D6.3 Application scenarios, business plan, road map: use of the new technology

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Executive Summary

This deliverable, "Application Scenarios, Business Plan, and Roadmap: Use of the New Technology," presents the consolidated results of the activities undertaken to identify, evaluate, and select the most promising application scenarios for the HOLDEN project's technological innovations. The work builds on close collaboration among consortium partners and integrates technical, ethical, legal, and socio-economic considerations to support a sustainable and responsible exploitation strategy.

The initial list of potential applications covered a wide range of market domains: infrastructure monitoring, surveillance and security, industrial operations, logistics, healthcare and assisted living, building automation, crowd management, automotive, gaming, VR/AR, and arts and entertainment.A structured assessment process was used to determine which of these areas offer the best alignment between technological maturity, ethical acceptability, and market potential.

To prioritise these applications, a Multi-Criteria Decision Analysis (MCDA) approach has been adopted. This method ensured a transparent and evidence-based selection process, incorporating partner expertise through a jointly defined set of criteria and weights. The evaluation covered aspects such as innovation value, technical complexity, cost and market relevance, laboratory reproducibility, privacy, ethical and social impact, and legal compliance. Partner inputs were collected through a questionnaire, aggregated, and translated into a ranked list of candidate applications.

Based on the MCDA results, three application scenarios, each corresponding to one of the project's core technological innovations, were selected. The selection was further refined using SWOT analysis and market size estimation (details in 6.2). Once validated, these final applications were approved to proceed to the in-depth market analysis in Task 6.2.

Each application scenario was then described in detail, with functional requirements defined to support the Appropriation Study (Task 6.1). This work clarifies how the technology is expected to operate under real conditions, describing the system behaviours, interactions, and operational constraints relevant to each use case. It also identifies the target users to ensure that functionality and usability are aligned with their needs and expectations.

The definition of functional requirements further specifies the RF-sensing components, hardware and software modules, and supporting infrastructure required for each solution. Complementing this, process and information flows were mapped to detail how data is generated, transmitted, processed, and transformed across the system and how users engage with the technology during typical operations.

Together, these structured scenario descriptions provide a solid basis for assessing each application's practical relevance, technological feasibility, and potential for market uptake, while ensuring alignment with the project's ethical and legal framework.

Finally for each application scenario, Key Performance Parameters (KPPs) were established to quantify the expected impact and added value of RF sensing in the selected domain. These parameters combine technological metrics, such as accuracy, responsiveness, reliability, and sensing range, with ethical and privacy safeguards, including data minimization, fairness, transparency, and user autonomy. This approach ensures that RF-based systems deliver high performance while remaining trustworthy and compliant in real-world use.

The evaluation methodology defines target performance values that each application must achieve (e.g., gesture detection accuracy at specified distances) to be achieved by experimental testing. By comparing available performance levels with experimental validation results, the project can determine how effectively the technology meets practical requirements and identify if and where the technology require further development. This evidence-based process links RF sensing capabilities to realistic business cases and supports the development of a credible and actionable exploitation pathway. The detailed market analysis for the three selected scenario application, together with the associated business plan and roadmap, is presented in Deliverable 6.7 “Results of the Market Analysis” as part of Market Analysis framework.

Table of Contents

1. Introduction

1.1. About HOLDEN

The ubiquitous perception by sensing of objects, subjects, and gestures is a pivotal challenge for future technology: it enables personalized services such as smart living, automated logistics, or interaction through free-space gestures. However, it also challenges ethical and moral boundaries and threatens privacy. HOLDEN proposes a radically new approach to RF-based perception by concisely analysing ethical constraints and privacy risks while re-thinking RF-based sensing. We establish necessary conditions for privacy preserving and ethically compliant sensing and develop new paradigms respecting these constraints.

For the first time ever, HOLDEN constitutes a concentrated effort to explore social aspects of RF-sensing to guide the technological advance, and to derive technology for ethically and privacy compliant perception. The development of ethical and privacy constraints is central to HOLDEN. We use these findings to derive privacy- and ethically compliant concepts for RF-based perception. We will develop a system of distributed multi-antenna devices for simultaneous multitarget recognition and ubiquitous perception with unprecedented accuracy, which constitutes a radical paradigm shift from a technology-centric perspective to a privacy-centric one via a privacy-by-design approach.

HOLDEN achieves this goal along three high risk, complementary, and privacy-centric paths:

Path 1: Continuous-space measurement points: Radio-based 3D vision by holographic image processing of RF wavefronts.

Path 2: Discrete-space measurement points: Advanced 3D beamforming for human-scale recognition and tracking through dense, massive, and connected antenna arrays.

Path 3: Signal processing and learning: High-dimensional tensor processing for the distinction of complex activities and motion from massive-dimensional RF data. The resulting breakthrough approaches and algorithms will be compared against application-level benchmarks via usage scenarios in the fields of logistics, smart living, and free-space.

1.2. Partners

The consortium consists of four academic partners and a high-tech SME partner: (a) Aalto University (AALTO), Finland, (b) Technical University of Munich (TUM), Germany, (c) Consiglio Nazionale Ricerche (CNR), with third party Politecnico di Milano (POLIMI), Italy, (d) University of Twente (TWE), Netherlands, and (e) Adant (Adant), Italy. This consortium features the specialized and complementary expertise required to achieve the project objectives. AALTO will be responsible for the project management (WP1), covered by an experienced and dedicated project manager. Ethical aspects (WP2) will be addressed by TWE (Prof. Ciano Aydin) who is a pioneer in the field. Eventual gender differences in the ethical perception will be considered. TUM pioneered RF holography, which makes TUM (Prof. Thomas Eibert) the ideal leader of WP3. In advanced distributed signal and information processing, CNR has through Prof. Stefano Savazzi more than 14 years of experience. CNR will lead WP4. Since more than 10 years, AALTO is active in radio sensing and machine learning based activity recognition. This expertise makes AALTO (Prof. Sigg) the ideal leader of WP5. Adant (Daniele Piazza) will contribute to the market analysis, application possibilities, and validation (WP6). Led by AALTO, dissemination with the website as one the media will be addressed by all partners. All academic partners are committed to early publication of results, e.g., via arXiv (open science).

2. Innovations and Application Scenarios

2.1. Innovations in Holden

The HOLDEN project develops three core RF sensing innovations, each investigated within a dedicated work package: WP3 (Static Holography), WP4 (Dynamic Holography) and WP5 (Gesture Recognition). These innovations provide a tiered set of capabilities, ranging from the detection and localization of static objects and individuals to real-time monitoring of human movement and activity, and finally to interactive control of systems through gestures. Together, they illustrate the versatility and transformative potential of RF sensing, supporting applications across security, assisted living, industrial monitoring, smart living, and interactive environments, while embedding privacy, ethical, and social considerations from the outset.

2.1.1. Static Holography

Static holography captures images of static objects and individuals within a fixed environment by leveraging ambient RF waves as a "light source." Unlike conventional scanners that rely on actively emitted signals, static holography reconstructs scenes using algorithms such as back-projection or linearized inverse source solving, leveraging the stray fields generated by existing radio sources like Wi-Fi routers, without the need for machine learning. The technology can operate through walls and in complete darkness, detecting conductive objects more easily than dampening materials. While high-resolution imaging requires longer processing times, changes between scenes are often easier to identify than interpreting a single snapshot. Applications include body imaging, metallic object detection, and precise mapping and localization, offering non-intrusive sensing that minimizes exposure of sensitive information and preserves privacy by design.

2.1.2. Dynamic Holography

Dynamic holography builds upon static capabilities to monitor and analyse movements, activities, and environmental changes in real time. It integrates Wi-Fi-based localization and people counting with machine learning algorithms for activity recognition, along with 2D and 3D imaging that may require dedicated RF emitters and receivers. This system functions effectively through walls and in low-visibility conditions, enabling robust monitoring of multiple targets simultaneously. It supports applications such as security surveillance, elderly care, and industrial process monitoring, while ensuring that ethical, social, and privacy considerations guide both deployment and data handling.

2.1.3. Gesture Recognition

Gesture recognition extends the technology to interactive applications, allowing users to control devices and systems through hand or body movements. The system extracts spatial and temporal features from point clouds and interprets them with machine learning algorithms to distinguish gestures across varying lighting conditions, angles, and movement speeds. Gesture recognition is suitable for smart home appliances, VR/AR systems, interactive services, and industrial or public environments. Because point clouds may contain sensitive information, privacy and ethical principles are embedded from the design phase, ensuring user autonomy, control, and respect for social and interpersonal boundaries.

2.2. From Innovations to Application Scenarios

This report marks the starting point for translating the HOLDEN project's technological innovations into real-world applications. The initial set of potential applications was identified through close collaboration with project partners and a detailed review of key project documents, including the ESM (Ethics Status Monitor) and the Innovation Exploitation documentation. These sources enabled the identification of a diverse range of use cases across multiple market domains, highlighting both the transformative potential of RF sensing technologies and the wide spectrum of practical applications they enable.

Examples include detecting the presence of people or objects in restricted areas, which addresses critical surveillance and security needs and provides advanced safety solutions in both private and public environments; assisted-living scenarios, which support remote monitoring of older adults or vulnerable individuals by enabling assessment of daily activities, falls, presence, and other health-related behaviours, while aiding healthcare professionals and improving quality of life; and consumer applications, where gesture-based interaction for Smart TVs, home appliances, wellness applications, or gaming offers more intuitive and immersive forms of user interaction, reduces reliance on touch interfaces, and enables energy-saving features such as presence-based device activation.

Importantly, the application selection process integrates ethical, social, and privacy considerations from the outset. Applications are designed to respect user autonomy, protect sensitive information, and promote socially responsible adoption in real-world environments. This approach ensures that sensing capabilities operate with the least intrusive data processing necessary, avoid exposing sensitive information, and align with users' expectations of control and privacy. It also acknowledges the potential impact of these technologies on social practices, interpersonal interactions, and the boundaries between public, private, and intimate spaces, embedding safeguards from the design phase to prevent unintended harms and support trustworthy deployment.

The selection of these initial applications provides the foundation for the next phases of work. It supports the analysis of functional requirements and ethical profiles in Task 6.1 (Deliverable

D6.1) and guides experimental validation of performance in real scenarios in WP6, Task 6.6 (Deliverables D6.8–D6.10). Together, these processes ensure that the chosen applications not only demonstrate technological feasibility but also adhere to ethical, social, and privacy principles in their deployment.

The table below presents the initial set of applications identified from project documents, detailing their associated market segments, innovation types (static, dynamic, gesture-based), and corresponding technical capabilities, such as imaging, localization, activity recognition, and gesture detection. This structured mapping provided a clearer overview of potential use cases and served as the foundation for the MCDA-based evaluation process, which guided the selection of the three final target application scenarios.

Source Document	**Application**	**Description**	**Market Segment**	**Innovation Type**	**Technical Capability**
Innovation Exploitation Document	Analyse the surface status of civil and industrial structures	Assessment of deterioration, criticalities, post-event damage, surface quality, and restoration outcomes	Infrastructure Monitoring	Static (1)	Imaging of objects
ESM	Analyse surface deformation of reflector antennas	Monitoring deformation, post-event damage, and surface condition	Facilities Monitoring	Static (1)	Imaging of objects
Innovation Exploitation Document	Monitoring the presence of objects and/or people in a restricted area	Indoor/outdoor detection for safety and access-control purposes	Surveillance / Security	Static (1)	Localization & Object/People Detection
ESM	Device-free measurement	Measuring distance between recognized objects without dedicated sensors	Civil / Industrial Applications	Static (1)	Localization & Object/People Detection

ESM	Printed Circuit Board (PCB) analysis	Localization and analysis of equivalent currents for antenna diagnostics (e.g., fault detection)	Manufacturing / Quality	Static (1)	Imaging of objects
ESM	Through-wall imaging	Imaging of persons or objects through obstructing materials	Surveillance / Security	Static (1)	Localization & Object/People Detection
ESM + Innovation Exploitation Document	Fenceless industrial robot interaction	Passive localization of workers in predefined industrial areas; robot behavior adapts to proximity and movement	Manufacturing / Logistics	Dynamic (2)	Activity Recognition
Innovation Exploitation Document	Elderly care	Remote monitoring for health assistance, fall detection, presence monitoring, etc.	Assisted Living	Dynamic (2)	Activity Recognition
Innovation Exploitation Document	Monitoring presence of people for security	Detection and localization of human presence in indoor spaces	Building Security	Dynamic (2)	Localization & Object/People Detection
ESM + Innovation Exploitation Document	Human behavioral monitoring for chronic diseases	Analysis of daily routines and health-related behaviors for medical insight and early detection	Healthcare / Assisted Living	Dynamic (2)	Activity Recognition

ESM + Innovation Exploitation Document	Marketing-driven human behavior insights	Understanding user patterns and preferences to enable tailored services	Marketing	Dynamic (2)	Activity Recognition
Innovation Exploitation Document	Process behavior analytics for industrial efficiency	Data-driven insights for optimization and quality control in manufacturing	Quality / Manufacturing	Dynamic (2)	Activity Recognition
Innovation Exploitation Document	Remote control of appliances, 2D/3D user interfaces	Presence-based activation of appliances (lights, HVAC, etc.)	Building Automation	Dynamic (2)	Localization & Object/People Detection
Innovation Exploitation Document	People counting	Counting and tracking people in crowded indoor settings	Crowd Management	Dynamic (2)	Localization & Object/People Detection
Innovation Exploitation Document	Smart TV	Gesture-based control of interactive TV systems	Interactivity	Gesture (3)	Gesture Detection
Innovation Exploitation Document	Smart devices	Gesture control of home appliances and facilities	Home Automation	Gesture (3)	Gesture Detection
Innovation Exploitation Document	Gaming	Gesture-based interaction with gaming technologies	Gaming Solutions	Gesture (3)	Gesture Detection
Innovation Exploitation Document	Car control	Gesture-based interaction with in-vehicle systems	Automotive	Gesture (3)	Gesture Detection

Innovation Exploitation Document	VR / AR interaction	Gesture-based interaction with extended reality systems	VR / AR	Gesture (3)	Gesture Detection
ESM	Embedded arts (dance, music, painting)	Using movement feedback for interactive artistic creation	Arts & Entertainment	Gesture (3)	Gesture Detection

Table 1 *– Initial set of candidate applications*

3. Overview of the selected application scenarios

In this section, the three final application scenarios are presented. Each scenario includes a description of the context, the system architecture integrating the technology into a complete solution, the users involved, the data flow, and the key processes that characterize its operation.

3.1.1. Context

This defines the environment and conditions in which the application will be used. It clarifies how users interact with the system to achieve specific goals and supports the identification of functional requirements and expected system behavior

3.1.2. Target Users

This identifies the intended users or user groups for the application. Understanding the users helps tailor functionality, usability, and design to their needs.

3.1.3. Technologies and System Components

This outlines the tools, platforms, and components used to build, deploy, and operate the application. It highlights System capabilities (e.g., scalability, integration with other systems), Constraints (e.g., performance, security, compatibility), Development and maintenance considerations.

3.1.4. Processes and Information Flow

This describes the sequence of activities and movement of data within the system, answering questions such as how data flow between system components, how is information processed, stored and accessed, how users interact with the system.

3.2. People and Object Detection – Innovation 1

RF sensing technology provides a non-invasive and reliable method for detecting the presence of objects and individuals. By leveraging radio waves, RF sensing can identify people or objects even when they are hidden from view or concealed behind barriers. This capability offers a robust, complementary monitoring solution that enhances the effectiveness of traditional surveillance methods. Moreover, RF sensing functionality can be seamlessly integrated into existing technologies, such as cameras, presence sensors, IoT and Wi-Fi devices, eliminating the need for standalone solutions in many cases.

Conventional systems, including CCTV cameras and motion sensors, are widely used but have inherent limitations. CCTV relies on clear lines of sight, which can be obstructed by walls, furniture, or metallic objects, while motion detectors often struggle to detect static or slow-moving entities and can be prone to false alarms triggered by environmental factors like temperature changes.

3.2.1. Context

RF sensing can address these challenges in a variety of settings, such as museum exhibit spaces, storerooms, airside areas at airports, and baggage handling zones, where asset protection and object detection are critical. For example, in a museum, it can monitor high-value assets while ensuring visitor safety or unauthorized attempts to remove items. Similarly, at airports, the technology could be used to detect suspicious activities or objects in, enhancing security measures without the need for intrusive inspections.

3.2.2. Target Users

Primary Users: Visitor and security personnel who is present in the restricted area under control. RF sensing detects their presence or absence.

Secondary Users: Facility managers, museum curators, airport operations managers, and administrators who remotely monitor the restricted areas, respond to alerts, and take immediate action. Besides law enforcement, and emergency response teams who analyse data or respond to incidents but do not actively monitor in real-time.

3.2.3. Technologies and System Components

- **RF Sensing:** embedded in specific devices or positioned on surfaces, or other strategically placed sensors to monitor the presence of people and objects, even behind barriers (e.g., ceiling-mounted sensors for unobtrusive, wide-range monitoring).
- **Edge Processing**: Basic data is processed locally to reduce latency, enabling faster response times.
- **Cloud Platform**: For storing data and performing historical analysis of detected security events.
- **Edge Processing**: For rapid analysis and real-time alerts when unauthorized activities are detected.
- **Cloud Platform**: For data storage and historical analysis of detected security events.
- **Mobile App / Web Dashboard**: Allows secondary users to monitor data, receive alerts, and interact with the system remotely.
- **Telecommunication Integration**: Connects with emergency services for immediate alerting in critical situations.

3.2.4. Processes and Information Flow

RF Sensing and Object Detection:

- RF sensors for example embedded in ceiling-mounted systems continuously monitor the area for any presence/absence of people or objects, analyzing changes in the environment.
- If the sensors detect an attempt to hide or move an unauthorized object/valuable object, an alert is generated using connected device.

Edge Processing and Alerts

- The data is processed at the edge to identify threats or unusual patterns, such as concealed weapons or attempted theft.
- Real-time alerts are sent to on-site security personnel via their monitoring devices or dashboards.

Data Transmission to the Cloud

- All data is transmitted to a secure cloud platform for further analysis, allowing for trend identification and the improvement of future security strategies.

Security Dashboard and Emergency Response

- Security teams monitor real-time data from the cloud using a dashboard, which provides a comprehensive view of all activities and alerts within the restricted area.
- In case of emergencies, integrated telecommunication systems notify law enforcement or emergency response teams, enabling swift action.

3.2.5. Example Use Case Flow

Object/People Detection at Airport Security

- RF sensors detect an anomaly in a designated area.
- Edge processing identifies the object as a potential threat and sends an immediate alert to security personnel.
- Security staff review the data via the dashboard, verify the situation, and take appropriate action, which may include notifying law enforcement for further investigation.
- If necessary, the system alerts emergency response teams for rapid intervention.

Asset Protection in Museums

- RF sensors continuously monitor the area where high value items are placed.
- If a visitor attempts to remove or hide an item, the system processes this data locally and sends an instant alert to the museum's security team.
- Security personnel review the alert and take action to prevent theft or damage.
- The system records the event data for future analysis and security protocol enhancement.

3.3. Elderly Care – Innovation 2

Providing effective care for elderly individuals presents unique challenges that require personalized, adaptive, and continuously evolving strategies. Achieving holistic support necessitates integrating modern technologies and professional services to promote physical, emotional, and social well-being. Recent advancements in Information and Communication Technologies (ICT) are setting the stage for innovative and transformative progress in a way that can significantly improve the "Elderly Care" process.

Among these, RF sensing technology embedded in IoT and Wi-Fi-enabled devices has the potential to emerge as a game-changer. This technology provides a non-invasive, continuous monitoring solution, capable of tracking vital signs such as heart rate, breathing frequency, body movement, and location, all without the need for physical contact or wearable devices.

This continuous data stream can enable real-time health monitoring, including activity tracking, mobility assistance, heartbeat analysis, and cognitive behaviour monitoring. Additionally, local data analysis, such as fall detection or identifying irregular heartbeats, is facilitated by edge processing within connectivity devices. This capability allows for instant alerts to secondary users or emergency services when needed.

Besides, RF sensing technology offers caregivers actionable insights, allowing for a deeper understanding of the elderly's needs and fostering a more proactive, tailored approach to care. Furthermore, these features empower family members and caregivers to respond swiftly and effectively when immediate intervention is needed.

3.3.1. Context

RF sensors continuously monitor the user's movements within the home environment, detecting transitions between rooms as well as prolonged inactivity in a specific area, which may indicate a potential fall or health-related issue. This system relies on RF sensing technology integrated into existing IoT and Wi-Fi devices throughout the home for continuous, non-intrusive health monitoring.

3.3.2. Target Users

Primary User: The elderly person being monitored. The primary user resides at home or in assisted living. RF sensing can track the movement, location, falls, and health indicators like heart rate.

Secondary Users: Secondary users may be remote (e.g., family members) or on-site (e.g., caregivers or healthcare providers who receive health data and alerts through an app, web dashboard or telemedicine platform to monitor the elderly person's well-being).

- **Caregivers:** Oversee health and safety either remotely or on-site.

- **Healthcare Providers:** Review data to make medical decisions.
- **Emergency Services:** Respond to urgent alerts (e.g., falls).

3.3.3. Technologies and System Components

- **RF Sensing**: Embedded in IoT/Wi-Fi devices (e.g., routers, smart speakers) to detect movement, presence, and physiological changes like heart rate without wearables.
- **Edge Processing**: Basic data (e.g., falls, heartbeat irregularities) is processed locally to reduce latency and enable quick responses.
- **Cloud Platform**: Central storage and analysis of health and movement data, accessible to secondary users in real time.
- **Mobile App / Web Dashboard**: Allows secondary users to monitor data, receive alerts, and interact with the system remotely.
- **Telecommunication Integration**: Connects with emergency services for immediate alerting in critical situations.

3.3.4. Processes and Information Flow

Health Data Collection via RF Sensing:

- **Movement and Position Detection:** RF sensors in IoT/Wi-Fi devices track user location and movements (e.g., in bedroom, living room).
- **Heartbeat Detection:** RF technology detects subtle radio wave changes from physiological activity, allowing continuous heart rate monitoring without wearables.
- **Fall Detection:** RF sensors detect abrupt movements (e.g., falls) and can trigger alerts if the user is in a vulnerable position.

Edge Processing:

- Local data analysis (e.g., fall or irregular heartbeat detection) enables instant alerts to secondary users or emergency services.

Data Transmission:

- RF sensing data (movement, heart rate, etc.) is sent to the cloud via IoT protocols (Wi-Fi, Zigbee, LoRa), allowing secondary users real-time access to the elderly person's status.

Health Status Monitoring:

- Caregivers or family monitor health/location using an app or dashboard, receiving alerts for significant changes, such as unusual movement patterns or falls.

Emergency Response:

- For critical alerts, the system notifies secondary users and emergency services via telecom integration for immediate response.

3.3.5. Example Use Case Flow

Fall Detection:

- RF sensors embedded in Wi-Fi devices (such as routers or smart speakers) detect an abrupt change in the primary user's position (e.g., a fall).
- The edge device processes this data and sends an immediate alert to secondary users via a mobile app or dashboard.
- The caregiver or family member checks the primary user's status using the app and, if necessary, contacts emergency services through the integrated telecommunication system.
- Emergency services arrive at the primary user's location promptly, minimizing response time.

Heart rate and breath rate Monitoring:

- RF sensors embedded in IoT and Wi-Fi devices, such as smart speakers or Wi-Fi routers, detect subtle changes in the primary user's heart/breath rate based on radio wave reflection.
- If the heart/breath rate exceeds a certain threshold, the system sends a notification to the secondary user (e.g., caregiver or healthcare provider).
- The secondary user can then assess whether the primary user needs medical attention and takes appropriate action.

Position Tracking:

- RF sensors track the primary user's movement throughout the house, detecting when they move from room to room or remain stationary in one spot for too long (potentially indicating a fall or health issue).
- If the system detects that the primary user has remained in one position for an extended period, it sends an alert to the caregiver or family member.

3.4. Smart TV – Innovation 3

In the evolving landscape of home entertainment, Smart TVs have become integral to the connected home ecosystem, driven by advancements in Wi-Fi integration and diversified media content. Beyond delivering superior audio-visual experiences, Smart TVs now serve as interactive hubs for IoT technologies, facilitating information access, interaction, and smart home control. By incorporating RF sensing technology, Smart TVs can further enhance user experiences by enabling advanced personalization through the recognition and interpretation of physical movements, all without physical contact. RF sensing opens possibilities for gesture control, user presence detection, and even health and wellness tracking. The integration of RF sensing within Smart TVs represents a transformative leap, offering intuitive and non-intrusive features that redefine interaction and usability.

3.4.1. Context

In a smart home, a family of four enjoys an enriched living experience with a Smart TV enhanced by RF sensing. The family includes two parents, a teenage son who enjoys gaming, and a grandmother who uses sign language due to hearing impairment. The Smart TV serves as a hub for interaction and entertainment, offering gesture-based control, personalized content, immersive gaming, and fitness routines. Its inclusive design ensures accessible communication for all family members, while parental controls and adaptive settings make it an essential part of their connected lifestyle.

3.4.2. Target Users

Primary User: The entire family, using the Smart TV for entertainment, including interactive media content for the grandmother, who communicates using sign language due to a hearing impairment, and the teenage son, who enjoys gaming.

Secondary Users: Family members who remotely interact with and control the media content, enhancing the family experience.

3.4.3. Technologies and System Components

- **RF Sensing**: RF sensors embedded in Smart TVs detect user presence, gesture movements, and support interactive gaming activities. This non-contact technology enables hands-free navigation, gesture-based control for adults (especially useful for the grandmother who communicates using sign language), and immersive gaming experiences for the teenage son. It detects movements for gaming control, creating an interactive, engaging environment.
- **Edge Processing:** Local data processing ensures quick response times for activities like gesture recognition and gaming interactions. By processing data on-site, it reduces latency, enhancing the responsiveness of gesture controls and gaming activities.
- **Cloud Platform:** Stored data related to usage patterns, screen time, gaming preferences, and personalized content insights. Secondary users can access this data remotely via the cloud, allowing them to monitor usage or adjust settings for entertainment and gaming content.
- **Mobile App / Web Dashboard:** Provides secondary users (like parents) with remote access to TV settings, screen time data, and gaming activity. The app supports notifications for both media content and gaming, allowing parents to manage and monitor the family's entertainment experience, including interactive gaming for children.

3.4.4. Processes and Information Flow

Data Collection through RF Sensing:

- **Gesture Control:** RF sensors interpret gestures like swiping, tapping, or pointing, enabling users to control the TV hands-free. This includes gesture-based control for the grandmother (using sign language) and the teenage son for gaming interactions. The system also allows parents to monitor children's interaction with media content by limiting options based on gestures.
- **User Presence Detection:** Detects when someone is near or away from the TV, adjusting settings like power, brightness, and volume accordingly. It also enhances the user experience by triggering personalized content based on who is present (e.g., gaming suggestions for the son or media content for the parents).
- **Gaming Interaction:** RF sensors detect gestures specific to gaming (e.g., hand movements or controller-like gestures) to control gameplay without physical controllers.

Data Transmission and Analysis:

- **Edge Processing:** Processes movement and user interaction data locally, enabling instant responses for high-priority tasks, such as gesture recognition or gaming control or wellness insights. This minimizes latency for a seamless gaming and media interaction experience.
- **Cloud Storage and Analysis:** Transmits non-critical data to the cloud, allowing secondary users (parents) to view trends, screen time data, and monitor gaming activity or media preferences remotely. This data can also inform personalized content recommendations for family members.

Content Personalization:

- **User Recognition and Content Suggestion:** Recognizes individual users and suggests personalized content based on preferences, past activity, and interactions (e.g., media for the parents, gaming content for the son). The system adjusts settings such as volume or brightness based on user distance or presence, ensuring an optimal viewing or gaming experience for each user.
- **Gaming Preferences and History:** Tracks the son's gaming history and preferences, allowing the system to provide personalized gaming suggestions or notifications based on his activity, such as new game options or multiplayer opportunities.
- **Parental Control Features:** Allows parents to set screen time limits or restrict certain types of media or gaming content based on the son's activity, ensuring a safe and balanced media experience for children.

Mobile App / Web Dashboard:

- **Remote Parental Controls:** Secondary users (parents) can use the mobile app or dashboard to remotely manage gaming content, set screen time limits, and restrict certain types of media or gaming content. The app provides control over the family's media interaction, ensuring safe usage and age-appropriate content for children.
- **Gaming Preferences and History:** Parents can remotely monitor and review the son's gaming preferences, usage history, and gameplay data, allowing them to make informed decisions about restrictions or recommendations.
- **Screen Time Management:** Allows parents to track and limit screen time for each family member, ensuring a balanced media consumption experience

3.4.5. Example Use Case Flow

Gesture-Based Media Control:

- As the family gathers in the living room, the Smart TV automatically detects their presence through embedded RF sensors.
- The parents begin scrolling through content simply by swiping their hands in the air. The system recognises their gestures instantly, thanks to edge processing, and updates the interface without any noticeable delay.
- When the grandmother enters the room, the TV shifts into accessibility mode. It interprets her sign-language gestures to navigate menus, select programmes, or adjust volume, removing the need for physical remotes or complex interfaces.
- Throughout the interaction, the TV adapts brightness and sound levels based on who is present and their distance from the screen.

Immersive Gaming Interaction:

- The teenage son launches his preferred game. As he starts playing, RF sensors pick up his rapid hand movements and body gestures, translating them into in-game actions without the need for controllers.
- The edge processor ensures the gameplay remains smooth and responsive, even during fast-paced sequences.
- At the same time, the system records his gaming activity (play duration, gesture intensity, and interaction patterns) and uploads non-critical data to the cloud.
- The parents receive a notification summarising gaming time and can remotely decide whether to allow continued play or enforce a break.

Presence Detection and Personalized Content:

- When a family member remains near the TV for a short period, the system recognises the intention to interact, automatically powers on, and displays that person's personalised dashboard with tailored menu options.
- If multiple individuals sit together in front of the Smart TV, it adapts by shifting to shared content recommendations suitable for group viewing.

- These personalised experiences continuously evolve as the system analyses interaction patterns and usage data through the cloud platform.

Remote Monitoring and Parental Controls

- Parental control features allow the Smart TV to send notifications to the parents' mobile app, alerting them to how children are using the device. The app provides real-time insights into screen time, ongoing activities, and viewing or gaming preferences for each household member.
- If a child reaches their predefined gaming limit, the parent can remotely activate a temporary screen-time restriction. Within seconds, the Smart TV automatically pauses the game, displays a friendly reminder, and transitions to a family-safe mode, ensuring balanced and responsible media consumption even when parents are not at home.

4. Application selection methodology

Identifying optimal applications for each Holden innovation and defining precise design requirements involved a structured, multi-criteria decision analysis (MCDA) guided by detailed assessment criteria. This approach enables us to effectively evaluate each application's feasibility, innovation potential, and practical impact in the market [1].

Decision theory in MCDA provides a framework for making decisions involving multiple, often conflicting criteria. It encompasses models, techniques, and principles that guide to identify and evaluate trade-offs, incorporate uncertainties, and make rational choices that align with their preferences or goals [2]. MCDA methods support this by structuring and quantifying the decision-making process, enabling a more systematic comparison of alternatives based on multiple criteria [3]. For the application selection, we followed WSM (Weighted Sum Model), which is a popular method within MCDA for evaluating and ranking options based on multiple criteria [4]. In WSM, each criterion is assigned a weight representing its importance relative to others. Each option is then scored on each criterion, and these scores are multiplied by the respective weights. The weighted scores for each criterion are summed to produce an overall score for each option. The option with the highest score is considered the best choice.

$$A_i^{\text{WSM-score}} = \sum_{j=1}^{n} w_j a_{ij}, \text{ for } i = 1, 2, 3, \ldots, m$$

Drawing insights from key project documentation, including the Innovation Exploitation Document and ESM Report, we initially screened and figured out a wide range of potential applications. This review helped us narrow down promising applications relevant to diverse use case scenarios.

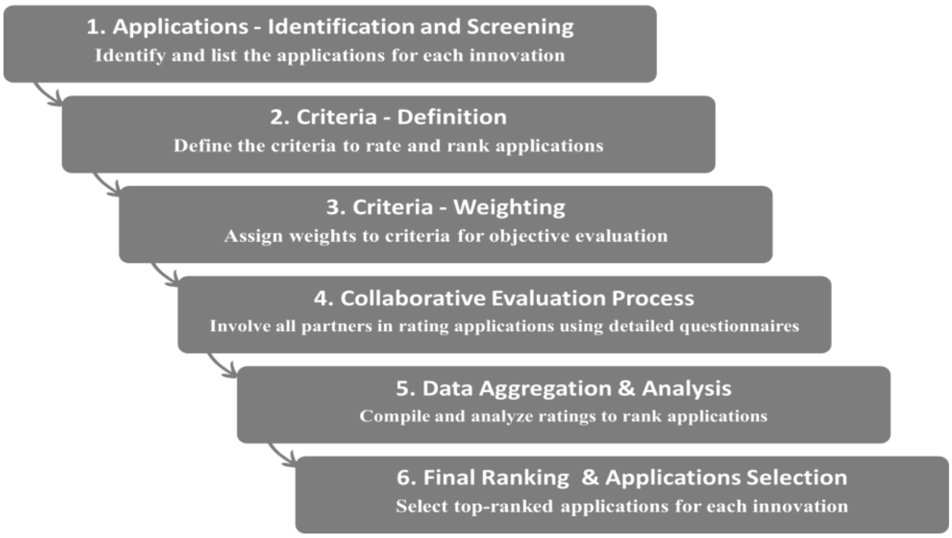


***Figure 1** – Application Selection Process*

4.1. Application Ranking and Selection

The evaluation process was designed to ensure inclusivity by involving all project partners in a structured and transparent rating system. Partners conducted independent evaluations, rating each application against a series of clearly defined sub-criteria, using a detailed questionnaire prepared for each application. This questionnaire enabled partners to assess the applications consistently according to the established criteria. To calculate the final scores, the Weighted Sum Model was applied, multiplying the weights assigned to each criterion by the individual scores provided by each partner. The applications were then ranked based on their total weighted scores across all criteria. The highest-scoring applications for each innovation were identified. This methodology ensured a fair, transparent, and comprehensive selection process, drawing on the collective expertise of all partners.

4.1.1. Criteria and Weight

Defining clear criteria and assigning appropriate weights are essential steps in the MCDA process before scoring the technological applications identified for each innovation. While these applications are still in the early stages of development, they have the potential to significantly impact real-world systems once refined and integrated. By establishing a balanced set of criteria - spanning technical, market, ethical, and social dimensions - we create a comprehensive evaluation framework. This approach allows us to rank the applications based on their diverse impacts, technical feasibility, and market potential. Properly defined criteria and weight assignment ensure a fair, objective, and strategic selection process.

Innovation

The Innovation criterion aims to assess the degree of advancement of the innovation within its application scenario, focusing on how it differentiates from existing solutions, its readiness for market adoption, and its potential for success. This criterion is divided through three sub-criteria: the technology’s Novelty, its Stage of Development, and its Market Impact.

- **Novelty Level:** it assesses how groundbreaking the technology is compared to existing solutions, with higher scores indicating a significant leap forward in innovation.
- **Innovation Readiness:** This evaluates the maturity of the technology on its path to commercialization, considering stages such as early concept, prototype development, or market readiness.
- **Market Potential:** it focuses on external factors, including demand, market segment attractiveness, and overall market conditions that could influence the innovation’s success.

Scoring was based on a scale from 0 to 100, where 100 represented a technology with revolutionary novelty, high readiness for market adoption, and exceptional market potential, while lower scores indicated limitations in one or more of these areas.

In the evaluation framework, the Innovation criterion accounted for 15% of the total criteria weight, with the following sub-criteria weights: Novelty Level (40%), Innovation Readiness (30%), and Market Potential (30%).

Complexity

The Complexity criterion evaluates how complex the final system and its components are in making the application operational. It considers factors such as the need for additional components, ease of integration, scalability when required, and deployability. This criterion is divided into four equally weighted sub-criteria: Autonomy, Scalability, Integrability, and Deployability.

- **Autonomy:** Assesses how easily the system can function as a stand-alone module without requiring external dependencies.
- **Scalability:** Evaluates how easily the system can be expanded in size or capacity to meet future needs.
- **Integrability:** Measures how easily the system can be integrated with other systems or components, ensuring smooth interoperability.
- **Deployability:** Focuses on how easily the system can be installed, configured, and made operational.

Scoring for the Complexity criterion ranges from 0 to 100, with a higher score indicating a system that is fully autonomous, highly scalable, seamlessly integrable, and easy to deploy, while lower scores signify significant inefficiencies or limitations in one or more of these aspects.

In the evaluation framework, the Complexity criterion accounts for 15% of the total criteria weight, with each sub-criterion receiving equal weight: Autonomy (25%), Scalability (25%), Integrability (25%), and Deployability (25%).

Economics

The Economics criterion evaluates the cost-effectiveness, funding needs, and market appeal of each technology. This criterion is divided into three equally weighted sub-criteria: Total Cost of Ownership (TCO), Initial Public Funds, and Compelling Investment Appeal.

- **Total Cost of Ownership (TCO):** Assesses the lifecycle cost of the technology, evaluating how cost-effective the technology is over its entire lifespan.
- **Initial Public Funds:** Evaluates the degree of public funding required to create favorable market conditions and support successful market entry.
- **Compelling Investment Appeal:** Measures the technology's ability to attract investors, based on its market readiness and potential return on investment (ROI).

Scoring for the Economics criterion ranges from 0 to 100, with a higher score indicating a technology that is cost-effective, requires no initial public funds, and is highly attractive to investors. Lower scores indicate significant inefficiencies or limitations in one or more of these aspects. In the evaluation framework, the Economics criterion accounts for 15% of the total criteria weight, with the following sub-criterion weights: TCO (40%), Initial Public Funds (30%), Compelling (30%).

Privacy and Ethics

The privacy and ethics criteria in the questionnaire accounted for 40% of the final score. The ethics section worth 20% was divided into personal ethics such as individual rights and the ability to self-govern (autonomy) 30%, collective ethics such as the impact on the collective wellbeing, equality and safety (equity) 30%, and precision, reliability, and understandability of the system (accountability) 40%. The idea being that if the system is unaccountable then both personal and collective rights may be more challenging to maintain. For each of these criteria it was foreseeable that a technology could be capable enhancing and or mitigating the domain. Thus, the scoring worked such that 50 was neutral (the enhancing and mitigating factors canceled out), 100 signified that the technology fully enhanced the domain, and 0 was a significant reduction. All technologies could be ranked anywhere from 1-100.

Privacy received its own subsection of the questionnaire worth 20% of the final score. This criterion was equally divided between amount and level of sensitivity of data used in the application (sensitive data) 25%, amount of sensitive data shared with other third-party systems (sensitive data shared) 25%, whether the app requires long-term and historical data storage (data retention) 25%, and the degree to which those monitored have control over their data and its management (control) 25%. For these categories 100 represented the most privacy preserving system with the most user control and least historical data storage and 0 was the least privacy sensitive.

Legal

The Legal criterion evaluates how well a technology adheres to regulatory standards, assessing its readiness for legal approval within its application context. This criterion is based on the level of adherence to laws and regulations, ensuring that the technology is positioned for successful market entry.

Scoring for the Legal criterion ranges from 0 to 100, where a score of 100 represents full compliance with all applicable laws and regulations, while a score of 0 indicates non-compliance and significant regulatory challenges.

In the evaluation framework, the Legal criterion accounts for 10% of the total criteria weight.

Lab Reproducibility

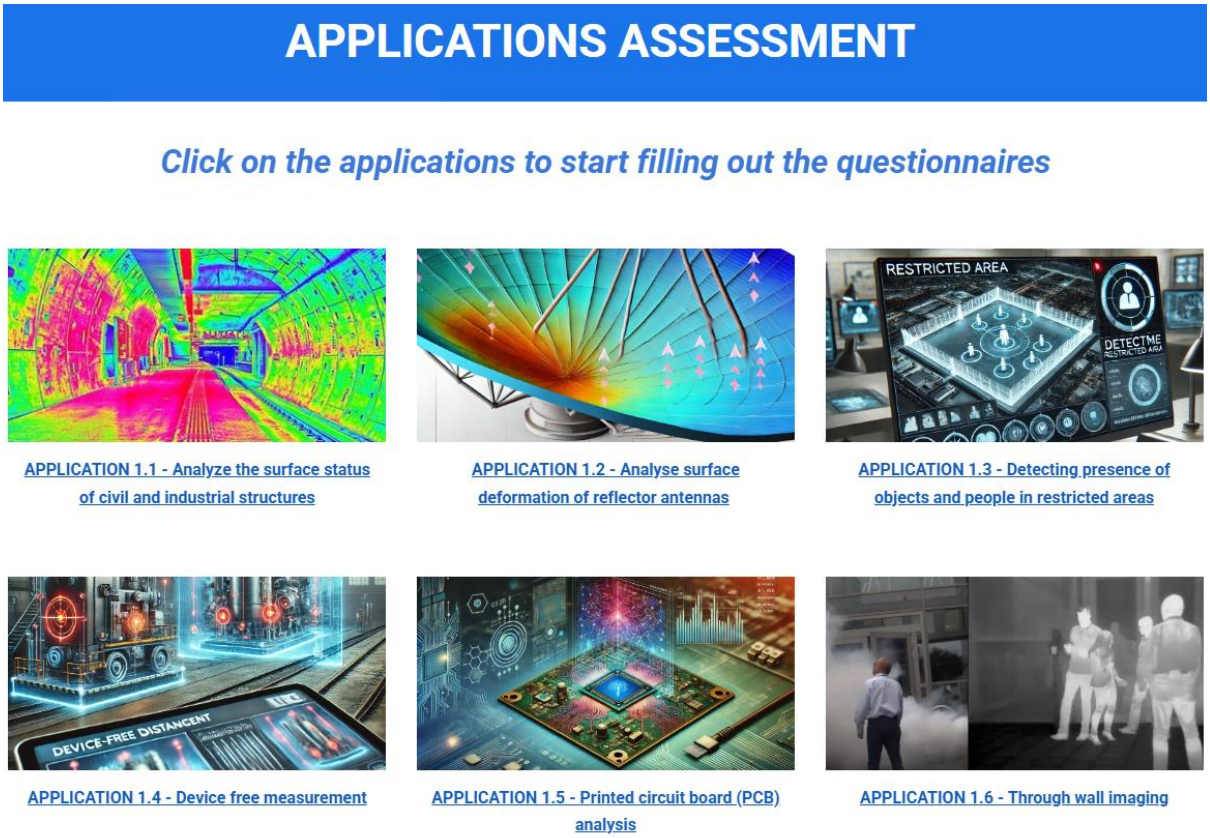
Lab Reproducibility Criterion evaluates the application's ability to be consistently reproduced in a partner laboratory within the consortium. This criterion is critical for assessing the technology's robustness and its suitability for further development and deployment.

The scoring for Lab Reproducibility ranges from 0 to 100, where a score of 100 indicates full reproducibility in the lab, and a score of 0 reflects significant challenges in achieving consistent and reliable results across tests.

In the evaluation framework, the Lab Reproducibility criterion accounts for 10% of the total criteria weight.

4.1.2. Scoring and Rating

The scoring process followed a systematic and collaborative methodology to ensure fairness and accuracy. A separate structured questionnaire was prepared for each candidate application. All partners were asked to independently evaluate the applications using predefined criteria (see Appendix for an example of the detailed questions.



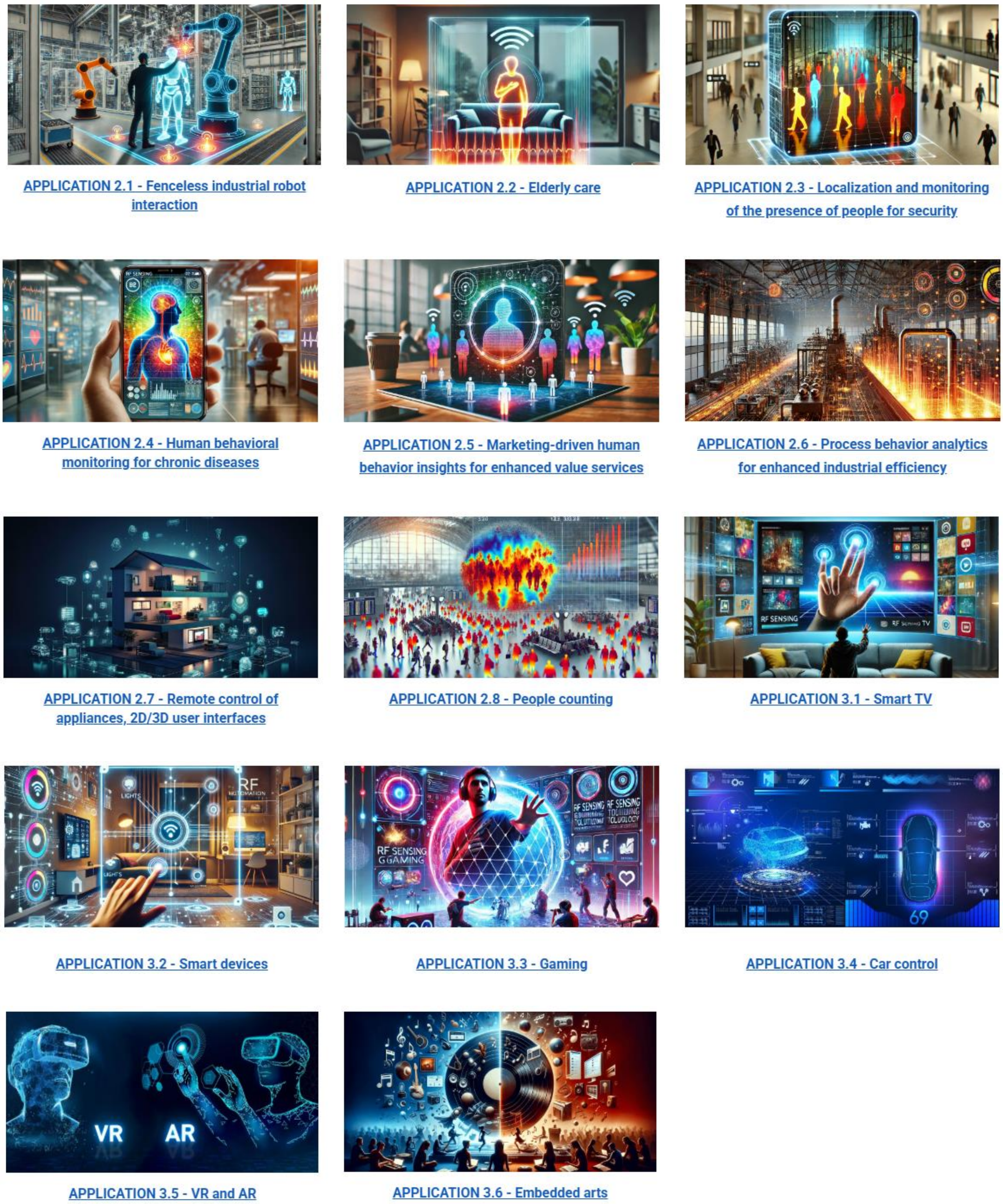


Figure 2 *– Homepage for Questionnaire Access*

All partners actively engaged in the individual scoring process, ensuring diverse and thorough input. Once completed, the consolidated scores from each partner were aggregated to generate a final ranking.

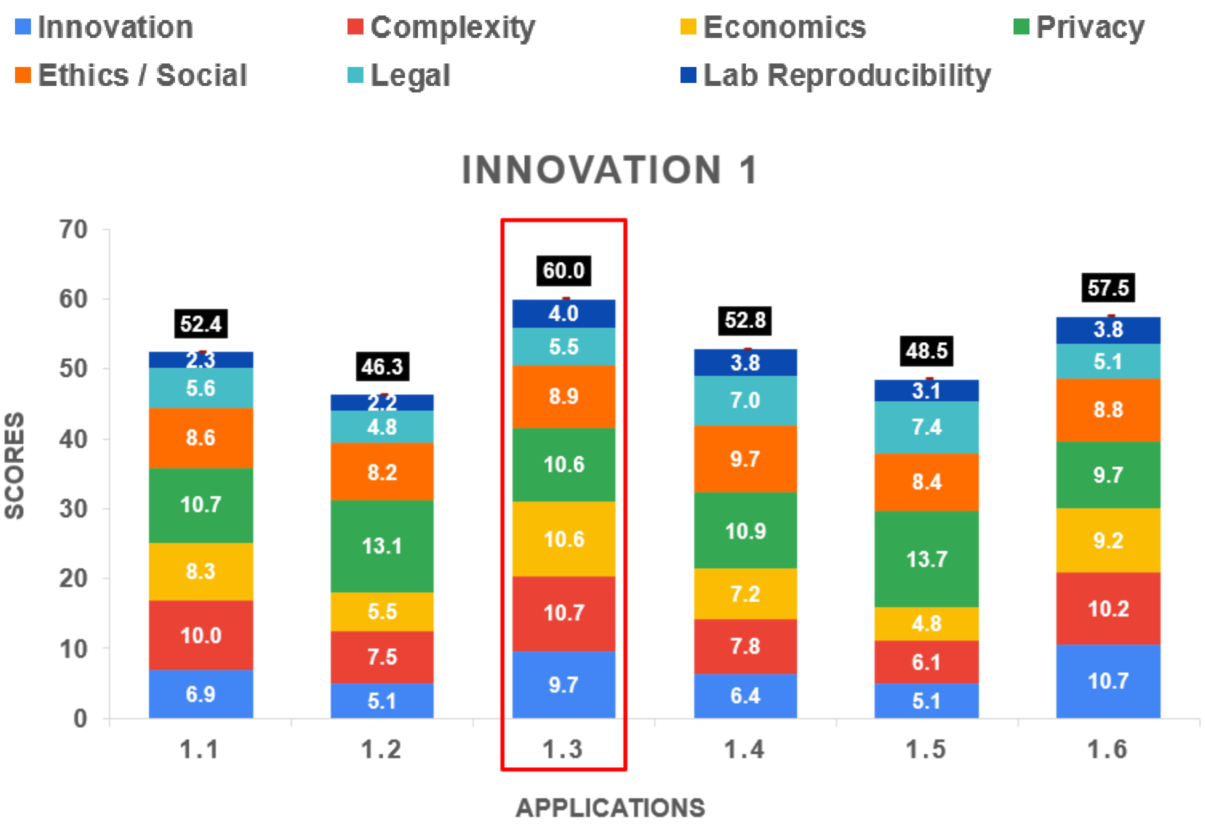


Figure 3 *– Scoring Results and Ranking of Candidate Applications for Innovation 1*

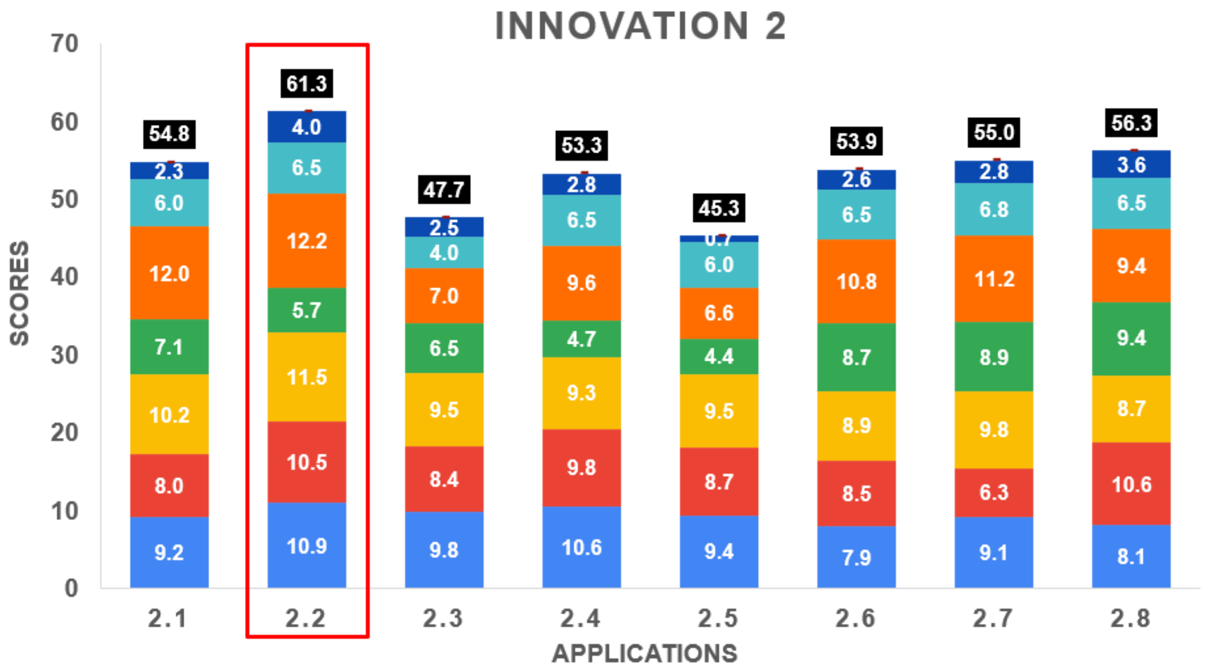


Figure 4 *– Scoring Results and Ranking of Candidate Applications for Innovation 2*

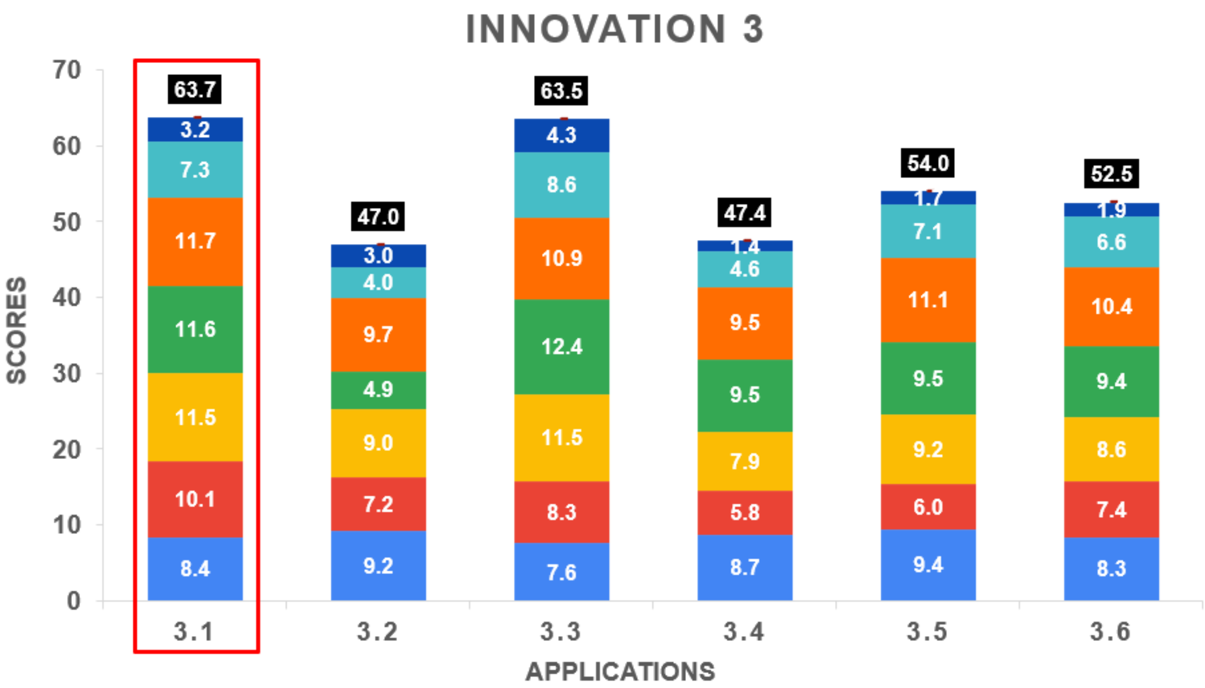


Figure 5 *– Scoring Results and Ranking of Candidate Applications for Innovation 3*

This approach is particularly effective in an MCDA scoring and ranking process for several reasons:

- **Objectivity and Consistency:** By requiring each partner to independently score the applications, the process minimizes the risk of bias and ensures that the evaluation is based on clear, predetermined criteria. This helps maintain consistency across all assessments and avoids skewed results from any single perspective.
- **Diverse Expertise:** The participation of multiple partners ensures that the evaluation process captures a broad range of expertise and viewpoints. Each partner may bring a unique perspective, whether from a technical, market, or ethical standpoint, leading to a more comprehensive and balanced assessment of each application.
- **Collaboration and Collective Judgment:** After the independent scoring, the scores from all partners are aggregated. This step ensures that the final evaluation reflects the collective expertise of the consortium, rather than any one individual's opinion.
- **Transparency:** The structured approach, with clearly defined criteria and independent assessments, enhances the transparency of the process.
- **Thoroughness:** The individual scoring **process** ensures that each partner carefully considers all aspects of the technological applications, leading to a more thorough and detailed evaluation. Aggregating these individual assessments ensures that no critical dimension is overlooked.

By combining independent assessments with a collaborative aggregation process, the final ranking provides a well-rounded and unbiased evaluation of the technological applications. This methodology not only enhances fairness and accuracy but also fosters confidence in the results, ensuring that the best applications are selected based on a comprehensive, multi-faceted evaluation.

Finally, the three final application scenarios, each aligned with one of the Holden's core technological innovations, were further refined through SWOT analysis and market size estimation (see Section 6.2). Once validated, these scenarios were approved to move forward into the detailed market analysis outlined in Task 6.2.

As an example, a summary of the Market Size analysis and the SWOT analysis related to the Elderly Care application scenario is presented below.

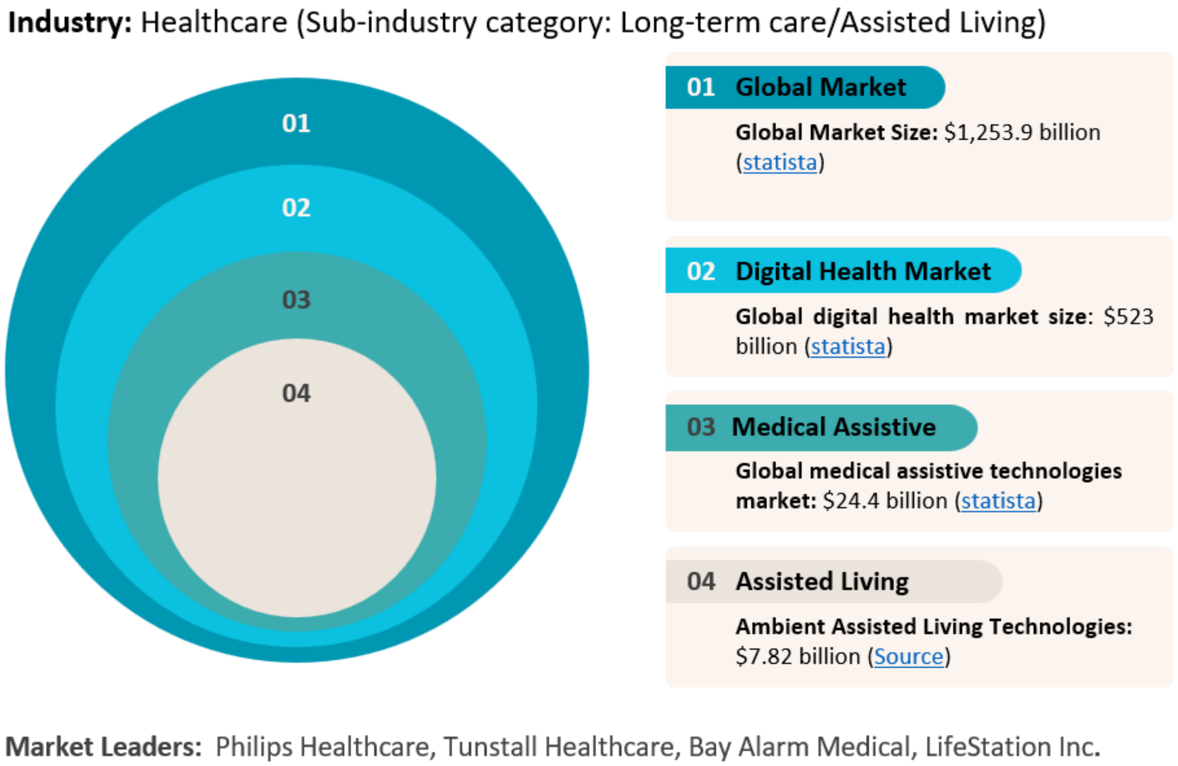


Figure 6 *– Scoring Market Size Results for the Elderly Care Application Scenario*

Strengths

- RF sensing systems can detect falls with up to 98% accuracy without any other wearables (source)
- Passive Wi-Fi sensing technologies can monitor vital matrix with 87% accuracy (source)
- Tele homecare with RF sensing saves cost $63 per patient by reducing rehospitalization (source)
- IoT applications, including RF sensing, support independent living for the elderly, making it an affordable option.

Opportunities

- By 2030, 1 in 6 people will be over 60; by 2050, this doubles to 2.1 billion, highlights the need for RF technology to monitor health metrics (source).
- Falls in the US cost $50B (non-fatal) and $754M (fatal), highlighting RF sensing's market potential (source).
- 80% of older adults prefer non-intrusive monitoring over wearables/camera for comfort and ease (source).

Weaknesses

- Environmental changes, like moving furniture or adding obstacles, can disrupt signals, reducing sensing accuracy by up to 30% (source)
- Only 13% of adults 50+ use technology for health management, despite 69% having chronic conditions. (source)
- Approximately 47% of older adults express concerns about data privacy (source).
- Standard RF sensing devices have a 10-meter range, requiring multiple units for larger areas (source).

Threats

- 60% of healthcare data breaches stem from IoT devices, raising regulatory concerns (source).
- Initial RF sensing system setup costs exceed $10,000 per unit, limiting adoption in eldercare facilities (source).
- Approximately 40% of RF sensing systems are vulnerable to cyber-attacks (source)
- 65% of RF sensor data in healthcare is redundant, hindering analysis and decision-making (source).
- Technological Obsolescence.

***Figure 7** – SWOT Summary for the Elderly Care Application Scenario*

5. Key Performance Parameters (KPPs)

5.1.1. Overview

To evaluate the practical suitability of the HOLDEN technological innovations within the selected application scenarios, a structured set of Key Performance Parameters (KPPs) was defined. These parameters provide measurable indicators of technological performance, reliability, user relevance, and ethical compliance. A central principle of the KPP framework is that each parameter represents a minimum target requirement that technology should achieve to deliver value in a real application context. These targets are derived from the operational constraints, user interactions, and ethical considerations of each selected scenario, ensuring that system performance aligns with practical feasibility, societal expectations, and regulatory compliance. By translating contextual requirements into concrete performance values, the KPPs form a critical bridge between technological capabilities, application-specific functional requirements, and the experimental validation activities carried out in WP6 (Tasks 6.4 and 6.6). Importantly, the KPPs may be refined or adjusted based on the outcomes of validation experiments, allowing the framework to evolve as empirical evidence emerges. This iterative alignment enables a structured assessment of market readiness and supports the development of credible and realistic exploitation pathways.

5.1.2. Purpose

KPPs are intended to quantify how well each technological innovation supports the functional needs of its target application scenario:

- translate RF-sensing capabilities into measurable, application-oriented performance targets;
- provide objective and repeatable criteria for laboratory and real-world validation;
- ensure alignment with ethical, privacy, and social constraints identified in Task 6.1.

The KPP framework integrates core technical metrics, such as accuracy, responsiveness, reliability, sensing range, and robustness, with ethical and privacy safeguards, including data minimization, fairness, transparency, and user autonomy. This ensures that validation focuses not only on what the system can achieve, but also on how responsibly and acceptably it operates in practice.

KPPs also play an essential role across multiple WP6 tasks:

- Laboratory validation: establishing measurable benchmarks for assessing prototype performance;
- Real-world experiments: enabling scenario-based evaluation under realistic conditions;

- Market analysis and business planning: demonstrating quantifiable added value and supporting the development of feasible exploitation models;
- Appropriation study: ensuring compatibility with ethical principles, privacy expectations, and broader societal acceptance.

5.1.3. Methodology

The definition of KPPs followed the following approach:

1. Identification of Core RF-Sensing Capabilities
For each application, the fundamental sensing features were identified, for instance:

- detection accuracy;
- localization precision;
- sensing coverage and spatial resolution;
- system latency.

These capabilities describe what the technology should deliver at a basic operational level.

2. Integration of Application Context Conditions
Performance expectations were adapted to the application scenario constraints, such as:

- single vs. multiple active users;
- near, mid, and far sensing distances;
- line-of-sight (LOS) vs. non-LOS environments;

These conditions shape the minimum acceptable performance thresholds for each scenario.

3. Integration of Key Ethical KPPs
For each application scenario key ethical KPPs have been defined. This category of KPPs translates the project's ethical, privacy, and fairness requirements into quantifiable metrics that can be systematically monitored during design, testing, and deployment. They address critical risks such as re-identification of individuals, data exposure, fairness and accuracy across demographic or physical groups, and transparency in public spaces.
Each ethical KPP specifies what it measures, how it relates to the ethical dimension of the technology, and the target value required to demonstrate compliance.
For example, these indicators ensure that RF-based people and object detection systems deployed in contexts such as museums and airports operate in a manner that is privacy-preserving, fair, explainable, and socially acceptable. In the Elderly Care application scenario, the KPPs translate key ethical risks into measurable safeguards, ensuring privacy-by-design, user autonomy, and transparency with non-discriminatory performance. Local processing and limited data retention protect sensitive health information, while override controls and comprehension checks preserve user dignity and informed consent. Fairness and transparency measures maintain trust and usability, ensuring that the system supports care without becoming intrusive or supervisory. Finally, in the Smart TV application scenario,

although no visual imagery is captured, RF reflections can still reveal personal characteristics such as body size, motion patterns, or presence duration and may indirectly allow identification or profiling if data are mishandled. Therefore, it is essential to carefully evaluate the technology's ethical impact in this context. Although ethical, privacy, and fairness KPPs are intended to assess whether the technological innovations embed ethical and privacy-by-design principles, their full validation is not feasible at this stage. Proper evaluation would require complete, application-specific system prototypes, which are not yet available. For now, these KPPs will primarily serve as design guidelines, ensuring that ethical, social, and fairness considerations are embedded from the initial design and revisited once more mature prototypes can be assessed.

4. Derivation of Application Target Values

Target values specify the performance that technology must achieve to be viable in its intended context. This structure links **technology**, **application requirements**, and **experimental evidence**, providing a transparent and reproducible method for assessing the maturity and applicability of each innovation.

Key Performance Parameter	Available Performance	Application Target Values
Single-user detection accuracy	≥95% <1 m; 85–90% at 1–3 m; 70–80% >3 m	Reliable operation within 3 m

Table 2 *– RF Sensing Capabilities, Application performance, Target Values*

5. Experimental Validation Framework

As part of WP6 validation activities, controlled laboratory experiments are conducted to compare three key elements:

- the available performance demonstrated by the current prototypes;
- the target values derived from the application scenarios;
- the actual experimental results obtained during testing.

This comparison provides a structured and measurable assessment of how effectively technology meets real-world requirements and identifies areas where further refinement or development is needed.

Key Performance Parameters	Available Performance	Application Target Values	Experiments / Results for Validation
Detection accuracy of single targets	• ≥ 95% for distance <1 m; • 85–90% for 1–3 m; • 70–80% beyond 3 m	• Reliable recognition for near/mid range (≥85% within 3 m). • Usable up to 5 m in ideal LOS.	Single target test performing X repetitions per range: • <1 m: 96% accuracy ✅ • 1–3 m: 88% ✅ • >3 m: 72% ⚠️ (below target but still functional)
Detection accuracy of multiple targets	• 90–95% for 2 users separated >0.5 m; • 70–85% when users closer or overlapping.	• Maintain ≥80% accuracy when two users interact within 3 m.	Multi-target test (2–3): • 2 targets: 87% ✅ • 3 targets: 76% ⚠️ (slightly below target)
Coverage (sensing range)	• Reliable LOS coverage up to ~5 m.	• Minimum 4 m coverage in LOS.	Range test in home layout: • Reliable detection up to 5 m ✅

***Figure 8** – RF Sensing Capabilities and Performance, Target Values, Results for Validation*

5.1.4. KPPs for the People and Object Detection Application Scenario

This section presents the KPPs defined for the People and Object Detection application scenario, covering both categories of parameters: those related to technological performance and those addressing ethical, privacy, and fairness requirements.

<u>KPPs related to technological performance</u>

1. **Detection Accuracy**: probability of correctly detecting individuals or objects:

   a. People's presence / absence (≥ 95%)

   For people detection (even children), standing within the "ideal" (predefined/working) area in front of the system, a yes/no detection rate can be very high.

   b. Object's presence / absence (≥ 80%)

   This strongly depends on the type of object (size, material). For metallic objects larger than 15 cm x 15 cm, a yes/no detection rate is > 90%

2. **Localization accuracy**: average localization error within the environment:

The smaller the room/enclosed area, the more severe are reflections/multi-path effects which deteriorate the image quality right now. Moreover depending on the final arrangement actually the performance can be better in larger rooms/outdoors, but this is probably diminished by weaker signals/lower SNR since the transmitters might be further away/distance to objects can be larger.

   a. People's localization (<1 m)

   This value can be different for different dimensions. Transverse to the array there's the best resolution, in distance direction the resolution is far lower. The performance will also depend on the arrangement of the transmitter.

b. Object's localization (< 0.5 m)

This value can depend on the type of object (size, material).

3. **Resolution:**

   a. Ability to distinguish two closely spaced people / objects (>=0.5 m)

   b. Minimum size of people / objects that can be detected (defined by sensing hardware and frequency range)

   Minimum size is related to the probability of correctly detecting the presence of the object, defined in connection to the localization accuracy (above), e.g., metallic objects above (15 cm x 15 cm) >95% presence accuracy, smaller than (5 cm x 5 cm) > 70%.

   c. Ability to differentiate between materials (e.g., metal, plastic, wood, liquid)

   Not aimed for in the current state of the technology; requires calibration and assumptions on the objects within the region of interest.

4. **Coverage area:**

   a. Maximum range / area reliably monitored in line-of-sight (LOS) (≥ 4 m radius)

   In principle it depends on the size of the receiver array and is somehow limited to the near-field region of the array, once objects are too far away (in the far field) other performance figures will deteriorate. In addition, everything depends on the TX power/SNR at the receiver.

   b. Maximum range / area reliably monitored in non-line-of-sight (NLOS) conditions (through obstacles) (≥ 2 m radius)

   Same considerations as with LOS, here, in addition reduced due to the lower SNR caused by blockage + lower image quality due to multipath effects; so there is a factor of /2 between LOS and non-LOS.

5. **Latency:** Time delay between event occurrence and detection

   a. ≤ 1-3 seconds

6. **Reliability:** Percentage of time the system operates without service interruption or failure.
   Depending by the system complexity. Continuous operation is essential for real-time safety and security monitoring.

   a. ≥ 99% uptime (≤ 87.6 hours downtime per year)

<u>KPPs related to ethical, privacy, and fairness requirements</u>

1. Privacy

KPP	What it Measures	Target Value
Data Identifiability Risk	Probability that RF signal data (raw or derived) could be linked back to a specific person (e.g., via unique movement, body shape, or temporal patterns). Quantified through re-identification tests on anonymized datasets.	≤ 5%
Raw Data Retention (Local vs Cloud)	Proportion of total raw RF data stored and processed locally on edge devices rather than transmitted to cloud servers. Indicates how much sensitive data stays within the sensing perimeter.	≥ 70% stored locally
Anonymization Compliance	% of datasets anonymized before model training, testing, or reporting (unless explicit permission obtained). Measures compliance with data minimization and privacy-by-design.	≥ 95% anonymized

2. Accountability & Autonomy

KPP	What it Measures	Target Value
False Positive Rate (FPR)	Fraction of system detections where no human/object is actually present (false alarms). Measured per operational scenario (museum vs airport).	≤ 5%
False Negative Rate (FNR)	Fraction of missed detections (true presence not detected). Important for safety-critical zones (security gates, exits).	≤ 5%
Transparency Coverage	% of sensing zones with clear signage, notice, or digital disclosure informing visitors/staff that RF-based presence detection is active. Ensures informed awareness.	100% of zones covered

3. Equity

KPP	What it Measures	Target Value
Statistical Parity Difference (SPD)	Difference in positive detection probability across protected or contextually relevant groups (e.g., mobility aids, body sizes). Reflects fairness of detection outcomes.	≤ 0.10
Detection Rate Parity (DRP)	Ratio between detection rates for minority/atypical groups vs overall average detection rate. Applied to both museum and airport datasets.	≥ 0.90

KPI	What it Measures	Target Value
Fairness Performance Variance	Whether the system works equally well for people with different body shapes, mobility levels, or assistive devices.	≤ 0.10 difference in accuracy
Affordability & Inclusion Index	How many deployments are financially supported (e.g., insurance, municipality) so that vulnerable users are not excluded.	≥ 60% of installations supported/subsidized

5.1.5. KPPs for the Elderly Care Application Scenario

This section presents the KPPs defined for the Elderly Care Application scenario, covering both categories of parameters: those related to technological performance and those addressing ethical, privacy, and fairness requirements.

<u>KPPs related to technological performance</u>

1. **Detection Accuracy**: probability of correctly detecting one or multiple individuals and their movement patterns:

   a. People's presence / absence

   From Testhouse measurement (see Deliverable 6.4) ≥80% for 1-3 targets , ≥75% for more than 3 targets

   b. Walking (≥ 80%)

   From Testhouse measurements (using ONE single WiFi device): >95% single and >90% double target walking motion detection, 80% up to 3-4 targets, 75-70% up to 4-5, 65-60% above 5.

2. **Localization accuracy**: average positioning error (in meters) within different rooms of the monitored environment

   a. Small rooms (<10sqm) ≤ 0.5 m
   b. Medium (25-30sqm) < 0.75m
   c. Large rooms (> 30sqm) ≤ 1 m

3. **Resolution:** minimum distance at which two closely spaced individuals can be distinguished (to ensure correct assignment of events to the right person).

   a. ≤ 0.5 m

4. **Coverage area:** Maximum range or area that can be reliably monitored under (LOS provides full-room coverage; NLOS ensures monitoring through obstacles ex. walls):

From Testhouse measurements (Deliverable 6.4) 30 sqm in non-LOS. In LOS: 50sqm (in lab), 100sqm LOS and NLOS (in simulation).

5. **Latency:** Time delay (in seconds) between the occurrence of an event and its detection/notification.
    a. Walking (≤5 seconds)

6. **Reliability:** Percentage of time the system operates without service interruption or failure.
    a. ≥ 99% uptime (≤ 87.6 hours downtime/year)

<u>KPPs related to ethical, privacy, and fairness requirements</u>

1. Privacy

KPI	What it Measures	Target Value
Data Identifiability Risk	How likely it is that RF data can be traced back to a specific person.	≤ 5%
Local Processing Rate	How much data is processed and stored inside the home instead of being sent to the cloud.	≥ 70% local
Data Retention Duration	How long personal data is kept before being deleted.	≤ 30 days (unless medically needed)
Access Log Transparency	Whether users (or caregivers acting on their behalf) can see who accessed their data.	100% of accesses visible
Anonymization Compliance	How much data is anonymized before being used for analysis.	≥ 95% anonymized

2. Accountability & Autonomy

KPI	What it Measures	Target Value
Consent Comprehension Score	Whether the user/caregiver actually understands what is being monitored.	≥ 85% correct understanding
Assisted Consent Implementation	Whether the system supports caregiver-assisted consent for users who need help.	Required where needed
User Control & Override Rate	How easily users can pause, stop, or change monitoring settings.	≥ 95% of features controllable

Private Activity Protection Mode	Whether the system can be temporarily disabled during private activities (e.g., bathroom use).	Available and adjustable
False Alarm Burden	How often the system sends alerts that turn out to be unnecessary.	≤ 15% false alarms
System Explainability Score	Whether caregivers can understand and explain why the system sent (or did not send) an alert.	≥ 80% correct explanation

3. Equity

KPI	What it Measures	Target Value
Fairness Performance Variance	Whether the system works equally well for people with different body shapes, mobility levels, or assistive devices.	≤ 0.10 difference in accuracy
Affordability & Inclusion Index	How many deployments are financially supported (e.g., insurance, municipality) so that vulnerable users are not excluded.	≥ 60% of installations supported/subsidized

5.1.6. KPPs for the Smart TV Application Scenario

This section presents the KPPs defined for the Smart TV Application scenario, covering both categories of parameters: those related to technological performance and those addressing ethical, privacy, and fairness requirements.

<u>KPPs related to technological performance</u>

1. **Detection Accuracy**: probability of correct detecting for one / multiple individuals, to ensure reliable interaction and avoids false or missed commands.
   Performance depends on body orientation.
   a. Presence ≥90% is expected in LOS;
   b. Gesture ≥85% is plausible at near and mid-range (≤3 m) for a limited, well-defined gesture vocabulary and controlled conditions, at higher distances it becomes challenging because of multipath and low SNR, reflections).

   Targeting values:
   - Near (<1 m): 85–95%
   - Mid (1–3 m): 75–90%
   - Far (>3 m): 60–80%

2. **Localization accuracy**: Average positioning error for one / multiple individua within the environment surrounding the TV (line of sight):

- Near (<1 m): ≤0.3 m
- Mid (1–3 m): ≤0.5 m
- Far (>3 m): ≤1.0 m

3. **Resolution:** Ability to distinguish two closed spaced individuals and correctly attribute gestures or movements to ensure the system can differentiate users standing or sitting near each other.

    - Near (<1 m): 0.5–0.8 m
    - Mid (1–3 m): 1.0 m
    - Far (>3 m): 1.5 m

4. **Coverage area:** Maximum sensing range / area reliably monitored

    a. LOS ≤5 m
    b. Non-LOS (expected a substantially reduced effective range)

5. **Latency:** Time delay between physical movement and system response (seconds) to ensure smooth, real-time responsiveness.

    Target: ≤100–200 ms for gesture UI responsiveness.
    Maximum tolerable: ≤300–500 ms for less interactive gestures (e.g., launch/stop)

6. **Reliability:** Percentage of time the system operates without service interruption or sensing failure (continuous responsiveness is crucial for usability and user trust).
    Depending by the system complexity. Continuous operation is essential for real-time safety and security monitoring.

    a. ≥ 99% uptime (≤ 87.6 hours downtime per year)

<u>KPPs related to ethical, privacy, and fairness requirements</u>

1. Privacy

KPI	What it Measures	Target Value
Data Identifiability Risk	How likely it is that stored RF data can be traced back to a specific person that has not registered to be personally identifiable	≤ 5%
Local Processing Rate	How much data is processed and stored inside the TV instead of being sent to the cloud.	100% of all <u>raw</u> data locally – the cloud only receives data necessary for processing of

		essential or approved features 100% of all personal data stored locally unless explicit permission given for cloud features on case by case basis
Data Retention Duration	How long personal data is kept before being deleted.	≤ 1 day for non-registered users Relevent (essential for approved tasks) processed personal data for opt in users can be stored locally until storage runs out or until its use is no longer needed for approved features
Anonymization Compliance	How much data is anonymized before being used for analysis on the cloud	≥ 95% anonymized ID should be decoupled from the user for any comparative analysis

2.Accountability & Autonomy

KPI	What it Measures	Target Value
Consent Comprehension Score	Whether the user understands what is being monitored.	≥ 85% correct understanding
Manipulation	Whether opportunistic sensing is used to change user behavior especially in financially beneficial ways for smart tv shareholders. Ex: automatic TV turn on	0% non-user approved/transparent behavioral nudging 0% of **biometric** data can be sold to third parties for marketing purposes (breath, heartrate, posture, sleep tracking).
User Control & Override Rate	How easily users can pause, stop, or change data collection and storage settings	System must be able to completely shut off and stop data collection System must have a non smart mode that stops gesture features and RF data collection that can be switched on and off and is transparent when RF collection is on and biometric information is being stored

		Users should be able to opt out of all third party services
Access	Whether the users can download their data	100% of cloud data should be downloadable 100% of local processed data should be downloadable 100% of raw local data should be deletable
Bodily extension dissonance	How often the systems biometric and gesture features are innacurrate creating a sense of discomfort between the user and the system	≤ 5% inaccuracy for basic features ≤ 20% for experimental features and gestures that the user self trains
Transparency	Whether the system has an easily understandable page explaining how it works, data stored, and third party application permissions	Must be understandable to 90% of adult population in user's language
System Explainability Score	Whether system errors are presented as a manufacturer as opposed to user, error?	≥ 80% of machine errors caught

3. Equity & Sustainability

KPI	What it Measures	Target Value
Fairness Performance Variance	Whether the system works equally well for people with different body shapes, mobility levels, ages, cultures	≤ 0.10 difference in accuracy
Sustainability	How much energy the system uses compared to a standard TV when performing similar operations.	Must use <130% of energy of a regular TV when performing similar tasks 100% of features designed with energy consumption in mind. Ex: Gesture detection system should have a turn on feature to save energy, TV should not have automatic turn on unless someone is in progress of watching a show/playing a game and returns.

6. Conclusion

This deliverable has identified, evaluated, and refined a set of application scenarios aligned with the project's core technological innovations. Through a structured and collaborative methodology that also leveraged the results of previous deliverables of WP2-5, the project team selected three high-potential scenarios that best reflect realistic needs, exploitable opportunities, and technological feasibility. These scenarios now form a solid foundation for the subsequent market analysis and business planning activities to be carried out in Task 6.2 and Deliverable 6.7. The results ensure that the project's technological developments remain grounded in practical, high-value use cases and contribute to a credible exploitation pathway for the project's outcomes.

A key result of this process is the definition of Key Performance Parameters (KPPs) and target performance values for each scenario. These targets reflect both the technical capabilities demonstrated so far and the functional requirements emerging from real application contexts. They therefore serve a dual purpose: guiding the expected evolution of the technology and establishing the minimum performance thresholds required for market viability. These KPP targets will also form the baseline performance criteria for the validation activities planned in Task 6.4, where the innovation partners will perform experimental assessments of the RF-sensing technologies in controlled laboratory conditions. The alignment between application scenario requirements and measurable KPPs ensures that validation activities are not only technically meaningful but also directly relevant to future exploitation and commercialisation pathways.

Finally, this deliverable ensures that the technological efforts of the project remain tightly integrated with market needs, practical constraints, and user expectations. It establishes a clear link between early-stage research and realistic application scenarios, providing a robust foundation for market analysis, business planning, and the overall exploitation strategy.

7. References

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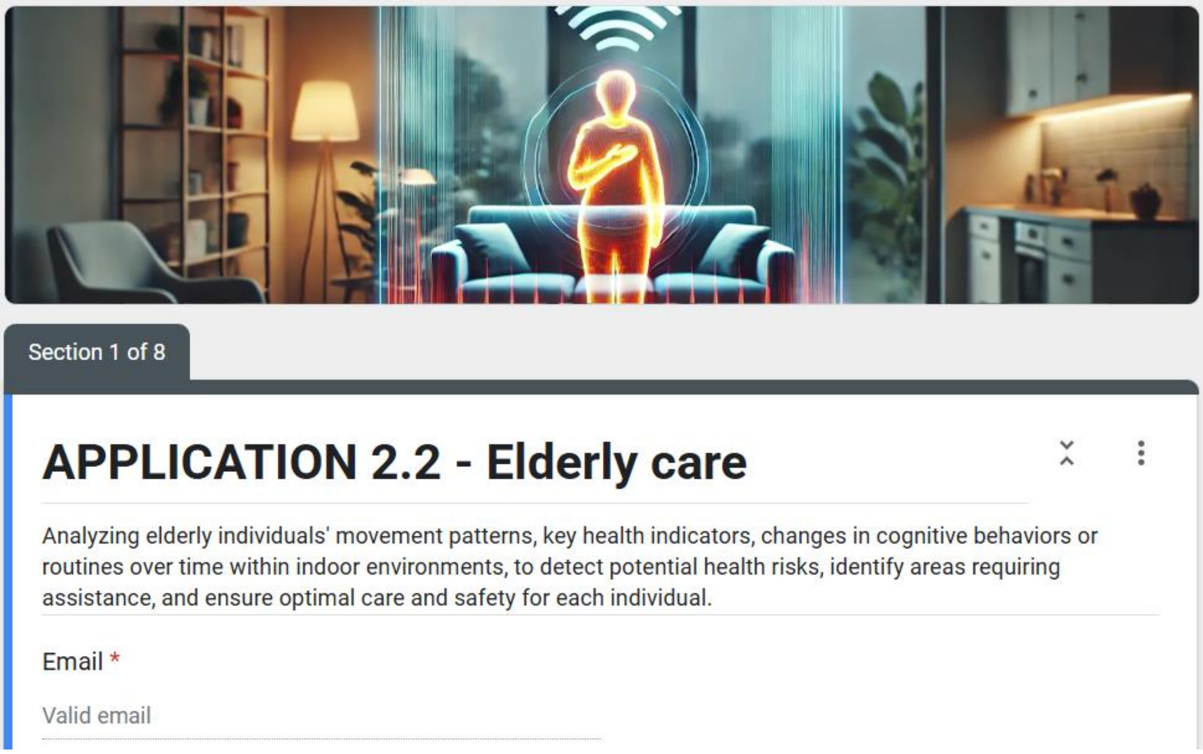
8. List of Figures

9. List of Tables

Appendix A – Application Survey Questionnaire

Example of questionnaire.



Section 1 of 8

APPLICATION 2.2 - Elderly care

Analyzing elderly individuals' movement patterns, key health indicators, changes in cognitive behaviors or routines over time within indoor environments, to detect potential health risks, identify areas requiring assistance, and ensure optimal care and safety for each individual.

Email *

Valid email

APPLICATION 2.2 - Elderly care

Analyzing elderly individuals' movement patterns, key health indicators, changes in cognitive behaviors or routines over time within indoor environments, to detect potential health risks, identify areas requiring assistance, and ensure optimal care and safety for each individual.

Email*

Name*

Surname*

Partner Institution *

1. AALTO

2. ADANT

3. CNR

4. POLIMI

5. TUM

6. TWENTE

INNOVATION

App 2.2 - Type Of Innovation

Considering this application, which type of innovation would you consider more appropriate?

1. It's appropriate for Innovation 1 - Static

2. It's appropriate for Innovation 2 - Dynamic

3. It's appropriate for Innovation 3 - Gestures

4. It can't be considered a potential application1.

App 2.2 - Technical Capability enhanced with this application

What type of technical capability does this application enhance?

1. Activity recognition

2. Imaging of objects

3. Localization & Object/People Detection

4. Gesture Detection

5. Others

If **"Others"** - What type of technical capability does this application enhance?

App 2.2 - Novelty Level

Given this application alongside the existing technologies or solutions currently in use, how groundbreaking would you rate this innovation?

(0=Not Innovative, 100=Very Innovative)

App 2.2 - Innovation Readiness

Given this application, how would you rate this innovation's readiness for commercialization?

(0=Early Concept, 100=Market Ready)

App 2.2 - Market Potential

Given this application, how would you rate this innovation's potential in relation to market conditions such as demand, segments, and attractiveness?

(0=Week, 100=Optimal)

COMPLEXITY

App 2.2 - Autonomy

Given this application, how would you rate the ease with which this innovation could function as a stand-alone module?

(0=Inoperable, 100=Autonomous)

App 2.2 - Scalability

Given this application, how would you rate the scalability of this innovation in terms of how easily it can be expanded in size or capacity?

(0=Restricted, 100=Highly Scalable)

App 2.2 - Integrability

Given this application, how would you rate the integrability of this innovation in terms of how easily it can be integrated with other systems or components?

(0=Difficult, 100=Seamlessly Integrable)

App 2.2 - Deployability

Given this application, how would you rate the deployability of this innovation in terms of how easily it can be installed and configured for operation?

(0=Complex, 100=Straightforward)

ECONOMICS

App 2.2 - Total Cost Of Ownership

Given this application, how would you rate the total cost of ownership throughout the asset's lifecycle?

(0=High Cost, 100=Cost Effective)

App 2.2 - Initial Public Funds

Given this application, how would you rate the initial need for public funds to create favorable market conditions?

(0=High Need, 100=No Need)

App 2.2 - Compelling

Given this application, how would you rate the compelling nature in attracting investors and companies in terms of return on investment (ROI)

(0=Not Attractive, 100=Highly Attractive)

PRIVACY

App 2.2 - Sensitive Data

Given this application, how would you rate the amount and level of sensitivity of the data used?

(0=Excessive, 100=Negligible)

App 2.2 - Sensitive Data Shared

Given this application, how would you rate the amount of sensitive data shared with other third-party systems?

(0=Excessive, 100=Negligible)

App 2.2 - Data Retention

Given this application, how would you rate the need for long-term and historical data storage, particularly in light of the requirement to implement this innovation?

(0=Extensive historical data storage, 100=Temporary data only)

App 2.2 - Control Over Data

Given this application, how would you rate the degree to which users have control over their data and its management

(0=No Control, 100=Full Control)

ETHICS - SOCIAL

App 2.2 - Autonomy (Individual)

Given this application, how would you rate the potential impact of this innovation on individual rights to self-governance, in terms of reduction or enhancement?

(0=Significant Reduction, 100=Significant Enhancement)

App 2.2 - Equity (Collective)

Given this application, how would you rate the potential impact of this innovation on collective well-being, equality, and safety, in terms of reduction or enhancement?

(0=Significant Reduction, 100=Significant Enhancement)

App 2.2 - Accountability

Given this application, how would you rate the accountability of this innovation in terms of precision, reliability, trustworthiness, and transparency of decision-making

(0=Not Accountable, 100=Fully Accountable)

LEGAL

App 2.2 - Ease Of Regulatory Compliance

Given this application, how would you rate the ease with which this innovation can adhere to existing laws and regulations?

(0=Challenging to Comply, 100=Easily Fully Compliant)

LAB REPRODUCIBILITY

App 2.2 - Lab Reproducibility

Given this application, how would you rate its reproducibility in a partner laboratory within the consortium?

Insights and Recommendations (If any)