Multidisciplinary Project (MDP)

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1 Introduction / Description of the Case

European healthcare systems are facing mounting pressure from aging populations, increasing care demands, and persistent inefficiencies in the collection, sharing, and use of health data [1]. These pressures manifest in delayed treatments, fragmented communication among providers, and rising administrative burdens—challenges often traced back to the absence of integrated, system-wide data infrastructures [2].

In this context, digital twins are emerging as a promising approach to enhance healthcare delivery. A digital twin is a continuously updated virtual replica of a physical entity—such as a patient, a hospital ward, or an entire care pathway—that integrates real-time data to simulate outcomes, monitor processes, and support clinical decision-making [3]. While pilot applications have demonstrated potential, large-scale implementation of digital twins within national healthcare systems remains a distant goal. Realizing their full value depends on the establishment of reliable, interoperable, and ethically governed data ecosystems—prerequisites that are still lacking in most European countries.

This research considers the creation of a European Health Record (EHR) system as a crucial first step. Such a system would enable structured, secure, and conditional data exchange between providers, countries, and institutions, laying the groundwork for more advanced applications such as digital twins. An EHR would not only standardize how patient information is stored but also make it possible to responsibly share and re-use data when beneficial to care or public health.

Sweden and the Netherlands are selected as comparative cases due to their relatively advanced digital health systems. Sweden benefits from high public trust and progressive e-health policies, while the Netherlands combines strong infrastructure with greater public hesitation toward centralized data use [4, 5]. Yet in both contexts, institutional, legal, and infrastructural gaps still hinder large-scale digital twin implementation. *The aim of this comparative analysis is to understand what specific conditions and reforms are required in each country to enable responsible and effective use of digital twins in healthcare.*

The purpose of this research is not only to assess the current state of readiness in Sweden and the Netherlands, but also to identify the concrete actions, frameworks, and stakeholders needed to move closer to successful implementation. Rather than assuming that digital twin adoption is imminent, this study aims to clarify what needs to be in place—technically, legally, and societally—for such systems to function responsibly and effectively. This leads to the following research questions:

1. To what extent are Sweden and the Netherlands ready to implement digital twins in healthcare?

2. What are the main legal, technological, and societal challenges that must be addressed for successful implementation?

3. Which stakeholders are responsible to take the next step toward a more connected and future-proof healthcare system?

By addressing these questions, this study contributes to a realistic and actionable perspective on digital transformation in European healthcare. It outlines not only the potential of digital twins, but also the practical and institutional groundwork required to support their development in an inclusive and responsible way.

2 Background and significance, literature

2.1 Definition and Current Challenges of Digital Twins

According to Guo et al., a digital twin is a virtual simulation model of a technical or physical asset that evolves based on information collected from its real-world counterpart [6]. It receives real-time sensor data and integrates historical information to maintain an *up-to-date* and *dynamic representation* of the physical object. Machine learning algorithms, artificial intelligence, and neural networks are often used to analyze and optimize the performance of the digital twin. Similarly to Guo, Grieves originally described a digital twin as consisting of three key elements: the physical asset in real space, the virtual product in virtual space, and the flow of information that connects the two, enabling continuous interaction and feedback [7].

Despite Guo and Grieves' simplistic definitions, one can gauge the true complexity of digital twins by considering their main components, which can be summarized as follows:

- **Physical Entities**: The real-world units, systems, or products whose behavior the digital twin simulates;
- **Virtual Models**: Behavioral models based on the physical laws governing the entity, including response mechanisms to environmental changes;
- **Digital Twin Data**: A multi-temporal scale, heterogeneous, multisource, and multidimensional data set. Some of this data is generated by the twin itself (e.g., results of simulations), while other parts come from a pool of experts or historical records, incorporating fields such as state-of-the-art medical knowledge;
- **Services in Digital Twin**: These include simulation, monitoring, verification, optimization, and prognosis, alongside algorithmic, data, and knowledge services necessary to construct and maintain the twin;
- **Connections in Digital Twin**: Refers to the integration and interaction between the physical entities, virtual models, data, and services.

In addition to the *technical* challenges listed above, digital twins also face several significant *social* and *practical* challenges that must be addressed for their successful implementation. From a *practical* perspective, adequate IT infrastructure is essential, requiring robust, interconnected systems to support the continuous operation of digital twins. Also, the accuracy and precision of data inputs, along with a constant and uninterrupted data stream, are critical to ensuring reliable simulations and predictions. From a *social* perspective, privacy and data security are major concerns, as digital twins require handling vast amounts of sensitive data, making them attractive targets for malicious actors; building and maintaining user trust is therefore a top priority, as users must have confidence in the twin's integrity and performance. Additionally, managing expectations is key, as thorough and well-maintained documentation of the target population or system is necessary to ensure the effectiveness

of the digital twin. These challenges highlight that the full realization of digital twins is still far ahead of current capabilities, and that a fundamental paradigm shift in technology is a crucial first step.

2.2 THE *Learning Health System* AND THE ELECTRONIC HEALTH RECORD

According to Braunstein, at the foundation of a functioning healthcare system powered by digital twins lies the concept of a "Learning Health System" [8]. A Learning Health System is defined as a sustainable system that delivers the right care to patients when needed and captures the outcomes to inform about continuous patient development. This system gathers data from care already delivered, aggregates it, and analyzes it to learn from the collective results of many care episodes, creating a positive feedback cycle. To enable such a cycle, it is necessary to undergo a transition from the already existing *Electronic Medical Record* (EMR) in use to an *Electronic Health Record* (EHR): While an EMR primarily consists of clinical data recorded by healthcare providers, an EHR is broader and also includes data contributed directly by patients themselves through wearables or home monitoring devices.

Currently, the adoption of Electronic Health Records (EHRs) faces several significant challenges. According to Tripathi, many current healthcare systems are not ready for the implementation of EHRs as they do not meet the necessary criteria to fully realize their potential: *A core of consistent, structured, clinical content that would be uniform across vendor systems and care settings; Automated alerts and reminders; Consistent, robust measurement capabilities; Data mining capabilities; Public health reporting;* and *Interoperability with other systems* [9]. Furthermore, Stead highlights that today's IT applications largely mimic outdated paper-based tools rather than facilitating the cognitive tasks and workflows of clinicians [10]. These systems are not optimally designed for effective human-machine interaction, thereby increasing the likelihood of errors that are difficult to detect. A "one-size-fits-all" approach (as often applied in the case of EMRs) simply fails to capture the nuances and complexities of patient care.

Overall, Braunstein proposes the following core elements of the Learning Health System founded on the implementation of EHRs [11]:

- Detailed and comprehensive data collection on diseases, treatments, and patient outcomes;
- Assistance for healthcare providers and patients in integrating individual patient data into clinical decisions, while managing any uncertainties;
- Tools that support the application of evidence-based guidelines and the latest research into everyday practice;
- Systems to help providers oversee care for multiple patients, highlighting issues both at the individual and population levels;
- Rapid adoption of new medical technologies, biological discoveries, and treatment methods;

- Flexibility to support a broad range of care environments, including home monitoring, lifestyle integration, and remote healthcare services;
- Empowerment of patients and families to take an active, informed role in healthcare decision-making and management.

Despite numerous initiatives to develop comprehensive EHRs, achieving a truly effective and integrated system remains a complex and ongoing challenge.

2.3 EHR IMPLEMENTATION CHALLENGES: THE DUTCH AND SWEDISH CASES

To effectively design a suitable digital-twin implementation framework for the Netherlands and Sweden, it is important to preliminarily assess the distinct healthcare contexts of the countries under analysis.

According to the OECD [12], a major structural issue in the **Dutch** healthcare system stems from its current decentralized organization, characterized by the presence of numerous private insurers and healthcare providers. This fragmentation poses a significant barrier to seamless data sharing and system-wide integration.

While this model promotes competition and market-driven efficiency, it also leads to significant *fragmentation*, which hampers seamless data sharing and system-wide integration. This fragmentation is further exacerbated by a lack of coordinated incentives from both governmental institutions and private stakeholders to unify existing "data silos" into a national health information infrastructure. As a result, effectively implementing data-intensive innovations such as digital twins remains difficult. Therefore, the Dutch healthcare system requires targeted reforms to overcome these barriers and move toward a more cohesive and interoperable digital health environment, including:

- The establishment of a central agency dedicated to collaboratively developing and executing a unified national strategy alongside the Ministry of Health;
- The development and operation of a centralized national data platform to serve as a secure and efficient hub for health data exchange.
- The creation, enforcement, and continuous maintenance of uniform national standards for health data;
- A robust certification framework to ensure compliance of IT solutions and digital healthcare tools with national interoperability standards;
- Continuous stakeholder engagement and extensive public consultation processes to build consensus and ensure successful implementation and broad acceptance of the integrated system;

Conversely, the **Swedish** healthcare system provides a fundamentally different setting characterized by universal coverage and high levels of public trust and acceptance, sustained by a tax-funded structure that prioritizes equity and affordability [13].

Despite these considerable strengths, Sweden still faces notable challenges, primarily stemming from the *decentralized, regionally-administered healthcare* model. Such decentralization can result in uneven quality and accessibility of healthcare services across different regions, thereby potentially undermining the equitable ideals of the system [14]. Addressing these regional disparities and enhancing uniformity in healthcare provision is crucial for Sweden and would involve [15]:

- Strategic coordination efforts aimed at aligning regional healthcare services and reducing variability;
- Strengthening central oversight to monitor and address inequities in service provision;
- Expanding national standards and guidelines to ensure consistency in healthcare quality and accessibility across all regions;
- Leveraging the existing high public trust and societal acceptance to implement changes that reinforce nationwide equity in healthcare services.

Recognizing these distinct healthcare landscapes and their unique requirements is essential for the successful development and implementation of a digital-twin implementation framework in both countries.

2.4 Comparative Context: Health System Characteristics in the Netherlands and Sweden

A comparative overview of key health system characteristics in the Netherlands and Sweden is presented in Table 1. This comparison highlights structural and cultural factors that influence the readiness for digital twin implementation and the ethical considerations emerging from their respective healthcare environments.

Table 1: Comparison of healthcare system characteristics between the Netherlands and Sweden.

Aspect	**Netherlands**	**Sweden**
Technological Integration	High adoption of EHRs and digital tools	Moderate, with ongoing efforts to enhance e-health
System Structure	Decentralized with private insurers and providers	Decentralized, publicly funded and administered
Public Trust and Acceptance	Moderate, with emphasis on efficiency and innovation	High, with strong societal support for equity
Access to Care	Generally efficient, though complexity exists	Universal, but with regional disparities
Preventive Care Focus	Emerging, with growing initiatives	Strong emphasis on prevention and public health

These differences inform the contextual readiness and ethical landscape for digital twin adoption. The Netherlands demonstrates higher technological integration

but operates within a more privatized and efficiency-driven system. Sweden, in contrast, is characterized by stronger public trust and a more equity-focused, publicly administered system.

Such structural and cultural distinctions are likely to influence stakeholder perceptions, data governance expectations, and ethical priorities in the implementation of AI-driven health technologies. Accordingly, the comparative analysis provides an essential baseline for interpreting the study's findings across the two national contexts.

3 Multidisciplinary Background

This chapter provides a retrospective evaluation of our research process, with a particular focus on the multidisciplinary nature of our collaboration.

3.1 Multi-faceted Problem

A key strength of our project was the authentic multidisciplinarity embedded throughout the process. Our team was composed of students from diverse fields of study within TU Delft—Strategic Product Design, Applied Mathematics, and Global Law—each of whom brought unique perspectives, experiences, and problem-solving styles. Beyond academic disciplines, we represented different nationalities, professional trajectories, extracurricular involvements, and personalities. Importantly, none of us had met prior to this project. This unfamiliarity quickly became an asset, as we made it a shared value to learn from each other and emphasize our differences as a strength.

Our collaboration extended beyond disciplinary and personal backgrounds. Through the four international modules—Lecco, Zurich, Aachen, and Gothenburg—we engaged with a variety of academic cultures and methodological traditions. Each location brought a distinct lens: Lecco focused on stakeholder dynamics and political framing; Zurich on methodological design and survey construction; Aachen on legal and ethical rigor; and Gothenburg on stakeholder engagement and real-world feedback. Back in Delft, we synthesized these insights into a coherent and actionable blueprint. The different perspectives were not merely tolerated—they were a natural element of our discussions and shaped the way we interpreted the problem and explored solutions.

The wealth of information and the volume of perspectives occasionally led to information overload, especially when stakeholder needs clashed or proved difficult to prioritize. Legal experts emphasized privacy and compliance, clinicians focused on usability and trust, and policymakers were concerned with regulation and interoperability. These tensions were actively addressed in our ethical reflection chapter and shaped the final design of our implementation framework.

Each team member contributed a distinct and valuable lens: students from Strategic Product Design brought strategic foresight and stakeholder-centric tools; the mathematical background ensured quantitative rigor in the construction of our readiness index; clinical insights grounded our thinking in real-world feasibility; and international experience helped maintain direction and clarity when the problem space became ambiguous.

Rather than conforming to a rigid research model, we developed a tailored approach that responded dynamically to our context, data, and ambitions. In doing so, we crossed boundaries of disciplines and comfort zones alike—co-creating a responsible innovation process grounded in both methodological soundness and societal relevance.

3.2 Group Work, Division and Responsibilities

An essential element of our success was the deliberate and balanced division of tasks based on both disciplinary strengths and the willingness to step outside comfort zones. All team members contributed a fair amount of work, not only in areas of personal expertise but also in domains where they developed new capabilities.

Annamaria ensured theoretical coherence across all outputs. Drawing on her Aerospace Engineering background, where group-based, systems-level thinking is core, she synthesized diverse inputs into a structured narrative. Her extensive international experience enabled her to bridge cultural and institutional differences, especially during multi-university modules.

Marlou, a master's student in Strategic Product Design, led the visual and conceptual development of the dashboard. Her design perspective was indispensable in structuring a product that was not only functional but compelling and accessible. Her leadership role on the GreenTU board also added a strong sustainability lens to our thinking, prompting us to integrate long-term system implications into our design.

Sophie brought clinical insight and methodological expertise. Her medical background helped us realistically evaluate the daily constraints faced by healthcare professionals, while her consulting experience was invaluable in designing stakeholder interviews, structuring the research phases, and presenting results. She also initiated a peer training session on constructive feedback, which contributed to a high-performing and supportive team dynamic.

Fenna played a connecting role throughout the project. She took initiative in stakeholder engagement, made sure everyone remained aligned with the overarching research objective, and synthesized diverse strands of input into coherent results. Her proactive communication and coordination helped the team remain focused and agile throughout the project.

This distributed yet cohesive structure meant that no member was confined to their disciplinary silo. Instead, we consciously engaged with each other's expertise and encouraged boundary-crossing. This collaborative model not only supported project excellence but also fostered deep personal and academic growth.

3.3 Fulfilment of Deadlines

Our team maintained a consistent track record of timely delivery throughout the project. Each of the four international modules—Lecco, Zurich, Aachen, and Gothenburg—served as structured checkpoints for setting intermediate goals, followed by biweekly internal deadlines to keep progress continuous and transparent.

Scheduling meetings was challenging given the variability in our academic and extracurricular commitments. Nonetheless, once sessions were planned, they were treated as non-negotiable commitments. This discipline, paired with high mutual accountability, allowed us to stay ahead of deliverables without the need for intensive external supervision.

Every two weeks, we reviewed outcomes, reassigned tasks if necessary, and anticipated upcoming challenges. These internal steering moments helped us remain

flexible and responsive while maintaining steady momentum.

The most significant external deadline was our presentation to the Sahlgrenska University Hospital board in Gothenburg. This milestone served as the project's integration point, demanding the finalization of our dashboard, Readiness and Willingness Index, and blueprint. We delivered all outputs on time and in full, with substantial internal reviews beforehand.

What stands out most is that we continued refining our work even after this formal delivery. This was not driven by requirement but by a shared sense of ownership and aspiration to exceed expectations—a mindset that underpinned our entire approach.

3.4 Integration into Client's Working Environment

A defining feature of our project was its embeddedness within the real-world context of our client. From the outset, we engaged closely with stakeholders from the Swedish healthcare ecosystem, culminating in a panel discussion with high-level experts: hospital directors, innovation managers, med-tech professionals, and data security specialists.

This discussion was not a formality—it was a test of whether our work could survive, adapt to, and contribute to the complex realities of a healthcare institution. The feedback was affirming: stakeholders found our research human-centered, technically sound, and practically relevant.

Panelists appreciated our stepwise implementation roadmap and its grounding in stakeholder needs. They especially highlighted our inclusion of trust-building, explainability, and data ethics—not as add-ons, but as core principles of the design. Our clinical framing and interviews were seen as enablers of concrete action.

Furthermore, several stakeholders envisioned integrating elements of our work into ongoing innovation projects. This indicated a high degree of practical transferability—an uncommon but important benchmark in academic design research.

By actively involving the client throughout, tailoring the product to fit their ecosystem, and responding to direct institutional feedback, we ensured that our outputs were not abstract proposals but grounded contributions to an evolving system.

3.5 Client Satisfaction

Client satisfaction was both a metric and motivator for our work. From early interviews to the final panel presentation, we maintained regular and transparent communication with stakeholders—sharing progress, seeking feedback, and aligning deliverables with institutional priorities.

The feedback we received in Gothenburg exceeded expectations. Stakeholders acknowledged the relevance, usability, and integrity of our dashboard and blueprint. More than one expert remarked that our approach was "surprisingly human" for a technically oriented team, highlighting our emphasis on co-creation, trust, and long-term system value.

Most notably, stakeholders saw direct applicability in our work. There were mentions of follow-up conversations, potential pilot integration, and compatibility with innovation platforms already in place. This degree of alignment between academic

deliverables and client ambition speaks to our project's maturity and collaborative ethos.

Even after the formal project concluded, we continued refining our materials—out of intrinsic motivation and respect for the client's investment. That extra step, though not expected, was recognized and appreciated. As one panelist succinctly put it: *"You didn't just deliver a report—you thought about how it will actually be used."*

This level of stakeholder engagement and appreciation confirms that our project succeeded not only on paper but in the eyes of those we aimed to serve.

4 METHODOLOGY

This study adopts a mixed-methods, comparative case study approach to assess the readiness of Sweden and the Netherlands for implementing digital twins in healthcare. This approach is well-suited for investigating complex, real-world phenomena that span technical, societal, and institutional domains, and where context plays a critical role in shaping outcomes [16]. By combining both quantitative and qualitative data, the study captures the breadth of stakeholder perspectives while allowing for in-depth exploration of key readiness factors across diverse groups. This design enables triangulation, enhances validity, and ensures that findings are grounded in empirical evidence from multiple angles.

A multi-stage strategy is applied, integrating (1) a stakeholder survey to develop a Digital Twin Readiness Index, (2) a document and policy analysis to identify best practices from Sweden and the Netherlands, and (3) the synthesis of these insights into a visual implementation blueprint.

The methodology unfolds in a structured sequence: from case selection and data collection, through data analysis and index construction, to blueprint design and an actionable implementation plan. The overarching goal of this approach is to translate diverse forms of evidence—ranging from stakeholder input to best practices—into concrete, context-sensitive policy recommendations for responsible digital twin adoption in European healthcare systems.

4.1 OVERVIEW OF METHODOLOGICAL STEPS

1. **Theoretical Modules:** Integrate academic insights from international workshops and lectures.
2. **Data Collection and Analysis:**
   (a) **Case Study:** Select Sweden and the Netherlands as contrasting digital health cases and identify best practices.
   (b) **Interviews:** Collect qualitative data across stakeholder groups to receive insights.
   (c) **Surveys:** Collect quantitative data across stakeholder groups and construct a Readiness and Willingness Index.
3. **Blueprint Design:** Synthesize findings from the Readiness Index and case study into an actionable implementation blueprint.
4. **Implementation Plan:** Develop a step-by-step roadmap including priorities, responsible actors, and timeline based on the blueprint.
5. **Discussion and Ethical Reflection:** Critically assess ethical, societal, and economic implications of digital twin implementation.
6. **Reflection:** Evaluation on limitations and validity of our study and teamwork.

The flowchart in Figure 1 illustrates this multi-stage research process.

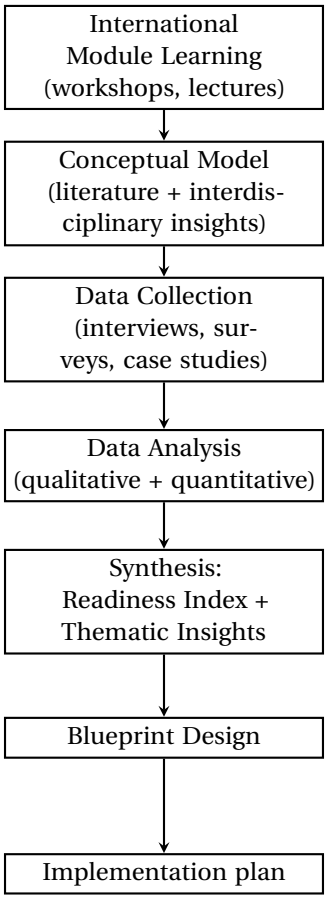

Figure 1: Flowchart of the research process from module learning to dashboard output.

4.2 Theoretical Modules

Throughout the project, the team participated in four academic stays at different European universities, each offering a distinct but complementary perspective on the central research problem of digital twin implementation in healthcare. These disciplinary lenses were deliberately selected to reflect the multifaceted nature of the challenge—spanning governance, data infrastructure, societal trust, and ethical responsibility.

In Milan, the focus was on power dynamics and the role of scientists in broader societal contexts—an essential lens for understanding stakeholder influence and institutional adoption dynamics. In Zurich, methods for data collection and survey

design were explored, which directly informed the construction of the stakeholder readiness index. The Aachen module emphasized legal and ethical dimensions, including stakeholder rights, privacy, and regulatory frameworks—critical areas for responsibly embedding digital technologies into healthcare systems. In Gothenburg, final findings were presented to the hospital board, aligning theoretical work with stakeholder communication and practical feedback loops.

Individually, each module addressed a necessary dimension of the problem; combined, they provided a robust and integrated foundation for understanding how technical, legal, social, and political factors interact in the real-world deployment of digital twins. This unique interdisciplinary structure strengthened the conceptual model and ensured that both design and recommendations are grounded in a holistic view of healthcare innovation.

These modules combined lectures from local professors with input from field professionals and were complemented by sessions in Delft. Group workshops across modules helped bridge abstract theoretical concepts with real-world stakeholder dynamics. Relevant academic literature spanning ethics, systems thinking, survey methodology, and data governance was critically reviewed and integrated into both the conceptual model and the data interpretation.

4.3 Data Collection and Analysis

4.3.1 Case Study

Sweden and the Netherlands were selected as comparative case studies due to their prominent but distinct positions in the European digital health landscape. Both countries are considered digital health frontrunners, yet represent contrasting institutional, societal, and technological contexts that provide valuable comparative insights.

Sweden has been internationally recognized for its progressive e-health policies and high levels of public trust in government-led digital initiatives (European Commission, 2022). Its healthcare system benefits from decentralized data infrastructures and early adoption of electronic health records (EHRs), creating a conducive environment for innovation in health data management (OECD, 2022).

In contrast, the Netherlands features a highly structured and centralized healthcare system with extensive electronic record usage, but faces comparatively greater societal hesitance toward centralized data-sharing and governance (HealthRI, 2022). While the Netherlands shows technological readiness, concerns about privacy, data ownership, and legal harmonization remain salient in public and professional discourse.

Selecting these two countries allows for the exploration of readiness across different healthcare governance models, legal environments, and cultural attitudes toward digital health transformation. Their contrasting profiles offer a meaningful basis to identify transferable lessons, structural barriers, and context-specific enablers for the implementation of digital twins in healthcare.

4.3.2 INTERVIEWS

To capture in-depth, context-rich insights on the institutional, technical, and societal conditions surrounding digital twin implementation, this study makes use of semi-structured interviews. These are particularly well suited to complex or emerging fields, where the exploratory nature of qualitative data is essential to understanding stakeholder perspectives. Semi-structured interviews combine predetermined questions with the flexibility to explore themes as they arise, allowing for both comparability across interviews and responsiveness to individual expertise [17].

Interviews are conducted with representatives from five key stakeholder groups:

1. Policymakers (e.g., hospital boards, legal advisers)
2. IT professionals in hospitals
3. Medical staff (e.g., physicians)
4. Technology developers
5. Legal and ethics experts

The selection of these groups is based on their direct or indirect involvement in data infrastructures, ethical decision-making, and the operational context required for digital twins to be adopted at scale. Their insights contribute to the assessment of readiness in both Sweden and the Netherlands.

The interview approach is grounded in the methodological principles set out by Kvale and Brinkmann (2009), who emphasize the importance of creating an open but purposeful dialogue to uncover meaningful insights in complex, real-world settings. Each interview follows a structured guide designed around the core research dimensions: data governance, digital infrastructure, legal boundaries, and perceived barriers to digital twin adoption. This guide is used consistently across stakeholder groups to ensure comparability, while also allowing flexibility for elaboration, personal examples, and emergent themes.

This dual focus—on both consistency and openness—aligns with the interpretivist paradigm in qualitative research, which prioritizes contextual depth and participant meaning-making over standardized measurement. It also supports the case study design outlined by Yin (2014), where semi-structured interviews serve as a key tool for triangulating evidence across sources and deepening understanding of stakeholder-specific conditions in the studied healthcare systems. The interviews aim to meet the following criteria for high-quality qualitative data collection:

- *Credibility*: Ensured through preparation, informed consent, and clearly defined roles.
- *Transferability*: Enhanced by selecting interviewees from different professional roles and national contexts.
- *Dependability*: Supported through systematic documentation of procedures, interview guides, and coding decisions.

- *Confirmability*: Enabled by researcher triangulation and reflexivity during the analysis phase.

All interviews are recorded (with permission), transcribed verbatim, and analyzed using thematic coding. Coding is based on an inductive approach, allowing themes to emerge from the data, but guided by the overarching theoretical framework developed in the conceptual model. Quotes may be used illustratively in the results section to ground the findings in participants' lived experiences and professional perspectives.

In line with the ethical standards of qualitative research, participants are anonymized, and interview data is stored securely. Where applicable, summaries of the interview findings are shared back with respondents to validate interpretations and ensure fairness.

While the initial sampling aimed to include representatives from five key stakeholder groups across Sweden and the Netherlands, actual interviews focused on medical professionals, hospital administrators, and patients in Sweden, reflecting recruitment feasibility and project scope.

Thematic coding was conducted using an inductive approach, allowing themes to emerge from the data.

4.3.3 SURVEYS

To complement the qualitative insights from interviews, this study incorporates a structured survey to quantify stakeholder attitudes toward digital health, data-sharing, and the potential implementation of digital twins in healthcare systems. The survey is designed to assess levels of trust in healthcare data infrastructures and AI-supported decision-making, perceived risks and benefits of digital twin technologies, and willingness to share health data for both primary (care) and secondary (research) purposes. The survey was administered across three key stakeholder groups:

- Healthcare professionals (including doctors, nurses, administrators)
- Patients (particularly those with chronic conditions or frequent healthcare usage)
- Public sector representatives (e.g., policymakers, health department staff)

The survey design is informed by Dillman's *Tailored Design Method* [18], emphasizing question clarity, logical ordering, and motivational techniques to improve response quality and rate. All questions were constructed as closed-ended items, primarily using Likert scales and categorical choices to facilitate statistical analysis and cross-group comparison.

To ensure conceptual rigor, Likert items were adapted from established constructs in digital health and trust literature, including the Technology Acceptance Model (TAM) for perceived usefulness and ease of use [19], and constructs from the Trust

in Automated Systems framework for measuring data trust and willingness to share health information [20]. These scales have been widely used in prior studies assessing public and professional attitudes toward digital technologies in healthcare.

SAMPLING STRATEGY A stratified sampling approach was employed to ensure diversity across age, gender, and professional roles within each stakeholder group. Stratification improves representativeness and helps reduce sampling error, aiming to obtain a balanced sample across the three groups for meaningful comparisons.

To determine the minimum required sample size per group, a statistical power analysis was performed. Assuming a two-tailed test with medium effect size, the minimum sample size (n) was calculated using the formula:

$$n = \left(\frac{Z_{\alpha/2} + Z_{\beta}}{d} \right)^2 \cdot p(1-p)$$

Where:

- $Z_{\alpha/2}$ = critical value for significance level α (1.96 for $\alpha = 0.05$)
- Z_{β} = critical value for statistical power $1-\beta$ (0.84 for 80% power)
- d = minimum detectable effect size
- p = estimated proportion (0.5 for conservative estimate)

With $p = 0.5$, $d = 0.15$, the required sample size per group was approximately:

$$n = \left(\frac{1.96 + 0.84}{0.15} \right)^2 \cdot 0.5(1-0.5) \approx 171$$

This yields a target of at least 170 respondents per stakeholder group, totaling approximately 510 participants. The survey was designed to target 510 participants across stakeholder groups to quantify readiness and willingness dimensions. Due to recruitment constraints, the final sample size was smaller than anticipated; specific results and sampling limitations are discussed in Section 9.

Collected data will be analyzed using descriptive and inferential statistics. Frequencies and means will be reported for each question. Group comparisons (e.g., between professionals and patients) will be conducted using t-tests or ANOVA where appropriate, and multivariate regression models may be applied to explore predictors of willingness to share data or adopt digital twin technologies.

This survey provides a structured and statistically grounded complement to the qualitative findings, allowing for broader generalization and the triangulation of attitudes toward digital health readiness in Sweden and the Netherlands.

Quantitative data obtained from the survey is processed using standard statistical techniques:

- *Descriptive statistics*: Central tendencies (mean, median) and distribution characteristics (variance, skewness) are computed for key variables. This provides

an overview of stakeholder attitudes toward data-sharing, AI trust, and perceptions of digital twin potential.

- *Group comparisons and correlations*: Inferential statistics (e.g., ANOVA, chi-square tests, Pearson's r) are used to compare stakeholder groups and assess relationships between variables such as willingness to share data and trust in data systems.
- *Readiness and Willingness Index construction*: A composite index is developed to synthesize the survey findings into measurable indicators of digital twin readiness. Following normalization, survey items are grouped into conceptually coherent sub-indices such as:
  - Data Infrastructure Readiness (DIR) – items related to perceived technical capabilities, data availability, and system interoperability.
  - Governance and Trust (GT) – items on data privacy, regulatory frameworks, and public trust.
  - Stakeholder Willingness (SW) – items reflecting individual and institutional openness to innovation and data-sharing.

  The overall readiness score is computed using weighted aggregation:

$$R_i = w_1 \cdot DIR_i + w_2 \cdot GT_i + w_3 \cdot SW_i$$

  where R_i is the readiness score for respondent i, and w_1, w_2, w_3 are weights assigned to each sub-index (default equal weighting unless sensitivity analysis suggests otherwise). Scores are standardized to allow comparability across countries and stakeholder groups.

  A sensitivity analysis is conducted to assess the robustness of the index to different weighting schemes. Results are visualized using radar charts and heatmaps to highlight strengths and weaknesses in national readiness profiles.

This dual approach ensures that stakeholder narratives and institutional contexts are considered alongside generalizable trends, strengthening the reliability, validity, and policy relevance of the study's findings.

INDEX CONSTRUCTION To systematically assess and compare digital twin preparedness across stakeholder groups and countries, a composite index is constructed. This index combines multiple dimensions into two overarching categories:

1. Readiness, capturing the objective capacity for digital twin implementation, including:
   - Data infrastructure availability
   - Interoperability of electronic health records
   - Maturity of governance and regulatory structures

2. Willingness, reflecting the socio-cultural and institutional openness to change, including:
    - Trust in data systems and responsible AI
    - Perceived benefits and risks of digital twins
    - Ethical awareness and innovation culture

Each sub-index is derived from specific survey items, scaled on a 5-point Likert scale, and normalized to range from 0 to 1. A weighted linear aggregation method is used to compute the final index score per respondent i:

$$R_i = \alpha \cdot Readiness_i + \beta \cdot Willingness_i$$

where α and β are weights reflecting the relative importance of technical vs. social capacity (initially set to 0.5 each for balance, but subject to sensitivity analysis). A radar plot and cluster analysis (e.g., k-means or hierarchical clustering) are used to visualize and interpret the variation across stakeholder types and national contexts.

The approach is inspired by composite index methodology in policy science, notably the OECD Handbook on Composite Indicators [21], which emphasizes transparency, normalization, weighting, and robustness checks as critical steps in index design.

ETHICAL CONSIDERATIONS The survey is designed in accordance with the principles of informed consent and respondent anonymity. Participants are informed of the purpose of the research, the voluntary nature of their participation, and how their data will be handled. No personal identifiers are collected, and data is stored securely on encrypted servers.

4.4 BLUEPRINT DESIGN

The design phase synthesizes findings from qualitative interviews, survey data, and conceptual modeling to formulate practical and actionable outputs. These include (1) a composite readiness index to compare countries and stakeholder groups and (2) a blueprint that outlines concrete steps for digital twin implementation in healthcare settings.

Building on the insights from interviews, surveys, and country case studies, a context-sensitive implementation plan—or "blueprint"—is developed to guide the adoption of digital twins in healthcare. The blueprint aligns with principles of participatory design, incremental development, and regulatory alignment. It is constructed along three interlinked layers:

1. Strategic Layer: Identifies key actors (government, hospitals, tech developers), roles, and long-term system goals.
2. Tactical Layer: Proposes policy and organizational measures, including legal reform, data governance, stakeholder training, and incentive structures.

3. Operational Layer: Specifies pilot projects, technical standards, data integration workflows, and implementation milestones.

The blueprint is developed using design thinking principles [22], combining stakeholder empathy, system mapping, and iterative refinement based on feedback from practitioners and policy experts. It is tailored to the healthcare contexts of Sweden and the Netherlands, while highlighting generalizable lessons for broader European adoption.

This blueprint is presented as a 10-step roadmap, starting from foundational actions (e.g., establishing interoperable EHRs) and gradually advancing toward full-scale digital twin integration, with checkpoints for ethical evaluation, stakeholder consultation, and system testing.

4.5 Implementation plan

In the final phase of the study, findings are interpreted through an ethical and societal lens to assess the broader implications of digital twin technologies in healthcare. The goal is not only to evaluate technological feasibility but to critically reflect on normative considerations that arise when integrating AI-driven, data-intensive systems into public health services.

4.6 Discussion and Ethical Reflection

In the final phase of the study, findings are interpreted through an ethical and societal lens to assess the broader implications of digital twin technologies in healthcare. The goal is not only to evaluate technological feasibility but to critically reflect on normative considerations that arise when integrating AI-driven, data-intensive systems into public health services.

This reflection draws upon key principles from biomedical ethics—autonomy, beneficence, non-maleficence, and justice—as articulated by Beauchamp and Childress [23]. These principles are used to guide the assessment of emerging trade-offs in digital health, including:

- Privacy, trust, and algorithmic bias: Digital twins rely on continuous, multi-source data streams. This raises concerns about informed consent, data reuse, and the risk of amplifying bias in clinical decision-making.
- Responsibility and liability: As AI-driven decision support tools influence diagnosis or treatment planning, the legal attribution of responsibility among developers, clinicians, and institutions becomes increasingly complex.
- Quality of care: While digital twins may enhance diagnostic precision and care coordination, there is a risk of depersonalized care or over-reliance on automated systems.

- Public vs. private value: There is a tension between public health goals and commercial interests, especially when proprietary algorithms or data platforms are introduced into national health systems.
- Employment and professional identity: The increasing role of data and AI may shift the responsibilities and required skill sets of healthcare professionals, raising questions about the future of medical education and job design.

The Ethics Canvas methodology, developed by the University of Oxford, is used as a structured tool to identify, map, and address these ethical issues. The canvas supports stakeholder deliberation and helps formulate safeguards to ensure digital twin deployment aligns with societal values and public good.

4.7 Reflection on Limitations and Teamwork

This section describes the methodological approach used to critically reflect on potential limitations of the study design and the collaborative process underlying the research. The evaluation of limitations follows a structured process of identifying methodological constraints inherent in qualitative and quantitative methods, assessing risks to validity and reliability, and explicitly acknowledging potential sources of bias or sampling challenges. This reflection is guided by established principles of research quality, including credibility, transferability, dependability, and confirmability.

In addition, the teamwork process is evaluated as an integral component of research quality, recognizing the impact of interdisciplinary collaboration on study design, data interpretation, and project management. Reflection on teamwork dynamics is informed by peer debriefing, process documentation, and critical self-assessment of group coordination, task distribution, and integration of disciplinary perspectives. The methodological goal is to ensure transparency and reflexivity regarding both the procedural and collaborative aspects of the research.

5 THEORY, LECTURES IN MODULES

At the heart of our framework for deploying digital twins within European healthcare (especially in the Netherlands and Sweden) lies a multidisciplinary methodology that does not purely rely on technical considerations. To capture the full complexity of real-world healthcare systems, we have partnered with leading academic institutions to examine four critical dimensions.

The political landscape has been navigated in collaboration with Politecnico di Milano and TU Delft, whose policy analysts have helped us explore regulatory pathways and stakeholder engagement strategies. ETH Zurich has guided our socio-analytical investigations, drawing on sociologists and data scientists to unpack the societal implications of data collection for the scope of creating virtual replicas of care environments. RWTH Aachen's ethicists have steered an in-depth exploration of data privacy, consent models, and equity in access, ensuring our solutions respect fundamental patient rights. Finally, economists and systems modellers at Chalmers University of Technology have brought a design-thinking perspective, guiding us on how to design solutions that integrate into the already present system as smoothly as possible, while also maximizing the level of utility and innovation brought, pushing us to propose concrete solutions that could make a real impact on the Swedish healthcare system.

Together, these partnerships have enabled us to systematically define challenges, map diverse stakeholders, and make pivotal considerations ranging from policy harmonization and social acceptability to ethical safeguards and economic viability, ultimately shaping a digital-twin implementation framework that is not only technically sound but also socially responsible and politically feasible.

5.1 POLITICAL PERSPECTIVE

The first step to successfully develop a digital-twin implementation framework suitable for the Swedish and the Dutch healthcare systems is to define the *problem* in its full complexity, identifying its technical, social, ethical, political, and economic dimensions. At the heart of the problem definition lies a thorough *stakeholder analysis*, where *stakeholders* are broadly defined as those groups or individuals who can affect or are affected by the achievement of an objective [24]. The aim of the stakeholder analysis is threefold: to determine who the stakeholders are by identifying their roles within the healthcare ecosystem; to understand what they think and want, including their opinions, interests, and the negotiability of those interests; and to explore how to involve them through mechanisms that enable meaningful participation throughout the design and implementation process.

A fundamental element that emerges from the various aspects of the stakeholder analysis is the need for *effective communication*, intrinsically based on negotiation. In fact, by definition, each stakeholder wields distinct forms of power: *production power*, *blocking power*, *connection power*, *expert power*, and *reputational power*, which must be understood in the context of this specific framework and mapped to leverage their support for digital-twin adoption.

The key to coming up with an effective framework is, counterintuitively, to

broaden the agenda to surface all values and perspectives rather than narrowing the scope to simplify the problem, as a typical engineering research approach. The aim is not a single “best” solution, but rather, in political jargon, a true “win–win” outcome.

In our framework, the main stakeholders include:

- **The hospital,** specifically the Sahlgrenska University Hospital as an organization, as the primary implementer of digital-twin systems;
- **Home-care patients,** the most vulnerable both physically and in terms of data privacy;
- **Doctors,** who may benefit from enhanced decision support;
- **Nurses,** who stand to be empowered with new roles and responsibilities;
- **Insurance companies,** whose data access and potential for misuse must be carefully governed;
- **Data analysts and technology firms,** as emerging actors responsible for data collection, management and platform development.

Our proposed framework attempts to integrate all of this complexity to ensure that digital-twin solutions are robust, equitable and sustainable.

5.2 SOCIO-ANALYTICAL PERSPECTIVE

The political analysis presented above must be integrated with social tools, such as *surveys*, which can contribute to the robustness of the policy or, in the present case, the digital-twin implementation framework. *Public opinion surveys* are essential in policy research and applications because public sentiment significantly influences the feasibility, effectiveness, and success of any policy framework under consideration.

Conducting such surveys implies taking into account several critical points. First, ethical concerns must be carefully addressed: researchers should ensure that the survey has a clear purpose, protect participants from harm, obtain informed consent without deception, and uphold principles of transparency and objectivity. Second, a well-defined and specific research question is essential for ensuring the study’s reproducibility. At first glance, the requirement for a narrow research question might appear to contradict the political principle of increasing a problem’s complexity to reach a "win-win" solution, as discussed earlier. However, political studies benefit from multiple socio-analytical investigations, which capture diverse perspectives and ultimately enrich the overall framework. Third, sampling is a crucial methodological consideration. Surveys typically investigate a sample—a subset of the population to be analyzed. The sampling frame, or the set from which the sample is drawn, must accurately represent the broader population to avoid systematic bias. A mismatch in this frame can lead to systematic errors and distort the results. Finally, the measurement of attitudes is central to understanding public opinion and involves

three key components: Affect (emotional responses and conditioned associations), Cognition (knowledge, beliefs, and evaluations), and Behavior (actions taken in relation to the policy or issue). This so-called "ABC model" allows for a more nuanced understanding of how individuals perceive and respond to political or policy matters.

5.3 ETHICAL PERSPECTIVE

The two main aspects of the transition to digitalized healthcare through the implementation of digital twins are *enhanced collection of patient data* and the *move from hospital-centered care to home-centered care.* While these changes aim to improve treatment outcomes and patient autonomy, they also raise significant ethical challenges at a practical level. Among many: While advanced algorithmic tools, fed by large volumes of sensitive data, can predict which patients may benefit most from additional care, they may also inherit biases, leading to discriminatory outcomes; Mishandling or exposure of health data can harm patients' employment or insurance prospects, especially when patients may not fully understand or consent to the monitoring; Furthermore, although home-based care can improve well-being and privacy, the use of monitorable non-medical data, such as TV habits, ethnicity, or consumer behavior to predict healthcare costs introduces risks of unjustified profiling and discriminatory insurance practices, even as it offers potential for system improvement if biases are addressed transparently.

These practical challenges highlight ethical concerns regarding the usage of patients' data:

- *Potential for harm:* harming them in a variety of ways;
- *Autonomy violation:* manipulating their choices or act as an enabler for paternalism;
- *Justice violation:* serving as the basis for discriminatory treatment by medical personnel, employers, insurance companies, and other relevant stakeholders;
- *Breaches of privacy:* preserving privacy requires that access to data is strictly based on the patient's consent; however, as more data is collected and stored, the risk of security measures failing increases.
- *Loss of trust:* patients are less likely to trust a system where any of the above concerns are experienced, but also to further lose trust in the system as a whole, resulting in withdrawal from valuable services and assistance.

Overall, to ensure ethical and effective integration of data-driven technologies into healthcare, the proposed digital-twin implementation framework must be guided by clear, fundamental principles inspired by Beauchamp and Childress' *Principles of Biomedical Ethics* [23]. Data collection should be purpose-driven, i.e. only the data necessary for a given context should be gathered, avoiding unnecessary or excessive accumulation. Patients must be meaningfully informed about what data is being collected, why, and how it will be used, enabling them to give or withhold informed

consent. Robust policies should govern data storage, specifying what is stored, where, for how long, and whether it aligns with actual needs. Security measures must be regularly updated to protect sensitive information, especially in telemedicine settings. Additionally, ethical considerations should be integrated into experimental planning. As technological and societal changes evolve, there is a pressing need for continuous development of new policies and practices to safeguard patient privacy and uphold trust in digital healthcare systems.

5.4 Design Thinking perspective

Understanding how to drive meaningful change within healthcare requires a comprehensive knowledge and awareness of ***hospitals*** as core entities within the broader healthcare system. Hospitals, serving as primary hubs of care, are uniquely structured organizations that operate on *strong ethical foundations*, *dual hierarchies* — administrative and professional — and *specialized professional communities*. The professional hierarchy, centered around medical specialties, often defines individuals' primary loyalties, job satisfaction, and career advancement, while administrative performance evaluations coexist alongside professional metrics established by specialized licensure boards.

At a more general level, healthcare systems consistently face pressures to improve patient care efficiency, manage resource allocation effectively due to cost sensitivities, rapidly respond to emerging diseases and crises, and innovate care methodologies, all while maintaining accessibility and delivering compassionate human interaction. Moreover, contextual challenges, such as an aging population, antibiotic-resistant bacteria, hospital-acquired infections, and the rapid transmission of diseases, compound these systemic pressures. Consequently, preliminary phases of any transformational initiative, such as the adoption of a digital-twin implementation framework as a concrete step in the direction of *home care*, should employ an **Activity System** approach to thoroughly overview and analyze system processes, organizational structures, resources, competencies, and capabilities. This approach ensures clarity in value propositions, thereby facilitating smooth integration and acceptance within the complex operational environment of hospitals.

6 OUTCOMES RESEARCH

6.1 CASE STUDY ANALYSIS

This study employs a comparative case analysis of Sweden and the Netherlands to contextualize and interpret stakeholder readiness levels for digital twin implementation. Both countries were selected for their advanced positions in digital health, but their contrasting institutional arrangements and governance traditions allow for a meaningful exploration of system-level enablers and barriers.

The analysis focuses on three readiness dimensions derived from the conceptual model and supported by academic literature:

- **Data infrastructure and access:** Technical capacity to capture, exchange, and integrate health data across regions and institutions.
- **Social acceptance and trust:** Public confidence in data governance and support for data-driven health innovation.
- **Legal and regulatory preparedness:** Institutional clarity regarding data usage rights, ethical review processes, and cross-border interoperability.

Document analysis, stakeholder interviews, and expert inputs were synthesized to assess each country's strengths and gaps along these dimensions. Key findings are presented in Table 2.

Table 2: Comparative Case Summary: Sweden vs. the Netherlands

Dimension	**Sweden**	**Netherlands**
Data Infrastructure and Access	Decentralized EHR landscape; limited standardization across regions; good longitudinal data quality.	Technologically advanced EHR systems with strong semantic interoperability; centralized standards via Nictiz.
Social Acceptance and Trust	High trust in government-led digital initiatives; openness to secondary data use for research.	Greater public skepticism toward central data governance; data sharing more contested.
Legal and Regulatory Preparedness	Clear ethics board procedures for secondary data use; fragmented implementation at regional level.	Well-developed legal frameworks; barriers around data ownership, consent models, and regulatory alignment persist.

This comparative assessment reveals that Sweden offers strengths in trust-based governance and ethical legitimacy, whereas the Netherlands demonstrates advanced technical readiness through standardized infrastructure. Neither country, however, is fully equipped to support digital twins at scale across all dimensions.

The hybrid potential of combining Sweden's governance model with Dutch infrastructural capabilities forms a key input for the development of a context-sensitive implementation plan (Section 7).

6.2 Qualitative Analysis

Qualitative data from interviews and policy documents were analyzed using two core techniques:

The first consists of thematic coding of interview transcripts. A grounded theory approach was used to identify recurring themes, categories, and patterns in stakeholder interviews. Coding was performed inductively, with categories emerging from the data rather than being imposed beforehand. NVivo or similar qualitative analysis software was employed to support consistent and replicable coding. Particular attention was paid to dimensions of legal uncertainty, trust in data-sharing, and institutional barriers to digital twin implementation.

The second technique is content analysis of policy documents and expert lectures. Key regulatory documents and academic lectures were analyzed using directed content analysis, where codes were derived from the study's conceptual model. The goal was to examine how national policies in Sweden and the Netherlands align with the identified preconditions for digital twin readiness, such as data interoperability, ethical governance, and stakeholder roles.

Each transcript and document was reviewed independently by multiple researchers to reduce interpretive bias and enhance inter-coder reliability. Themes from qualitative analysis were cross-referenced with survey data to validate emergent hypotheses or contradictions.

To complement the quantitative survey data, a qualitative analysis was conducted across four semi-structured interviews, covering perspectives from medical professionals, hospital administrators, and patients in Sweden. The interviews were thematically coded, following a deductive-inductive approach, to identify key patterns relevant to digital twin implementation in healthcare. Three core themes emerged: (1) trust and governance, (2) technological infrastructure and readiness, and (3) evolving roles and educational needs.

1. Trust and Governance. Across interviews, a high baseline trust in healthcare institutions was evident, particularly in Sweden, where respondents described general public openness to data sharing for both clinical care and research purposes (Interview Diabetes Patient; Interview Cecilia & Magnus). However, ethical concerns were raised regarding data misuse and unclear consent processes, especially in secondary data use. Hospital administrators highlighted the tension between respecting patient autonomy and maximizing data utility: "*There's a grey zone between primary and secondary data use—sometimes it's unclear where the line should be drawn.*" (Interview Cecilia & Magnus)

   Patients expressed trust as conditional on robust data governance and transparency, emphasizing the need to prevent data breaches to maintain societal confidence (Interview Diabetes Patient).

2. Technological Infrastructure and Readiness. Respondents noted significant variation in the digital maturity of healthcare IT systems. Clinicians pointed to

outdated, fragmented record systems that hinder interoperability and workflow efficiency (Interview Responses IDEA League Module 3): *"The systems are far too old and don't utilize today's technology, leading to unnecessary admin that takes time away from patients."* Several respondents stressed the potential of AI and automation to reduce administrative burdens and enhance clinical decision-making, but warned that technical implementation must avoid creating additional complexity for end users.

From an organizational perspective, procurement and regional autonomy over EHR systems in Sweden were seen as barriers to standardized, scalable solutions (G1 Interview Data). The lack of unified systems across regions complicated data-sharing and interoperability.

3. Evolving Roles and Educational Needs. A recurrent theme was the transformation of the physician's role in a data-rich healthcare environment. Both educators and practitioners acknowledged that younger doctors are expected to handle more digital tools, yet medical education has not kept pace with technological developments (Interview Cecilia & Magnus): *"I would like to say medical education is completely different from 20 years ago, but I'm not sure that's true."* There was optimism about the emergence of hybrid professional roles—such as medical engineers or doctor-technologists—that could bridge the gap between clinical practice and data science. However, respondents warned that ethical training and regulatory clarity must accompany technical upskilling.

Across stakeholder types, respondents valued technology as a tool to support—not replace—human clinical judgment. Trust in digital innovation was conditional upon transparent governance, interoperability, and meaningful integration into care workflows. The distinction between primary (clinical) and secondary (research) data use remained a recurrent ethical and operational challenge.

Overall, the qualitative interviews highlight readiness strengths in societal trust and openness to innovation, alongside critical gaps in infrastructure standardization, legal clarity, and professional education. These insights provide contextual depth to the survey-based Readiness Index and inform the subsequent blueprint design by identifying priority focus areas and stakeholder-specific needs.

Each transcript and document is reviewed independently by multiple researchers to reduce interpretive bias and enhance inter-coder reliability. Themes from qualitative analysis are cross-referenced with survey data to validate emergent hypotheses or contradictions.

Theme	Stakeholder Group	Representative Quote
Trust and Governance	Hospital Administrator	“There’s a grey zone between primary and secondary data use—sometimes it’s unclear where the line should be drawn.”
	Patient	“I trust the healthcare system, but only if they’re clear about how they use my data.”
Technological Infrastructure and Readiness	Medical Professional	“The systems are far too old and don’t utilize today’s technology, leading to unnecessary admin that takes time away from patients.”
	IT Specialist	“Procurement rules make it difficult to create national interoperability—we have regional silos.”
	Hospital Administrator	“Even within the same hospital, systems don’t always talk to each other.”
Evolving Roles and Educational Needs	Medical Educator	“I would like to say medical education is completely different from 20 years ago, but I’m not sure that’s true.”
	Clinician	“Future doctors will need to understand data science basics to work effectively with AI tools.”

Table 3: Representative Quotes by Theme and Stakeholder Group

6.3 Quantitative Analysis

This section reports the quantitative findings from the structured survey, organized by stakeholder group. The results provide descriptive and comparative insights into stakeholder attitudes toward digital health, data-sharing, and digital twin adoption, consistent with the survey design and index construction outlined in Section 2.3.

6.4 Healthcare Professionals

A total of 11 healthcare professionals (6 physicians, 3 nurses, 2 administrators) completed the survey. The group included 6 women and 5 men, and consisted of 7 respondents working in hospital settings and 4 in primary care.

Perceived Usefulness and Trust On a 5-point Likert scale, the mean perceived usefulness of digital twins was 4.1 (SD = 0.7), with 8 respondents rating it "quite useful" or "extremely useful." Comfort with interpreting digital twin outputs was lower (M = 2.8, SD = 1.1), with 6 reporting "slightly uncomfortable" or "quite uncomfortable."

Ethical Concerns and Barriers Data privacy was the most cited ethical concern (7/11), followed by transparency (4/11). Key barriers identified were patient accep-

tance (5/11) and resource constraints (4/11). One respondent highlighted liability in AI-supported clinical decisions as a critical barrier.

READINESS AND WILLINGNESS INDEX Healthcare professionals achieved an average Readiness and Willingness Index score of 0.62 (SD = 0.10), with sub-index means of Data Infrastructure Readiness (0.75), Governance and Trust (0.58), and Stakeholder Willingness (0.55). Sensitivity analysis showed minor variation across weighting schemes.

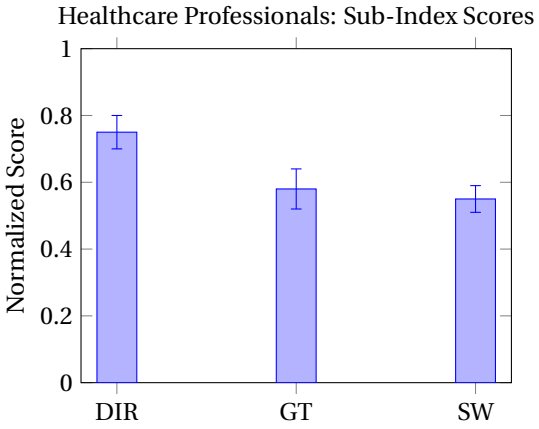

Figure 1: Readiness and Willingness sub-index scores for healthcare professionals.

OUTLOOK Five respondents predicted "widespread adoption across systems" within a decade; four expected "limited adoption in niche areas"; two expressed uncertainty due to technical and ethical uncertainties.

6.5 PATIENTS

Eleven patients, of which 6 female (mean age = 57), participated, all with chronic conditions or frequent healthcare usage.

FAMILIARITY AND WILLINGNESS Familiarity with digital twins was low: 2 reported some familiarity, 9 indicated none. Mean perceived usefulness was 3.7 (SD = 0.9). Willingness to consent to data sharing increased under dynamic consent models: 8/11 indicated they would be more willing if they could restrict data access over time. Trust in data handlers was highest for hospitals (6/11), followed by university researchers (4/11).

ETHICAL CONCERNS Privacy was the dominant concern (9/11), followed by profiling (3/11) and reduced human oversight (2/11).

READINESS AND WILLINGNESS INDEX Patients scored an average index of 0.53 (SD = 0.12), lower than professionals ($t(20)=2.45$, $p<0.05$). Sub-indices: DIR (0.46), GT (0.60), SW (0.52).

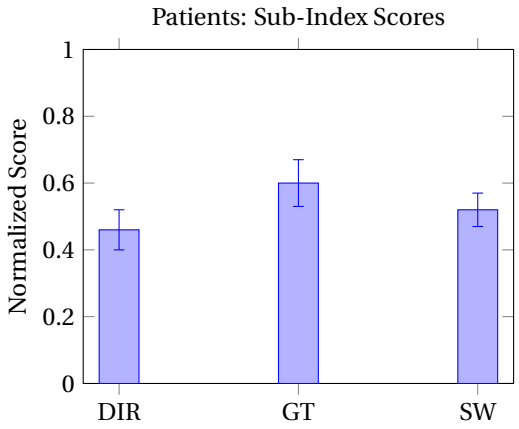

Figure 2: Readiness and Willingness sub-index scores for patients.

ADOPTION OUTLOOK Seven predicted "limited adoption in niche areas," three foresaw "moderate adoption," and one expected "no significant adoption," citing skepticism toward algorithmic care models.

6.6 PUBLIC SECTOR REPRESENTATIVES

Seven public sector respondents (health department, regulatory agencies) completed the survey.

PERCEIVED IMPORTANCE AND FAMILIARITY Five rated digital twins as "very important" for future healthcare, despite variable familiarity (M=2.9, SD=1.0). Familiarity with regulatory implications averaged 3.1 (SD=1.0).

ETHICAL AND POLICY CONCERNS Data governance and accountability were primary concerns (7/7). Four cited gaps in cross-border data sharing regulation; three emphasized the need for algorithmic explainability.

READINESS AND WILLINGNESS INDEX Public sector scored highest (M=0.68, SD=0.09), driven by Governance and Trust (0.78); DIR = 0.62; SW = 0.59.

POLICY OUTLOOK Four anticipated "moderate adoption across multiple hospitals"; two predicted "limited adoption"; one remained uncertain.

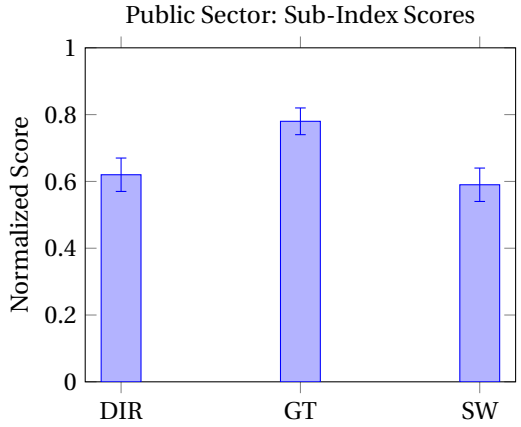

Figure 3: Readiness and Willingness sub-index scores for public sector representatives.

6.7 Comparative Analysis

ANOVA indicated significant differences between groups ($F(2,26)=4.32$, $p=0.023$). Post-hoc tests showed public sector scored significantly higher than patients ($p=0.019$); professional vs. patient difference was marginal ($p=0.07$).

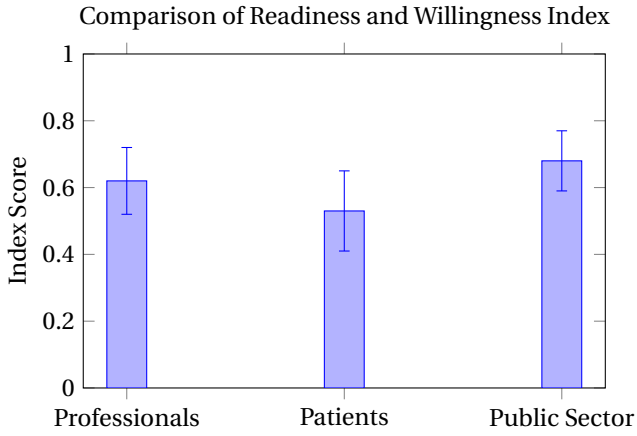

Figure 4: Comparison of overall Readiness and Willingness Index scores across stakeholder groups. Values reflect the average of the three sub-indices (DIR, GT, SW) per group.

These results demonstrate divergence in readiness profiles, perceptions of benefit and risk, and trust dynamics across stakeholder groups. The findings provide an empirical foundation for the ethical reflection and policy recommendations discussed in Section 4.

7 Blueprint Dashboard Design

The outcomes of the comparative analysis between Sweden and the Netherlands, derived from stakeholder interviews, surveys, and literature review, form the basis for the design requirements in this project. These results are translated into specifications to ensure that the proposed platform and roadmap align with existing technical capacities, legal frameworks and societal expectations.

7.1 Requirements dashboard design

To ensure the dashboard effectively supports both policymakers and healthcare providers from both the Netherlands and Sweden, a structured list of requirements was created as the foundation for its design.

The requirements for the dashboard are divided into three categories to ensure a structured and comprehensive design approach. These include the functional requirements, the non-functional requirements and the wishes.

7.1.1 Functional Requirements (R)

The functional requirements define the essential capabilities of the platform, such as the ability to visualize readiness and willingness scores, compare countries, filter by stakeholder group, and present qualitative insights.

Nr.	Description	Explanation
R1	Netherlands and Sweden comparative view	The dashboard must display data for both Sweden and the Netherlands side-by-side using visualizations (e.g., radar chart).
R2	Readiness and willingness index visualization	The dashboard must visualize the index across dimensions such as data infrastructure, EHR interoperability, legal/regulatory preparedness, public trust, and willingness to share data.
R3	Stakeholder filter	Users must be able to filter data by stakeholder group (e.g., patients, healthcare professionals, policymakers, hospital administrators, tech developers).
R4	Access to qualitative insights	The dashboard must display stakeholder quotes and thematic insights derived from interviews and policy analysis for each dimension.
R5	Timeline policy developments	A timeline feature should present key policy and technology milestones (e.g., EHR adoption, AI regulations, pilot projects).
R6	Timeline public trust development	Timeline to include major public events, scandals, or campaigns that influenced stakeholder trust in data systems.
R7	Best practices	Section that showcases real-world best practices, pilots, or policies in the Netherlands and Sweden.

Table 4: Dashboard Requirements (R)

7.1.2 NON-FUNCTIONAL REQUIREMENTS (NFR)

Non-functional requirements specify performance and quality criteria, including language availability, data privacy and accessibility standards.

Nr.	Description	Explanation
NFR1	Language	The interface should be available in English, with optional support for Dutch and Swedish.
NFR2	Data privacy	All displayed data must be anonymized and based on publicly available or authorized sources. Compliance with the EU GDPR framework is required.

Table 5: Non-Functional Requirements (NFR)

7.1.3 WISHES (W)

Wishes represent additional features that improve stakeholder experience and insight generation, but are not critical to the core operation of the dashboard.

Nr.	Description	Explanation
W1	Interactive heatmap by stakeholder group	A heatmap that highlights variation in readiness/willingness scores between stakeholder types.
W2	Element explanations	Hovering over elements (e.g., axes or indicators) reveals short explanations of dimensions and data sources.
W3	Report integration	Key visuals can be automatically inserted into printable or shareable policy documents (e.g., PDF inserts).
W4	Index weight adjustment	Users can change the weights of sub-indexes (e.g., more emphasis on legal vs. social readiness) and view how scores shift.

Table 6: Dashboard Widget Features

7.2 DESIGN PLATFORM AND KEY COMPONENTS

The Digital Twin Readiness Dashboard offers a structured, data-driven foundation to understand how healthcare systems in Sweden and the Netherlands are positioned to adopt digital twin technologies. As Sweden and the Netherlands not yet have a combined health platform, it will be new.

By combining quantitative readiness and willingness indicators with qualitative stakeholder-specific insights and real-world policy examples, the dashboard bridges the gap between the two countries. Its comparative and visual format supports decision making by highlighting strengths, gaps across stakeholders and country in order to enable targeted interventions. This makes it a valuable tool for policymakers and healthcare providers in the Netherlands and Sweden.

The full dashboard can be viewed via this link: https://digitaltwindashboard.lovable.app The separate elements will be elaborated in the following chapter.

7.2.1 READINESS & WILLINGNESS INDEX

This component visualizes how Sweden and the Netherlands perform across five key dimensions essential for digital twin implementation: data infrastructure, governance, trust, technical readiness, and stakeholder willingness. By offering a side-by-side radar chart comparison and allowing filtering by stakeholder group, it helps identify national strengths and gaps in a clear format.

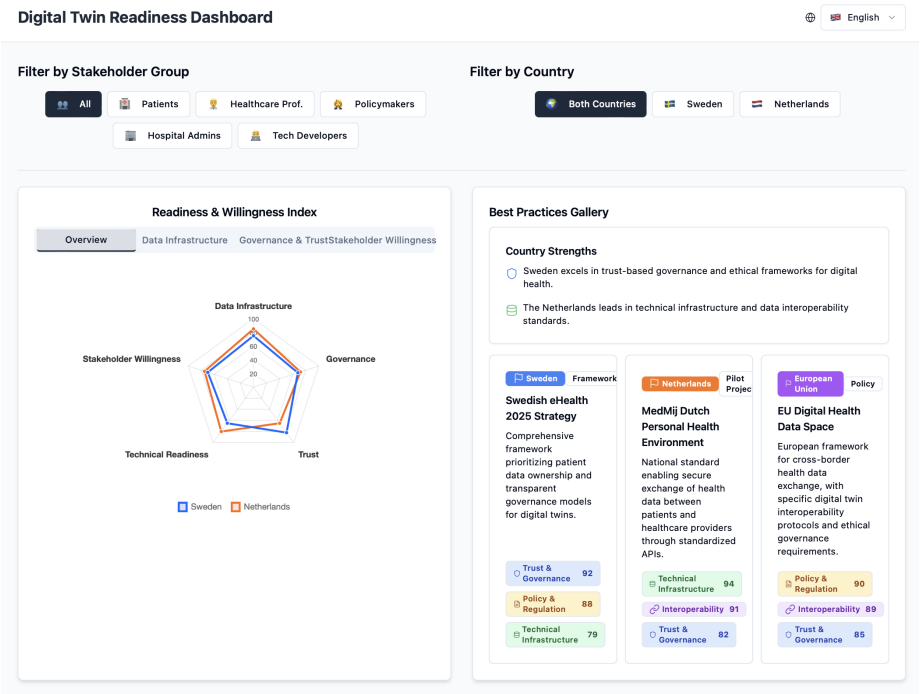

Figure 5: Dashboard part 1

7.2.2 Best practices

The gallery highlights successful frameworks, pilots, and policies that illustrate how different governance or technological approaches can be implemented in practice. Each card includes country-specific strengths and tags related to the most impacted readiness dimensions, making this section a curated resource for policy benchmarking and inspiration.

7.2.3 Timelines

Two timelines illustrate how key policy and technological developments, as well as public trust have evolved over time. These help contextualize readiness scores by connecting them to systemic trends, political decisions, or societal reactions to for example scandals, campaigns or other events.

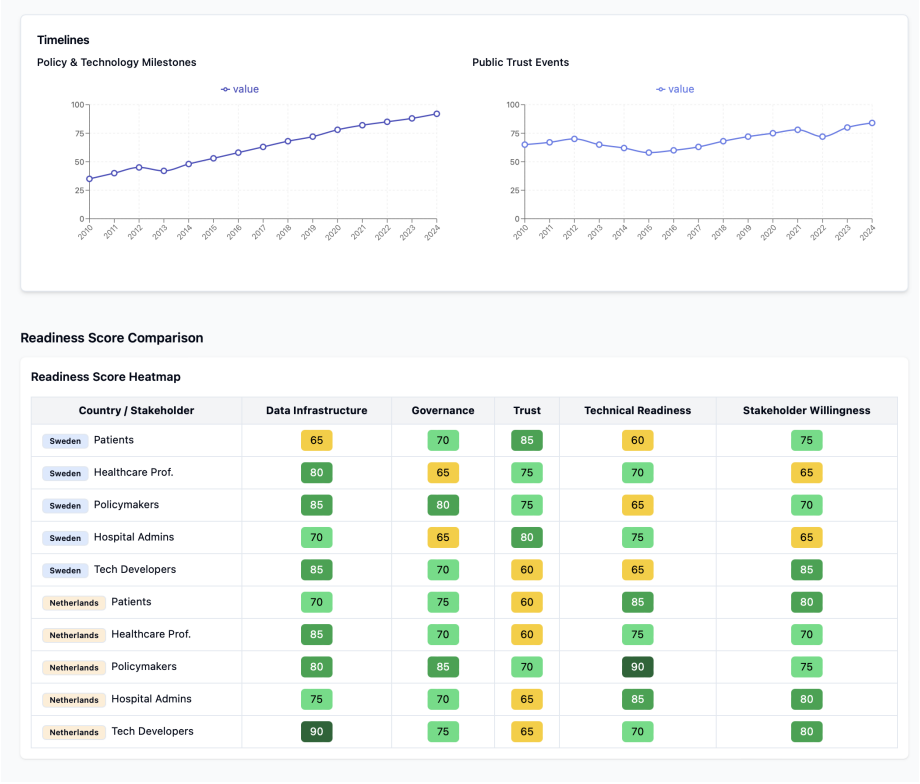

Figure 6: Dashboard part 2

7.2.4 Readiness score comparison

The heatmap breaks down readiness scores per stakeholder group from both the Netherlands and Sweden and dimension, revealing variation between countries and stakeholders. It allows users to pinpoint which groups are most or least prepared, guiding more targeted strategies for adoption, investment, or support.

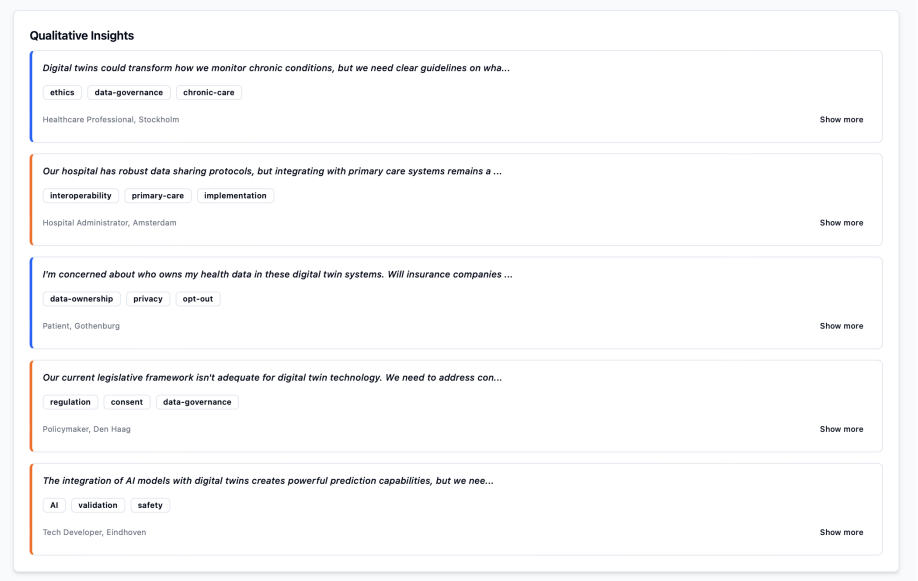

Figure 7: Dashboard part 3

7.2.5 Qualitative insights

This section brings in stakeholder opinions from qualitative interviews or surveys, categorized by themes such as data governance, ethics, and interoperability. By showcasing real concerns and expectations from patients, professionals and policy makers, it provides the human context behind the data and highlights nuanced barriers to adoption.

7.2.6 Additional elements

In the dashboard, some additional elements have been added. The dashboard includes a language toggle feature that allows users to seamlessly switch between English, Dutch, and Swedish. This ensures accessibility for a broad range of stakeholders and supports inclusive decision-making across both national contexts.

Most data points include contextual information; for example, the spike in 2018 marks the implementation of the GDPR, highlighting its impact on data governance. This feature helps users connect regulatory developments to overall readiness trends.

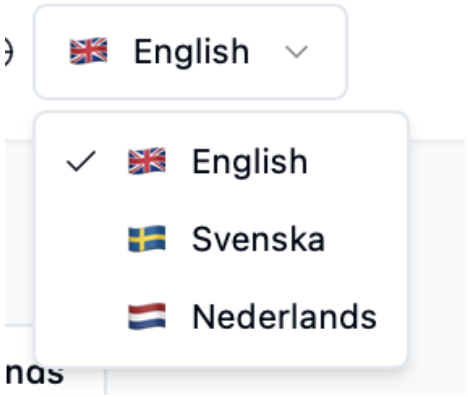

Figure 8: Language options

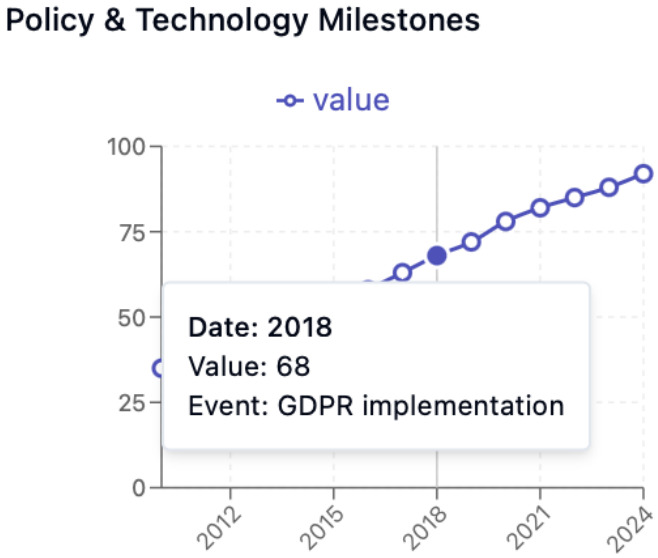

Figure 9: Toggle explanation

8 Implementation Plan

This implementation plan presents a phased roadmap for the deployment of digital twins in healthcare across Sweden and the Netherlands. It is designed to align technological readiness, stakeholder engagement, and legal-ethical frameworks, while accounting for national variations in trust, governance, and infrastructure maturity. The roadmap adopts a staged approach to leverage high-readiness actors, address infrastructure and governance gaps, and facilitate cross-country learning.

8.1 Roadmap for Digital Twin Implementation (2025–2030)

8.1.1 Phase 1: Activate High-Readiness stakeholders and mitigate Distrust (2025–2026)

The initial phase prioritizes actors with high technical readiness, including hospital IT teams and technology developers, to establish foundational interoperable data infrastructures. Currently, targeted outreach is directed to lower readiness groups, such as patients in the Netherlands and nurses in Sweden, to foster trust and participation. This dual-track strategy ensures early momentum without excluding critical end-users.

Action	**Stakeholder Focus**	**Country**
Launch pilot digital twin projects in university hospitals with high technical and governance readiness	Hospital IT teams, policymakers	Both
Engage technology developers in co-developing interoperable APIs and EHR integration layers	Tech developers (Tech ≥ 85, Infra ≥ 85)	NL
Design consent tools to enhance public trust in data-sharing	Patients (Trust = 70 NL, 85 SE)	Both
Provide targeted training to healthcare professionals with low digital willingness	Clinicians, nurses (65 SE)	SE

Table 7: Phase 1 Implementation Actions

8.1.2 Phase 2: Strengthen Legal Frameworks and Build Societal Trust (2026–2027)

In this phase, efforts shift to harmonizing legal and ethical governance structures. The Netherlands focuses on resolving fragmented consent models, while Sweden centralizes ethics review processes without undermining regional governance. Participatory governance pilots are launched to formalize ethical guidelines for secondary data use.

Action	Stakeholder Focus	Country
Reform consent and secondary data use protocols with clear opt-in/opt-out options	Legal experts, patients	Both
Expand hospital ethics committees to include AI and data literacy expertise	Policymakers, ethics committees	Both
Pilot participatory governance initiatives with patient panels and clinicians	Patients, clinicians	SE (lead)
Launch legal harmonization programs aligned with GDPR and cross-border data use	Data governance bodies	NL (lead)

Table 8: Phase 2 Implementation Actions

8.1.3 PHASE 3: UPSKILL MEDICAL PROFESSIONALS (2027–2028)

This phase targets mid-readiness stakeholders, notably clinicians and nurses with technical competence but limited digital confidence. Upskilling initiatives combine interdisciplinary education with co-design methodologies, integrating ethical literacy and explainability to prepare healthcare professionals for hybrid clinical-data roles.

Action	Stakeholder Focus	Country
Implement ethical AI training programs for hospital IT and clinical leadership	Hospital administrators, clinicians	Both
Conduct public campaigns to improve understanding of explainability and trust in digital twins	Patients	NL
Engage nurses in co-designing digital workflows and predictive analytics systems	Nurses (Willingness 65 SE, 75 NL)	Both

Table 9: Phase 3 Implementation Actions

8.1.4 PHASE 4: DEPLOY PILOTS (2028–2029)

Real-world pilots are deployed in high-readiness regions to evaluate system integration, user interaction, and predictive analytics. These pilots serve as experiments before scaling, overseen by hospital administrators and ethics boards to ensure compliance and risk mitigation.

8.1.5 PHASE 5: INSTITUTIONALIZE AND SCALE (2029–2030)

The final phase transitions from experimentation to institutionalization. Pilot outcomes are embedded into national strategies, while certification schemes and ethical standards are codified to ensure sustainable implementation.

Action	Stakeholder Focus	Country
Deploy pilots in regions where policymakers, IT, and clinicians meet readiness thresholds (≥75)	Full cluster of high-readiness actors	Both
Implement patient-controlled data interfaces with live feedback dashboards	Patients	Both
Monitor ethical impacts and revise implementation based on feedback loops	Multi-stakeholder panels	Both

Table 10: Phase 4 Implementation Actions

Action	Stakeholder Focus	Country
Institutionalize stakeholder learning cycles	Ministries of health, universities	Both
Establish certification standards for digital twin safety, fairness, and clinical efficacy	Regulators, ethics boards	NL (lead)
Expand implementation beyond initial pilot regions	Full cluster of mid/high-readiness actors	Both

Table 11: Phase 5 Implementation Actions

8.2 Summary of stakeholder readiness across phases

This roadmap staggers stakeholder engagement across phases, aligning implementation efforts with variable levels of digital readiness and trust. Phased activation mitigates risks of exclusion or resistance and ensures stakeholders are mobilized at optimal readiness stages.

Phase	**High Readiness Stakeholders**	**Low Readiness Stakeholders**	**Key Strategy**
Phase 1	Tech developers, hospital IT teams	Patients (NL), nurses (SE)	Activate leaders; mitigate mistrust
Phase 2	Legal experts, policymakers	Patients, ethics boards	Harmonize legal frameworks
Phase 3	Universities, medical professionals	Nurses, clinicians (SE)	Upskill professionals
Phase 4	Full cluster (IT, administration, policy)	Varying regional readiness	Pilot in high-readiness regions
Phase 5	Ministries of health	–	Institutionalize

Table 12: Stakeholder Readiness and Strategic Focus per Phase

9 Reflection

9.1 Limitations and Validity

Several limitations emerged during the research process. First, the most significant limitation relates to the quantitative survey data. The number of survey respondents (n = 11) fell well below the calculated minimum sample size of 171 participants required for reliable statistical inference. This substantial gap undermines the statistical power of our quantitative findings and limits their generalizability. It raises the possibility that the results are influenced by sampling error or unrepresentative responses. While the index offers exploratory insights, it cannot support definitive conclusions. This reinforces the importance of treating our Readiness and Willingness Index as indicative rather than conclusive. Although triangulation with qualitative interviews and document analysis offers contextual depth, future research should prioritize achieving statistically valid sample sizes to strengthen the empirical foundation for such indices.

Second, the qualitative interviews were disproportionately weighted toward the Swedish context due to logistical challenges and limited access in the Netherlands. This geographic imbalance constrains the depth of cross-country comparisons and requires caution when extrapolating findings across both settings.

Third, the readiness and willingness index is subject to methodological assumptions regarding indicator weighting and normalization. Although sensitivity analyses were conducted to evaluate alternative weighting schemes, the index's aggregated outcomes remain contingent on these design choices. These assumptions—such as the choice of equal weighting across sub-indices and the linear aggregation method—can significantly affect the resulting scores. For example, if stakeholder trust were weighted more heavily than infrastructure readiness, the national rankings or stakeholder group comparisons might shift. This raises important questions about how such indices should be interpreted and used: Are they reflective of true readiness, or do they embed certain normative priorities? Future work could explore participatory approaches to index design or apply alternative aggregation techniques (e.g., geometric means or machine learning-based clustering) to triangulate findings and reduce methodological bias.

Fourth, the study represents a cross-sectional assessment at a specific point in time (early 2025), acknowledging that digital health governance evolves rapidly. Consequently, findings must be interpreted in light of ongoing policy, technological, and regulatory developments that may alter the implementation landscape post-study.

Fifth, the integration of multidisciplinary perspectives introduced epistemological challenges in reconciling legal, technical, ethical, and policy frameworks within a unified analytical structure. Addressing these differences required iterative negotiation and synthesis to maintain conceptual coherence.

These limitations underscore the importance of transparency in methodological

assumptions and cautious interpretation when generalizing findings beyond the studied contexts. Despite these constraints, the study offers a multi-dimensional analysis of digital twin readiness that contributes empirical and conceptual insights for future research and policy initiatives.

9.2 Group Work and Multidisciplinarity

The project was shaped by a multidisciplinary research team comprising students from engineering, law, and policy disciplines. Responsibilities were allocated based on disciplinary expertise, allowing each member to lead distinct components while contributing to integrated deliverables.

Multidisciplinarity was further enhanced through participation in international academic modules, which facilitated engagement with peers from other European universities. These interactions broadened the analytical perspective by exposing the team to comparative insights on health systems, regulatory regimes, and ethical considerations relevant to digital twin adoption.

Balancing disciplinary contributions required deliberate coordination, iterative peer review, and openness to divergent analytical approaches. The diversity of expertise enriched the comprehensiveness of the study but also introduced challenges in aligning terminology, analytical depth, and evidentiary standards across disciplines. Integration sessions and structured feedback mechanisms were critical in synthesizing disciplinary inputs into a cohesive analytical framework.

This collaborative process illustrates both the opportunities and complexities inherent in multidisciplinary research. It highlights the need for intentional integration strategies to bridge disciplinary boundaries and facilitate shared understanding in addressing complex socio-technical challenges.

10 Discussion and Ethical Reflection

10.1 Conclusion

This study investigated the readiness of Sweden and the Netherlands to implement digital twin technologies in healthcare, guided by three research questions. The findings integrate quantitative and qualitative data to provide a multi-dimensional assessment.

First, regarding the question *"To what extent are Sweden and the Netherlands ready to implement digital twins in healthcare?"*, the results indicate moderate overall readiness in both countries, with Sweden exhibiting slightly higher Governance and Trust sub-index scores (0.78) compared to the Netherlands (0.70), while the Netherlands showed stronger Data Infrastructure Readiness (0.75 vs. 0.62). The average Readiness and Willingness Index across stakeholder groups was 0.68 for Sweden and 0.62 for the Netherlands, reflecting structural and governance differences but similar levels of stakeholder willingness. The findings suggest that both countries possess foundational capacities but lack full alignment across technical, legal, and societal domains necessary for large-scale implementation.

Second, addressing the question *"What are the main legal, technological, and societal challenges?"*, the study identified data governance, algorithmic transparency, and public trust as primary barriers. Stakeholders across all groups consistently cited data privacy as a dominant concern (patients: 9/11; professionals: 7/11; policymakers: 7/7). Concerns about explainability and liability in AI-supported decisions emerged among healthcare professionals and policymakers, while patients expressed skepticism regarding automated decision-making and potential depersonalization of care. Qualitative insights underscored the need for regulatory harmonization, particularly concerning cross-border data sharing and AI liability frameworks.

Third, in response to *"Which stakeholders are responsible to take the next step?"*, the analysis highlights shared but differentiated responsibilities. Policymakers are positioned to address regulatory gaps and establish ethical governance structures; healthcare professionals play a critical role in ensuring human oversight and clinical integration; technology developers must prioritize algorithmic transparency and bias mitigation; and patient groups should be engaged in co-design processes to align innovations with user values. While responsibility spans multiple actors, coordinated governance mechanisms are essential to ensure accountability and alignment.

Based on these findings, the key recommendation to the responsible stakeholders—especially policymakers and healthcare leaders—is to urgently invest in secure and interoperable health data infrastructures, co-develop transparent consent models with patients, and embed ethical AI oversight into national health strategies. Without such targeted action, digital twin adoption will remain limited to fragmented pilots rather than delivering systemic value. This requires not only technical upgrades but also trust-building and long-term institutional commitment across sectors.

Overall, this study demonstrates that while Sweden and the Netherlands are relatively well-positioned to adopt digital twin technologies, targeted efforts are needed to strengthen governance, address ethical concerns, and build cross-sector

collaboration to enable responsible and effective implementation.

10.2 Ethical Assessment

The ethical assessment of digital twin technology in healthcare reveals a nuanced and multi-dimensional landscape, intersecting with questions of data governance, social justice, clinical responsibility, and institutional accountability. As outlined in previous sections, particularly the analysis of stakeholder engagement and technical infrastructure, the integration of large-scale health data into AI-enabled systems has triggered persistent concerns regarding privacy and trust. Stakeholders repeatedly questioned whether patients can retain meaningful control over their longitudinal health records once these are incorporated into dynamic, continuously learning models. Informed consent becomes especially difficult to safeguard when data are repurposed across time, institutions, and use cases.

Concerns related to algorithmic bias also emerged as a recurrent theme across interviews and policy documents. When digital twin systems are trained on datasets that lack sufficient demographic or contextual diversity, there is a tangible risk of reinforcing or even exacerbating existing disparities in care delivery. Participants stressed the importance of ensuring fairness through transparent development processes, routine bias audits, and external oversight.

The issue of responsibility and liability adds further complexity. As clinical decision-making becomes increasingly guided by automated recommendations, the attribution of accountability becomes blurred. Several respondents noted that legal frameworks have not yet adapted to clarify liability in cases where digital twin systems contribute to adverse outcomes, leaving clinicians and institutions exposed to uncertainty and risk.

A further point of tension concerns the quality of care. Although digital twins offer the potential for enhanced diagnostic precision and care coordination, some clinicians expressed concern about an over-reliance on automation. They feared this could diminish the relational and interpretive dimensions of medical care, with implications for patient engagement and trust.

Ethical challenges also arise from the growing presence of proprietary algorithms within public healthcare systems. The integration of commercially developed technologies into public infrastructure raises questions about data ownership, long-term sustainability, and the alignment of private incentives with public health goals. As discussed in the governance analysis, mechanisms for transparency, accountability, and public oversight are critical to addressing these tensions.

Finally, the deployment of digital twins has implications for professional identity and labour dynamics. Stakeholders pointed to an emerging need for data literacy and interdisciplinary competencies among healthcare professionals. These shifts may redefine roles, alter the boundaries of clinical practice, and raise concerns about job displacement, particularly in settings with lower digital maturity.

Collectively, these findings underscore the importance of embedding ethical inquiry into every phase of digital twin development—from conceptual design to real-

world implementation. Addressing these challenges proactively, through inclusive governance and continuous ethical reflection, will be essential to ensuring that digital twins are not only technologically viable and societally accepted, but also morally robust.

10.3 Implementation Considerations

Alongside the ethical dimensions, stakeholders identified a series of technical, legal, and sociocultural barriers to implementation. Cross-border regulatory discrepancies between Sweden and the Netherlands—particularly in relation to data protection, consent frameworks, and interoperability standards—present significant hurdles for the development of harmonized digital twin infrastructure. Moreover, the analysis revealed notable differences in institutional trust: Swedish respondents demonstrated relatively high confidence in national data governance, while Dutch stakeholders expressed more pronounced skepticism, particularly regarding the commercialization of health data.

To navigate these barriers, a phased implementation strategy was proposed. This approach emphasizes the need for small-scale pilot studies, iterative evaluation cycles, and the active involvement of diverse stakeholder groups. Such a strategy allows for the early identification of ethical and operational risks, and enables adaptive governance in response to emerging challenges.

10.4 Ethics Canvas Synthesis

The ethical evaluation was further structured through a stepwise ethics canvas analysis. This structured approach guided the identification of stakeholder concerns and the development of mitigation strategies:

Stakeholder Identification. Core stakeholder groups included patients, clinicians, hospital administrators, policymakers, insurers, and technology vendors.

Key Ethical Concerns. Participants highlighted issues such as privacy and data security, algorithmic bias, informed consent, transparency and accountability, responsibility and liability, public-private alignment, quality of care, and employment impacts.

Risk Mapping. Short-term risks include data breaches, algorithmic misclassification, and misdiagnoses. Long-term concerns encompass systemic bias, proprietary data lock-in, and diminishing clinical autonomy.

Societal and Cultural Implications. Notable themes included regional differences in trust toward digital health systems, evolving clinician-patient dynamics, inequities in access to data-driven services, and cultural variation in the acceptance of AI in healthcare.

LEGAL AND REGULATORY CHALLENGES. Key challenges include GDPR compliance, divergent national regulations, and unresolved liability frameworks in the context of AI-supported clinical decision-making.

ETHICAL GUIDELINES. Ethical system design should prioritize fairness, accountability, and transparency. Explainability of AI outputs and the integration of ethical principles into institutional practices are critical.

MITIGATION STRATEGIES. Proposed actions include encryption and patient-controlled access to health data, the use of representative training datasets, and the retention of human oversight in clinical workflows.

IMPLEMENTATION PLANNING. Stakeholders recommended piloting digital twin applications in controlled settings, incorporating iterative feedback, and embedding independent ethics monitoring mechanisms.

EVALUATION AND ITERATION. Continuous ethical evaluation was advised, involving interdisciplinary advisory panels, regular audits, and the tracking of unintended outcomes over time.

This canvas-driven approach offers a practical foundation for structuring ethical deliberation and governance as part of the broader digital transformation of healthcare.

10.5 ETHICAL RECOMMENDATIONS

Building upon the ethical analysis and stakeholder insights presented above, the following recommendations are offered to guide the responsible development and deployment of digital twin technologies:

1. Integrate bias auditing protocols into model development. Systematic audits of training data and algorithmic outputs should be mandated to ensure demographic representativeness and mitigate unintended discrimination.

2. Implement dynamic, tiered consent mechanisms. Patients should be enabled to express granular data-sharing preferences with the flexibility to modify them as digital twin capabilities evolve.

3. Establish interdisciplinary ethics oversight bodies. Independent committees with expertise in law, medicine, technology, and ethics should monitor compliance and review emerging ethical challenges across the system lifecycle.

4. Mandate explainability in AI-driven decision tools. Requirements for interpretable outputs should be enforced to support clinical accountability and build public trust in algorithmically guided care.

5. Adopt participatory design practices. Co-designing systems with patients, clinicians, and other stakeholders can surface context-specific concerns early, ensuring that technological systems reflect societal values and practical realities.

Taken together, these recommendations translate ethical principles into actionable governance mechanisms. They aim to safeguard human dignity and professional integrity while enabling innovation in data-intensive healthcare.

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