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ACTIONABLE CULTURAL RESOURCES FOR SUSTAINABLE LOCAL TOURISM DEVELOPMENT – MERITS OF DIGITAL SUPPORT SYSTEMS

RECURSOS CULTURAIS ACIONÁVEIS PARA O DESENVOLVIMENTO SUSTENTÁVEL DO TURISMO LOCAL – MÉRITOS DOS SISTEMAS DE SUPORTE DIGITAL

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Abstract: Sustainable tourism development is a major policy challenge for many cities, regions or countries. This paper describes various novel analytical ingredients to ensure a consistent and professional policy strategy in tourism destinations. In all cases, reliable and accessible data are necessary for an actionable tourism policy. In the present study advanced digital support systems for cultural resource-use in local tourism strategies are presented. The paper uses the region of South-Limburg in the Netherlands as a data-driven test case and as a cultural tourism showcase for demonstrating the great potential of digital twins as digital visual policy and participation tools for co-creative local sustainable tourism development.
Keywords: Actionable cultural resources. Historical-cultural heritage. Sustainable tourism. Digital technology. Digital twins.
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1. Introduction

Many countries, regions and cities have an abundance of cultural amenities, in the form of historical-cultural heritage, people's traditions and language, unique ecological or archeological sites, religious artifacts, and so forth (see e.g. Fusco Girard & Gravagnuolo, 2017). The old city of Belem – in the Amazon area in Brazil – is a great example of a place with rich geographical-architectural resources. The intriguing question for an economist is now whether such a culturally-rich place may only employ its historical-cultural heritage as a passive durable memory of its great past, or whether its historical-cultural heritage can be developed as an actionable economic asset with a great urban development potential. For instance, the harbor front development of Belem is a showcase of a creative exploitation of its great past.

The present study takes for granted that cultural resources are not passive assets, but may – under certain conditions – provide a boost to local or regional development. If carefully managed, such resources may lead to sustainable, inclusive and resilient development of places, serving the interest of citizens and local business. Essentially, cultural resources may prompt actionable strategies for local leisure and tourism areas, which go beyond just tourism or recreation by focusing on a strategic place-based sustainability approach that puts people at the heart of development while also preserving historical-cultural heritage and ecological landscapes.

While cultural tourism in an urban area offers great opportunities, it also carries risks. Tourism as a whole can be unpredictable economically or unsustainable ecologically. If not handled carefully, cultural tourism and entertainment can become an industry that extracts value without giving back, leading to negative impacts on the environment, society, and local culture. This paper intends to discuss strategies that shift the focus of cultural tourism away from mere consumption towards a model that prioritizes people, history and sustainability, considering nature, communities, and cultural diversity. This study values the unique spirit of a location (genius loci) and recognizes people as co-creators of its culture, art, traditions, and productivity. The paper seeks to propose long-term circular-economy development strategies for a given area.

The main aim of this paper is to design, examine and test sustainable innovations centered around people for circular cultural tourism and to support place-based initiatives that are often either neglected or over-exploited, aiming to boost economic growth, community

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well-being, historical awareness and nature conservation. It seeks to achieve its overarching goals through a focus on specific, measurable, achievable, realistic, and time-constrained (SMART) objectives, which encompass:

● Conducting a comprehensive assessment of the impacts and market potential of sustainable historical-cultural tourism, employing multidimensional quantitative and qualitative indicators, innovative statistical methods, and advanced data management in the context of smart digital technology systems.

● Stimulating a community-wide place-based interest dedicated to experience- and knowledge-sharing within the realms of sustainable cultural tourism.

● Evaluating actionable plans for the advancement of sustainable cultural tourism, illustrated for a target region in the Netherlands, viz. South-Limburg, with its main historical center Heerlen.

● Engaging in the iterative process of prototyping and testing innovative solutions aimed at enhancing the sustainability and attractiveness of cultural tourism offerings by deriving and using so-called *digital twins*.

The paper is organized as follows. After this general introductory section, we will in Section 2 introduce our illustrative case study (South-Limburg, the Netherlands), followed by an exposition on the tension between cultural heritage and sustainable tourism in Section 3. In the next section (Section 4) the notion of 'cultural epochs' is introduced and put in perspective, while Section 5 introduces a new geoscience tool, '*digital twins*'. Section 6 offers a detailed description of the elements of a digital twin. Then, in Section 7, a numerical illustration of the use of digital twins for sustainable tourism in South-Limburg is given, while Section 8 offers conclusions.

2. Area Description

2.1 *The relevant region*

South-Limburg is one of the Netherlands' most attractive and visited vacation destinations, serving not only local residents and Dutch guests but also drawing visitors from abroad, especially from Germany and Belgium. In the post-coronavirus era, where individuals increasingly prioritize factors like green spaces and active recreation such as cycling and hiking,

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it becomes crucial for this region's amenities to align with tourists' preferences. While South-Limburg boasts a wealth of tourism-related information and initiatives, there is still much to do and to know, particularly regarding visitors' motivations in the post-coronavirus era. This lack of understanding hampers the formulation of effective and strategic (private and public) investment plans, especially concerning dispersion strategies from crucial visitors' hotspots like the unique hilly landscape to less crowded areas. The geographically fragmented layout of attractions in this area, coupled with occasional gaps in facilities like hospitality offerings, underscores the need for a comprehensive assessment of the region's key attraction factors and pain points, specifically in regard to its historical-cultural sector.

Culture is regarded here as a broad economic resource that comprises inter alia art, history, architecture, entertainment, performing arts, creative professions, and so forth (see e.g., Nijkamp 2012; Kourtit & Nijkamp 2022). It goes without saying that tourism is all over the world predominantly attracted by rich local or regional cultural amenities. However, in the age of mass tourism, an uncontrolled influx of visitors may lead to countervailing crowding effects. In the area under study, namely South-Limburg, in the year 2023 4.3 million tourists visited the area. Mass tourism can lead to environmental decay and a decline in the quality of life of the local community.

Motives of tourists to visit this region include nature, culture, history, shopping, and entertainment. Often tourists combine various distinct motives (nature, history), and that explains the beneficial interaction between cultural assets and ecological resources. The combination of these assets and resources is therefore responsible for a positive actionable role in becoming/creating important tourist attractions. However, in the age of mass tourism, an uncontrolled influx of visitors may lead to countervailing crowding effects and negative environmental externalities.

Our research tries to explore ways to stimulate local tourism in a sustainable way. This research framework seeks to address these multifaceted challenges and opportunities associated with tourism development in South-Limburg. The favorable tourist development in this region has emerged from strong collaboration, both among entrepreneurs themselves and between entrepreneurs, governments, and other parties or stakeholders. This development is still ongoing. The COVID-19 crisis, which has resulted in declining visitor numbers and sometimes significant revenue losses for many agents involved, has presented everyone with significant

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challenges. Especially now, many people see good and structural collaboration as an important strength that they want to boost, sharing ideas, questions, and offerings with each other and other parties active in the leisure economy in the region.

2.2 A data-driven approach

In the vein of digital advances in data-handling for proactive policy and environmental management, the use of digital analytics has become increasingly popular in the tourist sector, and hence also in the region of South-Limburg. In recent years, the region has embraced a data-driven approach to enable better-informed policy decisions across various domains. This highlights also the necessity to identify inter alia residents in need and to enhance the understanding of the externalities of mobility patterns among residents and visitors. The collaboration with local, regional and national statistical data agencies has also brought professionalism in policy preparation, particularly from a credibility, security and privacy perspective. Moreover, it has facilitated networking with adjacent other municipalities in the same region, fostering joint and consistent policy planning.

2.3 Strategic focus

Unlocking the geographic-economic potential, the area possesses a significant economic growth opportunity, particularly through cross-border collaboration with the Aachen region in Germany. This collaboration leverages the expertise and resources of both regions to optimize their economic potential, focusing on areas like innovation and digital technology in various sectors, including tourism. The main critical policy concerns in the area are:

- *Mobility*: Understanding mobility intricacies within South-Limburg is crucial for comprehending visitor behaviors and preferences in relation to tourist amenities. By identifying opportunities to enhance transportation infrastructure while minimizing negative impacts, the region seeks to improve visitor experiences sustainably.

- *History and Ecosystem*: Studying South-Limburg's rich history alongside its diverse ecosystem provides valuable insights into the region's cultural and natural heritage potential. Preserving and promoting these assets sustainably requires a nuanced understanding of their interplay, thus promoting a circular economy.

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● **_Recreational Facilities_**: Evaluating the quantity and quality of recreational amenities across South-Limburg is integral to enhancing visitor experiences.

2.4 Tourism mobility

To facilitate data visualization and analysis in the contemporaneous digital era, an interactive digital tool, _Digital Twin_, will be designed and integrated into the research framework. This tool, including advanced digital mapping techniques and immersive virtual experiences, aims to enhance stakeholder engagement and decision-making processes and to induce citizen participation.

Efforts to improve mobility and accessibility are paramount for sustainable tourism development everywhere, and hence also in South-Limburg. Leveraging innovative digital solutions can promote alternative modes of transportation and reduce dependence on traditional vehicles. By prioritizing sustainability and inclusivity in mobility planning, South-Limburg seeks to position itself as a leading destination for eco-conscious travelers. The ongoing research should address the multifaceted challenges and new opportunities associated with tourism development in South-Limburg. By adopting a holistic approach that integrates data-driven insights, stakeholder collaboration, and innovative digital technologies, the region can map a course towards a more sustainable and resilient tourism ecosystem. This approach will be further outlined in this paper, with a view to providing insights that can also be applied to other tourist destinations like Belem in Brazil.

3. Cultural Heritage and Sustainable Tourism: An Uneasy Relationship

Over recent decades, the tourism sector has witnessed a rapid structural expansion, both locally and globally. It has evolved into one of the world's foremost industries, driven by factors such as increased leisure time, reduced transportation costs, globalization, logistical accessibility, and the proliferation of mass tourism benefiting from local scale advantages. Additionally, there has been a surge in global tourism participation from visitors originating from emerging economies (Yang and Wong 2021; World Tourism Organization 2021, 2022; Kourtit et al. 2022). More recently, the advent of digital technology has emerged as a catalyst for global tourism growth. This is evident through the widespread adoption of e-booking systems, digital information dissemination covering virtually all corners of the globe, social

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media engagement, and electronic platform utilization (Lau 2020). Tourism has transitioned from being a relatively low-tech physical mobility activity for visitors to becoming a high-tech, information-driven, and data-based industrial sector (Daldanise 2016; Kourtit et al. 2022). It embodies the characteristics typical of an advanced Industry 4.0 sector.

However, modern tourism also presents numerous challenges. Environmental degradation stands out as one of the prominent consequences of tourism in destination areas, manifesting in forms such as noise pollution, waste accumulation, air, and water pollution. Additionally, negative externalities such as local overcrowding effects and the erosion of local identity and authenticity pose significant concerns (Gössling 2020a,b; Lu et al. 2022; Song et al. 2022). Cities like Venice and Barcelona serve as stark reminders that tourism is not without controversy and can have adverse impacts on the local economy. Is it possible to transform tourism into an economic activity that fosters environmentally friendly, climate-neutral, or circular outcomes for tourist destinations? Can digital technology offer tools to facilitate the journey towards sustainable outcomes at the local or regional level, supported by the local community, while also mitigating insider versus outsider conflicts? Addressing these multifaceted and complex challenges requires evidence-based creative solutions (Angrisano et al. 2016; Hampton 2005), based on practical arguments.

This paper will showcase the potential of three-dimensional (3D) visualization methods in local cultural tourism planning. Emphasis will be placed on the utilization of '*Digital Twins*' as new spatial imaging tools to furnish policymakers and planners with pertinent, place-based information, enabling them to adopt an integrated perspective on cultural resources in sustainable tourism planning.

Culture encompasses in general, a broad economic sector that includes art, history, architecture, entertainment, performing arts, and creative professions, among others (Alberti and Giusti 2002; Coccossis and Nijkamp 1995; Kourtit & Nijkamp 2023). It comprises both material and spiritual components and serves as a reflection or manifestation of societal trends and mindful developments that bridge the past with the present. It is evident from recent experience that tourism is drawn to rich local or regional cultural amenities worldwide, as evidenced by cities like Venice, Paris, Amsterdam, Florence, Boston, Cape Town, Mumbai, and Shanghai. This attraction extends as a spatial spillover also to smaller cities such as Haarlem in the Netherlands, Bruges in Belgium, Delphi in Greece, or Bandung in Indonesia. Tourism

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represents a significant economic asset capable of generating substantial financial resources for the host area. However, in the era of mass tourism, an uncontrolled influx of visitors can lead to counterproductive crowding effects that jeopardize the cultural and ecological assets that form the foundation of tourism. The tourism paradox, illustrated in Figure 1, encapsulates this dilemma.

Figure 1. The tourism paradox

Source: Kourtit et al. (2024), p.2

There exists a wealth of literature addressing the above-mentioned paradoxical developments in tourism (Fusco Girard and Nijkamp 2009; Greffe 2004; McManus and Carruthers 2014). Several studies have explored various aspects including crowding effects, environmental degradation, and the decline in the quality of life of residents in destination places (Gössling et al. 2020a,b; Hall et al. 2020; Yang and Wong 2021; Song et al. 2022). We will now provide an empirical illustration for the case of South-Limburg.

## 4. Relevant Epochs in the History of South-Limburg

It is crucial to note that cultural-historical heritage is not merely a static asset from the past but a dynamic phenomenon influenced by different periods in history, or *cultural-historical epochs*. This will be elucidated using the case of South-Limburg in the Netherlands, a region endowed with rich cultural-historical and vulnerable ecological resources near the German and Belgian border. While considered a peripheral region for Dutch nationals, it boasts accessibility for Germans (proximity to Aachen) and Belgians (proximity to Liege and Brussels). It is also

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among the most attractive natural areas for Dutch tourists, boasting a plethora of cultural-historical and ecological resources dating back to the Roman period (Kourtit & Nijkamp 2023). This will now be further elucidated by a distinction in five relevant epochs, which are landmarks of its unique history:

- The Roman period; 750 BC – 500 AC ('*Carrefour of the Romans*')

- The Medieval period; 500 AC till the 17th century ('*Knights and Bandits*')

- The coal mine era; modern time till the 1970s ('*Golden Mining*')

- The intermediate era; the breakdown period at the end of the last century ('*Dramatic Transition*')

- The modern era; beginning of the 21st century ('*New Revival*')

Each epoch contributes to the region's narrative and has left behind significant characteristic imprints or 'icons' (see Annex A, Figure A.). For each epoch, a map can be generated depicting the location of cultural-historical landmarks in the area. Overlaying these five maps yields a comprehensive map of the entire region encompassing cultural-historical assets in an integrated manner (see Figure 2).

Figure 2. An integrated representation of the cultural-historical assets across South-Limburg in the form of a comprehensive map of icons.
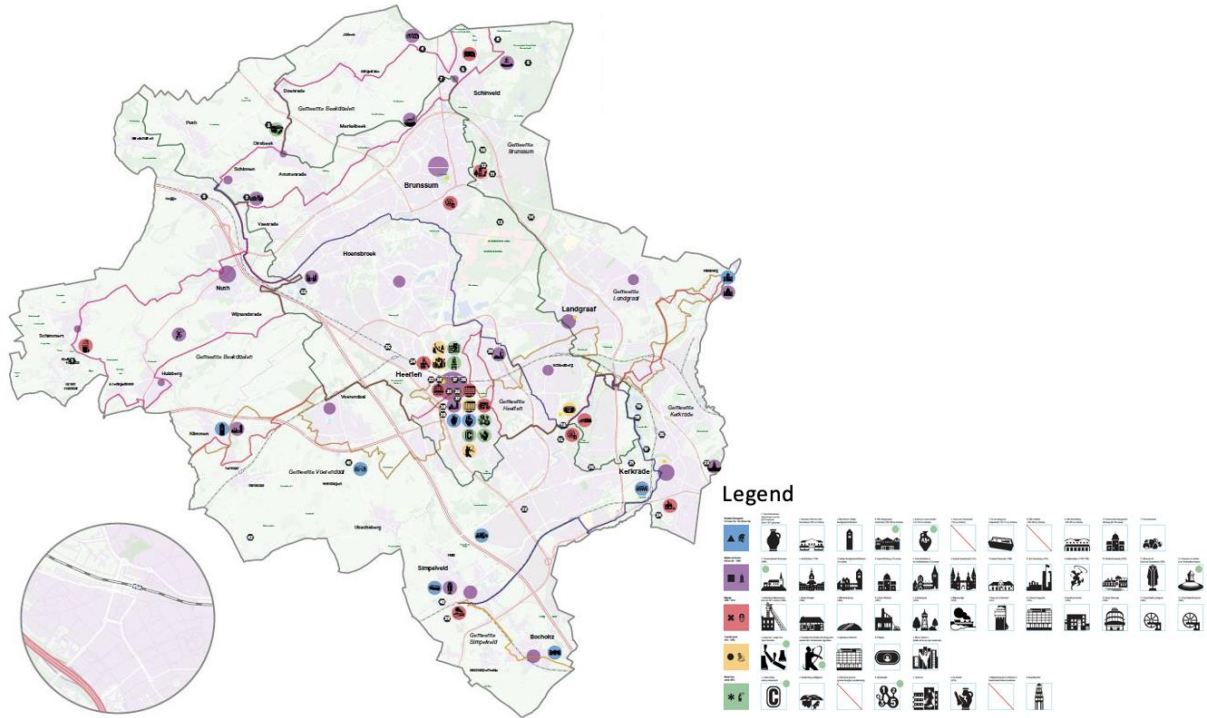
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Source: The Story of Parkstad, and its implementation within the Customer Journey Model; a visual PowerPoint presentation by Anya Niewierra (General Director Visit *Zuid Limburg*, 8 September 2022, Heerlen, p. 27).

In visual comprehensive form, the cultural-historical evolution of South-Limburg can be systematically depicted from a synthetic multi-faceted temporal perspective (see Figure 3).

Figure 3. Sketch of the cultural-historical epochs in South-Limburg.
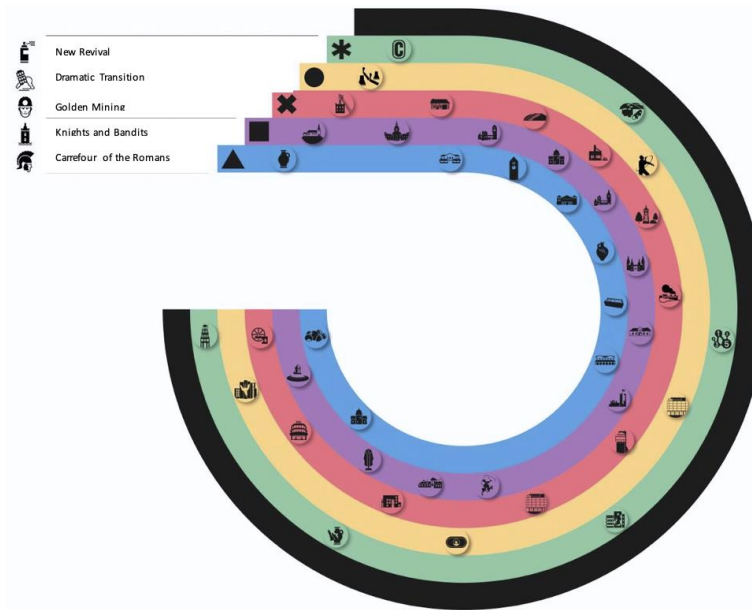
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Source: The Story of Parkstad, and its implementation within the Customer Journey Model; a visual PowerPoint presentation by Anya Niewierra (General Director *Visit Zuid Limburg*, 8 September 2022, Heerlen, p.27).

It is evident that visitors to South-Limburg are driven by various motives including nature, culture, history, shopping, and entertainment. Particularly during the summer season, overcrowded areas are apparent, diminishing the tourist appeal of the region and causing dissatisfaction among local residents. Tourism policy thus necessitates to achieve a delicate balance between many conflicting interests. Achieving such a balance requires detailed, user-friendly information on tourist attractions, tourist pressure, and negative externalities. To this end, the use of digital support tools in particular, Digital Twins, is indispensable. This will be articulated in Section 5.

5. Relevance and Application of Digital Twins in Planning

5.1 Introduction

Over the last few decades, academics, engineering companies, and asset managers have embraced various digital technologies to tackle end-of-service life challenges for infrastructural and land use objects. For instance, detailed Finite Element Models (FEM) have been employed to compute stress levels in various spatial planning components, advanced fatigue growth models have been updated using dynamic inspection data, and innovative sensor solutions have been deployed to monitor actual loads, stresses, and various condition levels in public sector issues (Zhang et al. 2024; Khajavi et al. 2019). Traditionally, these methods relied heavily on

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geographical-physical knowledge (soil condition, geology, densities, etc.), but recent years have witnessed a significant surge in data availability, data-driven methods, computational power, and visualization technology, with this trend expected to continue. This raises the question of how these digital technologies can be effectively applied to address the end-of-service life challenges faced by environmental asset managers and land use planners.

Geo-science has in recent years become a popular approach to multi-scalar land use planning. And *Geographic Information Systems* (GIS) technology experiences a significant advancement through the integration of diverse data sources. Conventional datasets are enriched by the inclusion of demographic, behavioral, sectoral, and structural data. However, leveraging these datasets, which are dispersed across various administrative and spatial levels globally, poses a formidable challenge in such applications. Hence, data integration emerges as a critical component for advancing, particularly, public warning systems. The solution nowadays lies increasingly within the realm of Digital Twins.

A Digital Twin is defined as 'a digital replica of a living or non-living physical entity[6]. By establishing a connection between the physical and virtual domain, spatially-relevant data seamlessly represent flows, facilitating the coexistence of the virtual entity alongside its physical counterpart. These models are capable of encapsulating detailed information across diverse domains and scales.

Digital Twins have in recent years demonstrated considerable value in modern urban planning and in integrating data pertaining to individuals and spaces, thereby facilitating decision-making processes (Al-Sehrawy et al. 2021; Niu & Qin 2021). In the case of South-Limburg, a Digital Twin offers an integrated perspective, consolidated within a unified information infrastructure to streamline data enrichment and modeling activities for sustainable planning.

Nowadays, there is a burgeoning interest in Personal Digital Twins (PDTs). PDTs serve as digital representations of individuals, constructed from their digital footprints. This technology is already in widespread use across various industries. PDTs encompass a broad spectrum of information, encompassing activities, behaviors, and more, thereby providing

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[6]Joint Research Centre, Ispra, Digitranscope - The Governance of Digitally-Transformed Society. 2021.

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substantial support for numerous environmental and land use studies, particularly those focusing on aggregated data analysis.

In this context, early warning systems are essential tools required to enhance efforts in preventing emerging hazards. These systems depend on a Digital Twin framework, acknowledged as a cornerstone for comprehending, modeling, and simulating complex phenomena. Digital twinning emerges as a solution to bridge the gap between the physical and digital worlds by creating virtual replicas of real-world assets. This virtual environment enables data-driven operations and facilitates more efficient decision-making and asset management in an increasingly digitized society. While the concept of digital twinning finds application across various sectors and industries, its definition varies sometimes, often emphasizing intelligent systems enabled by continuous interaction, communication, and synchronization between the Digital Twin, its physical counterpart, and the surrounding environment, frequently incorporating predictive elements (Barricelli et al. 2019; Grieves 2023). We will offer an illustration of this possibility in Section 5.2.

5.2 Digital Twin Maturity model

The Digital Twin Maturity Model (see Rook, 2019) outlines a progressive evolution in Digital Twin applications, reflecting increasing levels of sophistication and integration across organizational and operational domains (see Figure 4). It contains various use components, which will concisely be described:

1. *Visualization and Exploration*: At the initial stage, Digital Twins serve primarily as visualization tools, allowing stakeholders to explore and understand the digital representation of a given area or environment.

2. *Internal Process Optimization*: Moving forward, the focus shifts towards optimizing internal work processes within specific organizations. Digital Twins become more tailored to the unique needs and workflows of the organization, facilitating enhanced operational efficiency and effectiveness.

3. *Shared Goals and Projects*: The maturity model advances as Digital Twins evolve into platforms for collaborative goal-setting and project management.

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Organizations utilize Digital Twins to share objectives and initiatives, fostering alignment and coordination across teams and departments.

4. *Operational Integration and External Connectivity*: As Digital Twins mature further; they transition into operational tools for real-time production and asset management. Importantly, they also become open to external stakeholders, enabling connectivity with external systems, partners, and stakeholders.

Figure 4. Digital Twin Maturity model
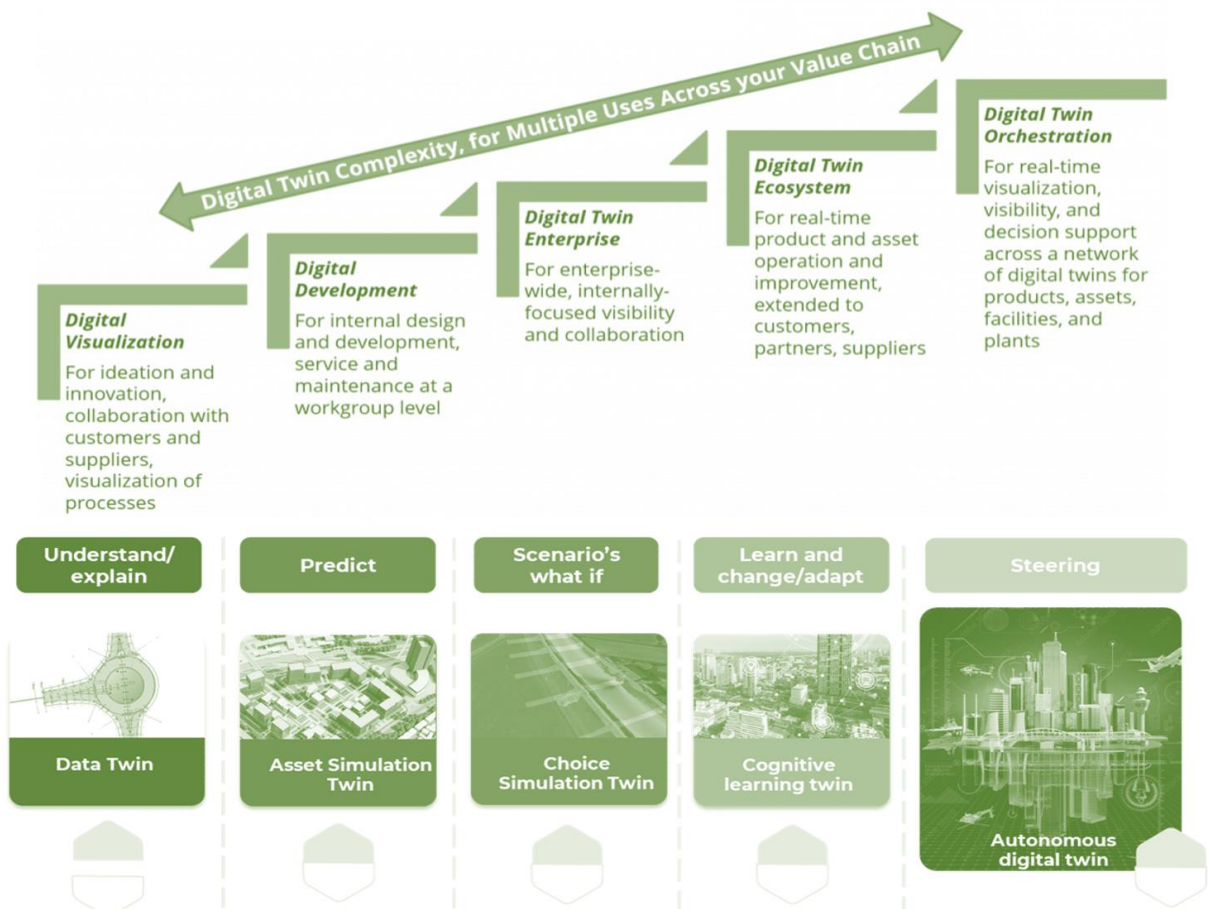
Source: Rook (2019)

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7. *Shared Goals and Projects*: The maturity model advances as Digital Twins evolve into platforms for collaborative goal-setting and project management. Organizations utilize Digital Twins to share objectives and initiatives, fostering alignment and coordination across teams and departments.

8. *Operational Integration and External Connectivity*: As Digital Twins mature further; they transition into operational tools for real-time production and asset management. Importantly, they also become open to external stakeholders, enabling connectivity with external systems, partners, and stakeholders.

9. *Networked Digital Twins for Holistic Decision-Making*: In the final stage of maturity, Digital Twins transcend individual organizations and processes, forming interconnected networks of Digital Twins. These networks facilitate real-time visualization, exploration, and decision-making across a broad spectrum of processes and stakeholders, fostering holistic and integrated approaches to problem-solving and innovation.

As organizations progress through the Digital Twin Maturity Model, they transition from basic visualization tools to interconnected networks of Digital Twins, fostering holistic decision-making and innovation across diverse processes and stakeholders.

5.3 Digital Twin application potential

In the built environment and land use planning, Digital Twins are gaining prominence, particularly for inspection and predictive maintenance purposes, leveraging sensor data and model results (Khajavi et al. 2019). The currently popular *Building Information Models* (BIM) also play a crucial role, providing detailed architectural information essential for creating accurate Digital Twins (Lu et al. 2022; Deng 2021). However, advancements in data and technology present opportunities for developing more sophisticated Digital Twin infrastructures, including comprehensive Digital Twins for the Physical Living Environment (DTFL), integrating geospatial data and dynamic processes on a regional scale (see e.g. De Raat et al. 2023).

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Standardization of architecture is envisioned as a key strategy to unlock the full potential of Digital Twins. A standardized Digital Twin System Architecture (see Figure 5) is described to enable the creation of asset-specific Digital Twins in a flexible, repeatable, and efficient manner. Standardization enhances efficiency by optimizing system architecture, interfaces, and building blocks while maintaining the flexibility to accommodate various asset types and problems. Decoupling system layers and standardizing interfaces also mitigate vendor lock-in, fostering interoperability and information retention throughout the asset life cycle.

Figure 5. Standardized Digital Twin System Architecture.
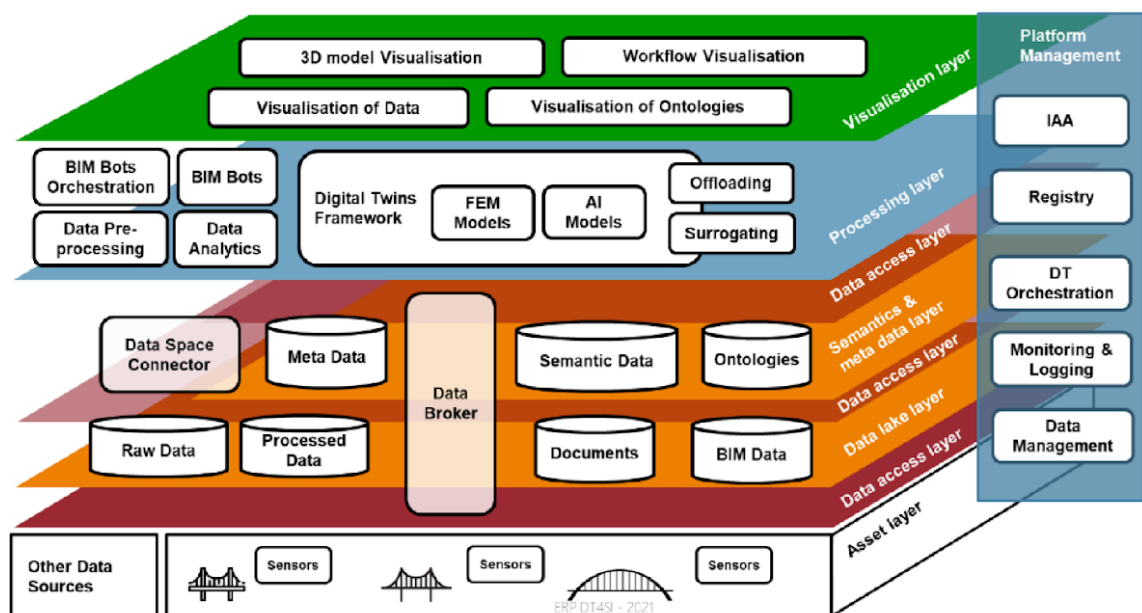
Source: De Raat et al. (2023), p. 1005

Integration of data from the Internet of Things (IoT) into Digital Twins presents opportunities for real-time monitoring and simulation, enhancing decision-making in e.g. cultural tourism and heritage management. By incorporating IoT sensor data into Digital Twins, stakeholders gain immediate access to critical information about the condition and usage of cultural assets. This integration enables informed decisions about resource allocation, visitor engagement strategies, and maintenance prioritization to enhance the overall visitor experience.

Moreover, the development of open-source data infrastructure and standards is crucial for fostering collaboration and innovation in the field of Digital Twins for cultural tourism and heritage preservation. Open-source platforms provide a common framework for data sharing

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and integration, facilitating interdisciplinary collaboration and knowledge exchange among stakeholders. This collaborative approach enables the co-creation of Digital Twins tailored to the unique needs and challenges of cultural heritage sites.

5.4 European perspective

Digital Twins have in the meantime also become important analytical tools in spatial planning in many European cities, regions and countries. The Digital Twin technology operates on a foundation of data, making data quality and standardization crucial. As the EU advances its data strategy, the concept of a common data space has emerged as an important component. This strategy encompasses various sectors, aiming to create interconnected digital environments where data can seamlessly flow between producers and consumers (see Figure 6).

Among the envisioned common European data spaces are those dedicated to industrial manufacturing, green initiatives under the European Green Deal, mobility, health, finance, energy, agriculture, and public administration. Each data space serves as a platform for facilitating the exchange of valuable data assets, driving innovation and enhancing Digital Twin capabilities across sectors in Europe.

Figure 6. European Union data strategy and Digital Twin

Source: EU 2020, http://dataeconomy.eu/eu-data-strategy-2020/#page-content[7]

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[7] https://ec.europa.eu/digital-single-market/en/policies/building-european-data-economy

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Indeed, data is increasingly recognized as a valuable and precious good (the 'new gold'), and the establishment of digital spaces aims to streamline its movement within and across industries. By fostering a conducive environment for data sharing and collaboration, these initiatives are poised to significantly enhance Digital Twin functionalities, also in the tourism sector. An early exemplar of such a shared data space is INSPIRE, which encompasses diverse datasets related to tourism, including sea regions, building and facilities, commercial uses, and Natura 2000 sites. By harmonizing and integrating these datasets, INSPIRE lays the groundwork for comprehensive data-driven insights in the tourism sector and beyond. We will now concisely present critical cornerstones of a Digital Twin.

6.   Building Blocks of a Digital Twin

The Digital Twin of the physical environment comprises several generic components, akin to a cookbook with recipes and necessary ingredients. These components can be applied across multiple specific Digital Twins and thus reused, as illustratively depicted in Figure 7.

Figure 7.   The Digital Twin of the physical environment consists of several generic components.
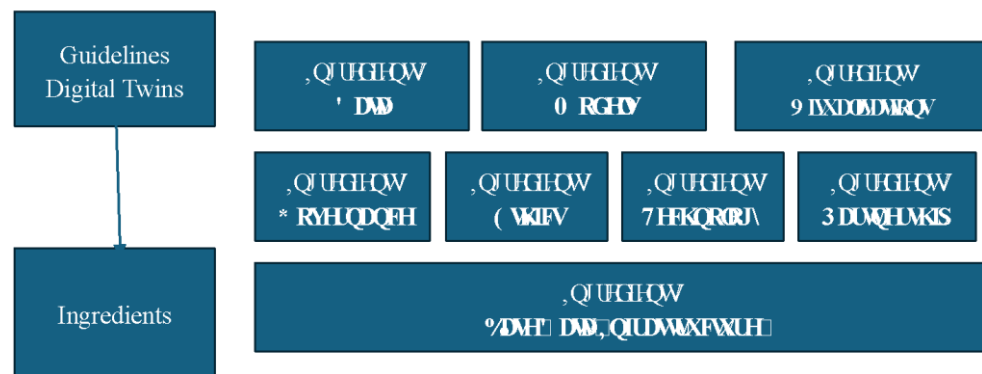
Source: Bruijn & Padding (2021), p. 13[8]

6.1 Data

Data serves as the raw material for the Digital Twin, with geospatial databases forming its core. These databases, including Cadaster, Addresses, Buildings, Topography, Large-Scale Topography, and Subsurface, each provide detailed and socially relevant reflections of the

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Netherlands and its regions. Together, they form the national geodata foundation to which various parties can relate their additional (sector-specific) data.

6.2 Computational models

In addition to data, computational models are utilized to simulate the consequences of interventions in the environment and develop alternatives. These models often leverage dynamic data collected, sometimes with sensors, and processed with AI algorithms.

6.3 Visualization

While basic data of the physical environment is available in two dimensions, increasingly, it is also accessible in three dimensions (3D). For the Digital Twin, visualizing in 3D is crucial to enhance understanding and clarify the (im)possibilities, both above and below the surface level. Virtual Reality (VR), Augmented Reality (AR), and other technologies are employed to create as realistic a depiction of reality as possible, depicting both static elements (buildings, roads, agriculture, water, etc.) and dynamic data like traffic, groundwater, energy, noise, particulate matter, etc. Here, in addition to space (3D), time is also depicted.

6.4 Platform technology

Several technical platforms commercially available enable clients to form a Digital Twin around a physical challenge. These platforms allow the integration of various ingredients into a Digital Twin for a specific situation.

6.5 Ethics

The Digital Twin can be viewed within the broader context of societal datafication. The digital and physical worlds increasingly intersect, with emphasis placed on ethical and public values, enshrined in legislation regarding data and AI usage (privacy, transparency, reuse, participation, and openness).

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6.6 Responsible use

Organizing and utilizing the Digital Twin in a responsible manner is paramount. We have a collective responsibility to ensure that technology and data serve people's needs. This is achieved through various ethical design principles, such as legality, purposefulness, openness, transparency, human-centeredness, data sovereignty, and faithful reflection of the physical environment. Continued engagement with these principles ensures that technological advancements remain aligned with societal values.

6.7 Infrastructure

A country like the Netherlands boasts an advanced National Geo-Information Infrastructure. Geo-base registrations, established with relatively modest means, serve as essential utilities for Dutch society. They are indispensable for various societal and economic activities, ensuring that our infrastructure functions smoothly.

6.8 Collaboration

The Digital Twin, formed to address a physical challenge, is the product of co-creation among all stakeholders (both public and private). Collaboration and sharing ensures that the maximum potential of this tool is realized and that all interests are balanced.

6.9 Security

For the widespread applicability of Digital Twins, it is crucial to trace the origin and integrity of data. This transparency and integrity are vital for stakeholders affected by processes involving Digital Twins, as well as for government users in public safety and defense, ensuring they are working with unaltered and consistent data. Additionally, it safeguards against reputational damage for owners of Digital Twins caused by malicious actors manipulating information components.

In conclusion, Digital Twins offer immense potential for advancing cultural tourism and preserving cultural heritage in the 21st century. By integrating IoT data, modeling data gaps, and facilitating behavioral simulations, Digital Twins empower stakeholders to make informed

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decisions that enhance the visitor experience and ensure the long-term sustainability of cultural assets. Through open-source data infrastructure and collaboration, the full potential of Digital Twins can be realized, unlocking new opportunities for circular cultural tourism and heritage preservation.

7. An Illustration of the Use of Digital Twins for Sustainable Local Tourism Planning in the Case of South-Limburg

As mentioned, we will use the region South-Limburg in the Netherlands as an illustrative case for showing the policy potential of Digital Twins. Effective sustainable local tourist planning requires customized information that encompasses the supply and demand profiles of tourist areas, including key amenities, attractive features, and constraints from both physical geography and other contextual factors. This includes an assessment of strengths and weaknesses at both local and regional levels (Niccolucci et al. 2022; Singh et al. 2022). Additionally, planning should consider broader sustainability goals, such as the fulfillment of the 17 Sustainable Development Goals (SDGs), urban circularity, and climate neutrality, while addressing the varied objectives of multiple stakeholder groups.

Over the past decades, a wide array of evidence-based digital planning support tools has been developed. These tools include digital scoreboards, interactive user-oriented dashboards, community-based geodesign tools, 3D visualization techniques, and maps. Recently, Digital Twins have emerged as new powerful tools in this domain. Digital Twins can be understood as virtual 3D mappings of real-world, complex phenomena, organized spatially and temporally using systematically arranged micro-based or meso-based data. They not only provide static depictions of urban features through multi-scalar data collection, but also incorporate a range of time-varying digital data sources, from cadastral information to GPS data. Thus, a Digital Twin surpasses a mere 3D atlas by being systematically and thematically organized, interactive, and capable of 3D simulation, such as virtual museums, historical experience centers, and metaversal digital cultural heritage.

To this end, a digital data toolbox using a Digital Twin approach proves invaluable. This approach can generate the necessary data for spatial digital planning support tools, such as interactive user-oriented dashboards for sustainable cultural tourism at both urban and regional levels (see Figure 8).

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Figure 8. A cascade of hierarchical data use and monitoring.
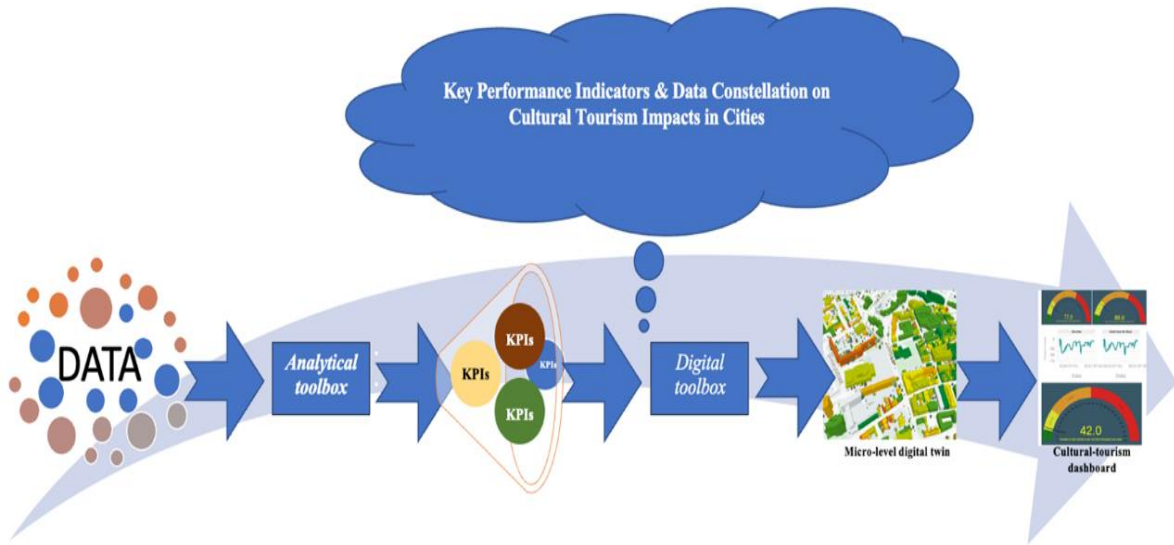
Source: Kourtit et al. (2024), p. 4

Based on a coherent visualization of the empirical database for a sustainable cultural tourism system, we can now design the architecture of the relevant key performance indicators (KPIs) for a balanced evidence-based urban tourism policy (see Figure 9).

Figure 9. Architecture of KPIs in the urban tourism architecture system

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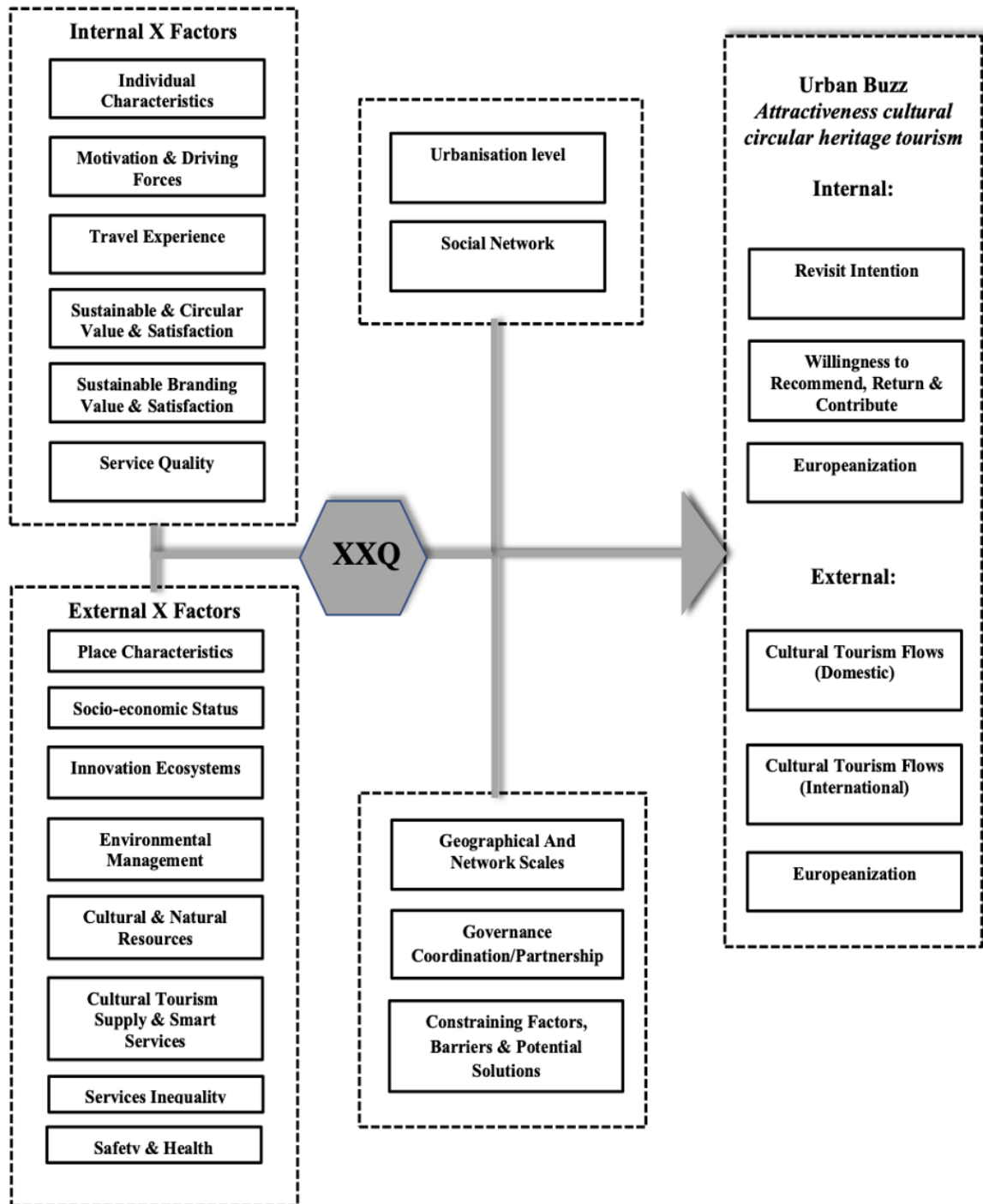
Source: Authors' elaboration

7.1 Operational Twin Architecture

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For the vision regarding the aforementioned research and policy challenge, a pilot twin architecture[9] has been outlined to further elaborate on it. In further elaborating on the design, this reference architecture guides the relevant policy issues. Components/parts of the solution must fit into the architecture and can be tested and explained accordingly. In this project, fruitful use can be made of the architecture developed for the National Digital Twin of the Physical Environment[10].

Figure 10. Proposed reference architecture Digital Twin[11]
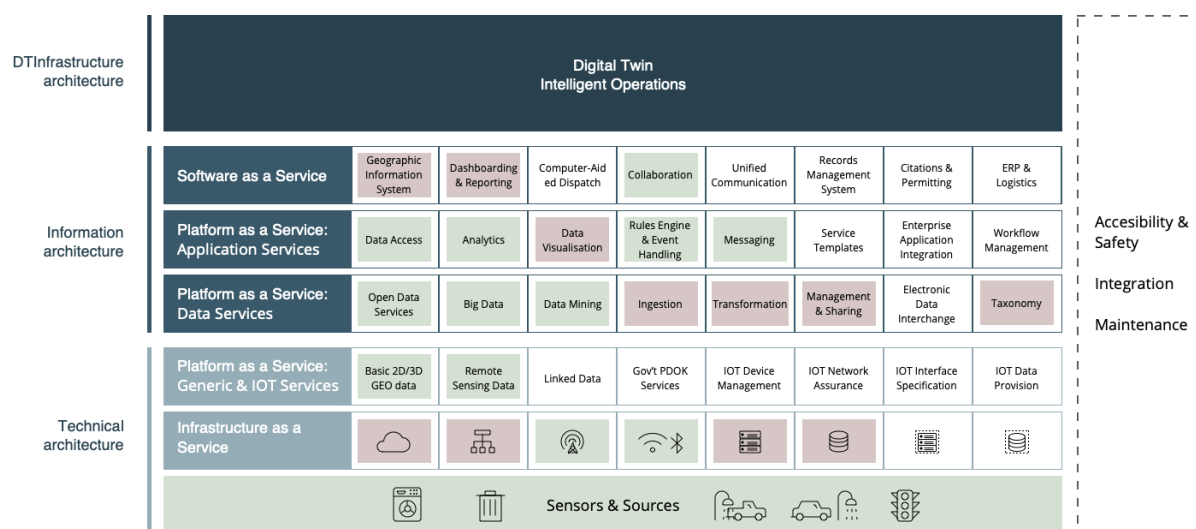
Source: Geonovum (2021)[12]

As a pedagogical example of the spatially varying tourist amenities in the main center of South-Limburg, Heerlen, we present a GIS map of local hospitality provisions, including hotels, restaurants, bars, and cafés (see Figure 11). The city center and main transport axes emerge as popular locations for these visitor facilities.

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[9] What is reference architecture? Reference architectures are reusable architectures based on best practices . They provide a template for developing specific enterprise architectures and solution architectures. Developing a specific architecture thus becomes a matter of selecting reusable principles and models and adapting them to the specific situation. This greatly accelerates the architecture design process.

[10] https://www.geonovum.nl/over-geonovum/actueel/consultatie-referentiearchitectuur-stelsel-digitale-tweeling-fysieke

[11] https://www.geonovum.nl/over-geonovum/actueel/consultatie-referentiearchitectuur-stelsel-digitale-tweeling-fysieke

[12] https://www.geonovum.nl/over-geonovum/actueel/consultatie-referentiearchitectuur-stelsel-digitale-tweeling-fysieke

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Figure 11. Location of hospitality amenities in the center of Heerlen, categorized by SBI numbers

Legend

- 🟣 55102 OR 55201 OR 55101 OR 5530 OR 55202 OR 5590
- 🟢 56101 OR 5590
- 🟠 56101 OR 56102
- 🟤 56102
- 🟢 56102
- 🔴 56102 OR 5630
- 🟡 5630
- 🟢 5630 OR 85522 OR 85521 OR 5914
- 🔵 91011 OR 85522 OR 90042 OR 90041
- 🔴 9103 OR 91011 OR 91022 OR 92001 OR 91012 OR 93211 OR 93299 OR 91019 OR 92009 OR 91042 OR 91021 OR 91041
- 🔴 93299 OR 94911
- 🟣 94911 OR 9604

The subsequent phase involves presenting Digital Twin prototypes for Heerlen's central area. We will showcase initial results from an empirical proof-of-concept experiment focusing on two KPIs: (i) the spatial sustainability/circularity dimension of the housing stock, measured by energy efficiency as a proxy for favorable conditions of the built environment, and (ii) the density and spatial distribution of urban greenery relative to the buildings' construction years, serving as a proxy for neighborhood quality of life. Detailed spatial 3D images of these KPIs for Heerlen's city center are shown in Figures 12 and 13, respectively.

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Figure 12.   Prototype Digital Twin of Heerlen for energy efficiency of buildings at micro scale (based on

energy labels of houses and presence of trees).

Figure 13.   Prototype Digital Twin of Heerlen for Age of Buildings at Micro Scale

(based on year of construction and presence of trees).

This Digital Twin experiment only scratches the surface of geoscience techniques' potential. Future research should explore deeper into creating Digital Twins for various attractiveness characteristics of the city, such as cultural amenities, entertainment venues, synergies among tourist attractions, and visitor accessibility. Additionally, analyzing the

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interactions between different thematic Digital Twins presents an exciting challenge for further exploration.

To further extend the scope of this prototype, more detailed and expansive datasets will need to be integrated. This includes real-time data from IoT devices, which can provide up-to-the-minute insights into visitor flows, environmental conditions, and infrastructure use. Such integration will allow for dynamic updates to the Digital Twin, making it an even more powerful tool for planners and stakeholders.

8. Conclusion

The development of user-friendly interfaces and visualization tools is critical to making digital technology, in particular Digital Twins, accessible to a broader constituency. By enabling interactive exploration of the data, stakeholders from various sectors—including tourism, urban planning, and local government—can better understand and utilize the insights provided by the Digital Twin.

In addition to technical enhancements, a Digital Twin project may also incorporate participatory approaches. Engaging local communities and stakeholders in the development process can ensure that the Digital Twin reflects the needs and priorities of those who live and work in the area. A participatory approach can also help build local capacity for using digital tools in cultural heritage management and sustainable tourism planning.

Ultimately, the goal is to create a comprehensive and adaptive Digital Twin that not only supports current planning and management efforts but also anticipates future needs and challenges. By continuously updating and refining Digital Twins, we can ensure that it remains a valuable resource for promoting sustainable and inclusive cultural tourism in South Limburg and beyond.

By embracing these advanced digital techniques, we can significantly enhance our understanding and management of cultural heritage sites. This not only preserves the past but also paves the way for innovative and sustainable tourism strategies that benefit local communities and economies.

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ANNEX A Photos of Icons in five epochs in South-Limburg

A1. Icons of the Roman junction

A2. Icons of the middle ages to the 18th century

A3. Icons from the coal mining era (after the Industrial Revolution)

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A4. Icons from the social collapse & transition years

A5. Icons from the 'new élan' today

Figure A. Five distinct cultural-historical epochs (Visit Zuid Limburg 2022), pp 10-14.

Source: The Story of Parkstad, and its implementation within the Customer Journey Model, a presentation by Anya Niewierra (General Director Visit South-Limburg, on 8 September 2022, p. 27).