Digital Ecosystems that Empower Communities

Exploring case studies to develop digital ecosystems theory and templates for technology stacks

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GPAI | THE GLOBAL PARTNERSHIP ON ARTIFICIAL INTELLIGENCE

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Report overview

This report is the first from Global Partnership on Artificial Intelligence (GPAI)'s Digital Ecosystem project. The concept of digital ecosystems aims to empower communities with digital technologies to enhance their capacity to solve problems and address challenging issues they face. This report presents and discusses the digital ecosystems concept, lays out a proposed methodology to explore the concept further using case studies, and then presents some case studies from various communities gathered by the project team. The report concludes with some suggested future research directions and observations from the project's work over 2024.

Key findings

- Digital ecosystems are related to but distinct from other problem solving methodologies and require genuine connections with the communities involved.
- Digital ecosystems show the potential to have an effective portfolio of technologies that can be combined into powerful technology stacks.
- Indigenous and local knowledge can make a key contribution to digital ecosystems and digital ecosystems can support the application of community knowledge and culture.
- By providing accessible, playful engagement with advanced technology, digital ecosystems enable diverse, inclusive problem solving that supports higher levels of innovation.
- A co-creation based approach can facilitate the knowledge exchange and diffuse upskilling necessary for the longevity of technological projects and community ownership of digital ecosystems.
- The digital ecosystems approach has the potential to put data justice and digital sovereignty principles in practice by allowing a community-level ownership of data and digitally induced value creation.
- The community empowerment created by the digital ecosystems approach has the potential to foster an environment where local economies can thrive, leading to healthier and more resilient societies.

Recommendations

- **Explore the potential of digital ecosystems to support problem solving for complex systems**
  - A digital ecosystems approach can be applied to practical pilot projects that both investigate and solve real-world problems for communities.
- **Develop the digital ecosystems theory and technology stack(s) with a case study approach**
  - By applying a pilot approach to a broad range of case studies, the project aims to identify the crucial parts of a generic technology stack template that can be adapted and applied to totally new case studies.
- **Make digital ecosystems available to communities**
  - The intention of this report is to build a case for funding digital ecosystems pilots that solve real-world problems for communities, actively empowering them, and to extract learnings that can be applied to other communities and other problems.
  - In conducting such practical pilots, we commit to helping communities work in the open, share learnings and knowledge, and develop a reusable pipeline that can be applied widely by others while protecting the autonomy of communities participating to the exercise.
- **Facilitate the scaling and sustainability of the digital ecosystems with continuous support during the transition phase to community autonomy**
  - Expertise, human resources, time, funding and effort are all vital elements to the development and maintenance of healthy and functional digital ecosystems.
  - Explore knowledge augmentation partnerships as an efficient means to support upskilling and capacity building.
- **Ensure an approach that is aligned with responsible AI, data justice and data sovereignty principles**
  - A digital ecosystem that empowers a community should have an inclusive approach that shows genuine respect to individuals and communities. The community should play a central leadership role.
  - Make sure to build digital ecosystems on safe, fair and ethical data governance foundations.
- **Fund further research at the intersection of AI safety and digital ecosystems that empower communities**
  - As for any AI and data-powered tool, digital ecosystems come with the amplified risks of biases and other harms. More research should be dedicated to this intersection to enable communities to develop and use those tools safely.

Glossary

AI An Artificial Intelligence (AI) system is "a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments." (OECD, 2019). 5

BIM Building Information Models (BIMs) are defined as "a modelling technology and associated set of processes to produce, communicate, and analyze building models" (Sacks et al., 2018). 8

GIS A Geospatial Information System (GIS) is "a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information" (Folger, 2010). 8

GPAI The Global Partnership on Artificial Intelligence (GPAI) is "a multi-stakeholder initiative which aims to bridge the gap between theory and practice on AI by supporting cutting-edge research and applied activities on AI-related priorities." (GPAI, 2021). 1, 2, 19

HL7 FHIR Health Level 7 (HL7) "messaging standards are widely implemented by the healthcare industry and have been deployed internationally for decades." HL7 Fast Healthcare Interoperability Resources (FHIR, pronounced "fire"), i.e., HL7 FHIR, is a "standard to help achieve healthcare systems interoperability." (Bender and Sartipi, 2013). 13

IoT Internet of Things (IoT) "is an emerging paradigm that enables the communication between electronic devices and sensors through the internet in order to facilitate our lives." (Kumar, Tiwari, and Zymbler, 2019). 7

ML Machine Learning (ML) is a discipline of artificial intelligence (AI) and computer science that uses data and algorithms to allow AI to learn in the same way that people do, gradually improving its accuracy. (Beyerer, Kühnert, and Niggemann, 2019). 9

VR Virtual Reality (VR) "is a simulated experience that employs 3D near-eye displays and pose tracking to give the user an immersive feel of a virtual world" (Wikipedia, 2024b). 5

Acronyms

AI Artificial Intelligence. 5, 7, 9–11, 26, 28, 29, 33, 36, 37, *Glossary:* AI

BIM Building Information Model. 8, 9, 11, 13, 14, 32, 33, *Glossary:* BIM

GIS Geospatial Information System. 8, 9, 30, *Glossary:* GIS

GPAI Global Partnership on Artificial Intelligence. 1–3, 19, 35, 37, *Glossary:* GPAI

HL7 FHIR Health Level 7 Fast Healthcare Interoperability Resources. 13, 20, 32, *Glossary:* HL7 FHIR

IoT Internet of Things. 7, 12, *Glossary:* IoT

ML Machine Learning. 9, 10, *Glossary:* ML

SDG Sustainable Development Goal. 36

UN United Nations. 36

VR Virtual Reality. 5, 6, 10, 13, 14, 30, *Glossary:* VR

1 Introduction

The concept of digital (i.e., *in silico*) ecosystems is prefaced on five principles for successful problem solving and working with communities in a way that supports their wellbeing:

1. Innovation is enhanced by diversity;
2. Collaborative problem solving supported by technology helps find solutions and develops problem solving and technological skills among all people who are closely involved;
3. Measurement tools are key to success in problem solving.
4. Community empowerment – which includes the ability to understand the environment, influence decisions and have control over local matters – has a significant positive impact on community wellbeing.
5. Supporting community sovereignty, i.e., the community and its members make decisions about their data and control how their data will be used.

Digital ecosystems aim to provide an enhanced problem solving environment to agentic groups of people[1] that share common interests, broadly defined as communities, by providing a collaborative space layered on digital technology such as digital twins, Artificial Intelligence (AI), Virtual Reality (VR) and serious games.

Miller (2023) states that "diverse groups with people who have different backgrounds, genders, experiences and perspectives consistently generate more innovative solutions than homogeneous groups" and as "a result of considering a wider range of possibilities and challenging groupthink[2], diverse teams are more effective at solving complex problems". Hence, providing a problem solving environment that enables people from diverse backgrounds to participate will improve the ability of that group of people to innovate and solve problems.

Spires (2008) state that "certain features of serious games can promote the highly valued 21st century skills of expert problem-solving and complex communication" and Hatzipanayioti et al. (2019) state that VR "supports collaboration among partners across departments and fields, independent of physical boundaries". Also, Unal and Cakir (2021) state that "collaborative problem solving method and web 2.0 technologies may be useful to develop students'

[1] "Adjective. agentic (comparative more agentic, superlative most agentic) That behaves like an agent: able to express or expressing agency or control on one's own behalf or on the behalf of another." Wiktionary, 2024. Hence, an agentic group of people express agency and make decisions.

[2] "Groupthink is a psychological phenomenon that occurs within a group of people in which the desire for harmony or conformity in the group results in an irrational or dysfunctional decision-making outcome." Wikipedia, 2024a

knowledge and skills in their courses" and "they can be equipped with the competencies needed in the business sector after they graduated". Thus, problem solving environments supported by technology like serious games and VR provide collaborative environments that enhance problem solving skills which can also extend into capability for the future.

Leendertse, Schrijvers, and Stam (2022) follow the adage "measure twice, cut once" to reduce "policy failures with better measurement tools". Embedding accurate measurement tools within problem solving environments will improve the ability of solutions generated using those environments to be successful when implemented.

This approach is applicable both in targeted policy implementation (for example,during the renovation and reinvigoration of London's Drummond Street as part of HS2 works (Johnson, 2024), where a digital twin allowed the street's South Indian restaurant community to have input into the changes), and also more broadly in terms of realising all 17 of the UN Sustainable Development Goals (U.N., n.d.), for example as highlighted by the International Telecommunications Union (ITU, n.d.), among others.

Digital ecosystems also draw inspiration from Indigenous knowledge systems and the authors hope that they might be able to contribute to the Indigenous research agenda (Smith, 2021, Figure 6.1) by empowering Indigenous communities to realise transformative change and move towards states of Development and Self-determination and away from states of Survival and Recovery.

The World Health Organization recognizes the strong link between community empowerment and wellbeing (W.H.O., n.d.). Christens (2019) provides recommendations for integrating research and practice to achieve the goals of empowerment: building and exercising social power for systemic change and improving community wellbeing.

A digital ecosystem empowers a community to solve problems for that community by providing technology that supports participation across all individuals in the community, that enables collaboration amongst those individuals, that provides accurate measurement for evaluating suggested solutions, and that respects the sovereignty of the community across technology provided, a.k.a. the technology stack.

1.1 Report structure

The next section – §2 – presents the digital ecosystems theory, starting with the digital ecosystems concept – in §2.1 – before describing how a digital ecosystem would work – §2.2 – as a combination of a technology stack and software pipeline. Definitions and examples are provided throughout this section, with examples sourced from the case studies provided in §4. Before the case studies, the approach used in this research to build digital ecosystems theory, and identify potential technology stacks, from investigating case studies is presented in §3 with a discussion of relevant literature. The report finishes with our reflections on the research so far – in §5 – and our conclusions on this report's contributions and the future of digital ecosystems research in §6.

2 Digital Ecosystems

This section presents the theory of digital ecosystems. It starts – in §2.1 – with the concept of digital ecosystems and how they bring together data stores, digital models/twins, AI and advanced digital communication technology to empower communities to take ownership of problem solving for their systems of interest. Next, §2.2 highlights how digital ecosystems components may manifest in practice to give readers a sense of how the digital ecosystems theory might work in the real world. These highlights are sourced heavily from the case studies in §4.

2.1 Digital Ecosystems concept

At the core of a digital ecosystem is a community with a shared interest and that needs to make decisions within a complex system.

Community a group of people with a shared interest such as a local community or people with shared geography, people all within an organisation or network of organisations, people all within a facility, and/or people of shared ethnicity or shared cultural background.

Complex System a system that has two or more parts with the comprehension of the relationships between the parts, as opposed to the number of parts, that make it complex, and that it would be difficult to disassemble and reassemble with a predictable outcome, and, hence, is nonreductionist. (Beale, Dazzi, and Tryfonas, 2023)

Figure 2.1 presents the digital ecosystems concept. Building a digital ecosystem starts with the community that is grappling with a complex system. For example, it may be a local community trying to recover from flooding due to severe weather as a result of climate change or it may be the community of patients, clinicians and administrators within a hospital trying to improve the delivery of healthcare services. In addition to having a shared interest in a complex system and needing to make decision about that system, the community can contribute to the acquisition of data about the complex system. This contribution may be directly through routinely collected data, e.g., energy usage, through the use of digital technology like Internet of Things (IoT) sensors and/or in partnership with citizen scientists, industry or government.

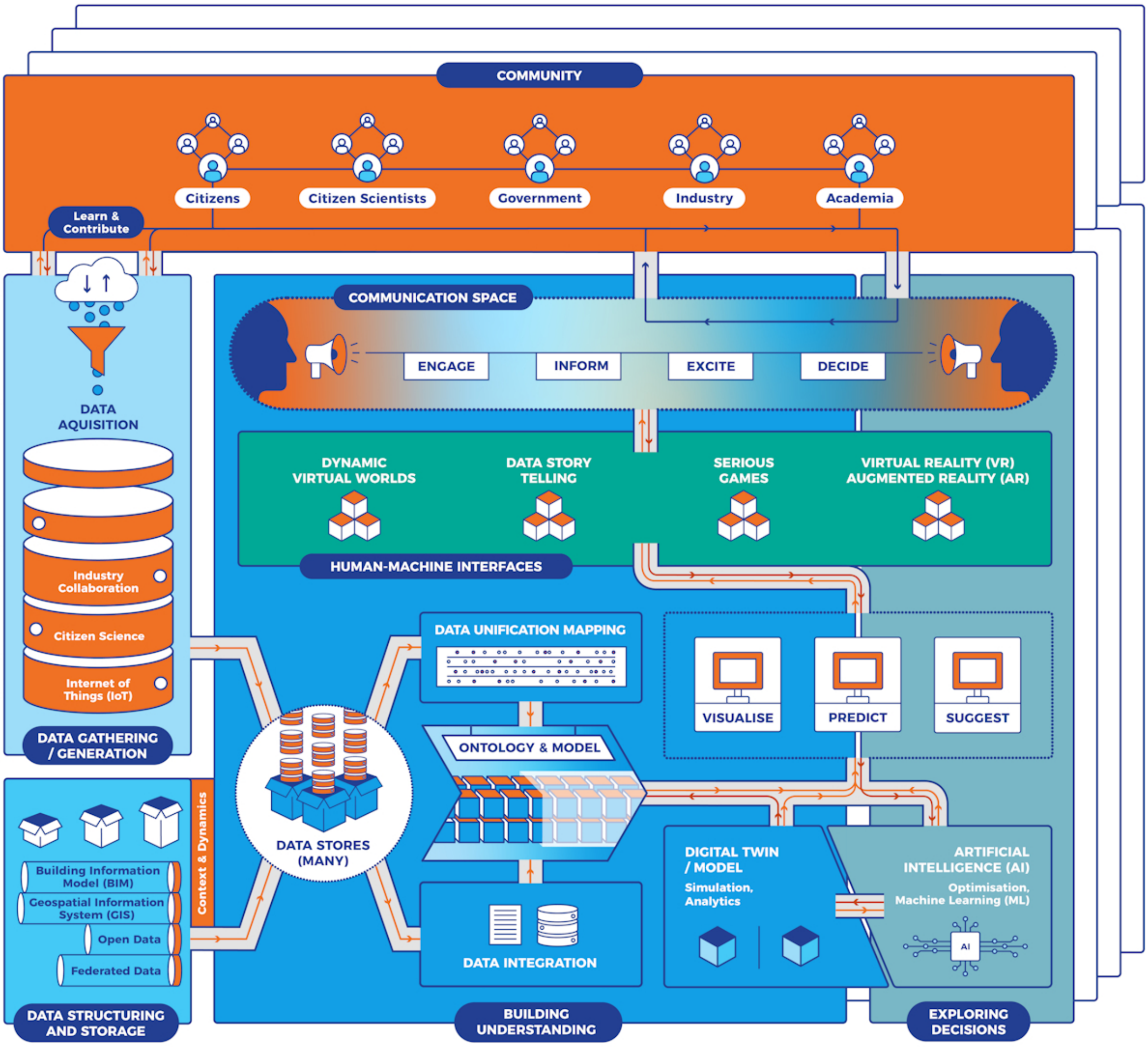

Figure 2.1: Digital Ecosystems Concept & Components

Citizen scientists a group of "citizens interested in science and able to participate in science discourse" (Jones et al., 2018).

In some cases capacity building within the community may be required as the community learns how to participate in the acquisition of data about the complex system, i.e., to inform the digital ecosystem, but this capacity building can provide benefits back to the community through new, local jobs with cutting edge skill sets.

Once data has been collected it must be stored. However, data store technologies enable data to be structured in different formats and enables data context such as Building Information Models (BIMs) and Geospatial Information Systems (GISs). In the flood modelling case study – see §4.6 – GIS is used to store information from various locations such as elevation. Data stores also provide for dynamic data as the data within given contexts can be updated to form time series information, e.g., the temperature within a room or the rainfall at a location

– using GIS with a times series as in §4.6. Note that the data which describes a complex systems, hence a digital ecosystem, may require multiple different data stores, e.g., the data for infrastructure requires the BIM context whereas the environment that infrastructure exists in requires the GIS context.

Data store "an umbrella term that includes the different hardware, technologies, formats, and architectures for storing and retrieving information. " (Services, 2024)

Ontology "represents a shared, explicit specification of a conceptualization of the domain of knowledge" (Gagnon, 2007)

The data collected in order to understand, make decisions, and problem solve in a complex system will reside in one or more data stores. To provide understanding and a decision making/problem solving environment this data must be integrated into a single digital model. This integration can be achieved using an ontology for how the data combines into the model and a process, such as a data unification mapping, to bring the data together into that model. The digital model can take many forms, such as a (relatively) simple regression model that transforms input data for the complex system into output metrics or a complex digital twin that embeds input data within a digital replica of the complex system that can be used to calculate the corresponding output metrics.

Digital twin is defined as "three components, a physical product in Real space, a virtual representation of that product in the Virtual space, and the connections of data and information that tie the virtual and real products together." (VanDerHorn and Mahadevan, 2021). In the context of digital ecosystems, the "Real space" is the complex system being considered – which may not exist yet and the "Virtual space" is a digital (i.e., in silico) replica of the system. The data collected ties the physical system to the virtual system and the calculated metrics and consequent decisions tie the virtual system to the physical system.

The digital model (e.g., digital twin) represents that state of the complex system with the current input data, including output metrics, but it does not evaluate the efficacy of decisions made about/within the system. However, the addition of AI/Machine Learning (ML) alongside the digital model enables the effect and, hence, efficacy of decisions to be predicted. This extension of the digital model transforms the model into an in silico "petri dish", i.e., a digital environment that can be "seeded" with different decision scenarios and then observed to see the effect of those scenarios. Being able to measure what happens under different scenarios provides the "measure twice, cut once" functionality and improves the chance of successful implementation once a successful solution has been identified. In addition, decision makers can use the digital model combined with AI/ML to explore and "play with" decisions as part of the problem solving process.

In order for community members to effectively be involved in the problem solving process, the predictive digital model – i.e., the digital model combined with AI/ML – needs to be accessible. It can either be embedded within or used to inform sophisticated engagement technologies such as VR or serious games. This engagement mechanism can also be tailored to the experience of the community, e.g., dashboards are often used in a hospital setting. By making the use of the predictive digital model accessible, members of the community can experiment with their ideas for solutions and evaluate the efficacy of their ideas. They can also combine these ideas with those of others to see how various solution approaches may complement or conflict with each other. Digital ecosystems provide a democratised problem solving environment, i.e., one that is accessible to diverse groups within a community, and – as noted earlier – improve the ability of that community to innovate and solve problems. The use of serious games and/or VR both supports members of the community working together as well as the problem solving of those members.

Providing access to the community via engaging and exciting human-machine interfaces means that members of that community with different backgrounds can participate in the problem solving enabled by a digital ecosystem. This, in turn, ensures diverse perspectives are brought to bear on complex issues and empowers the community to have an enhanced, innovative capacity when dealing with shared issues (Miller, 2023).

Once a digital ecosystem has been co-developed with a community and that community has experienced the empowerment of the digital ecosystems approach, the community is further incentivised to contribute/participate in the digital ecosystem. Improved and extended data, better understanding of data/integration of data stores, and deeper, more extensive engagement may all occur as a result. The overall digital ecosystem is further enhanced and a virtuous cycle may arise, continuing to empower the community to problem solve their complex system effectively and flourish together.

Figure 2.1 also depicts the 7 key components of digital ecosystems:

1. Community – the community (as defined previously) that the digital ecosystem is developed for and in partnership with. For a successful partnership and effective community empowerment, a digital ecosystem requires the direct involvement and representation of all key groups within a community. These groups may include citizens, citizen scientists, government officials, industry representatives, and academics. Each group should have representatives that are involved throughout the digital ecosystem life cycle, from the early development to the “business-as-usual” use of the digital ecosystem. This approach encourages fair and inclusive decision making and diffuses upskilling across the community;

2. Data Gathering/Generation – knowledge, methods, technology, partnerships, data justice/ethics safeguards, etc to collect data about the system of interest. In the case of a suggested/planned system, this component needs to instead generate synthetic data about the systems of interest, e.g., a digital twin of a hospital may use probability distributions as a model to generate the arrival of people to the hospital. It is impor-

tant to recognize that different sovereign communities have different philosophies and approaches in terms of open data and data sharing. Tool like the Data Spectrum developed by the Open Data Institute (ODI) can help people understand the language of data – from closed to shared to open data;

3. Data Structuring & Storage – knowledge, methods, technology, etc to add context to data and to store data alongside that context to support understanding of the data, e.g., from simple metadata on columns of a table to the detailed BIM ISO standard (Poljanšek, 2017);

4. Building Understanding – the core of a digital ecosystem's technology is a digital model that integrates all the data, along with its corresponding context, into an in silico model that represents the system of interest to the partner community. Examples of digital models range from simple time series to detailed 3-D digital twins. Attached to the model are knowledge, methods, technology, etc to visualise the model and make it accessible to the community, thereby engaging the community and building it's understanding of how the complex system they share behaves;

5. Exploring Decisions – in some cases building a community's understanding of the complex system they share an interest in will be sufficient for that community. However, in many cases the community will want to explore decisions to manage and/or improve various metrics of the system of interest. For example, a community might want to determine how to distribute pest control technology to reduce pest abundance and revitalise native flora and fauna. In order to explore decisions, scenarios and policies, the digital model of the system needs to be linked to one or more AI models. These models then predict what the system metrics will be when a given decision, scenario, policy is put in place. Note that many of the same approaches to provide accessibility and engagement from the Building Understanding component will also be useful for providing accessibility, engagement and interactivity for the Exploring Decisions components, but extra knowledge, methods, technology, etc is applicable too, such as suggestion engines and/or serious games, and can empower a community to "play" with decisions and problem solve in an innovative, inclusive, creative fashion.

The knowledge, methods, technology, etc for providing accessibility, engagement and interactivity on top of the the Building Understanding and the Exploring Decisions components is a layer consisting of human-machine interfaces that create a communication space. The *human-machine layer* represents the set of technologies used by the community to engage with the digital models and artificial intelligences. The *communication space* represents the safe exploration space at the junction of the community and the human-machine interfaces –maintained by the community – where community members can debate while they explore data-informed decisions until they reach agreement(s). The realisation of the communication space with a human-machine layer provides intelligence augmentation, i.e., it combines data, digital modelling and AI to enhance and improve how people within the community understand the system of interest and make decisions about it.

These components will be present in every digital ecosystem, although the knowledge, methods and technologies might be quite different. One of the goals of the research described in this report is to provide exemplars of these components as one or more digital ecosystem technology stacks that can guide others interested in using and developing digital ecosystems in the future.

2.2 Digital Ecosystems in practice

Sections 4.1-4.7 contain detailed case studies exploring the potential and practicality of the digital ecosystems concept. In this section we present a few highlights from those sections to illustrate a little of what digital ecosystems in practice look like. In doing so we will revisit each of the digital ecosystems components from the previous section.

1. Community – communities that could use digital ecosystems are varied and range from:
   - the population of a country that is considering the best response to a pandemic; through to
   - a regional community considering how best to cope with severe weather and flooding due to climate change; to
   - the community of patients, clinicians and support staff within a hospital; and
   - the people working at a facility such as a sawmill, steel production plant, or fruit packing company;
2. Data Gathering/Generation – data gathering in partnership with communities can involve:
   - standard data gathering such as records of disease spread and orders arriving to a facility; through to
   - time-stamped information of how people and/or products move through a system; to
   - time series data captured through periodic or automated monitoring – via IoT sensors – of a (natural or built or both) environment; and
   - logs generated by machines in an ICU or as part of a manufacturing line; or even
   - video/audio data from cameras, microphones, etc.

   When a digital ecosystem is being developed for a system that is in the planning and/or proof-of-concept stage, then the data may be generated rather than gathered and could take the form of estimates of:

   - rainfall levels during a 1-in-a-100-year flood generated from atmospheric models;
   - the time between patients arriving to the emergency department/room at a hospital generated by probabilistic models based on historic arrival rates and, potentially, a changing patient demographic; and

- demand for electricity generated from demand in similar areas, predicted uptake or electric vehicles, etc;

3. Data Structuring & Storage – some data stores that can be part of digital ecosystems technology stacks include:

   - BIMs with their 3-D representation of the built environment annotated with data such as single measurements or time series;
   - pathway data with tags, descriptions and time-stamps as the key format; and
   - health databases that conform to health data standards such as Health Level 7 Fast Healthcare Interoperability Resources (HL7 FHIR) (Bender and Sartipi, 2013);

4. Building Understanding – digital ecosystems help to build community understanding through

   - more straightforward approaches such as data visualisation and data storytelling, e.g., via dashboards, through to
   - more sophisticated approaches such as 3D "walk-throughs", VR or serious games.

   For example, the BIM model used for the aformentioned digital twin of the renovation and reinvigoration of London's Drummond Street (Johnson, 2024) enabled the street's South Indian restaurant community to explore the proposed works in a detailed 3D environment and have input into the changes;

5. Exploring Decisions – The same technology used for building understanding within a digital ecosystem can also be used to explore the effect of decisions. For example,

   - design changes to the BIM of Drummond St will be reflected in the 3D environment, so the community can evaluate the changes from their perspectives.
   - In the precursor digital ecosystems for flood modelling – see §4.6 – community members can enter a VR environment to observe the flooding caused by different rainfall events and, in a future version of the digital ecosystem, will be able to change the built environment, e.g., add stopbanks or culverts, and then observe how these changes affect where flooding occurs. This accessible, interactive engagement with the digital ecosystem will empower the community to explore decisions aimed to mitigate the effects of flooding.

Note that the practical examples for both Building Understanding and Exploring Decisions describe the human-machine layer that provides communication spaces:

- Dashboards that can provide aggregated, estimated or predicted data in quick-to-consume formats but that can be effective for communication with elements of data storytelling included;

- 3D models, e.g., BIM, for communities to explore their environment in detail;
- VR for walking through flooded environments to understand what has happened and begin suggesting solutions to mitigate against future occurrences.

This section has presented the digital ecosystems theory and a summary of examples in practice. Next we present the approach we proposed for developing digital ecosystems theory and practice further along with a summary of related literature.

3 Background

This section presents some concepts from the literature that are relevant to and inspire the digital ecosystems concept and then describes the methodology we propose for exploring and deepening the digital ecosystems theory and practice through case studies, namely the Eisenhardt method (Eisenhardt, 1989; Eisenhardt, 2021).

3.1 Relevant concepts

Recall from §1 that the three key principles of problem solving underlying the digital ecosystems concept are:

1. innovation is enhanced by diversity;
2. collaborative problem solving supported by technology helps find solutions and develops problem solving skills; and
3. measurement tools are key to success in problem solving.

There are other concepts that have similar principles and we summarise some key ones from the literature here.

3.1.1 Design Thinking & Human-Centred Design

Design thinking is an iterative problem-solving methodology focused on understanding user needs, generating creative solutions, and testing those solutions in real-world environments.

Design thinking and human-centered design share similarities with digital ecosystems in terms of community involvement, and adaptability. However, the focus is more immediate, practical problem-solving rather than a platform for continuous, evolving problem-solving over a longer period.

3.1.2 Agile Methodology

The Agile methodology is an iterative approach to software development (and increasingly, other fields), where small increments of work are tested, refined, and iteratively improved based on feedback (Fowler, Highsmith, et al., 2001; Rosenberg, 2008). The goal is continuous improvement and rapid adaptation to changes. There is an emphasis on collaboration and open working

Though highly adaptive, Agile is primarily (though not exclusively) used in software development context. It doesn't offer a theoretical framework for understanding community problems, nor does it provide a holistic digital ecosystem approach. However, by being a highly collaborative, adaptable and iterative methodology, it does offer a viable framework for identifying and addressing a community's needs.

3.1.3 Socio-Technical Systems Theory

Socio-technical systems theory emphasizes the interrelatedness of social and technical aspects in organizations and systems. It is often used to understand the interaction between people and technology in workplaces, aiming for systems that are both efficient and responsive to human needs. The term was coined by Eric Trist, Ken Bamforth and Fred Emery, who worked during World War II with British coal miners at the Tavistock Institute, and who were interested in the interplay of social and technical aspects (including processes and knowledge; not just material technology) in large organisations (Fox, 1995).

While socio-technical systems theory does integrate technology and human factors, it is usually applied to organizational contexts rather than community-focused digital ecosystems. Additionally, it lacks the evolutionary, iterative methodology proposed here for digital ecosystems.

3.1.4 Action Research

Action research involves practitioners actively participating in the research process, applying theories or models in practice, and refining those theories based on real-world outcomes (Cohen, Manion, and Morrison, 2017). It's inherently iterative and adaptive, aligning closely the digital ecosystems approach of exploration for problem solving.

While action research is adaptive and can evolve over time based on real-world feedback, it's typically used in organizational or educational settings, and it lacks a specific focus on community-based problem solving for complex systems.

3.1.5 Digital Ecosystems

Digital ecosystems are distinct from the other approaches described here because they aim to be self-sustaining in terms of empowering communities, by both delivering solutions to problems and also building capacity and agency in the community. They empower diverse perspectives in identifying the right technologies for the community and the problems that a community faces. There is a strong consideration of data sovereignty and value creation within the community itself.

While the relevant concepts from the literature have some individual pieces in common with the digital ecosystems concept, the holistic evolutionary methodology that integrates theory and application in digital ecosystems specifically for communities doesn't yet exist as a formalized theory. Digital ecosystems could become a significant contribution to fields like community informatics digital transformation, and social impact technology.

3.2 Building Digital Ecosystems Theory – proposed methodology

In order to validate and refine the digital ecosystems theory, as well as to identify a generic technology stack template for digital ecosystems in practice, we propose the use of a case study approach to theory building. The Eisenhardt Method is first and foremost about theory building and uses case studies to find the underlying commonality which, in turn, informs the theory (Eisenhardt, 1989; Eisenhardt, 2021). This approach is illustrated in Figure 3.1 with the information from the different case studies integrating into a common digital ecosystems theory and identifying a generic technology stack template both of which underpin all of the case studies. The steps of the Eisenhardt Method from Eisenhardt, 1989, Table 1 are reproduced in Table 3.1 for simplicity.

The Digital Ecosystems team has already worked through the Getting Started step from table 3.1 with the research questions being:

1. What is the efficacy of the digital ecosystems concept for empowering communities to problem solve?
2. Are the digital ecosystems components – see Figure 2.1 – sufficient?
3. What technology stack(s) are required for digital ecosystems in practice?

Note that implicit within these questions are the a priori constructs of the digital ecosystems concept and its components, but no theory or hypotheses has been suggested thus far, only the five principles – see §1 – that motivated the digital ecosystems concept. Hence, there is ample flexibility for a digital ecosystems theory to be developed.

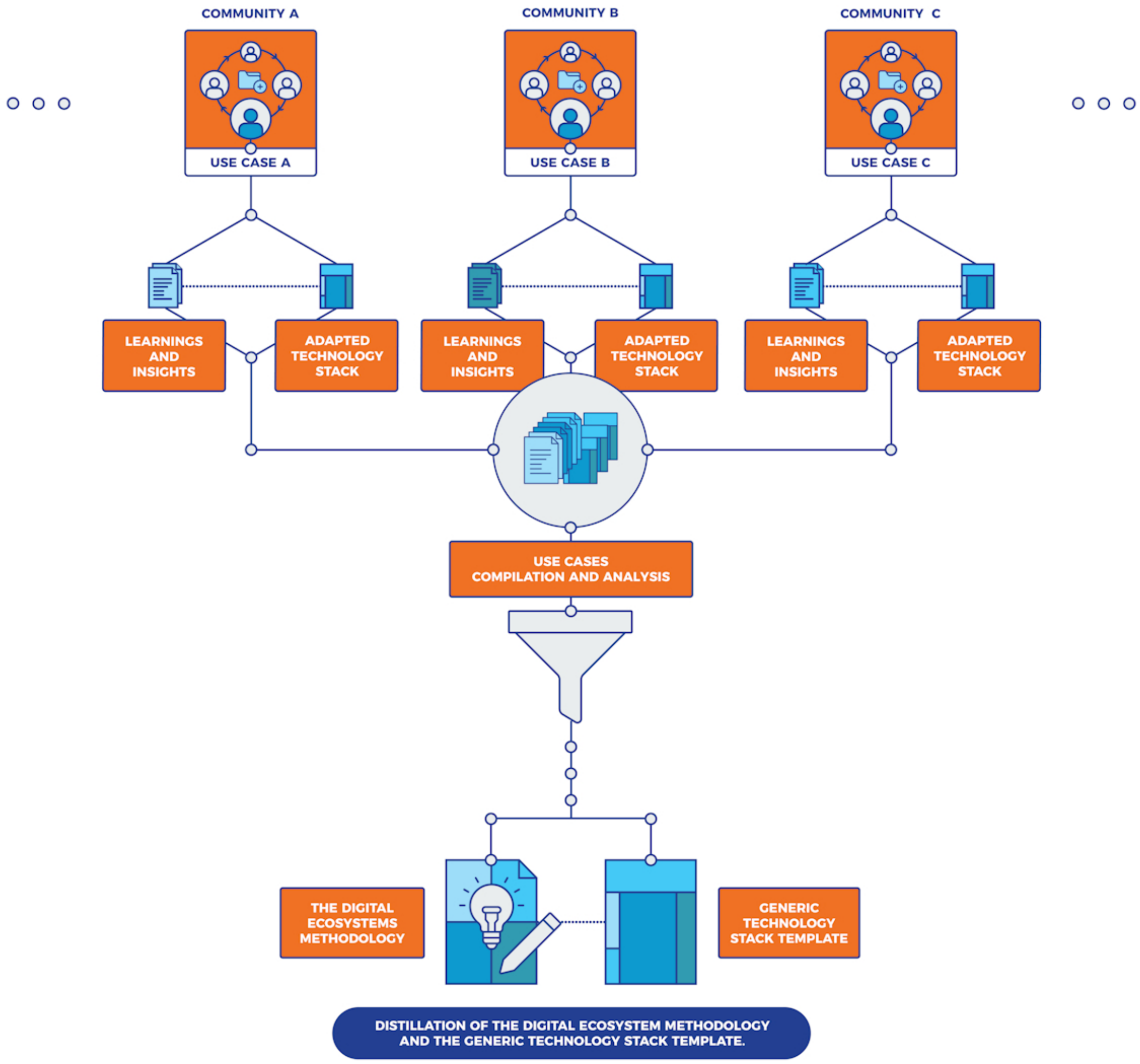

Figure 3.1: Theory building through case studies

Table 3.1: Process of Building Theory from Case Study Research

Step	Activity	Reason
Getting Started	Definition of research question	Focuses efforts
	Possibly a priori constructs	Provides better grounding of construct measures
	Neither theory nor hypotheses	Retains theoretical flexibility
Selecting Cases	Specified population	Constrains extraneous variation and sharpens external validity
	Theoretical, not random, sampling	Focuses efforts on theoretically useful cases-i.e., those that replicate or extend theory by filling conceptual categories
Crafting Instruments and Protocols	Multiple data collection methods	Strengthens grounding of theory by triangulation of evidence
	Qualitative and quantitative data combined	Synergistic view of evidence
	Multiple investigators	Fosters divergent perspectives and strengthens grounding
Entering the Field	Overlap data collection and analysis, including field notes	Speeds analyses and reveals helpful adjustments to data collection
	Flexible and opportunistic data collection	Allows investigators to take advantage of methods emergent themes and unique case features
Analysing Data	Within-case analysis	Gains familiarity with data and preliminary theory generation
	Cross-case pattern search using divergent techniques	Forces investigators to look beyond initial impressions and see evidence through multiple lenses
Shaping Hypotheses	Iterative tabulation of evidence for each construct	Sharpens construct definition, validity, and measurability
	Replication, not sampling, logic across cases	Confirms, extends, and sharpens theory
	Search evidence for “why” behind relationships	Builds internal validity
Enfolding Literature	Comparison with conflicting literature	Builds internal validity, raises theoretical level, and sharpens construct definitions
	Comparison with similar literature	Sharpens generalizability, improves construct definition, and raises theoretical level
Reaching Closure	Theoretical saturation when possible	Ends process when marginal improvement becomes small

This report presents a subset of the preliminary use cases selected for building the digital ecosystems theory (the "Selecting Cases" step of the Eisenhardt Method). We envisage these light touch use cases as a way to "cold start" the digital ecosystem theory building process and showcase the preliminary methodology. The Digital Ecosystems researchers have approached both the Global Partnership on Artificial Intelligence (GPAI) community and their own networks to gather case studies that may be aligned with the digital ecosystems concept. These case studies are presented next, in §4.1-§4.7, along with initial observation on how the each case study aligns with the current definition of digital ecosystems components. For each case study there is a brief description of the community, their context and the specific goals they aim to achieve by exploring the Digital Ecosystems methodology. The case studies were acquired via two requests for information sent to the Digital Ecosystems researchers' wider network, a long form and a short form, the former for case studies that have evolved in a similar way to digital ecosystems and the latter for case studies that are in their initial stages of consideration. These forms are given in Appendices A.1 and A.2 respectively.

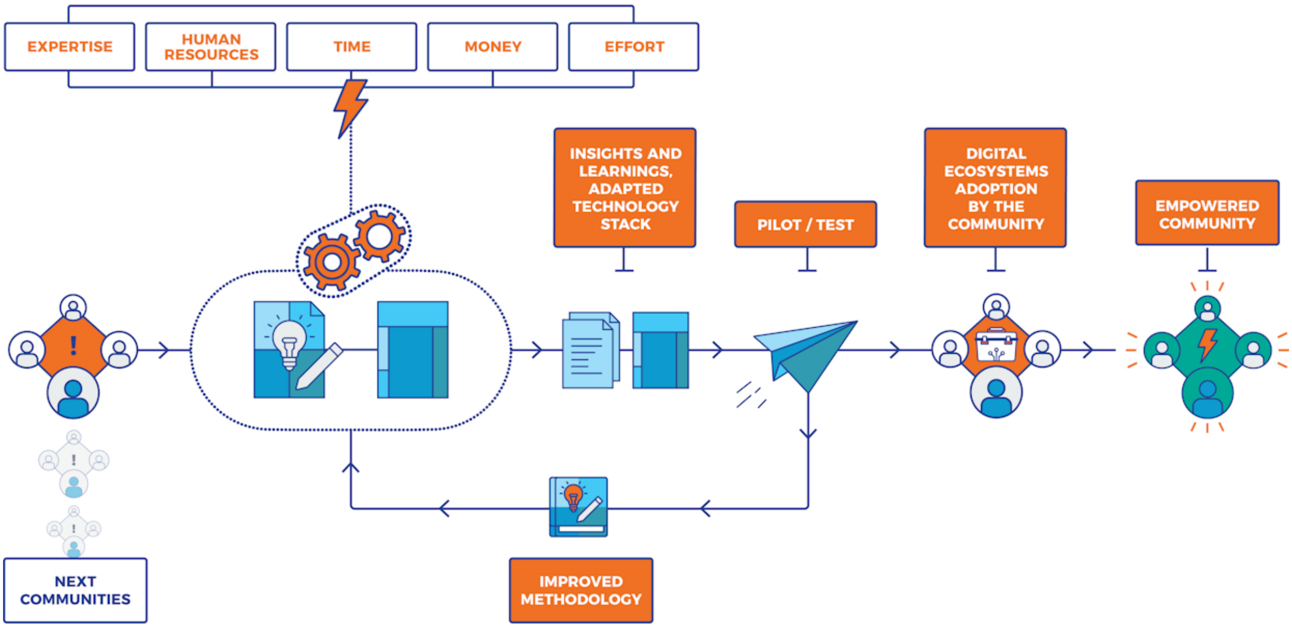

Figure 3.2: Evolving the theory

The Digital Ecosystems project aims to merge both the development of theory and its application into a single, iterative process. The theory evolves as it is applied to real-world community challenges, and digital ecosystems theory (and its components) evolve through constant feedback and refinement. Each cycle of application informs and reshapes the theory, hence the use of the Eisenhardt Method is both dynamic and scalable across different contexts. This approach fosters continuous learning, ensuring that the digital ecosystems theory is diversely applicable to the needs of communities.

By integrating theory-building and real-world testing in a unified way, the Eisenhardt Method enables both the Digital Ecosystems theory and the associated technology stack(s) to become more effective over time, empowering communities with practical, adaptable solutions.

4 Case studies of potential Digital Ecosystems

4.1 Case Study 1: Type II diabetes stabilization in Indigenous First Nations peoples in Canada

This case study involves the use of digital ecosystems to model the prevalence and impact of Type II diabetes in Indigenous First Nations people in Canada. Indigenous communities face various health challenges linked with the lack of contextualization of public health care services and induced systemic disconnection from traditional and cultural practice. The goal is to empower Indigenous First Nations communities to explore the potential of different approaches to preventing, treating and managing Type II diabetes, including approaches that come from Indigenous First Nations knowledge systems. This is coherent with the core directives from Diabetes Canada for health care providers: "ensure reciprocal relationships, recognize the diversity of patients, provide care specific to each patient's needs, support them(patients) in developing capacity for addressing social determinants of health, and respect patient priorities. These are embedded within a set of principles that recognize colonization as the predominant cause of health inequities for Indigenous peoples, health care equity as about providing appropriate resources according to need, and empowerment focused on building capacity with patients to address social drivers of disease."

Information for this case study was provided through the long form – see §A.1. The case study information is provided in §B.1. Further information was used from Diabetes Canada (Lynden Crowshoe, Rita Henderson, and Mariam Naqshbandi Hayward MSc, 2018) to strengthen the scientific evidence. The next subsection offers a summary of the digital ecosystems components for this case study is presented.

4.1.1 Digital Ecosystems components

Community The communities for this case study would be the various Indigenous First Nations communities that are adversely affected by Type II diabetes. Note that these communities could use digital ecosystems separately and share information between separate digital ecosystems or they could cooperate for a larger digital ecosystem that empowers joint decision making on initiatives for addressing Type II diabetes within the communities.

Data gathering/generation The data for this case study would be the health record of community members, including their demographics, pre-existing conditions and a record of treatment and treatment outcomes. This could be provided by individuals that wish to contribute to the digital ecosystem or, with consent of individuals, by healthcare providers.

Data structuring & storage The structure of the data should follow international standards for health data, e.g., HL7 FHIR. The data also inherently has a time series aspect as people's health condition changes over time and in response to treatment. Typical database storage would be sufficient for storing this type of data although multmedia data such as scans (either images or video) may also be useful and require more sophisticated data stores.

Building understanding In this case study the digital ecosystem would build understanding by visualising and quantifying how people from the community move along healthcare pathways, how their health condition changes in response to treatment, what resourcing is in place long the pathways, and where bottlenecks or overload occur. Differences in pathways due to demographics, geography, and treatment could also be visualised and quantified.

Exploring decisions Decisions on investment in resources, the implementation of different treatment programmes, e.g., programmes based on Indigenous knowledge, and policies for people receiving various treatment options could all be investigated in a digital ecosystem. The digital ecosystem would empower the communities to evaluate the effect of these decisions across all members in their community to inform their final decisions.

4.2 Case Study 2: Understanding transport and mobility in Dakkar

In many regions of the world, the government does not generally use modelling and simulations for urban applications such as mobility and construction. There is no model of public infrastructures to inform the decision making with predictions about the impacts construction of new infrastructure for example. It is a similar situation for the planning of mobility within large cities. in Dakar, it is usually policemen on the ground who try to manage the traffic by manipulating lights and stop signs using their own experience and intuition. But this method is limited and is it difficult to visualize and predict the delayed impacts impacts of decisions. Sometimes the decisions lead to successful outcomes, and sometimes they are leading to monster traffic jams. The lack of data acquisition makes it very difficult to understand the causality and effects of decisions. The aim of this case study is to model the road network of the Senegalese capital, Dakar, in order to better analyse and manage urban mobility.

Information for this case study was provided through the long form – see §A.1. The case study information is provided in §B.2. Next a summary of the digital ecosystems components for this case study is presented.

4.2.1 Digital Ecosystems components

Community The community for this case study would be the citizens and civic leaders of Dakar, Senegal, who see the opportunities of transport data sharing for improving day-to-day mobility and quality of life. There would be the involvement of stakeholders from the City of Dakar, the Dakar Urban Transport Executive Board, the Ministry of Transport, the public transport network, the local Police and so on.

Data gathering/generation Data would be gathered by a network of stationary and public transport on-vehicle sensors, and augmented by weather sensors and citizen science reports of extreme weather conditions. Other types of data such as sanitized demographic data, environmental data, technology infrastructure data could also be used to enrich the context of decision making process.

Data structuring & storage Given the grassroots/decentralised approach to installing sensors to get a better understanding of traffic flow, weather impacts etc., it would be important to either adopt or develop open data standards for public transportation and for sensor data. Many countries have and continue to develop such standards. Given the non-personal nature of transport and weather data, following pre-processing including sanitisation and structuring, it can be published as open data and made available as an API.

Building understanding By making data available openly and as an API (perhaps also building some simple webtools for understanding the transport issues around Dakar), the case study shows citizens and civic leaders the benefits of open data sharing. Modelling the variety of constants and variables in this complex system could help to identifying pattens between the different phenomenons affecting traffic. Insights on citizens habits and the local weather and environmental conditions and calendar events could significantly help understanding the causality links.

Exploring decisions Day-to-Day decisions on how a member of the public might choose to travel around Dakar, particularly responding to changes in public transport timetables due to congestion or other issues; or decisions to change a route or avoid travel in the case of adverse weather impacts. Civic leaders in Dakar might use data from this ecosystem to identify priorities for strategic investment in roads, transport infrastructure, public transport and other improvements.

4.3 Case Study 3: Public value frameworks for Nature-Based Solutions in urban environments

Nature-based solutions (NBS) have gained traction over the past decades as a urban design philosophy that reduces pressures of climate change by creating sustainable and resilient urban spaces. With an investment of over €240 million, the EU has demonstrated that NBS is “essential component” in its sustainable development strategy. However, the use of blue-green infrastructure –- a core component of NBS –- is often too technical, excluding the primary user and beneficiary –- the general public –- from giving input into NBS planning. This further leads to the lack of public acceptance of NBS projects, and subsequently devalues the currency of socially-responsible design. Hence, there is a need for better tools and processes to facilitate co-creation of NBS projects between public and planning professionals.

The aim of the Public Participatory Co-Creation Tools for NBS (PACT-NBS) project is to create a framework for facilitation of urban NBS co-design by using public value frameworks integrated within serious games to aid decision making. This will be achieved by: 1) using systematic approach to establish public values metrics relevant to diverse European com-

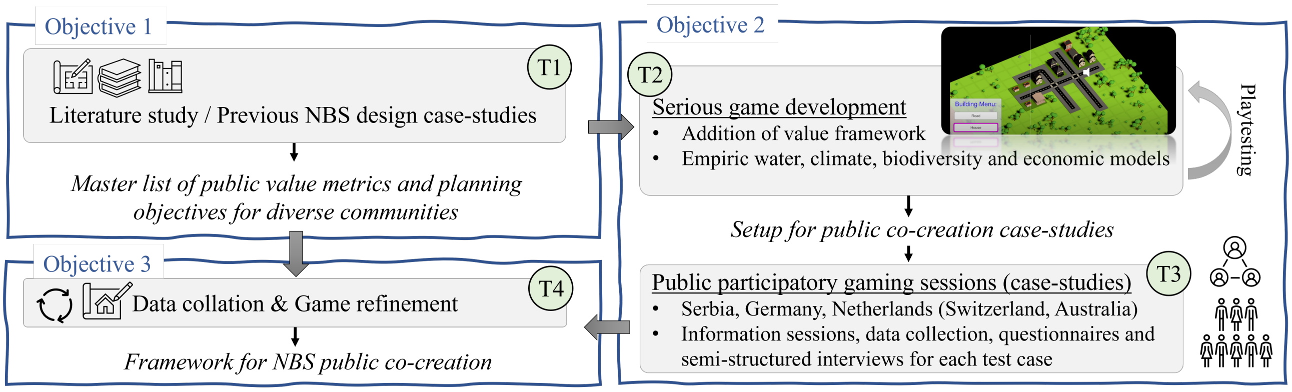

Figure 4.1: Schematic showing the PACT project methodology

munities; 2) developing and testing serious gaming tool integrated with environmental and social objectives for urban design; and 3) providing holistic co-creation framework for serious game application in NBS planning, based on the results of public and professionals testing across Europe. PACT-NBS goes beyond the state-of-the-art by addressing critical gaps in NBS public planning, but also captures EU's policy objectives and sustainability agendas through European Green Deal and SDGs 6 and 11, on *Ensuring availability and sustainable management of water and sanitation for all* and *Making cities and human settlements inclusive, safe, resilient and sustainable*, respectively.

Information for this case study was provided through the long form – see §A.1. The case study information is provided in §B.3. Next a summary of the digital ecosystems components for this case study is presented.

4.3.1 Digital Ecosystems components

Community The community comprises two main groups: urban planners, and the citizens who inhabit the neighbourhoods and urban spaces that could benefit from nature-based solutions to mitigating environmental impacts of climate change. The project is designed to engage diverse communities and stakeholders, including citizens from various socioeconomic and cultural backgrounds. By involving the public in serious gaming sessions, the project ensures that a wide range of perspectives is considered. Urban planners and professionals working on NBS projects are also key participants, as the framework aims to bridge the gap between technical experts and community members. International collaborators from Serbia, Germany, the Netherlands, Switzerland, and Australia are integral to the project, offering case studies and diverse environmental and social contexts. These groups, along with students, researchers, and stakeholders, will contribute to the gaming sessions, ensuring a holistic approach to understanding public preferences and planning needs.

Data gathering/generation Data is gathered from citizens' interaction with models, via a serious game, of how nature-based solutions can mitigate environmental impacts. The project generates a wealth of data through its participatory activities. A core aspect is the development of public values metrics, which are informed by an in-depth review of past NBS consultations, literature, and case studies. This data captures community preferences and decision-making priorities regarding NBS. During gaming sessions, in-game data such as decision-making paths, preferences, and reasoning processes will be collected. Additionally, qualitative data will be gathered through participant questionnaires and semi-structured interviews, offering insights into user experiences and attitudes. Metrics on environmental, social, and economic impacts will also be derived using integrated models within the game to simulate outcomes like water quality, biodiversity, urban heat mitigation, and economic performance.

Data structuring & storage Data is stored as the model that forms the basis of the serious game, mainly held locally on the machine running the game. Some data may be shared over the web. The project follows the FAIR principles (Findable, Accessible, Interoperable, and Reusable) for data management. All data is stored securely in trusted repositories maintained by the Institute for Artificial Intelligence Research and Development of Serbia (IVI), ensuring online and offline access for project participants. Personal data from participants is anonymized to comply with research ethics. The source code for the serious game and the project's research outputs are made publicly available under open-source licenses on platforms like GitHub, promoting transparency and collaboration. A comprehensive Data Management Plan ensures that all data can be validated and reused in future research and practical applications.

Building understanding A virtual reality digital twin of an urban neighbourhood is presented to citizens in order to demonstrate the benefits of nature based solutions in building more resilient urban environments. There will be a specific focus on issues relating to water supply and drainage in the first instance. The project seeks to foster a deeper understanding of urban planning challenges by involving communities in the design of their local environments. Serious gaming serves as an innovative tool that simplifies technical concepts, enabling the public to participate meaningfully in NBS planning. Through interactive scenarios, participants explore how their decisions impact urban spaces, fostering awareness of environmental and social trade-offs. This participatory approach addresses communication barriers often present in traditional consultations, promoting collaboration between professionals and communities. By integrating public values into planning frameworks, the project enhances inclusivity and ownership, encouraging greater public stewardship of NBS initiatives.

Exploring decisions The general public and urban planners will be able to see how the public reacts and responds to simulations of implementing nature-based solutions. The results of simulations could be discussed in local democratic setups such as citizen workshops at town city halls. The game is central to exploring decision-making in urban planning. It allows players to design urban spaces by placing various NBS elements, such as recreational, cultural, and educational features, within predefined scenarios. Players are guided by planning objectives and constraints, such as improving water quality, enhancing biodiversity, and balancing economic considerations. The game simulates the outcomes of these decisions using models that calculate environmental, social, and economic metrics. By presenting these results, the game provides immediate feedback to players, encouraging them to refine their strategies and consider diverse approaches. The iterative testing process ensures that the game effectively captures public preferences while allowing for the exploration of flexible and inclusive planning options.

Through its innovative use of serious gaming and participatory approaches, the PACT-NBS project represents a significant step forward in integrating public values into urban planning. By addressing key challenges in NBS co-creation, it paves the way for more inclusive, sustainable, and effective urban development practices.

4.4 Case Study 4: Understanding accesibility of water for the Yaqui Comunnity of Vícam, Sonora, Mexico

The Yaqui people is a tribe established in the south-west of North America. One of their main settlements, Vícam, in Mexico, is situated in an area where climate is hot, where resources like water are scarce. Mainstream solutions like digital map applications may not offer the information nor the granularity that the community need to thrive.

Through digital ecosystems, the community aims to understand water supplies. An interactive dashboard was designed specifically for the Yaqui community of Vícam, which integrates geospatial data, sociodemographic data, and the law data regarding management of water in Mexico to understand land use dynamics, water resource distribution, and population characteristics data about Sonora, specifically the Yaqui community of Vicam. This digital environment has the goal of democratizing access to this vital information to all members of the community, fostering a transparent and collaborative environment that is in touch with the reality of the community, where stakeholder can be also held accountable for their use and management of resources and services.

Information for this case study was provided through the long form – see §A.1. The case study information is provided in §B.4. Next a summary of the digital ecosystems components for this case study is presented.

4.4.1 Digital Ecosystems components

Community The population is the Yaqui community of Vícam, in the Sonoran desert of Mexico, a community that has had and continues to face problems regarding access to water and other facilities. The community could members and the leaders of the Yaqui community of Vícam, local authorities and other stakeholders that are involved with the water resources.

Data gathering/generation The project aggregates geospatial, land cover analysis, Classification, history of water, evapotranspiration, accumulations of water flows and other hydrological data, sociodemographic data and information on water laws in Mexico into a public dashboard.

Data structuring & storage A number of open datasets including geospatial and hydrological data are brought together in a single dashboard.

Building understanding By bringing together datasets in a single place, the case study builds understanding in the Yaqui community around environmental and particularly water impacts of services and amenities within the built environment.

Exploring decisions The dashboard tool is used to develop indicators to enable the Yaqui community of Vicam to make informed decisions about the use of their natural resources, especially water. Evaluating potential innovations suggested by the community within the digital ecosystem will also provide the community with more certainty on the efficacy of new initiatives before investing their time and resources.

4.5 Case Study 5: How leveraging digital health technologies can improve diabetic retinopathy care in rural communities in India

Integration with artificial intelligence is gaining traction in the domain of vision health, especially for conditions like diabetic retinopathy (DR), glaucoma, and age-related macular degeneration (AMD). Prompting a digital ecosystem model enables personalized care by simulating a patient's eye health in real time and enables integration of how a voice biomarker for digital health literacy influences patient behaviour along with other health input data such as blood glucose levels, patient-reported symptoms (e.g., blurred vision), and retinal health, adherence to early intervention, diabetes management, and timeliness of DR referrals.

Therefore, the objective of this case study is to understanding how leveraging digital health technologies can improve diabetic retinopathy care, focusing on prevention, timely detection, and personalized management through better communication and health literacy.

Information for this case study was provided through the long form – see §A.1. The case study information is provided in §B.5. Next a summary of the digital ecosystems components for this case study is presented.

4.5.1 Digital Ecosystems components

Community The community is the rural community of Punjab, India, particularly those at risk of diabetic retinopathy. Included in this community are also medical practitioners, local authorities and medical service/equipment providers.

Data gathering/generation Data from blood pressure, glucose monitoring, and retinal imaging is available for build patient-specific digital twins. Data from other modalities such as voice scanning can be added and, within the digital ecosystem with the use of AI, can be explored to understand potential voice biomarkers for conditions such as diabetic retinopathy.

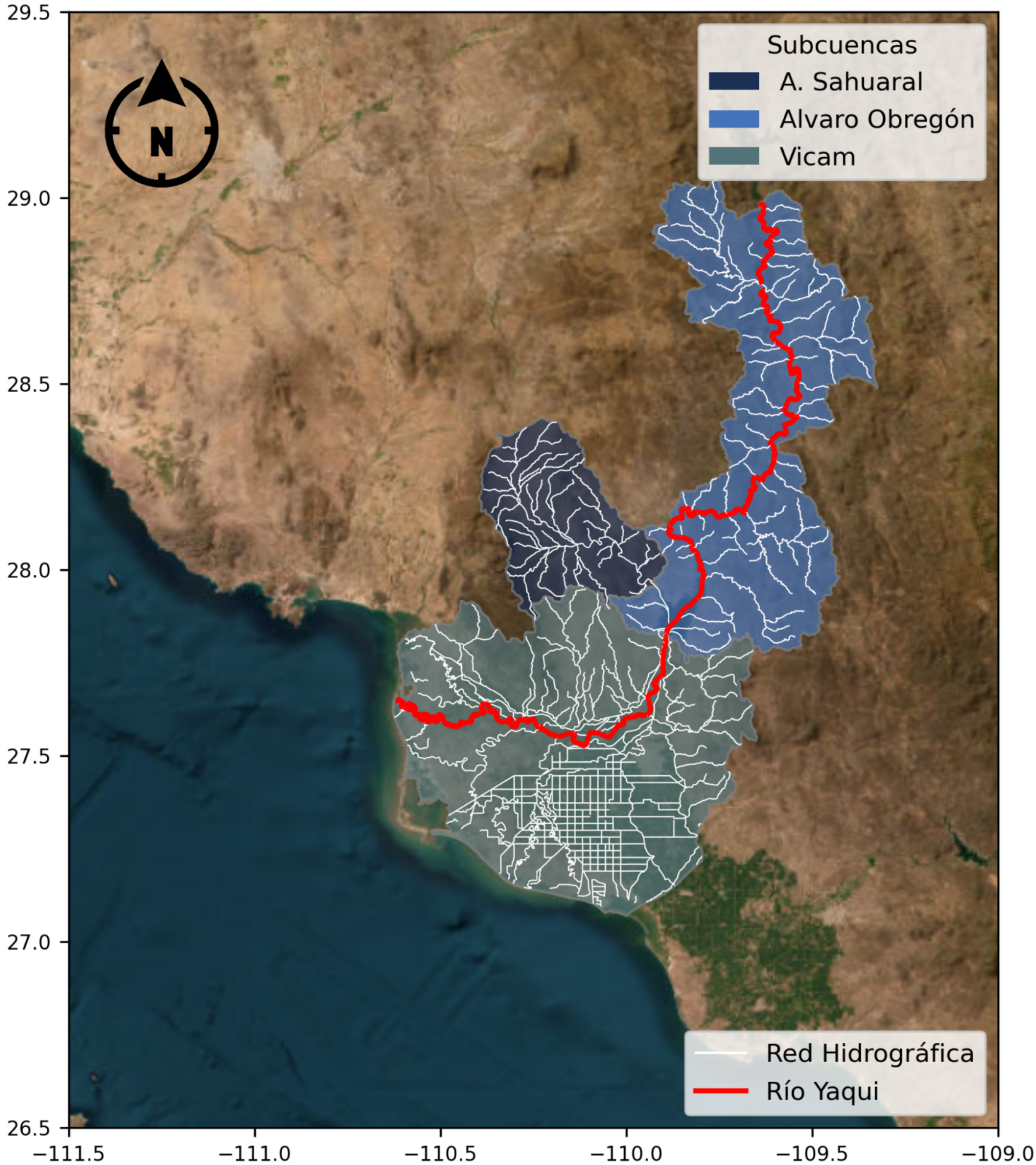

Figure 4.2: Map showing the Yaqui river in Sonora, Mexico

Data structuring & storage Typical data stores for health records can be combined with other data stores for time series, e.g., blood glucose monitoring, and self-reported outcomes. A different data store would be required for the voice scanning data in the form of time-stamped audio recordings. Secure data stores are important due to the personalised nature of the data being stored for integration in the digital twin.

Building understanding The model used in this case study would be a digital twin of a patients eye health. This digital twin would have traditional inputs such as the patient's health record, blood glucose levels and self-reported information. The presentation of this digital twin back to patients and clinicians will be key and an data storytelling via an analytics dashboard that shows changes in eye health, how this compares to others of similar demographics, and any suggested changes in behaviour could be appropriate. Given the community is from rural Punjab, India, access to the data storytelling via mobile phones maybe be the best communication channel, but further consultation with the community is important for the communication space. Being able to explore what is happening within a 3D model of the eye may be of interest for some patients and appropriate education within such a model may help engender important behavioural change to maintain and/or improve eye health. This communication channel will likely require good network connectivity to a tablet or computer. Note that the use of AI is not just about informing decisions, but linking the voice scanning data to the digital twin as an early warning sign for compromised eye health. Communicating this information to patients and clinicians effectively will be a key part of the human-machine interface.

Exploring decisions the decisions being explored in this case studies is both behavioural change by the patients and treatment options for the patient and clinicians. Being able to observe the benefits and disadvantages of various behavioural choices will help patients to have autonomy when caring for their eye health Both patients and clinicians can also observe the effect of treatment such as monitoring via voice scanning, making an appointment with a specialist depending on eye health condition, etc. Patients will be able to improve their eye health literacy and clinicians will be able to make evidence-based decisions within the digital ecosystem.

4.6 Case Study 6: Protecting communities from flooding during severe weather

The objective of this case study is to empower communities to mitigate against flooding in the event of severe weather. Communities around the globe face flooding events due to severe weather and the frequency of such events is expected to increase with climate change. Many people in these communities have lived in the affected areas for some time and their input into effective ways to mitigate against flooding risks is valuable, but they have limited access to the digital tools used to predict flooding events and the outcomes of initiatives to mitigate against flooding. In addition, the nature of these hazards are 'cascading' in nature – flooding can cause the failure of river banks, leading to trees and sediment becoming part of the flood water flows, which leads to dynamic changes in how the flooding evolves and/or damage to infrastructure. How flooding evolves is complex and affected by many factors including geological characteristics, land use decisions, severe weather and river morphology. The digital modelling and AI embedded within digital ecosystems aim to provide a way to better understand complex flooding systems as well as explore effect of different decisions on flood mitigation. By providing digital ecosystems to these communities, diverse perspectives can be included in investigating and evaluating initiatives to protect communities from flooding and, hence, more innovative approaches may be proposed and the communities will be given a “voice” in important decisions that affect them.

This case study arose from the activity of one of the Digital Ecosystems researchers working with communities affected by flooding, so neither the long form nor short form were used. The presentation of the digital ecosystems components for this case study that follows next is based on the experience and expertise of the Digital Ecosystems researchers.

4.6.1 Digital Ecosystems components

Community The community for each flooding digital ecosystem will be the community in the water catchment that floods. While only some of the community may be directly affected by flooding, others may be indirectly affected by, e.g., reduced access to food supply, being cut off from friends and family, loss of infrastructure networks, etc. Most or all of the community may be (directly or indirectly) affected by flood mitigation initiatives such as changes in land use and/or the industry sectors underpinning the community’s economy.

Data gathering/generation There are diverse data sources that could be access to populate a digital ecosystem, including some that could be provided directly by the community or community-based citizen scientists. These data sources include:

- Height data via either elevation (for terrain) or surface (for buildings) measurements with a typical format of (latitude range, longitude range, height measurement) – this data is often provided via Lidar (Light Detection and Ranging) scanning;
- Rainfall measurements – across multiple sites – which are usually captured by instrumentation and have a typical format of (latitude, longitude, rate, e.g., 10 mm/hr, time);
- Information on waters ways such as river networks and waterway flows. For example, waterway flows are usually captured by instrumentation and have a typical format (latitude, longitude, height –which is then used to estimate volume in cumecs, time range);
- Infrastructure information such as data on storm water and waste water networks, buildings, transport networks, etc;
- Images and/or video of water flows and water levels;

- Measurements of terrain "roughness", e.g., is an area pasture land or forested or scrub-like growth, with typical format (latitude range, longitude range, roughness measurement) – note that this kind of land use data could also include any hazards, e.g., forestry debris (a.k.a. slash), present on land areas;
- Soil properties such as moisture and/or absorption rate. Absorption rate has a typical format of (latitude range, longitude range, absorption rate, e.g., mm/h);
- The coordinates – (latitude, longitude) – for any additional structures such as stopbanks or culverts that may not have been included in the height maps;
- Information on terrain stability, e.g., susceptibility to landslips (a.k.a. slips or landslides).

Data structuring & storage The usual data store for flood modelling would be a GIS data store that stores data against coordinates, i.e., (latitude, longitude), and how those measures chance over time. Multiple different GIS data stores could be integrated, e.g., one for topography (i.e., elevation, surface), one for rainfall data and one for hydraulic data, i.e., waterway flows.

Building understanding The usual digital model for understanding flooding is a 3D GIS model which presents results from a numerical model for simulating shallow water hydrodynamics, e.g., BG Flood (Bosserelle, Lane, and Harang, 2022). Results from this type of modelling are typical shown in 2D with 3D information shown as contours or colour maps – both of which require some translation for audiences unfamiliar with these archetypes. However, this model can be used to visualise the flooding as a sequence of static images or as a 3D video which could then feed into the communication space of a digital ecosystem. Figure 4.3 shows a 3D visualisation of rainfall and flooding with a liquid special effects engine to model the hydrodynamics. An alternative is 2D images/video with contour plots or heat maps, but these representations are less accessible. Viewing the 3D model within a VR environment can enable community members to be immersed in the model and observe the effect of flooding by "walking" through the flooded environment. This can be useful for validating the model, e.g., "the flood waters reached this point on my house at their peak". Care needs to be taken to make sure that community members are not upset or re-traumatised by such an experience.

Other modelling can provide further insights into flood events such as estimating damage to houses/infrastructure or looking at life safety, i.e., when water levels and speeds become dangerous to children/adults/cars.

Exploring decisions Once the 3D digital model has been calibrated and validated as being an accurate representation of how flooding may occur, the same model can be used to explore decisions to mitigate against the effect of flooding. Examples include: raising the floor levels of houses to sit above flood levels; putting in place infrastructure like stopbanks and/or culverts to divert the flood water away from areas of value to areas of less value or that can better cope with flooding; and/or planned relocation of key infrastructure or assets,

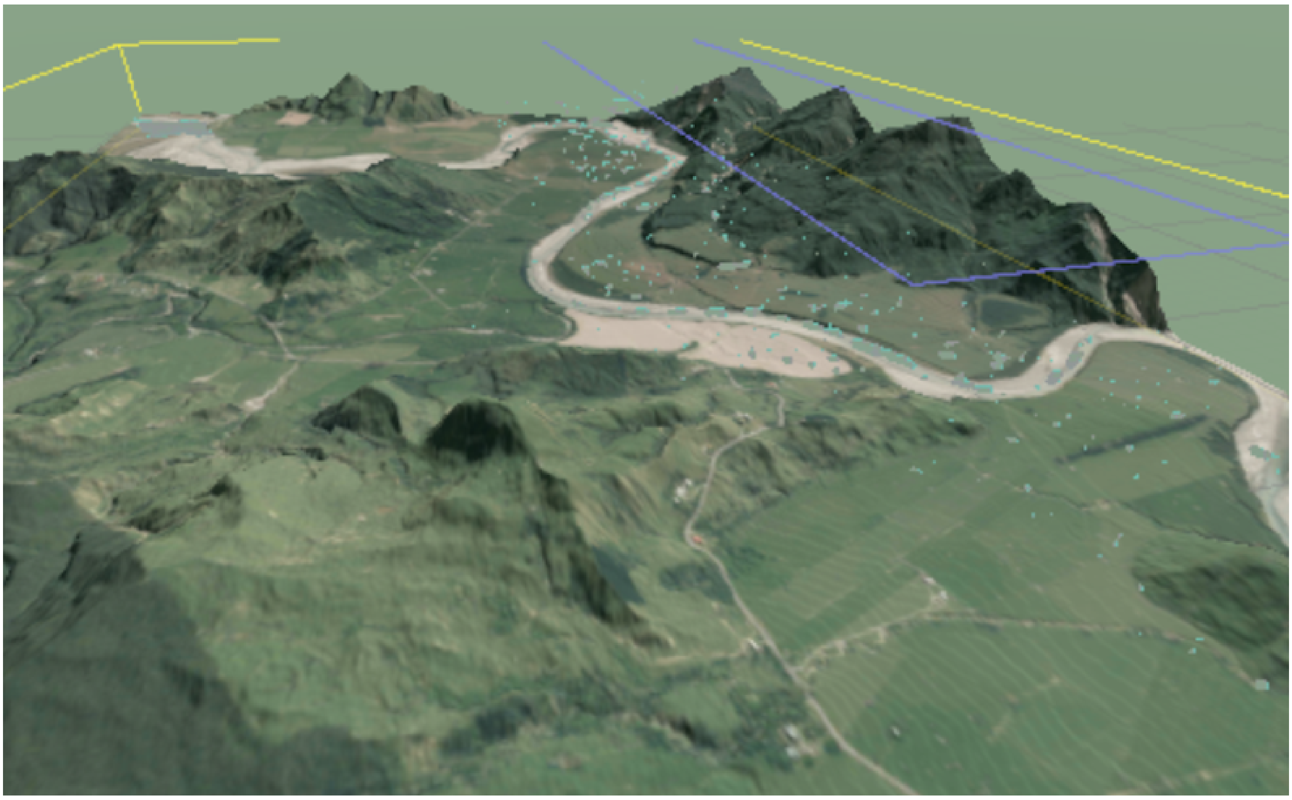

Figure 4.3: 3D model of rainfall and flooding within the Unity environment (Jerald et al., 2014)

e.g., arterial transport infrastructure, hospitals, residential homes for older people, community centres, Indigenous gathering spaces; to places that will be less affected by flooding. For all of these examples, creating a new scenario within the flooding digital ecosystem with modified data, running the digital model, and visualising the outcome can support decisions making by the community of the best approach(es).

4.7 Case Study 7: Improving healthcare delivery in a hospital setting

The objective of this case study is to improve the delivery of healthcare within a hospital setting. Separate departments within a hospital are often siloed, even when delivering care to the same patients, so understanding the effect of changes within a hospital is not straightforward. Upstream and downstream effects, e.g., more frequent evaluation of ward patients for possible discharge can help alleviate emergency room/department overcrowding, careful planning of the surgical schedule can help maintain the occupancy of intensive care units at a level that enables them to accept emergency patients. By providing digital ecosystems to hospital communities, all of the involved people including patients, clinicians, support staff, administrators and patient families can contribute to identifying how to improve the delivery of healthcare services at a hospital. Connecting up departmental processes and data to look holistically at patient journeys and clinician workloads empowers the hospital community to find innovative improvements that balance the needs of the community, e.g., patient outcomes, equity, clinician burnout, hospital costs, and anxiety of patient families and/or support people.

This case study arose from the activity of one of the Digital Ecosystems researchers working with healthcare organisations, so neither the long form nor short form were used. The presentation of the digital ecosystems components for this case study that follows next is based on the experience and expertise of the Digital Ecosystems researchers.

4.7.1 Digital Ecosystems components

Community The community for each hospital digital ecosystem will be the community that uses the hospital's healthcare services and that delivers these services. The perspectives of different members within that community will require trade-offs and balance in any decision making, e.g., dedicating radiology resources to cancer patients may result in delays to diagnosis and treatment for those with other conditions. Digital ecosystems can consider data and processes from multiple perspectives and provide outcome measurements of hospital processes from these perspectives to empower the community to identify initiatives that incorporate multiple points of view.

Data gathering/generation There are diverse data sources that could be sourced for this digital ecosystem, from the different community members. These data sources include:

- Patient demographics provided by patients themselves or by the administration of the hospital (with appropriate consents);
- Time stamped records of patient treatment from the patients, clinical administration and/or the patient support people;
- Records of tasks that clinical staff perform, including patient treatment but also tasks such as reviewing and updating patient records and providing advice and mentoring to junior colleagues;
- Key hospital data such as the number of ward beds, machines available for radiology services (along with the maintenance plan) and rosters for staff.

Data structuring & storage Hospitals usually have data in multiple, structured data stores. Information on patient condition(s), i.e., patient health records, are stored in a patient administration system that should follow an international standard such as HL7 FHIR . Data on patient treatment and associated patient (flow) pathways is usually stored in a database that records time stamps for steps in the pathway, i.e., the beginning and end of treatment, along with extra descriptive data. Staff rosters would usually be stored within human resources systems. Other data on, e.g., patient movement, may include information about the built environment, e.g., in a BIM platform.

Building understanding There are many different digital models that help build understanding of a hospital setting. For example, linked time series of the occupancy of the emergency

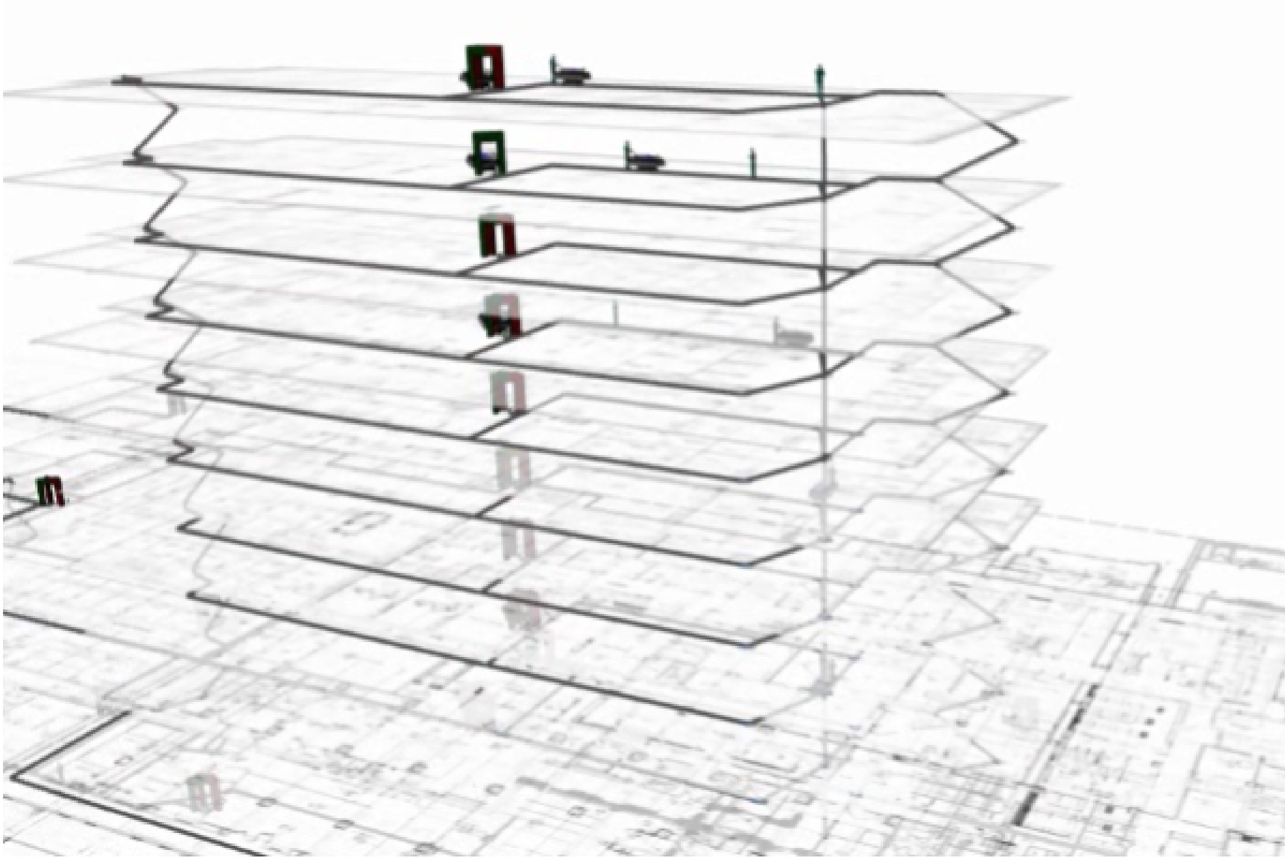

Figure 4.4: 3D simulation of patient transits in a hospital

room/department, intensive care models, and wards can provide insight through analytics dashboards and enable, e.g., observation of the downstream effect of a surge in arrivals to emergency facilities. If enough data is integrated, including and BIM information, then an "air traffic control" digital model which represents all people and equipment in a hospital is a possibility. Linking this kind of model to near real time data feeds can create a digital twin of the hospital and enable the hospital community to better understand the flow of patients, staff and equipment around the facility. Figure 4.4 shows a precursor of such a model with patient transits, i.e., the transport of patients from wards to treatment clinicians and vice versa, visualised within a 3D model of the hospital. Adding more layers and an advanced interface could move such a model towards a digital twin of all activity at the hospital.

Exploring decisions Different communication mechanism such as digital models presented via analytics dashboards or detailed digital twins empower the hospital community to better understand how their hospital functions. However, adding AI methods that predict the outcome of hospital initiatives, even those as simple as adjusting rosters, transforms these digital models/twins into digital environments for exploring the efficacy of such initiatives (and combinations of initiatives). Hence, digital ecosystems can provide in silico "Petri dish" environments that empower the hospital community to explore different initiative scenarios in detail, examine the associated outcomes from multiple perspectives, and identify how to improve the delivery of the hospital's healthcare services in a way that balances the needs of all members of the community.

5 Reflections on case studies

The survey-based method of collecting case studies for this report, perhaps predictably, yielded a wide variety of different types of community using different technologies to help them address problems that they face.

In most cases, while a deep understanding of the nature of the problem is shared throughout a community, digital and other specialist know-how is often outside the community. However, perhaps recognising from experience what can go wrong when an affected community is not properly consulted, the case studies all demonstrated digital technology experts and other specialists showing a genuine desire to work closely with communities. This includes, for example, giving the community input in co-designing solutions, to endeavouring to illuminate complexities through thoughtful and meaningful information, including visualisations and simulations.

A number of the case studies aimed to simplify complex interplays between natural systems and the human world, whether that's the built environment in urban or rural settings, or transport routes and weather systems. By showing either real-time impacts, or allowing a community to see how a change in the built environment might produce an impact (positive and negative), startlingly powerful visualisations, simulations and digital twins can offer a community further insight into the challenges they face, and also what the solution(s) might be. On the other hand, there are also digital ecosystems reported here that integrate health and medical data, which may not be easy to interpret without specialist knowledge, or which may lead a community to make real-world decisions that have impacts on real people's lives (for example, deciding where infrastructure is built to ensure healthy water supply, or deciding which buildings in a community may be at risk of flood, and may need to be relocated). In these latter examples, requiring specialist health knowledge or which may have real-world impacts, the importance of the specialist team working closely with the community is paramount: trust is absolutely key between the developers of the digital ecosystem, other specialists such as clinicians or geospatial/scientific experts and the communities they're working with.

All communities also have specific needs related to data governance in their own context. The University of Alberta defines Data Sovereignty as "the management of information in a way that aligns with the laws, practices and customs of the community in which it is located (University of Alberta, n.d.). In an Indigenous context this may manifest at a individual level or at a community level." They also define two Key Principles for Indigenous Data Sovereignty: "1. Indigenous nations and peoples have the right to ownership and governance over data about them, regardless of where that data is held. 2. Indigenous nations and peoples have the right to access data about them, this data often comes in the form of government documents, and historic/contemporary archival documents. Often these documents support nation rebuilding." In practice, this may require adapted data collection and storage solutions. In other use cases where sensitive data like personal health data is being used, extra care should go into ensuring that information is being managed properly and that the communities have given their informed consent. The practice of responsible data governance should be central to any digital ecosystem development.

Regardless of the different approaches presented, a key element of the digital ecosystem approach is present in all of the case studies: they empower the community by providing solutions to specific challenges, but also build capacity in those communities by building a sense of agency and optimism, as they realise that the approach can be applied to future problems. The digital ecosystems proponents aim to provide digital technology to a community in a way that the community can take ownership of both the technology as well as using it to find solutions so that the community can flourish.

As noted in the Acknowledgments:

- GPAI would like to acknowledge both people from and working with communities in Te Atatū (especially Rutherford College and Te Atatū Intermediate), Tairāwhiti, and Wairoa for their generosity in sharing their experience, knowledge and time. The development of the digital ecosystems concept has been enriched by working alongside these people.

  In particular, case study 6 would not have been possible without these people.

- GPAI would also like to acknowledge both people from and working with numerous healthcare organisations throughout Aotearoa | New Zealand as well as several locations throughout the world. Much of the initial digital ecosystems concept came through and was enriched by working alongside these people and their organisations.

  In particular, case study 7 would not have been possible without these people.

- We thank the following for providing case study information: Veljko Prodanovic of IVI, Novi Sad, Serbia; Jeff Ward, CEO of Animikii, Vancouver, BC Canada [*the traditional territory of the Lekwungen Peoples of the Coast Salish Nation*]; Seydina Moussa Ndiaye, Virtual University of Senegal; Diana Mosquera, Versa Studio, Quito, Pichincha, Ecuador.

6 Conclusion

We conclude this report by summarising the contributions made by the Digital Ecosystems research up to this point – see §6.1. Next, in §6.2, we discuss future directions for the Digital Ecosystems project. Finally, we discuss observations from the Digital Ecosystems research so far in §6.3. We reflect on the digital ecosystems concept, components, and the proposed approach to use case studies to validate, refine and potentially extend digital ecosystems knowledge and, ideally, identify promising technologies for the digital ecosystems technology stack(s).

6.1 Contributions

This report is the first publication to present the digital ecosystems concept and its components. Although this concept was initially informed by the research experience of the Digital Ecosystems project team it has been further developed throughout the project. The proposed methodology for further exploration of the theory of digital ecosystems and its validation follows the well established Eisenhardt Method for theory building from case studies.

In addition, this report considers how the digital ecosystems concept aligns with and supports the principles of Responsible AI (RAI) and addresses the United Nations (UN) Sustainable Development Goals (SDGs). The underlying principles of digital ecosystems are diversity-enhanced innovation, collaborative problem solving, measurement tools, and community empowerment, but these principles and the resulting digital ecosystems concept also provide democratisation of cutting edge digital technologies for communities, which are key now and into the future for addressing the SDGs – such as SDG 9: Industry, Innovation and Infrastructure, SDG 11: Sustainable Cities and Communities, and SDG 13: Climate Action. Digital ecosystems align directly with RAI as they are human-centred, inclusive, and aim to contribute positively to the public good (GPAI, 2021). They also explicitly aim to maintain sovereignty of communities over their data and their decision making. By empowering communities to problem solve effectively with AI, digital ecosystems can also support AI that is fair, equitable, and respectful of human rights and democracy.

6.2 Future directions

The future of the Digital Ecosystems project is arranged in this report. Using the Eisenhardt Method the selected case studies will be worked through with the commonalities across the case studies both building the digital ecosystems theory and identifying a generic template for the associated technology stack(s). Once (one more) technology stacks have been identified, a subset of the case studies will be chosen for proof-of-concept implementations of digital ecosystems along with the case studies communities. Funding will be required for these proof-of-concept implementations and this requirement may have some bearing on which case studies are selected or whether other case studies need to be considered.

The outcomes of the planned application of the Eisenhardt Method to case studies followed by proof-of-concept implementations will be:

1. Documented technology stacks for digital ecosystems with descriptions of how the stacks will realise digital ecosystems in a variety of scenarios;

2. Proof-of-concept digital ecosystems that will both demonstrate the efficacy of digital ecosystems in practice and the paradigm as a whole;
3. Documentation that will point the way for future digital ecosystems research and development (such as that planned by the The Digital Ecosystems Project in Aotearoa | New Zealand).

This future work is designed in two phases and presents a modular and flexible approach for theory building and proof-of-concept implementation via use cases. The number of case studies that can be considered both for the Eisenhardt Method and proof-of-concept implementation is dependent on funding for resources, particularly researchers. As more funding becomes available, more case studies can be added and the richness of the both the theory and the technology stacks will be enhanced.

Finally, the community empowerment paradigm applied to digital ecosystems also raises specific challenges that require the development of novel solutions and safeguards in terms of Responsible AI. As for any AI and data-powered tool, digital ecosystems come with the amplified risks of biases and other harms. Data Sovereignty and the appropriation of digital ecosystems by communities, which are core to the digital ecosystems framework, require the identification of practical means of ensuring that the Responsible AI principles are also embedded in information systems while fostering data sovereignty and community empowerment. For example, future work could explore how collaborative processes that provide diverse perspectives, e.g., participatory design, might combine with Indigenous approaches and/or knowledge systems to ensure Responsible AI principles are followed. As demonstrated in 2023 (GPAI, 2023) and 2024 by the Scaling Responsible AI Solutions (SRAIS) project from the GPAI Responsible AI Working Group, direct expert mentorship is efficient in identifying and addressing responsible AI and scalability challenges. Similar approaches could be explored as potential additions to the Digital Ecosystems methodology to ensure the embedding of responsibility principles within digital ecosystems, from their inception to their adoption by communities. Adding this component to the Digital Ecosystems framework could also contribute to raising of awareness and knowledge about Responsible AI and data governance, e.g., data sovereignty, as part of the diffuse upskilling within the communities. This human, relationship-based method also shows great potential to build trust between communities and other potential partners. Further research is needed to explore the contextualization of responsible principles for trustworthy and safe AI systems for digital ecosystems owned and operated by communities. With great power comes great responsibility is a popular saying that seems particularly applicable here.

6.3 Final remarks

Digital ecosystems are inspired and motivated by a desire to further support already impressive work and knowledge within communities. Communities have valuable local and, in some cases, Indigneous knowledge. Some communities already have rich repositories of data and are partnering with researchers to gather more data. Many communities are keen to innovate and pilot new technology. Often communities are amongst the most vulnerable with an imperative to explore ways to address this vulnerability, in its many forms. Digital ecosystems is a concept that aims to empower communities through principles of respect, collaboration, partnership and support, to honour existing knowledge and activity, and provide the community with digital tools to find a way to flourish.

The Digital Ecosystems research team would like to close with the following 3 remarks:

1. Digital ecosystems place the community at the centre of digital technology. They aim to empower the community with the technology, to upskill the community (as needed) to take ownership of the technology, and to protect the sovereignty of the community when using the technology. The digital ecosystem is a success if the community can flourish by engaging with it.

2. For digital ecosystems to operate at their peak, i.e., to be most effective, they needs to democratise the underlying digital technology, i.e., put it in diverse hands so that different perspectives and lived experiences can enhance innovation within the community.

3. By creating a place of belonging, accessibility and innovation digital ecosystems aim to enable a community to further unlock the creativity and curiosity of its people. Only then can playful problem solving and consensus building within the in silico environment of the digital ecosystem support the community to find solutions and flourish.

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Appendices

A.1 Long Form for Capturing Case Studies

Digital Ecosystems that Empower Communities - detailed form

The *Digital Ecosystems that Empower Communities Project* is a small-scale project from the Global Partnership on AI that is looking to scale up to practical action, and is collecting case studies of digital ecosystems empowering communities to seek funding to take this forward.

We're looking for examples where digital ecosystems use AI in creative, community-based ways to help those communities address problems they face, that is respectful of data sovereignty and promotes community wellbeing. We want to identify commonalities in technology stacks and approaches that could be replicated all around the world.

Here we define a community as a group of people with a shared interest such as a local community or people with a shared geography, people all within an organisation or network of organisations, people all within a facility, people of shared ethnicity and/or shared cultural background.

If you're pretty sure you have a case study that matches what we're looking for, please fill out this form. If you're not sure, you can also fill out the short form. We'll review it to to help decide whether a case study is what we're looking for.

Deadline: Midnight on Sunday 29 September, anywhere in the world

Terms of reference –

Consent

By submitting your Digital Ecosystems case study, you agree to our privacy policy and consent for us to use the information you provide. Note that you can withdraw your consent at any time. Please contact us to do so. You will find our contact information at the end of this page.

The information you provide by answering this survey will be shared with the GPAI Experts involved in the project to conduct case studies for research purposes.

If selected for use, you agree to consent to use of the information you provide in preparation of a report on the subject of digital ecosystems, which is currently in preparation.

Privacy Policy

We collect your personal data (your email address) in order to be able to contact you. In accordance with Quebec law, applicable to CEIMIA, your personal data is only retained for as long as we have a purpose and a lawful basis to do so – the sole purpose being to contact you should we need to, following review and evaluation of the submitted case studies.

The above summarises how we we will use your information. For full terms and conditions, please see the end of this form.

Community
How does this project aim to help a community?

1. Objective of the case study in one or two sentences

2. What community or communities are you working with?

3. What is the intended benefit to the community?

4. How will this project empower the community in question? Add examples

Digital Ecosystem

5. What digital models and data ontologies are likely to be needed for the digital ecosystem to function?

6. What data will the community provide? How will they provide it?

7. What (if any) supporting/other data will be used?

8. How is data being stored and integrated?

9. How frequently is the digital model being updated from the integrated data?

10. What kind of community engagement mechanisms are being used to communicate models/model findings back to the community?

Technology stack

11. What kind of digital model, e.g., digital twin, is being used or do you think will need to be used?

12. What kind of AI is being used alongside the digital twin?

13. What hardware or software technologies are needed to deliver this solution?

(Optional) Additional information needed to operationalise the project

14. Have you considered the following?

- Required budget
- Team composition
- Timeline

If so, please add them here

15. What is your email?

Full terms and conditions

Privacy Policy

This privacy policy describes how and why we might collect, store, use, and/or share your information when you use our services.It will help you understand your privacy rights and choices. By submitting, you are deemed to have read and agreed to the terms of use set out in this section. Use of this site is for personal, non-commercial purposes only. If you do not agree with our policies and practices, please do not use our Services. If you still have any questions or concerns, please contact us. You will find our contact information at the bottom of this page.

CEIMIA is committed to the protection of personal information of the users of its website. Staff and external processors who have access to personal information and are associated with the processing of that information are obligated to respect the privacy and confidentiality of information. We will use the information we receive only for the purposes that are described in this privacy notice or that are otherwise made clear to you on the relevant Services.

Information collection

If you submit case studies for the Digital Ecosystems that Empower Communities project, CEIMIA collects and stores the following information: your email address, and the information you provide on case studies.

Use of collected information

The information you provide by answering this survey will be shared with the GPAI Experts involved in the project to conduct case studies for research purposes.

Consent

We may process your information if you have given us specific permission (i.e., express consent) to use your information for a specific purpose, or in situations where your permission can be inferred (i.e., implied consent). For instance, by submitting your case study proposal, you agree to our privacy policy and consent to the use of the collected information. Note that you can withdraw your consent at any time. Please contact us to do so. You will find our contact information at the end of this page.

A.2 Short Form for Capturing Case Studies

Digital Ecosystems that Empower Communities - short form

This is to help decide whether a potential case study could be an example of a digital ecosystem that empowers communities – also see detailed form

The *Digital Ecosystems that Empower Communities Project* is a small-scale project from the Global Partnership on AI that is looking to scale up to practical action, and is collecting case studies of digital ecosystems empowering communities to seek funding to take this forward.

We're looking for examples where digital ecosystems use AI in creative, community-based ways to help those communities address problems they face, that is respectful of data sovereignty and promotes community wellbeing. We want to identify commonalities in technology stacks and approaches that could be replicated all around the world

Here we define a community as a group of people with a shared interest such as a local community or people with a shared geography, people all within an organisation or network of organisations, people all within a facility, people of shared ethnicity and/or shared cultural background.

If you think you have an example but are not sure, please fill out this form. Someone will aim to review it and come back within 2 working days.

If you're pretty sure you already have a good example, you can jump straight to the detailed form

Deadline: Extended!
Terms of reference –

Consent

By submitting your Digital Ecosystems case study, you agree to our privacy policy and consent for us to use the information you provide. Note that you can withdraw your consent at any time. Please contact us to do so. You will find our contact information at the end of this page.

The information you provide by answering this survey will be shared with the GPAI Experts involved in the project to conduct case studies for research purposes.

If selected for use, you agree to consent to use of the information you provide in preparation of a report on the subject of digital ecosystems, which is currently in preparation.

Privacy Policy

We collect your personal data (your email address) in order to be able to contact you. In accordance with Quebec law, applicable to CEIMIA, your personal data is only retained for as long as we have a purpose and a lawful basis to do so – the sole purpose being to contact you should we need to, following review and evaluation of the submitted case studies.

The above summarises how we we will use your information. For full terms and conditions, please see the end of this form.

1. Email *

2. Name a problem facing a community (in a few sentences)

3. How is the community currently disempowered?

4. Can AI or other digital technologies empower the community (and address the problem)? How? Any insight about the technology stack needed would be useful if you have this information

5. What do we need to do?/next steps

6. Enter your email address

Full Terms and conditions

Privacy Policy

This privacy policy describes how and why we might collect, store, use, and/or share your information when you use our services.It will help you understand your privacy rights and choices. By submitting, you are deemed to have read and agreed to the terms of use set out in this section. Use of this site is for personal, non-commercial purposes only. If you do not agree with our policies and practices, please do not use our Services. If you still have any questions or concerns, please contact us. You will find our contact information at the bottom of this page.

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Information collection

If you submit case studies for the Digital Ecosystems that Empower Communities project, CEIMIA collects and stores the following information: your email address, and the information you provide on case studies.

Use of collected information

The information you provide by answering this survey will be shared with the GPAI Experts involved in the project to conduct case studies for research purposes.

Consent

We may process your information if you have given us specific permission (i.e., express consent) to use your information for a specific purpose, or in situations where your permission can be inferred (i.e., implied consent). For instance, by submitting your case study proposal, you agree to our privacy policy and consent to the use of the collected information. Note that you can withdraw your consent at any time. Please contact us to do so. You will find our contact information at the end of this page.

B.1 Case Study 1: Type II diabetes stabilization in Indigenous First Nations peoples in Canada – long form response

B.1.1 Community

What is the intended benefit to the community? Reduction of new Type II Diabetes cases for pre-diabetics. Reduction of active Type II Diabetes cases.

How will this project empower the community in question? Puts the innovation and power into communities to leverage traditional and cultural practices. Increased language, cultural and health supports. Supports traditional food sovereignty and food security in remote First Nations communities.

B.1.2 Digital Ecosystem

What digital models and data ontologies are likely to be needed for the digital ecosystem to function? Indigenous Data Sovereignty

What data will the community provide? How will they provide it? Blood Glucose of participants, # of cultural/traditional interventions over time, number of language speakers.

What (if any) supporting/other data will be used? Financial impacts to reduce $ spent on managing Type II Diabetes.

No other information on a proposed digital ecosystem was provided at this time.

B.1.3 Technology Stack

No information on any technology stacks was provided at this time.

B.1.4 Additional Information

No additional information was provided at this time.

B.2 Case Study 2: Understanding transport and mobility in Dakkar – long form response

B.2.1 Community

What is the intended benefit to the community? It's about analyzing traffic and seeing how to improve urban transport.

How will this project empower the community in question? Reduce travel times, improve traffic flow, reduce carbon emissions, better plan transport infrastructures.

B.2.2 Digital Ecosystem

What digital models and data ontologies are likely to be needed for the digital ecosystem to function?

No other information on digital models or data ontologies was provided at this time.

What data will the community provide? How will they provide it? Transport data, pedestrian traffic, red light operation, periods of heavy congestion, etc. are all collected by sensors. These data will be collected by sensors.

What (if any) supporting/other data will be used? As there is sometimes flooding after the rains, which has an impact on mobility, it would be useful to also have data on the weather and perhaps also on the areas potentially impacted by flooding.

How is data being stored and integrated?

Data stored in personal computers. No integration yet.

No other information on a proposed digital ecosystem was provided at this time.

B.2.3 Technology Stack

No information on any technology stacks was provided at this time.

B.2.4 Additional Information

No additional information was provided at this time.

B.3 Case Study 3: Public value frameworks for Nature-based Solutions in urban environments – long form response

B.3.1 Community

What community or communities are you working with? General public (urban), community leaders, professionals (engineering, urban designers, etc.), policy makers

What is the intended benefit to the community? Ability of communities to co-create urban spaces with professionals through gaming platform (SimCity inspired - with real models in the background). Social resilience and inclusion.

How will this project empower the community in question? Serious game is the core of this EU funded project (starting in Nov.2024). When new part of the city is to be redeveloped, communities will be able to play through the scenario of redevelopment, creating their ideal space, while being shown environmental, social, financial details of their desired scenario. Makes it easier for everyday person to get involved in decision-making around the space they live.

B.3.2 Digital Ecosystem

What digital models and data ontologies are likely to be needed for the digital ecosystem to function? Water quality/quantity model (terrain, elevation, land-use), simplified thermal model (weather data related to the case study), simplified economic model (cost of different construction elements). Later development will have social maps + biodiversity maps (GIS-based).

What data will the community provide? How will they provide it? Community plays the game and provides in-game data + post gaming interviews (which are not publicly available).

What (if any) supporting/other data will be used? Current literature, government regulations/recommendations, etc.

How is data being stored and integrated? Project was planned for offline data storage, with specific data being publicly shared. But with more resources, the game can be integrated online, with centralised data storage.

No other information on a proposed digital ecosystem was provided at this time.

B.3.3 Technology Stack

No information on any technology stacks was provided at this time.

B.3.4 Additional Information

No additional information was provided at this time.

B.4 Case Study 4: Understanding accessibility of essential services for the Yaqui community of Vícam, Mexico – long form response

B.4.1 Community

What community or communities are you working with? 1. community of peripheral neighborhoods 2. Yaqui people from Sonora Mexico

What is the intended benefit to the community? 1. understand the availability and accessibility of essential services and public spaces or areas with high building density, finally this can give us many ideas of how basic services like stores, hospitals, schools are distributed in these places, what services are missing, do the people living there have accessibility to parks or green areas, this also influences their lifestyles

2. provide critical information for the development of water management strategies and policies. Currently, this is an open access dashboard that includes a large amount of data and analysis on water distribution issues in the region. This platform provides tribal leaders and the community with tools to understand and effectively manage water use, strengthening the capacity of indigenous peoples to use this data as a policy tool in their water struggles.

How will this project empower the community in question? 1. With this, it is possible to understand the availability and accessibility of essential services and public spaces or areas with high building density, finally this can give us many ideas of how basic services like stores, hospitals, schools are distributed in these places, what services are missing

2. In the pilot phase, we focused on how Artificial Intelligence (AI) can be a tool to develop indicators that enable the Yaqui community of Vicam to make informed decisions about the use of their natural resources, especially water. Through workshops and field surveys, we involved the community in the use of technological tools and their knowledge was essential to guide the analysis phase.

B.4.2 Digital Ecosystem

What digital models and data ontologies are likely to be needed for the digital ecosystem to function?

1. Mapping of access to basic services in peripheral neighborhoods,
2. Maps and time series analysis of the evolution of water and other natural resources.

What data will the community provide? How will they provide it? 1. The data collected includes points of interest, green areas, road networks, buildings and a spatial indexing system. Mainly, we integrate these data into various overlay analyses and network analysis, these data are on an open access dashboard.

2. land cover data for the Vicam territory in Sonora, evapotranspiration, historical classification, accumulations, sociodemographic data and data on water laws in mexico, these data are in an open access dashboard.

What (if any) supporting/other data will be used?

No information on any supporting/other data was provided at this time.

How is data being stored and integrated?

No information on any data storage or integration was provided at this time.

What kind of community engagement mechanisms are being used to communicate models/model findings back to the community? We have been developing our Inclusive AI design methodology that actively integrates an intersubsectional and participatory approach. This allows us to work with communities, decision-makers, and scientists, ensuring that technology is both inclusive and accountable.

For this we conduct collaborative workshops, surveys and co-design sessions that enable effective co-creation, with each stakeholder bringing their perspective, from lived experiences to technical expertise. This approach ensures that AI projects reflect local realities. At the same time, it prevents the perpetuation of structural inequalities, fostering transparency and accountability. By involving all these stakeholders in the process, our technology solutions directly address real needs and contexts, promoting fairer and more equitable systems.

No other information on a proposed digital ecosystem was provided at this time.

B.4.3 Technology Stack

No information on any technology stacks was provided at this time.

B.4.4 Additional Information

No additional information was provided at this time.

B.5 Case Study 5: How leveraging digital health technologies can improve diabetic retinopathy care in rural communities – long form response

B.5.1 Community

What community or communities are you working with?

We are working with patient individuals in rural community, Punjab, India and underserved area who may have limited access to eye care specialists. This community can include patients, healthcare providers, caregivers, researchers, and technology developers, all work closely and meaningfully to improve health outcomes.

What is the intended benefit to the community?

In this multi-stakeholder ecosystem, the community is central to reap the full potential of this digital health innovation. The patient community needs to be empowered to improve digital health literacy and engage in communication with healthcare providers. This helps ensure they receive timely interventions based on real-time monitoring from digital twin systems. Healthcare providers can gain insights from voice biomarker, which have the potential to detect early signs of health conditions that affect vision health. Support network or family member can be within the community as they can support for older adults managing vision health. Collaborating with healthcare professionals, developers focus on creating user-friendly interface for patient and providers.

How will this project empower the community in question?

Patient Empowerment: Self-management and proactive healthcare behaviour are fostered by patients' increased engagement and knowledge about their health. Streamlined Communication: Time and resources are saved while maintaining high-quality care when there is less need for in-person visits due to prompt and direct communication. Preventative Care: By using digital twin data to inform predictive analytics, health problems can be identified early on, averting complications, and enhancing patient outcomes. Reducing Communication Barriers: Patients who possess digital health literacy are more equipped to comprehend voice biomarker feedback and have meaningful interactions with healthcare professionals. Patients can arrange additional exams or ask their practitioner for explanation if the system flags a possible health concern based on voice analysis.

B.5.2 Digital Ecosystem

What digital models and data ontologies are likely to be needed for the digital ecosystem to function?

To enable individualised treatment and real-time monitoring, health data must be organised and integrated using a number of digital models and data ontologies. Health Literacy Skills Framework: The Health Literacy Skills Framework incorporates decision-making, interaction with health services, and processing health information into patient education. In a digital setting, it places a strong emphasis on instructing patients on how to use resources such as digital twin visualisations of their eye health and communication with patients via call.

Patient-Specific Digital Twin Models: By combining data from blood pressure, glucose monitoring, and retinal imaging, a digital twin in the field of eye health may mimic a patient's state of vision. algorithms powered by AI to forecast outcomes like vision loss or retinal injury. Real-time updates to the simulation are made in response to fresh data inputs, such as variations in retinal thickness or blood sugar levels. Voice biomarkers scan voice recordings for patterns associated with systemic health conditions—like stress, diabetes, or cognitive impairment—that may have an impact on ocular health. They do this by using AI-based algorithms. These models use machine learning and natural language processing (NLP) to identify health-related characteristics in speech data that may be incorporated into the digital twin for real-time health tracking. These algorithms identify early markers of systemic diseases, including eye ailments, by analysing speech patterns, pitch, and tone in voice data. Interactive patient portals: With these models, patients can interact with their healthcare providers and obtain information about their eye health, including retinal scans or simulations from their digital twin. Enhancing digital health literacy entails teaching patients how to make efficient use of these portals, comprehending the findings of their examinations, and managing their eye health proactively. In reference to data ontologies, healthcare information can be exchanged electronically, supporting the integration of patient data. In doing so a standard interoperability resource platform represented, facilitates communication between patients and providers by ensuring that data is compatible and easily shared across intervention.

What data will the community provide? How will they provide it?

Personal Health and Medical Data: How: Via Patient portals What: Patients provide basic personal health data, including: medical history: Data on chronic conditions like diabetes, hypertension, or previous eye diseases. Previous diagnoses and treatments: Information on past treatments for eye health issues, surgeries, or medications. Laboratory results: Blood sugar levels, cholesterol, and other lab tests relevant to eye conditions like diabetic retinopathy. Real-Time Health Monitoring Data: How: Through call via mobile What: Blood glucose monitoring: For diabetic patients, continuous glucose monitoring (CGM) data can be uploaded to platforms, which feed into the digital twin to assess risks related to diabetic retinopathy. Communication with healthcare providers: call records, interaction and communication between patients and healthcare providers and to record speech through voice biomarker Patient-Self-Reported Outcomes How: Through online surveys, digital questionnaires Symptoms and eye health status: Patients report symptoms like blurry vision, floaters, or other eye-related issues and behavioural and life style data Quality of life and treatment adherence: Patients share information about their daily life, medication adherence, and lifestyle factors that could influence eye health.

What (if any) supporting/other data will be used?

Feedback and Interaction with Digital Health Platforms How: Via direct messaging on patient portals. What: Real-time feedback and questions: Patients can ask questions, seek advice, and provide updates on their condition.

How is data being stored and integrated?

Continuous data streams are integrated into the digital twin immediately, enabling real-time updates of the model to reflect current patient conditions. Scheduled weekly updates for interaction with healthcare providers and other health data as required. Event-Triggered Updates regard to acute changes in patient condition. Monthly update for routine assessments such as lab results, medical checkups, and major interventions.

How frequently is the digital model being updated from the integrated data?

Voice biomarkers, retinal imaging, and real-time health indicators (such blood sugar levels) are just a few examples of the patient data that is frequently kept on safe, HIPAA-compliant cloud platforms. For example: Microsoft Azure Regard to data security and encryption, strong authentication protocols like two-factor authentication (2FA) are used to ensure that only authorized users can access the data.

What kind of community engagement mechanisms are being used to communicate models/model findings back to the community?

In order to ensure that patients, healthcare professionals, and stakeholders collaborate for improved health outcomes, community engagement strategies are essential. Establishing trust, raising awareness, enhancing digital literacy, and encouraging the co-design of health interventions are all benefits of effective involvement. The following are important mechanisms that are applicable: Health Education Campaigns and Digital Literacy Programs: Purpose: To enhance patients' and communities' understanding of digital health tools, voice biomarkers, and digital twins. Mechanism: Workshops: Local communities Patient Advocacy and Support Groups: Peer support networks: Patients managing chronic eye conditions like diabetic retinopathy can exchange information on navigating digital health platforms and accessing care through call. Patient advocates: Represent patient needs in discussions with healthcare providers and technology developers to improve the accessibility and usability of voice biomarker and digital twin technologies in eye care. Community-Based Participatory Research (CBPR): Purpose: Engage community through workshop and focus group discussion in the research process, allowing them to contribute insights and preferences to the development of digital health tools such as voice biomarkers and digital twins in eye care.

B.5.3 Technology Stack

What kind of digital model, e.g., digital twin, is being used or do you think will need to be used?

Digital twins integrate several data sets (e.g., blood glucose levels, speech biomarkers, retinal imaging) to provide a virtual, personalised representation of a patient's health. Based on the individual patient's data, the digital twin can mimic the course of eye health conditions, such as the management of diabetic retinopathy (DR). For instance, a diabetic patient is better able to understand how variations in blood sugar could impact the health of their retina, which encourages them to take a more active role in their treatment. Digital twins allow for continuous real-time monitoring of a patient's systemic health data, including metrics like blood pressure, glucose levels, and speech biomarkers (which may signal stress or cognitive abnormalities). This allows for early detection of health issues. This capacity is critical to the health of the eyes because it allows for the early detection of disorders such as diabetic retinopathy, in which systemic health problems have a major impact on ocular health. Digital twins can anticipate any problems by keeping an eye on certain variables, which enables early intervention. Improved Patient-provider Communication: By providing a dynamic, data-driven model of the patient's health, digital twins help to improve the quality of interactions between patients and healthcare providers. Improving Digital Health Literacy: Digital twins help to improve digital health literacy by providing an interactive and visual means of comprehending health data. Integration of Speech Biomarkers for Systemic Health: Speech biomarkers are a newly developed technique that can identify early indicators of disorders that may have an indirect impact on ocular health, such as stress, cognitive decline, or other systemic conditions. Including these biomarkers in the digital twin of a patient adds more context to the management of diseases like diabetic retinopathy. Predictive analytics in preventive care: By simulating possible outcomes based on available interventions and current health data, digital twins apply predictive analytics.

What kind of AI is being used alongside the digital twin?

Machine learning (ml) algorithms for personalized health predictions Natural language processing (NLP) for facilitating communication: NLP algorithms enable better communication between patients and healthcare providers by interpreting patient queries Computer vision for retinal imaging analysis Predictive analytics and simulation models for disease progression modeling, ai-driven predictive analytics enable the simulation of future health outcomes based on current patient data. Speech and voice analysis AI for voice biomarkers Explainable AI (xai): transparent decision-making

What hardware or software technologies are needed to deliver this solution?

Hardware Technologies: Continuous Glucose Monitors (CGMs) Smartphones: act as the interface for patients to engage with telehealth services, voice biomarker apps, and digital twin visualizations Portable fundus cameras: allow for retinal imaging in remote or clinical settings, feeding data into digital health platforms Data Servers and Cloud Infrastructure: Microsoft Azure, or Google Cloud provide scalable infrastructure for storing medical data and running machine learning models in healthcare environments

Software Technologies AI-Driven Digital Twin Platforms: for example GE Healthcare offer platforms that support healthcare digital twins.

Voice Biomarker Analysis Software: will choose software for machine learning to analyze voice data for detecting biomarkers Telehealth Platforms: for example Zoom for Healthcare

B.5.4 Additional Information

Have you considered the following?

- **Required budget**
- **Team composition**
- **Timeline**

If so, please add them here

- Required budget $240,000 in US dollars - Team composition Dr. Mona Duggal, Associate Professor, Advanced Eye Centre,Post Graduate Institute of Medical Research and Education, Chandigarh Dr. Vishali Gupta, Professor, Advanced Eye Centre,Post Graduate Institute of Medical Research and Education, Chandigarh

Dr Santosh Kumar Vipparthi, Assistant Professor, Computer Science and Engineering, Indian Institute of Technology, Ropar, India Dr Sujata Pal, Assistant Professor, Computer Science and Engineering, Indian Institute of Technology, Ropar, India Debarati Sarkar, PhD Student Indian Institute of Technology, Jodhpur, India, Dr Anshul Chauhan, PhD Student, Sonam Kumar, PhD Student, Harsh Rashtogi, PhD Student, Advanced Eye Centre,Post Graduate Institute of Medical Research and Education, Chandigarh, India - Timeline 24 Months