance, such solutions fit the description of a product that has been developed to the point where their offering exceeds the needs of some customers and ignores others.

Large companies should not be overly concerned when small competitors target the edges of their business operations. However, small companies do pose a greater threat when they are on a disruptive trajectory[3]. Simple digital twins that aim for the sweet spot of value and complexity before the jump to complex digital twins (see image below) could potentially disrupt the established industry players. To assess the potential of smaller players as disruptors, we must consider if they possess the following two characteristics[3].

VALUE

Sweet spot

Simple Digital Twins

Jump in Complexity

Complex Digital Twins

COMPLEXITY

Disruptive innovations originate in low-end or new-market footholds: Simple digital twins do originate in the low end of the market, by offering low to medium value solutions to multiple stakeholders. They also create new-markets footholds, for example the business intelligence dashboard offers new services to financial managers. They operate at such a low end of

> ## This starting point positions them in the higher end of the market right from the beginning.

the market and offer such a simple service that many of the established industry players may not even recognize the product as being a digital twin.

Disruptive innovations don't catch on with mainstream customers until quality catches up to their standards: Like other disruptive innovations, simple digital twins are initially considered inferior by most customers of the established digital twin solutions. The customers that are interested in complex digital twins, such as the fault detection and diagnosis business case of the building services digital twins, are not willing to switch to the simple version until its performance rises enough to meet their needs.

From this analysis, it can be argued that simple digital twins aiming for the aforementioned sweet spot are on a disruptive trajectory relative to the established industry players. The image above that plots product performance versus time is adapted from The Disruptive Innovation Model[3].

BOTTLENECK: MASTER GEOMETRY MODEL

One of the elements in the development roadmap for digital twins that remains uncertain is the choice of technological components to enable the overall system architecture. Our interviews focused on exploring the potential sources for the geometry of the digital twin, rather than the specific mechanisms chosen to embed or link the data.

If we assume that there will be four different digital twin categories in the future, then it is not clear how many separate sources of geometry will be needed. The geometry source is the file or database where all of the updates will be made. It is more realistic to think that there would be at most two separate geometry sources: One for complex twins (i.e. those that require 3D models) and another for simple

twins (those where an interactive 2D floorplan is sufficient).

However, if the business cases that can only be supported by complex digital twins do create enough value to justify their cost, then it raises another key question.

If the stakeholders need complex twins and simple twins, then should the highly complex twin be used as the master geometry model? This master digital replica would then be read by the other twins. For example, the floorplans used by the Interactive Floorplan and the Business Intelligence Dashboard twins would be extracted from it.

The idea of the complex twins being the master digital replica is a sensible approach. However, there are some concerns: First, how do we start our journey to develop digital twins? It is much easier to begin with the simple models and to convince a customer to pay for such a relatively low-cost service. The second concern is how likely the complex digital twins are of providing a balance between value and complexity. If the solution is built on the premise that the highly complex twin acts as the master digital replica, then what happens in the individual customer cases where the stakeholders are not interested in the complex twin business cases?

One element that must be considered here is the maturity of the concept and how market acceptance will change over time. It may be that the market will be cautious in the coming years and

"I don't see any problem why the more complex BIM model with all the details cannot be the source of light models. Light models like empathic building where we only show the wireframe of the building and we make the content more visible for the end users in their daily use cases. The problem currently is that the standards are missing."

Tomi Teikko, *Head and founder of Empathic Building at Haltian*

that stakeholders will initially be willing to only pay for simple twins. However, as time goes by and the adoption of digital twins becomes more commonplace, then stakeholders may be convinced to pay for more complex twins. Thus, there may be a point in time when complex twins do create enough value and can then start to act as the master geometry model.

Complex Digital Twin

Simple Digital Twin

Master Geometry Model and Data Platform
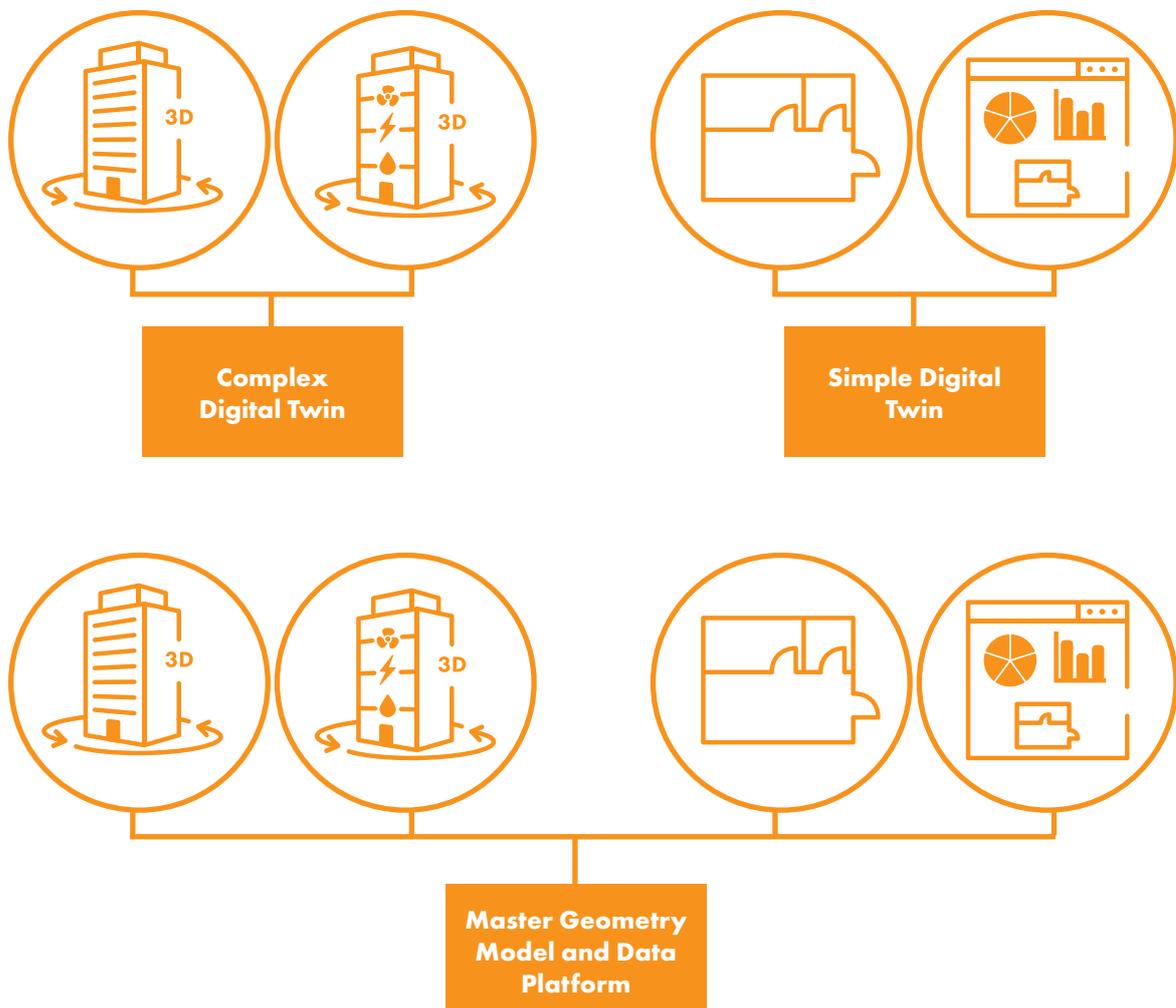
BOTTLENECK: REVENUE MODEL

Another element of the development roadmap for digital twins with a high level of uncertainty is the revenue model that can support the use of digital twins over various phases in the life cycle of a building. One of the biggest strengths of digital twins is their ability to be an enabler and solve numerous problems for different stakeholders. But which one(s) of those stakeholders would be willing to pay for it?

The majority of our interviewees argued that the building owner should pay for the implementation and maintenance of the digital twin. Owners have the primary incentive to maintain the functionality of the building and they currently have the responsibility for archiving the drawings of the building or for outsourcing this task to one of their subcontractors. If the owners do provide a digital twin that solves problems for many different stakeholders of a building, what could they receive in return? The answer to this question definitely needs to evolve over time. At the moment, some possible answers are:

Reduced vacancy rates and higher rents:
From more satisfied tenants from business cases related to concepts such as space finding & booking, indoor navigation, restaurant menus, etc.

More transparency on the activities of their subcontractors:
If they are paying for a certain level of service, then a twin can help them to analyse if this level is being reached. One example is smart cleaning.

Cheaper services:
A twin will make life easier for some service providers and they may offer a discount for using the twin. One example is facility management.

Higher building valuations:
Solving problems for numerous stakeholders may provide a more functional building and could positively impact the valuation.

The lack of mature business models for digital twins is one of the reasons why design and construction building information models are not created in a way that makes them easy to utilize in later phases. There are currently no incentives for the design and construction companies to create BIMs that can seamlessly be used once the building opens. At present, the whole purpose of BIM is to execute the delivery of a construction project. Quoting Riku Laiho from NCC: "We are building a Formula 1 car, a digital twin, for someone that we have not yet met. Who is the operator and how will they use the digital twin?". Any additional activities that are needed during the creation of the BIM have a cost to the construction company and this must be passed on to their customers, who are typically the building owners. Complex digital twins don't deliver enough

value and as a result, building owners currently have low incentives to pay additional fees in return for a complex digital twin upon completion of the building. This complex digital twin is not just an As-built BIM, it is a As-built BIM embedded with static and dynamic data and with different user interfaces for different stakeholders. Depending on the business case, this requires integration with various technical systems. This should also be done in a standardized and scalable way to expedite the setup of future projects. Having a standard approach also speeds up the learning curve of using a digital twin as many stakeholders will need to simultaneously interact with the twins of multiple buildings.

"We have a dedicated team to take in the data for our new properties but this data it might come on a USB stick or a CD or a cardboard box."
Antti Huhta, *Head of IT, Research and Digitalisation at Newsec*

"What we would need is an internal or external low cost process and service to keep the digital twin up to date. This is because now we are no longer taking about a single project but a real estate portfolio and every cost scales up to a huge amount when there are a lot of buildings."
Sami Korhonen, *Store Network Manager at Kesko*

WRAP UP

In a world where there is so much focus on the data economy, we set out to study digital twins in order to explore the benefit that could be created by connecting data to a digital replica of a building. We wanted to adopt a user-centric apporach by focusing on the needs of a wider range of stakeholders across different phases of the building life-cycle. The magnitude of the task of developing digital twins at times feels daunting, but the business cases that have been identified suggest that this effort should be worth it in the end.

A key finding of our research is the emergence of different categories of digital twins with varying degrees of complexity. We acknowledge that many of the stakeholders that are developing the most complex as-built digital twins may not even consider that simpler solutions like the BI dashboard can be digital twins. However, the latter fit our definition of offering an up-to-date visual representation of the physical asset that is embedded with static and dynamic data. The way these solutions are used to manage and view the performance of the asset also goes in line with our definition.

The observations regarding the development timeline of digital twins are also a significant output from this report. BIM has dominated the discussion on digital twins for buildings, because it is a free by-product of design and construction processes that can be leveraged to support the incumbents' primary goals of operational performance. However, the business models and technologies that enable complex digital twins may not develop as fast as the emerging stakeholder needs. If that is the case, the growth of simple digital twins in the next years will outpace that of complex twins, because these simpler solutions will achieve a better balance between the value offered to customers and the resources needed for their implementation and maintenance.

It is likely that simple digital twins will disrupt the complex ones in the coming years. However, complex digital twins will eventually become productive. It is difficult to predict how the market will evolve in the future. One possibility is that today's simple digital twins will incrementally add new features over time to become complex twins. The accumulated knowledge, customer base and continuous revenue from the simple twin business cases may put them in a position to successful compete with the companies who focus solely on higher end cases. Another possibility is that the market position of today's complex digital twins will weaken in the coming years, but these solutions might survive disruption and provide the master geometry model. This would then restore them to the position as the strongest player in the market.

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