



## D2.4 Responsible Design Approach

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0.1	20.03.2026	Draft	All (TWE)	First draft for circulation among our consortium partners to obtain input on technical midigation measures.
0.2	14.04.2026	Draft	All (TWE)	2 <sup>nd</sup> Draft prepared for discussion at the workshop in Prague.
0.3	12.05.2026	Draft	Nagenborg et al. (TWE)	Almost final version which incorporated the findings from the Prague Workshop.
1.0	22.05.2026	Final	Nagenborg et al. (TWE)	Final manuscript with additional input from partners.

## Executive Summary

This report addresses the results of our Responsible Design study conducted as a part of the European Innovation Council HOLDEN grant. The report examines how ethical and societal reflection can be integrated directly into the design and development of emerging RF sensing technologies. Recent developments in wireless communication, machine learning, and sensing infrastructures increasingly enable RF technologies such as Wi-Fi and 5G to function not only as communication systems, but also as systems for localization, gesture recognition, environmental sensing, and behavioral monitoring. At the same time, these developments raise important ethical and societal questions concerning privacy, autonomy, transparency, surveillance, and technologically mediated forms of visibility and control.

A central ambition of the HOLDEN project is to investigate whether RF sensing technologies could contribute to more ethically responsible forms of sensing than existing technologies such as cameras and other visually intrusive surveillance systems. Because RF sensing does not necessarily rely on directly identifiable visual imagery, the technology potentially enables forms of detection, monitoring, and care that are less intrusive while remaining functionally useful in contexts such as healthcare, elderly care, smart environments, and emergency response. At the same time, the project recognized that this ethical advantage is not guaranteed by the technology or its functionality alone, but depends strongly on ethical and social design choices, deployment conditions, governance structures, and application contexts. To address these challenges, the HOLDEN project developed a responsible design methodology combining Value Sensitive Design, Guidance Ethics, Techno-moral Scenarios, Technological Mediation Theory, Technological Gaze Theory, stakeholder workshops, exhibitions, appropriation studies, and qualitative empirical research. Together, these approaches enabled the project to identify key value tensions surrounding autonomy, privacy, transparency, fairness, trustworthiness, responsibility, and sustainability, while translating these concerns into concrete technical mitigation measures and design recommendations.

The report synthesizes the main ethical findings and mitigation strategies developed throughout the project, including recommendations regarding informed consent, selective sensing scope, local and split processing, data minimization, decentralized architectures, fairness metrics, transparency mechanisms, privacy preserving sensing representations, and confidence aware inference. Several of these recommendations were implemented by consortium partners through measures.

An important finding of the project is that responsible innovation in emerging sensing technologies cannot be reduced either to abstract ethical principles or to technical compliance alone. Ethical reflection evolved continuously alongside the technical work and was repeatedly refined through stakeholder engagement, exhibitions, technical experimentation, and changing application contexts. The project furthermore demonstrated that public engagement not only revealed concerns surrounding surveillance, privacy, and autonomy, but also showed that participants regularly recognized RF sensing as a promising and more privacy preserving alternative to camera-based monitoring in contexts such as healthcare, elderly care, and emergency response.

Finally, the report reflects critically on the HOLDEN methodology itself and formulates recommendations for future projects on RF sensing technologies and AI-driven sensing systems. The report emphasizes the importance of early use case exploration, continuous interaction between ethical researchers and technical developers, iterative stakeholder engagement, and

ethical documentation that can evolve alongside changing technologies and application contexts. More broadly, the report concludes that responsible development of emerging sensing technologies requires continuous interaction between ethical reflection, stakeholder engagement, technical experimentation, and societal feedback throughout the innovation process.

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# 1. Introduction

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## 1.1. The specific challenge of responsible RF sensing technology development

Sensors are essential building blocks of digital societies. Sensors shape visibilities, yet the choices to develop, produce, and deploy certain kinds of sensors do not always receive much systematic attention. Thus, the work towards an ethical design approach for optimal integration of ethical analysis in RF sensing technology development contributes to addressing this more general challenge. In this deliverable, we will summarize what we have learned in the context of the HOLDEN project and reflect on what could be beneficial for similar projects.

The HOLDEN project has sought to create ethical Radio-Frequency (RF) Sensing technology and provide recommendations for the technical and social mitigation necessary for morally engaged development. This new and emerging technology is potentially socially disruptive and is aided by recent progress in machine learning, chip technology and telecommunication. Essentially, progress across these fields has allowed for electromagnetic light (outside of the human visible light spectrum) that is typically used for telecommunication purposes, such as Wi-Fi and 5G to be adapted for surveillance. Radio-frequency electro-magnetic waves scatter, reflect, and interact with the environment and objects, living or otherwise within it. By understanding the nature of the movement of RF waves, the environment can be revealed.

Because RF waves do not rely on visible light, RF-based holography can operate even in complete darkness. RF waves also can travel long distances and through walls better than visible light, meaning that the waves are able to detect objects and movement through obstructions. As the infrastructures that generate RF waves continue to expand, these sensing capacities increasingly become embedded within everyday environments.

Wi-Fi and 5G are now considered to be necessities of life and are even considered by the UN to be a key infrastructure for freedom of expression, meaning that the environment of RF waves is projected to only grow denser.[1] Extended networks could join to follow or track subjects through infrastructures such as campuses, offices, airports, malls, or apartment buildings. The capabilities of this technology, that at its core utilizes the consistent speed of light to measure the distance between points to gain a sense of the shape the environment, are vast. It is possible to do movement tracking, breath and heart rate detection, activity recognition, fine gesture recognition, person recognition, and more, all in the dark and through objects that are permeable to RF waves.

The applications of such a technology are also vast. Within HOLDEN we focus on four main applications – Person Object Detection, Smart TVs, and Wi-Fi Care, which is an instrumentalization of one avenue within Wi-Fi Care. However, there are many more applications and uses being explored by groups outside our consortium (and even within our consortium on other grants and research projects) and uses yet to be discovered. Moreover, the capabilities of this technology shifts depending on the software and hardware with which it is built and encoded. A system can be built without the capability to identify individuals and then with an algorithmic update it might be able to distinguish people or vice versa. Similarly, a system might be built that only works in a set space and only collects limited data for short time periods and then the hardware is updated that lets the system “see” further and store data longer with additional storage capacity. Furthermore, the system might work better in certain environments. A building with metal walls might be too reflective for RF waves to penetrate through to adjacent rooms, while a dry wall apartment may be more easily peered through like a dollhouse.

RF holography is too open ended and context dependent to be shaped into one fixed ethical form whose morality will automatically hold across situations. What counts as acceptable or responsible use depends strongly on the specific application and context. At best, the technology can therefore be guided and constrained through application-specific frameworks that help shape it into socially acceptable forms.

This final WP2 HOLDEN report documents the development of such frameworks for the three applications explored within HOLDEN. The lessons learned from this effort to develop ethically responsible RF holography may help inform future applications of the technology, especially as interest in exploiting its still largely untapped potential is likely to grow.

## **1.2. A specific approach to enable responsible RF sensing technology development?**

Given the scope of HOLDEN's research aims, which included not only addressing ethical concerns emerging during research and development but also anticipating those likely to arise in the many possible real world implementations of RF sensing technologies, it was important to combine multiple ethical and design-oriented methodologies. Rather than relying on a single framework, the project brought together complementary approaches that each illuminated different dimensions of the ethical challenges surrounding RF sensing technologies. This combination proved particularly valuable because RF sensing technologies are highly context-dependent, can be implemented in many different ways, and may transform social practices and environments over time.

Our selected approaches each contributed distinct strengths to the project:

1. Value-Sensitive Design (VSD) and, by extension, Privacy-by-Design provided an important framework for identifying relevant values and exploring how these values might inform design choices. Within HOLDEN, VSD informed both the identification of key values and the formulation of ethically relevant design considerations. Although opportunities for large-scale stakeholder engagement remained limited during certain phases of the project, the framework nevertheless offered an important structure for identifying values at stake, clarifying possible tensions between them, and relating these tensions to design choices.
2. The Guidance Ethics Approach complemented VSD by emphasizing anticipation, moral imagination, and dialogue about emerging technologies. Even in the absence of fully operational prototypes and clearly defined stakeholder groups at the beginning of the project, the approach proved valuable because it encouraged participants to reflect on possible future applications, risks, and morally relevant changes associated with RF sensing technologies. This orientation toward anticipation and techno moral change stimulated the innovative use of interactive exhibitions and appropriation studies as alternative methods for engaging citizens and stakeholders.
3. Combined with desktop research and workshops, these exhibitions also enabled reflection on newly emerging Human Technology Relations through the lens of Technological Mediation Theory. This perspective helped us analyze how RF sensing technologies may mediate perception, behavior, decision making, and social interaction. At the same time, the project extended this mediation-oriented perspective through Technological Gaze Theory, which highlights a shift from identifiable human observers to environments that themselves sense, monitor, and interpret behavior. Surveillance is therefore no longer primarily experienced as the gaze of a visible external actor, but as an ambient and often invisible property of the technological environment itself. This is particularly relevant for RF sensing technologies, which

can operate continuously and unobtrusively through existing Wi Fi and communication infrastructures.

4. IEEE's Ethically Aligned Design ultimately played a smaller role than initially anticipated, partly because many of its methods also rely heavily on extensive stakeholder consultation processes (e.g., IEEE Std 7000 2021). Nevertheless, some of its concepts remained relevant for reflecting on smart environments and algorithmically mediated systems. In parallel, the emergence of the European AI Act increasingly shaped the broader ethical and regulatory landscape during the course of the project and therefore required growing attention.

Considering multiple approaches for both ethical analysis and ethical intervention proved valuable not only for the practical development of the project, but also from a methodological perspective. The combination of approaches helped clarify which methods were useful at different stages of technological development and under different practical constraints. Insights generated within one framework could inform the interpretation and use of insights from the others, resulting in a more layered responsible design approach for RF sensing technologies.

### 1.3. Our sources

This deliverable primarily draws upon insights found from our social impact and design-oriented work documented in the following deliverables:

- **D2.2** (Social implications and preconditions for technological design, update),
- **D2.3** (Privacy analysis and user requirements on societal implications of RF sensing),
- **D3.4** (Anticipated social implications for RF Holography in static environments following privacy by design approach),
- **D4.4** (Anticipated social implications for RF Holography in dynamic environments following privacy by design approach),
- **D5.5** (Anticipated social implications for networked data aggregation following privacy by design approach),
- **D6.1** (Functional requirements, privacy profiles for the scenarios) and
- **D6.8** (Results from the appropriation study).

Additionally, this deliverable notes the insights and techniques of the Hop-On partner, IRLaB and their work in **D9.1** (Ethical analysis of patient autonomy in healthcare for appropriate use of RF-sensing).

These aforementioned deliverables drew heavily upon research in Value Sensitive Design, Guidance Ethics, Techno-moral Scenarios, Technological Mediation Theory, Technological Gaze Theory, and Technological Environmentalism. The palliative care case explored in WP9 is grounded in bio ethics research and uses phenomenological interviews to address patient autonomy.

Work from our technical partners in terms of mitigation measures and how ethics shaped design choices is put most plainly in **D8.13** (Ethics Status Monitor). Therefore, this deliverable also cites technical mitigation decisions from that document. While WP2 was the source of ethical research and investigation with TWE at the helm, WP8 served as the holistic headquarters of ethical standards and documentation over the course of HOLDEN. Findings from deliverables across WPs gathered in WP8 and more specifically the ESM to coalesce standards created during the duration of the project.

## **1.4. Structure of the report**

In the following section, we will give an overview of the HOLDEN methodology before presenting our key findings in terms of values-at-stake and technical mitigation measures. We will focus explicitly on technical mitigation measures in the given context of ethical design approaches.

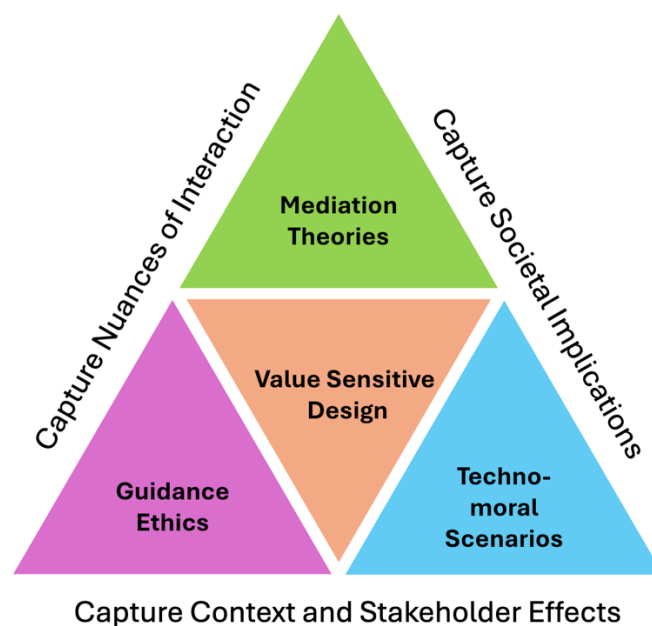
In the third section, we will reflect upon our recommendations and our methodology. Part of this reflection is the comparison with alternatives research approaches. We will focus on sensor-specific contributions to ethics as well as alternative approaches to ethics in the context of design and engineering. Here, we will explicitly address the tension between “Ethics as Research” and “Ethical Governance,” by reflecting on the EU AI Act as an example of institutionalized ethics. The section will be rounded off by reflections from our technical partners.

## 2. Lessons learned

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### 2.1. The HOLDEN methodology

The HOLDEN methodology uses insights from Mediation Theories (Technical Mediation Theory, Technological Gaze Theory, and Technological Environmentality), Value Sensitive Design, Guidance Ethics, and Techno-moral scenarios. The HOLDEN approach can be summarized in Figure 1. This approach and its benefits are further discussed in a 2026 issue of IEEE Communications Magazine titled “Holography with Dense Wireless Networks: A Case for Ethical Design”[2]. Over the course of the project six workshops were conducted based on these approaches (with the addition of phenomenological interviews that were utilized by WP9 partners in the palliative care case).



**Figure 1 HOLDEN Ethics Framework**

The HOLDEN project developed an integrated methodology to identify the most promising applications of RF sensing technologies and to turn them into concrete, ethically informed design requirements. Because several of the applications under development were still at an early stage and could not yet be tested through fully functional prototypes, the project adopted alternative methods for studying user perception and potential adoption. In particular, appropriation studies were designed to explore how people might engage with these technologies and perceive them. Public exhibitions played a central role in this approach: they created an accessible setting in which participants could encounter the technologies, reflect on possible applications (smart TV, object/person detection, elderly care), and provide feedback at their own pace, without requiring prior expertise or a long-term commitment. These exhibition-based appropriation studies were complemented by more in-depth qualitative activities, including follow-up discussions and workshops, allowing the project to capture both immediate reactions and more reflective forms of engagement.

A central element of this process was the active involvement of both internal and external stakeholders. Through structured workshops, participants were first introduced to the relevant

technologies and then invited to reflect on possible use contexts, balancing opportunities against potential risks. By alternating between groups of similar stakeholders and mixed groups, the process encouraged both depth of perspective and comparison across viewpoints. This made it possible to examine how different actors' values, expectations, and concerns might shape the acceptability and desirability of specific use cases. Participants were also asked to rank application contexts and outline ethically viable scenarios, taking into account not only social concerns but also regulatory constraints and technical conditions linked to software and hardware design.

These activities fed into a broader ethical framework developed within the project, largely centered on Value Sensitive Design. In HOLDEN, ethics is not treated as an external check applied after development, but *as a guiding principle embedded throughout the design process*. The methodology brings together several complementary approaches: it considers how technology mediates human experience, how it may reshape norms and values, how stakeholder perspectives can guide responsible innovation, and how broader normative frameworks such as contextual integrity and the EU Charter of Fundamental Rights can inform design choices. This creates a systematic way of connecting ethical reflection, stakeholder input, and technical development.

Within this framework, privacy occupies a particularly important role. HOLDEN treats privacy-sensitive design, or privacy by design, as a focused application of Value Sensitive Design, aimed at ensuring that privacy is built into the technology from the outset rather than added later as a corrective measure. More broadly, the project uses technological inquiry to compare alternative design options and assess how different technical choices may support or conflict with values such as privacy, autonomy, fairness, and trust.

The methodology then translates these ethical and conceptual insights into practical outcomes. It identifies morally relevant design alternatives and scenarios, examines their technical implications — including issues related to machine learning and networked systems — and turns the results into design requirements and operational recommendations. These recommendations extend beyond purely technical solutions, also addressing implementation issues and regulatory considerations necessary for responsible deployment.

To determine the most suitable applications for each innovation, the project finally adopted a *multi-criteria decision analysis*. This allowed different options to be assessed in a structured and transparent way according to factors such as feasibility, innovation potential, and likely market or social impact. Using the Weighted Sum Model, the project assigned weights to each evaluation criterion, scored the available options, and combined those scores into an overall ranking. In this way, HOLDEN linked ethical reflection, stakeholder engagement, technical assessment, and strategic decision-making into a single coherent process for selecting and shaping innovation pathways.

## **2.2. Synthesis of our findings**

### *2.2.1. Key values*

The following values were established as key values across different applications within the project. In earlier deliverables, we did organise our findings along considerations and challenges, which we translated for D2.4 into value conflicts. Not all these key values received the same attention in designing the technological mitigation measures, where related values also played a role. However, these key values helped us to structure our inquiries.

Following the VSD methodology, the key values were initially identified through desktop research as well as from our empirical research.

**Autonomy** is one of the key values at stake, because the HOLDEN project may contribute to a future where people have to spend more time in a sensor-networked environment with little to no option to opt out. Individuals who must engage with monitored environments will have less time in a space that offers true privacy, free from any technological gaze. Sensors also enable decision-making processes that can directly impact on the users' behaviour, which also will raise questions about truthfulness and accuracy. (D4.4) A key aspect of autonomy is, therefore, to safeguard that users remain in control. Informed consent has been traditionally a central condition for respecting autonomy, and so HOLDEN would likewise require informed consent procedures to mitigate privacy issues.

**Fairness, Equity, and Equality** also require attention, since some of the HOLDEN innovation builds on existing networks to monitor and analyze human behaviour. Given that the system works better with higher wave density, some parts of the population will be more exposed than others. On the other hand, we need to make sure that the systems work in the same manner across different user groups and is not exclusionary, especially to vulnerable populations who may benefit from HOLDEN most. The latter challenges are amplified by the use of machine learning and other data analytic techniques, which may introduce new biases. (D4.4)

**Transparency** is not only a value enshrined in the EU AI Act, but also a value that is necessary to ensure that the aforementioned values (especially autonomy) are capable of being realized. Users must be able to not only know how and why the system is running, how and why a space they are in is being monitored, but must also be able to make decisions about what is being monitored (including the decision to have monitoring turned off and to have one's data be deleted). Apps and signs can be a way to ensure transparency. (D4.4)

While **Privacy** was one of the central values guiding our research, it remained part of a broader constellation of ethical concerns addressed throughout the project. This relative emphasis on privacy may partly reflect the maturity of privacy research and privacy-sensitive design methodologies compared to some of the other values discussed here. HOLDEN explicitly sought to develop privacy-preserving forms of RF sensing by minimizing or removing potentially identifiable information such as facial characteristics. At the same time, RF sensing technologies may still collect sensitive forms of data, including medical information such as breathing patterns, and such data may potentially be combined with other datasets. This creates privacy risks that require continuous attention and mitigation. (D4.4)

**Sustainability** is a value that is becoming increasingly vital, especially in light of the climate change crisis. Thus, whenever possible we must use pre-existing infrastructure and devices, and sustainable materials, in order to prevent waste or other damage to the environment. Machine learning systems require a lot of electricity and water, and produce dangerous carbon emissions, and so this environmental impact must be limited as much as possible.

**Trustworthiness** is another key value because values such as autonomy can only be meaningfully protected if users are able to trust the system and its outputs. This means that users must be able to trust and depend on the data produced by monitoring systems, but at the same time that users not become so trusting that they become complacent when it comes to the possible need to question or even challenge the data. HOLDEN must therefore mitigate the risks of bias and inaccuracy that have been associated with machine learning systems.

One way to ensure trustworthiness is through **Responsibility**. The designers of sensor networks must be accountable for the creation of these networks, not only during the design phase, but also through the life of the project. Users must therefore be able to hold designers accountable for any issues that arise. HOLDEN has tried to ensure responsibility through our Guidance Ethics

approach, especially through holding multiple stakeholder workshops in order to bring potential users into the design process.

### ***2.2.2. Technical Mitigation Measures***

The following section summarizes the main recommendations from our previous deliverables. It also includes a temporal dimension, which distinguishes recommendations for the work in the project and for when the product is entering the market. We also include examples of how the advice has been implemented in the project or how our work contributed to addressing the recommendations at a later stage.

The implementation sections below are based on reports provided by the consortium partners. We acquired additional input during the final project meeting in Prague on May 2026. The input is referenced by "(Workshop Prague)" similar to **references** to previous deliverables.

The ESM also includes additional Technical Mitigation Measures that do not directly stem from our own ethical analysis, but for example from legal or regulatory requirements. We did not include these requirements because the following also provides us with the base for a self-evaluation of the chosen framework. We will return to the differences and the similarities between our findings and, e.g., the recommendations based on the AI Act, in our discussion in Section 3.3.

The language used in our first deliverables as well as in the ESM is slightly different from the wording used here. In the following, we will stick to "Technical Mitigation Measures" for what has been referred to as "design options" or design requirements.

#### **Autonomy / Informed consent**

To empower users to control how the HOLDEN innovations are used, protecting and fostering autonomy becomes a key challenge. The protection of autonomy is also a prerequisite to allow for forms of informed consent to mitigate privacy issues.

The most general recommendation is to maintain clear standards of what the technology is used for and can be used for (e.g., D4.4). While this recommendation mostly aims at the introduction of a corresponding policy, it is also informative for the following design decisions.

##### *R&D stage*

The system should always inform the user, when RF sensor data is collected, e.g. through a light or sound signal (D5.8).

When a commercial system is being trained on users' data, there is a strong need to obtain the informed consent of the users (which includes the consent of all persons living in a household). Informed consent is also to be obtained by all third-party applications. As usual, users need to be able to revoke their consent at any time. (D5.8)

If a system requires the registering as an individual user, the individual's clear informed consent is needed. (D5.8) In some context (e.g., safety and security), informed consent might be overruled by following other legal guidelines.

We further recommend that the system is capable of recognizing uncertainties when analyzing data and to inform the user about, e.g., conflicting interpretations of data. Ideally, the system would return the control to the users in such cases. (D5.8) We also recommend making uncertainties visible whenever data is being visualized to allow users to raise questions about such frictions and promote contestability (see below).

##### *Market-ready*

We recommend that applications such as Smart TV have a tutorial feature that explains how it works and how data management is being handled. The data should only be used for TV related activities and not become the source for nonconsensual nudging. (D5.8)

#### *Implementation in HOLDEN project*

At Aalto University, these recommendations were implemented primarily at the study-design and software-control level. In the technical studies, data collection was activated only in explicitly defined experimental sessions, with participation based on informed consent and with clear explanation of the purpose, capabilities, and limitations of the sensing system. In the current setup, explicit user notification is implemented as a dedicated hardware-level light or sound indicator; the application software running on the access point allows strict control over when sensing and recording are active, which already limits unintended data collection and provides a basis for later integration of explicit user-facing notification mechanisms.

Similar, at CNR, the application software running on the access point allows to control when data collection is activated, particularly during training phases, enabling regulation of the amount and timing of acquired data. The integration of explicit user notification mechanisms (e.g., visual or acoustic indicators) can be considered as a future extension in line with these recommendations.

At TUM, near-field measurements are currently implemented via two methods: single-antenna mechanical scanning or multi-antenna arrays. For the mechanical scanning setup, the physical movement of the antenna provides a clear, visible signal to the user. For multi-antenna arrays, indicators such as light or sound signals are possible for future implementation. Integrating informed consent mechanisms for future market-ready applications is considered technically straightforward and highly feasible.

Aalto's work also supports a stronger autonomy-oriented design for later deployment stages. The relevant HOLDEN deliverables emphasize visible notices or indicators when sensing is active, the possibility to deactivate sensing, low-confidence rejection, and explanation of system purpose and limits, especially for gesture-recognition and Smart TV use cases (see D8.1 and D8.2). In this sense, the present implementation does not yet exhaust all autonomy-related measures, but it establishes the required control points for future opt-in, user notification, and revocation mechanisms.

#### **Location and positioning**

The placement of the sensors in space as well as allowing for specifying the spatial range of the sensors are key elements in addressing privacy concerns (e.g., principle of data minimization), but also to give the users a better understanding of and control over the systems. While there might be mobile applications, stationary use was more common during the course of the project.

#### *R&D stage*

The range of data collection and, in extension, data stored should be limited. The boundaries of area, in which the data is being collected, should be evident. (D3.4) In the case of Smart TVs it should be limited to the viewing radius. (D5.8) The holographic data should not capture data outside of the restricted area. This helps fulfill expectations for implicit consent.

Sensors and emitters should be placed in such a way that they only collect the necessary data (e.g., overhead placement). (D4.4) Conscious placement can also help to avoid the challenges connected to opportunistic sensing.

Opportunities for limiting the penetration capacity should be employed to avoid collecting data from a neighbouring room in the elderly care contexts or ignoring data collected outside of certain zones in an industrial robotic factory context. (D4.4)

### *Implementation in HOLDEN project*

At Aalto University, these considerations were implemented by clearly defining the monitored area and limiting sensing to the strictly required operational zone. In the gesture-recognition and smart-living experiments, the placement of WiFi and radar devices was chosen so that only data relevant to the intended interaction space was captured, thereby reducing opportunistic sensing and unnecessary collection outside the target area. Aalto's work on sparse mmWave point clouds and direction-agnostic sensing also supports this principle, because higher-frequency and more spatially selective sensing can improve target separability while keeping the sensing scope bounded.

The current deliverables further show that Aalto's preferred technical path is selective perception rather than broad environmental capture. This includes targeted sensing scope, beam steering where applicable, and point-cloud representations that retain task-relevant motion information while avoiding richer visual-style reconstruction than necessary (see D5.4, D6.6, D7.4, D8.2). In general, the penetration has been limited to what was needed in a specific context (e.g., for the implementation in Prague). These choices support later deployment in which the sensing range can be more explicitly aligned with the intended viewing, interaction, or care area.

CNR applied these considerations in the Testhouse setup by clearly defining the monitored area and limiting the sensing range to the strictly required operational zone. The placement of WiFi devices and access points was designed to ensure that only relevant data is collected, reducing the risk of opportunistic sensing.

In addition, TUM laid down privacy and ethical considerations in D3.5, which included the following:

1. Beamforming and directional antennas to restrict data collection to specific observation domains, ensuring sensing does not exceed defined boundaries.
2. The developed localization system uses shape-specific passive tags as markers. Users can set rules to include or exclude these tags from the localization results, providing algorithmic-level control.
3. By limiting the measurement aperture or frequency bandwidth, we reduce imaging resolution. This allows for accurate positioning while preventing the reconstruction of sensitive features like faces.
4. Users have direct autonomy by rotating or modifying the tags to alter their electromagnetic scattering, allowing them to manually adjust or disable their visibility to the system.
5. On the side of the imaging algorithms, image computation is restricted to a predefined region of interest, which can be chosen such that, for example, parts of a room are completely excluded. No information about humans or objects in the excluded areas can then be obtained.

### **Fairness**

Fairness-related challenges can be distinguished into two kinds: There are general questions concerning universal accessibility and inclusion, and there are more specific questions raised by the use of machine learning (ML).

### *R&D stage*

**Inclusion:** In general, the system should work similarly for diverse individuals, regardless of size or mobility. This includes the representation of different users in visualizations and also holds true for gesture recognition. (D5.8) Aiming for a universal design is also reflected in the recommendations for using AI (especially ML). Especially in the case of gesture recognition, the

system needs to be capable of reading culturally acceptable and natural gestures, even if that means having varying options. (D5.8)

**ML:** When ML is employed, biases can arise at different stages of the workflow. Different kinds of bias in the training data can lead to unfair outcomes. In the academic literature, different kinds of biases are distinguished. Representation bias, e.g., refers to the under-representation of a group in a data set. A data set may include fewer people with disabilities, and as a consequence, the accuracy for identifying people with disabilities is lower than the accuracy for detecting abled-bodied people. Representation bias is often hard to detect because it requires a comparison with the 'real' world. It also often occurs when algorithms are transferred to a different local or social context. Therefore, at least a reliable documentation of the used data sets and, ideally, an evaluation of the quality of the data sets is required. (D4.4) As far as historical data is being used, it should be generalized unless the raw data is not necessary for the specific task the system is trying to achieve (D4.4). This measure also helps to preserve Privacy by minimizing data and promoting contextual integrity.

#### *Market-ready*

**Inclusion:** Especially in view of Smart TV applications, we strongly recommend making them operable without an account. (D5.8) This both helps to keep the technology accessible, but also supports inherent privacy-sensitive features, which can be undermined if the data is connected to an individual profile.

#### *Implementation in HOLDEN project*

The RF-based localization and holographic imaging techniques at TUM rely on physical electromagnetic scattering. This approach ensures the system functions consistently across diverse individuals regardless of body size or mobility, as it does not depend on biased biometric datasets. It does not require individual user accounts or profiling, either. Our implementation does not employ ML or AI algorithms. Therefore, challenges related to training data bias are not applicable to our current technical framework.

Aalto addressed fairness mainly through diversity-aware data collection, documentation of datasets, confidence-aware inference, and privacy-preserving model design. In the gesture-recognition work, the project explicitly recognized that performance could vary with age, body size, mobility limitations, gesture style, disability-related movement differences, and environmental context. Accordingly, Aalto's work supports review of subgroup performance, monitoring of confidence calibration, and adaptation of training data, thresholds, or privacy-preserving transforms where they degrade performance disproportionately for particular groups (see D8.1).

The following quantitative ethics metrics have been introduced D4.3 to detect and address biases:

- *Statistical parity* (to measure the difference between the probability of a prediction being positive between two different groups);
- *Equalized odds* (to ensure equal prediction accuracy across different groups);
- *Predictive equality* (to measure the accuracy balance by false positive rates), and
- *Expected Calibration Error* (ECE) (to quantify the mismatch between the accuracy and the confidence of the model). (D4.4)

Most of the implementation in D4.3 focused primarily on statistical parity, model confidence, and the balance/trade-off between classical accuracy metrics (e.g., precision and recall) and

quantitative ethics metrics. The inclusion of equalized odds and predictive equality metrics, which are also defined in the same deliverable, has been provided for completeness; however, they did not offer significant additional insights compared to statistical parity in our project.

Thus, in methodological terms, the HOLDEN work also incorporates quantitative fairness-oriented metrics such as statistical parity and expected calibration error, while equalized-odds and predictive-equality style measures remain available where they add value for a given use case.

For Aalto's contributions, the most important practical point is that fairness is not treated as separate from privacy: point-cloud abstractions, obfuscation, and minimization are combined with representativeness review and low-confidence rejection so that performance gains are not achieved at the cost of exclusion or disproportionate burden on specific users.

### **Transparency and contestability**

"Transparency" refers to the opportunity of the users to understand how the technology works and how data is being processed. As such, transparency is a condition for making informed choices (e.g., in the form of informed consent) and promotes autonomy. "Contestability" goes beyond transparency by empowering the users to question the system, correct data, and engage in dialogues with service providers and developers.

For example, if the system is clearly incorrect in its analysis of data, a user may contest the outcome and correct the data. This might be helpful to correct any shortcomings in the machine learning system as well. Contestability also needs to be understood as a way to open up the Blackbox of ML to address the political questions, which were raised, e.g., in our exhibition. (D4.4)

#### *R&D stage*

Transparency includes an opportunity for users to audit what is monitored by the system (D4.4)

#### *Market-ready*

In case that data is being stored in the cloud, users need to be able to access a log of local historical data by type and timestamp locally and for the cloud. (D5.8) All cloud data of an individual with a set profile should be downloadable and able to be deleted by that individual. (D5.8)

#### *Implementation in HOLDEN project*

TUM's holographic imaging system supports transparency by allowing users to monitor the sensing area in real-time. The technique relies on deterministic physical algorithms rather than "Blackbox" ML, any system inaccuracies can be easily identified and manually corrected or calibrated by the user through the interface. Cloud data management is so far not applicable, but highly feasible in the future.

CNR has already adopted standard cloud and data management tools to ensure appropriate storage (refer to DMP), logging, and access control functionalities. These tools provide mechanisms to manage stored data, including traceability by timestamp and data type, as well as the possibility to access, download, or delete RF measurement information where applicable.

At Aalto University, transparency and contestability were implemented through documented data-management procedures, controlled storage, logging, and participant-facing explanations during studies. The relevant project outputs specify restricted access to measurement data, separation of identifiers from scientific datasets, and use of standard storage and access-control mechanisms that support traceability by data type and time, as well as later access, download, or deletion where applicable (see D7.4). In the technical studies, participants were informed about

the sensing system's purpose, the kind of data being collected, and the capabilities and limitations of the gesture-recognition setup.

In the Prague case study, it has been considered to show the patients in real-time the output or conclusions of the sensing. However, it has eventually not been implemented because the medical personnel have advised against it. There has been the concern that the patients may be negatively affected when confronted in real-time with a confirmation that a continuous sensing process is ongoing.

For later-stage deployment, Aalto's work supports stronger transparency requirements, especially in domestic or care-related scenarios. These include visible indication that sensing is active, clear explanation of what is inferred and what is not, identification of who controls the system, and channels through which users or indirectly affected persons can raise concerns or request corrective action (see D8.1 and D8.2). Thus, while the current project setup mainly realizes transparency through controlled studies and documented data governance, it also creates the basis for more explicit user-facing transparency and contestability in future products.

## **Privacy**

### *R&D*

**Individual Privacy:** If feasible in a given context, the system should be built to recognize group patterns instead of individual people (D4.4) and to promote autonomy as well as privacy, the system must be able to fully shut off and stop collecting data. (D5.8)

### *Market-ready*

**Individual Privacy:** No historical data (post Smart TV usage) should be stored about non-registered users and non-users (for example: guests, passerby). (D5.8)

**Contextual Integrity:** Contextual integrity is a specific benchmark for informational privacy that highlights the different ways in which it is acceptable to produce and process data about individuals. Contextual integrity has been explicitly introduced to address privacy in networked systems.

In such cases, we recommend limiting the network size and how many networks can be connected together. (D4.4) The running time of specific sections of the network should also be limited (D4.4), which would allow for local networks to be switched off, if not needed. (D4.4).

In general, we recommend a decentralized network, where users can decide where the data will be processed. In general, it would be preferable to minimize the amount of data exchanged between the nodes of a network. Thus, we need to consider alternatives to centralized infrastructures like edge computing. (D4.4) Also, in the case of Smart TV, all raw data ought to be processed locally, deleting all features unnecessary for Smart TV operation before sending data to the cloud. (D5.8) We also recommend obfuscating all stored data that could potentially reveal identity to limit opportunistic sensing (D5.8)

### *Implementation in HOLDEN project*

TUM's holographic imaging system can be completely shut off at both the hardware (disabling receiving antennas) and algorithmic levels to stop data collection. For passive tag localization, unregistered users or passersby without tags are naturally excluded from the system. The holographic imaging algorithm is lightweight, allowing for full local execution or edge computing to ensure raw data remains on-site.

Aalto contributed concrete technical measures to protect privacy. In the gesture-recognition pipeline, Aalto used privacy-preserving sensing representations such as sparse point clouds

instead of richer raw modalities and developed an obfuscation filter intended to suppress identity-related information while preserving task-relevant gesture information (see D8.1). In addition, the project followed data-minimization principles by limiting retention of raw data, separating identifiers from measurement data, and favouring representations that reduce identifiable detail (see D7.4).

In the Prague implementation, the data of non-participants has been disregarded and was not stored. Given the limited size of the implementation, a cloud storage or network among sensors has not been implemented.

Aalto also worked toward decentralized and edge-oriented processing. In the relevant HOLDEN implementations, the number of sensing devices and the amount of exchanged data were intentionally constrained, and the processing chain was designed so that not all raw RF data needed to be broadly transferred or retained. This is aligned with the project's wider use of local or split processing, selective beamforming, reduced-data sensing, and targeted sensing scope (see D6.6 and D8.2). Overall, Aalto's implementation follows the recommendation to minimize exchanged and stored information while preserving the technical functionality needed for gesture and activity recognition.

In CNR's Testhouse data collection activities, we deployed a limited number of sensing devices and intentionally constrained the data exchange between the devices and the Wi-Fi access point, which operates using beamsteering technology to reduce unnecessary signal exposure. In line with D6.4 and D4.3 and D4.4, we also considered alternatives to centralized processing architectures (split learning) by implementing parts of the processing pipeline locally on each device (the access point is still the orchestrator/coordinator of the entire pipeline), avoiding the exchange of raw data whenever possible. The adopted setup limits the network size, reduces the number of interconnected nodes, and allows specific network components to be activated only when needed. Overall, the design follows a decentralized/edge-oriented approach that minimizes the amount of exchanged data and ensures that only features strictly required for the sensing task are retained, in line with the recommendations in D4.4.

### **Visualization of data**

Besides usability, the way that data is displayed might have a large impact on how well people understand how the data works. For example, there is the option to show what level of certainty the system has in a specific decision. There are also different choices to make in how a person is represented if movement is to be visualized. Are the avatars customizable? Do they reflect the sizes of individuals? Might that minimize the privacy of the system? (D4.4)

As far as the representation of users is concerned, there is a strong link to questions about Inclusion and, therefore, fairness. Making uncertainties visible would also help to protect the users' autonomy by acknowledging and demonstrating the need to make decisions. (D3.4)

#### *Implementation in HOLDEN project*

No special attention was paid to data visualizations to address the challenges mentioned above, while degrees of uncertainty were quantified via standard metrics (accuracy). Smoothing/filtering did give an impression of the accuracy of the data. Especially during the case study in Prague, our partners considered how to present the data. This suggests that visualization becomes significantly more important once technologies move closer to real-world deployment contexts. (Workshop Prague)

## **Sustainability**

Design for repair, upgrading, and recycling, power consumption, and lifecycle assessment should be on par with or equal to other TVs. (D3.4, D5.8) Chirping should only start when it is likely that someone is about to interact with the Smart TV (this may require some gestural cue that is more easily picked up on a low power setting). (D5.8)

### *Implementation in HOLDEN project*

Sustainability did not receive special attention besides considering technologies and algorithms suitable for low-power and/or low-complexity devices. TUM assumes that the energy consumption of the static system can be expected to be low, e.g., lower than that of an optical Camera. (Workshop Prague)

## **Alternative / additional technologies**

Early in the project, we specifically recommended the additional use of passive tags, which might be helpful with object tracking and differentiating between people, but do not guarantee accuracy or consent as they could be misused. (D3.4) Of course, passive tags also have a potential for misuse, especially if they have the power to shift responses from a system otherwise striving for neutrality. (D4.4) Still, we recommend considering the use of alternative technologies to overcome particular limitations of the HOLDEN innovations.

### *Implementation in HOLDEN project*

Passive tags are utilized by TUM as a technology to overcome the resolution and artifacts limits of standard RF imaging, enabling precise object tracking and differentiation between individuals. To prevent misuse, the tags are designed as user-controlled markers. While the system is optimized for tag detection, the underlying 3D holographic imaging remains functional for general spatial awareness, ensuring a balance between specialized tracking and general sensing neutrality.

Through the project CNR investigated RF sensing technologies operating at frequencies beyond Wi-Fi (see WP4 and WP5), including mmWave (70–80 GHz) and sub-THz (100–150 GHz), whose combined use is expected to mitigate some limitations observed in the 2.4/6 GHz Wi-Fi bands, particularly in terms of resolution and target separability. These technologies may provide alternative mechanisms for distinguishing objects and individuals. They also still use a passive setup, so without relying on additional tagging systems. While passive tags were initially considered as a complementary option, their potential misuse motivates the exploration of alternative sensing modalities that can achieve improved performance while maintaining alignment with the project ethical/privacy requirements.

In Aalto's HOLDEN work, passive tags were not taken forward as a core dependency of the WP5/WP6 prototypes. Instead, Aalto implemented alternative RF modalities and privacy-preserving representations that improve separability without requiring body-worn identifiers or camera-like sensing. The main technical route was sparse mmWave point-cloud sensing for gesture and motion recognition, including direction-agnostic learning across multiple azimuths. This allows robust discrimination of gestures and movement patterns while keeping the retained representation more abstract than raw visual data. In parallel, Aalto developed privacy-preserving transformations, data reduction, and an obfuscation filter to suppress identity-related information while preserving task-relevant gesture features.

These results also prepare later-stage implementation. The current project deliverables show a clear Aalto path based on higher-frequency sensing, selective beamforming, targeted sensing scope, and local or split processing so that raw RF data need not be broadly transferred or

retained. Synthetic and augmented point-cloud generation further reduce dependence on large personal-data collections. Accordingly, Aalto's preferred mitigation strategy is not additional tagging, but passive higher-frequency sensing plus privacy-aware edge processing that supports performance, proportionality, and data minimization.

## 3. Reflection and discussion

### 3.1. Analysis of and reflections on our recommendations

As indicated in Section 2.2.2, we clustered our recommendations in eight groups, of which three were based on design options (namely: Location and positioning, Visualization of data, and Alternative / additional technologies). The other groups are based on the key values.

Trustworthiness is the notable exception among the key values, as it was not translated directly into specific design recommendations despite “trust” and “trustworthiness” being central themes in AI ethics. The “Ethics Guidelines for Trustworthy AI” (2019) by the Independent High-Level Expert Group on Artificial Intelligence are a prominent example here. In the context of HOLDEN, we assumed that meeting all the other criteria will help to make the system more trustworthy without designing explicitly for trustworthiness. This is, indeed, in line with the mentioned guidelines, where trustworthy AI systems are marked by meeting seven key requirements (including, Human agency, Privacy, and Diversity).[3]

There are notable differences between the different categories regarding the number of recommendations and their specific nature. In most categories, we arrived at recommendations for both, the R&D phase as well as the future market-ready phase. Only in one case, Contextual integrity, most recommendations were actually aiming at the market-ready phase, while in all other cases, more recommendations were formulated for the R&D phase.

If we look at the implementation of the recommendations in the project, we can see that most clusters correspond with design decisions in all technological projects. We see this as a sign of a shared understanding of the ethical challenge in the project. However, it is striking that some clusters - particularly “Transparency” and “(individual) Privacy” - generated substantially more implementation activity than might be expected based on the relatively limited number of formal recommendations. Here, the technological partners implemented additional measures. We take this as an indicator that these areas are well-known in the technical communities and adequate tools are available, which help to address more common problems. At the workshop meeting in Prague, it was confirmed that “Transparency” and “Trustworthiness” are common values addressed in the involved Engineering fields, while the participants gave less emphasis on “Privacy”.

	1	2	3	4	5	6	7	8
Transparency	8							
Trustworthiness	7							
Sustainability	3							
Privacy	1							

**Table 1 – Ranking of total of weighted “values” commonly addressed in the fields of engineering of the participants of the HOLDEN workshop in Prague. We considered the first three responses and calculated the weight by subtracting the rank from 4. E.g., if a participant mentioned “Transparency” as the first value, we assigned the weight  $3=4-1$ .**

It's also worth noting that most of the recommendations do not explicitly address algorithmic challenges but have a broader scope. The notable expectations here are the recommendations regarding the use of machine learning and inclusion. Finally, as we have already pointed out, some topics (like sustainability or data visualizations) seemed to be less relevant for the technological partners.

## 3.2. Alternative Approaches and additional insights

This section maps the methodological choices made in HOLDEN against approaches developed concurrently in the literature, with the aim of identifying what could have been done differently — not as a retrospective critique, but as a resource for future projects working at the intersection of emerging sensing technology and ethical design.

The HOLDEN methodology sought to move beyond assessment from the outside and to embed ethical reflection into the design process itself. Its core toolkit — techno-moral scenarios, appropriation studies, Guidance Ethics workshops, exhibitions, and interviews — drew primarily on the anticipatory tradition of Techno-Moral Change Scenarios,[4] and oriented itself toward influencing the design of RF sensing technology before harmful configurations could solidify. This was a deliberate and coherent choice. But it also involved trade-offs, and parallel research offers a clearer view of what was gained and what was set aside.

In the following section, we provide a brief overview of alternative approaches that help clarify both the specific contribution and the potential limitations of the HOLDEN methodology. The second part is based on a presentation at Design Research Conference 2024,[5] which has been part of our preparatory work for CLICKNL's "Agenda Key Enabling Methodologies. 2024-2027." (Online: <https://www.clicknl.nl/en/the-creative-industries/key-enabling-methodologies/>) CLICKNL is the "Top Consortia for Knowledge and Innovation" for the Top Sector "Creative Industry" in the Netherlands. (Online: <https://www.clicknl.nl/en/>)

### 3.2.1. *Sensor-specific ethics: what concurrent research illuminates*

Three studies published during the HOLDEN project develop ethical frameworks directly applicable to sensor-based contexts, and each point to a gap that HOLDEN could have addressed more explicitly.

Psihogios et al. (2024) organize their ethical analysis of sensor research around the three Belmont principles — respect for persons, beneficence, and justice — and argue that children and families must not be reduced to the outputs their bodies generate for a sensor system. [6] They treat consent and assent as active design requirements rather than procedural formalities and insist that sensor-based data should never be treated as more authoritative than the lived accounts of users and caregivers. This framing is directly relevant to HOLDEN's palliative care and Wi-Fi Care use cases, where RF sensing operates in environments of vulnerability and unequal power. HOLDEN's own deliverables acknowledge the risk that sensor outputs may be trusted over subjective experience — for instance, in the concern that the system "will dictate the truth" — but the project does not mobilize an explicit principled architecture to address it. Structuring the ethical analysis of HOLDEN's care-oriented use cases around a Belmont-like framework from the outset would have provided a more systematic language for the tensions the project kept encountering around autonomy and trust.

Lahr et al. (2025), writing specifically on autonomy and sensors in healthcare contexts, draw a distinction that is directly useful for HOLDEN: sensors do not limit autonomy directly, since they

do not act on their own, but they shape it indirectly through the decisions they enable or foreclose for caregivers and staff.[7] An alert can serve either to support a person in doing what they intend, or to stop them — and the difference is not technical but organizational. Their analysis is especially relevant to HOLDEN's palliative care use case, where patients in advanced stages of dementia may be unable to provide valid consent and where decisions must rest on previously expressed values and presumed wishes. HOLDEN's own documentation raises this challenge, noting that "the more time one must spend in a sensed environment, the less autonomy they have over whether or not they are monitored", but without a systematic account of how care institutions should govern the translation of sensor outputs into decisions. Had HOLDEN developed an explicit framework for this translation layer — distinguishing configurations that extend user agency from those that constrain it — it would have moved from identifying the ethical tension to equipping practitioners to act on it.

Nhem et al. (2025) illustrate, by contrast, an approach HOLDEN was right to avoid: treating ethics as risk management, bolted onto a technological development already underway.[8] Their analysis of RF-based sensing systems acknowledges risks and proposes technical countermeasures but never confronts the fundamental tension that makes the technology ethically distinctive — namely, that it operates invisibly and cannot be disabled by the user. This is precisely the tension that the HOLDEN project took seriously and that distinguishes its methodology from a compliance-oriented approach. The comparison also underlines why the choice to embed ethical reflection within the design process, rather than appending it afterward, was not arbitrary but responsive to specific features of RF sensing as a technology.

### *3.2.2. General ethical frameworks: alternative starting premises*

At a more general methodological level, several frameworks developed in parallel offer alternative premises for how a project like HOLDEN might have been conceived.

Van de Poel's Technology-as-Social-Experiment (2011, 2013) shares HOLDEN's intuition that ethical reflection cannot be completed before a technology is deployed, since deployment itself generates new insights.[9][10] But van de Poel formalizes this into a structured approach: the conditions under which it is legitimate to introduce a technology into society mirror those governing clinical trials — phased introduction, monitoring, the possibility of withdrawal. HOLDEN gestures toward something similar in its concern with adaptability and in the temporal distinction it draws between R&D-stage and market-ready recommendations, but without explicitly framing the deployment of RF sensing systems as a social experiment with corresponding obligations of monitoring and reversibility. Making this framing explicit would have strengthened the normative basis for HOLDEN's recommendations and provided clearer criteria for when a design configuration should be considered insufficiently tested to justify deployment.

Dilemma-Driven Design treats value conflicts not as problems to be dissolved but as generative starting points for design exploration.[11] This resonates with what HOLDEN's techno-moral scenarios were intended to do — surface and make explicit the tensions latent in RF sensing — but Dilemma-Driven Design begins from the mixed emotions and conflicting intuitions already present among users, rather than from scenarios constructed by researchers. The exhibition work in HOLDEN moved in this direction, generating genuine responses from participants rather than testing pre-formulated scenarios. A more systematic application of Dilemma-Driven Design logic to the exhibition data — attending to where participants hesitated, where they expressed ambivalence, where they changed their minds — could have extracted richer design-relevant insight from material that was already collected. The risk of paternalism inherent in selecting and

framing dilemmas for users remains a genuine limitation of this approach, but one that HOLDEN's own team was well-positioned to navigate.

Critical Design [12][13] and the related Design Fiction framework [14] both produce artifacts that make future implications of technology tangible and contestable. Design Fiction in particular — which materializes possible products into "diegetic prototypes" embedded in coherent narrative worlds — shares a family resemblance with HOLDEN's appropriation studies, which were themselves conducted in the absence of fully realized prototypes. Had HOLDEN drawn more deliberately on the Design Fiction toolkit, it might have been able to produce richer speculative materials for use in the Guidance Ethics workshops and exhibitions, making the ethical stakes of specific RF sensing configurations more immediately graspable for participants without requiring them to imagine an abstract technology.

Design Justice [15] represents the sharpest alternative orientation. Where HOLDEN's methodology asked how ethical values can be integrated into a design process oriented around specific use cases and technical feasibility, Design Justice asks who bears the costs and who captures the benefits of design decisions — and insists that this question be answered before use cases are chosen. HOLDEN did incorporate an ethics rating into its use case selection architecture, which reflects a genuine sensitivity to this dimension. But the project's distributional analysis remained largely implicit. Design Justice would have demanded an explicit account of which social groups are most exposed to the risks of invisible RF surveillance — including those who cannot leave monitored environments, those whose data is most likely to be misused, and those whose interests are least represented in the design process. The values of equity and fairness that emerge prominently in HOLDEN would have been given a stronger structural foundation had this analysis been foregrounded from the project's outset.

Pluriverse Design [16][17] and Feminist HCI [18] (see also Frade et al., 2025; Freires, 2025) both challenge the premise that the design team occupies a neutral position relative to the communities it designs for. Escobar's framework treats every community as already engaged in designing itself and defines the role of the external team as contributing to that self-realization rather than solving a problem on the community's behalf. Feminist HCI asks who holds the power to define what counts as a design problem in the first place. Applied to HOLDEN, both approaches would have invited a more reflexive account of how the project's framing of its four use cases — and the selection of which ethical tensions to prioritize — was itself a set of design decisions with normative consequences. This would not have required abandoning HOLDEN's methodology, but it would have made more visible the choices embedded in its starting conditions.

### *3.2.3. A map of alternatives, not a hierarchy*

Taken together, these concurrent developments do not suggest that HOLDEN pursued the wrong methodology. They suggest, rather, that the choices it made were more consequential than any single project can fully reckon with in real time. The literature reviewed here therefore does not undermine the HOLDEN approach, but rather helps to clarify the methodological trade-offs and strengths that shaped the project. The anticipatory, design-embedded orientation that distinguishes HOLDEN from pure assessment approaches was well-suited to the specific challenges of RF sensing — a technology that is invisible, contextually adaptable, and capable of generating harms that are difficult to anticipate at the point of design. What the literature reviewed here adds is a set of more precise instruments: for structuring the ethics of consent in care contexts, for formalizing the conditions under which experimental deployment is legitimate, for extracting design insight from user ambivalence, and for anchoring the entire enterprise in a clearer account of distributional justice. Future projects working in this space will be better

equipped if they engage with this map before, rather than after, their methodological commitments are made.

More specifically, our literature review suggests, the following: The particular studies on sensor-specific ethics suggest that future work on sensors in the context of health care could adopt use the Belmont-approach to structure their inquiry and highlight the tensions related to “autonomy” and “trust.” Following Lahr et al. (2025), we also advise paying systematic attention on how institutional decision making is informed by sensor technologies and if these decisions enable or enclose opportunities of actions. This would resonate well with our discovery that Autonomy is the most relevant Key Value in our context (see above, section 2.2.1)

In accordance with Van de Poel's Technology-as-Social-Experiment, it will be helpful to frame the deployment of RF sensing systems as a social experiment with corresponding obligations of monitoring and reversibility. Making this framing explicit would strengthen the normative basis for HOLDEN's recommendations and provided clearer criteria for when a design configuration should be considered insufficiently tested to justify deployment. From Dilemma-Driven Design we can learn that we also need to focus on where users contradict themselves and where they changed their minds as it was visible in the data collected at the exhibitions.

We also recommend to draw more deliberately on the Design Fiction toolkit to produce richer speculative materials for use in the Guidance Ethics workshops and exhibitions, making the ethical stakes of specific RF sensing configurations more immediately graspable for participants without requiring them to imagine an abstract technology; and given that fairness has become a key value in our inquiries, the Design Justice framework should be considered as an important instrument in the tool box to do justice to the social groups that are most exposed to the risks.

### **3.3. Between Ethics Research and institutional forms of Ethics policies: The example of the EU AI Act**

One of the methodological challenges of an ethical-minded project such as HOLDEN is the tension between the philosophical-ethical *research* and the *ethical* governance of the project, which is based on the Ethics principles of the European Commission. In the case of HOLDEN, the tension wasn't so much caused by obvious and strong contradictions between the research results and the institutionalised forms of ethics. The main cause was the different approach: While in HOLDEN we used a very open, bottom-up approach, institutionalised forms of Ethics review is based on established principles, which precede the current project. This is not to suggest that standardized ethical guidelines are inherently problematic. After all, there is no need to reinvent established ethical frameworks for every new project. Yet, we need to realize that standardized guidelines are not neutral tools and, e.g., may give emphasis to general challenges in a specific domain, which are less relevant in the specific case.

This methodological challenge also builds on a basic assumption about Applied Philosophy, namely that application is a simple process, where an already well-defined ethical or philosophical framework is 'merely' applied to a given case. However, such a model of application doesn't do justice to the hermeneutical nature of application and the role of application in philosophical knowledge production.[19] As we have already seen, this is not the case in a project like HOLDEN.

This tension became very apparent when the European AI Act entered into force in August 2024. The original intent of the project was to use the IEEE standards connected to the Ethical Aligned Design initiative to address questions raised by the use of Machine Learning as a specific form of AI. However, since the first HOLDEN application did not use any form of Machine Learning and

Ethical Aligned Design heavily relies on stakeholder involvement (see, above), the approach didn't receive much attention at the beginning of the project.

For the 2nd and 3rd application, the use of Machine Learning became prominent and, therefore, there was a growing need to incorporate AI Ethics, including the EU AI Act. From the perspective of the EU AI Act, HOLDEN appears normatively ambitious but only partially aligned with the formal compliance structures required under the Act: it is strong in stakeholder engagement, contextual analysis, and value-sensitive design, yet it does not on its own provide the formal compliance structure required for AI systems under the Act. At the same time, from the perspective of HOLDEN, the AI Act can seem more operational than reflective: it offers binding obligations, oversight, and accountability, but it is less equipped to ask whether a technology is socially desirable in a given context or how competing values should shape design before deployment, especially since the AI Act aims at the regulation of the market for AI, rather than the research and development of AI. This also means that any application of the AI act necessitates a clear idea about the potential role of the RF sensing on the market. As a regulatory instrument, the AI act also requires detailed legal expertise which was missing in the project.

However, when looking at the "Ethics Guidelines for Trustworthy AI" (2019) by the Independent High-Level Expert Group on Artificial Intelligence,[3] we will find a lot of similarities between our findings and the guidelines, which were prepared to inform the EU AI Act as can be seen in Table ## below. These findings underline that the tensions are, indeed, rooted in different methodologies rather than the content of the values stated and recommendations given.

Key requirements for "Trustworthy AI"	Key values from HOLDEN
Human agency and oversight	Autonomy / Transparency and contestability
Privacy and data governance	Individual Privacy / Contextual Integrity
Transparency	Transparency and contestability
Diversity, non-discrimination and fairness	Fairness: Inclusion and ML
Societal and environmental well-being	Sustainability
Accountability	Contextual Integrity / Transparency and contestability

**Table 2 – Comparison between key requirements from "Ethics Guidelines for Trustworthy AI" (2019) and the key values identified in the HOLDEN project.**

In the current discussion on how to operationalize the requirements of the EU AI Act, some authors have regained interest in the IEEE standards as they might provide at least a good starting point.[20] While we couldn't make a direct contribution to this debate, this potential role of the IEEE guidelines should remain a question for future research projects.

### 3.4. Lessons learned: Reflection by the technical partners

#### Major insights

When asked, how the ethical inquiries impacted their work, some technical partners reported that they were surprised by how easily algorithms based on deterministic physical models, i.e., models without knowledge about the shape or physical properties of an object or human standing in front of an imaging system, could still lead to biased results. Even seemingly trivial design

choices, e.g., “Where shall be put the sensor array? Side wall? Ceiling?”, could indirectly create the potential for discrimination against diverse groups in society.

At the same time, certain ethical constraints would introduce additional technical problems, e.g., “How can a user opt-out of the imaging system?!” that lead to solutions which do not only make sense from an ethical point of view, but also could be beneficial from a purely technical point of view, e.g., passive tags that define areas where no image is computed, while at the same time allowing for a more precise localization of humans/objects to be tracked.

As another major takeaway, the discussion with laypersons as part of science-communication activities, e.g., exhibitions, strongly contributed to a deeper understanding of technical researchers for ethical aspects of potential realizations of the technology in the future. The results obtained from the palliative care experiment, also, showcased the extreme importance of the visual appearance of any prototype when being deployed in a real-world test scenario.

### **Formats of collaboration**

Within HOLDEN, workshops and other (online) meetings have played a central role to stimulate the discussion with our engineering partners. During our final meeting in Prague, the participants confirmed that such interactions are useful and productive. The meetings were seen most productive, when they were based on concrete (drafts of) deliverables.

It was also suggested to turn the recommendations into a joint paper. Not only should all partners be involved in writing such a paper, but it should also be published so that it can be cited in future works. This would at the same time contribute to the project’s legacy.

Our partners also indicated the need for constant exchange on a regular schedule throughout the whole runtime of the project to “identify misunderstandings, and better align ongoing and future activities” (quote from participant). The nature of the intervention may vary over time: In the beginning, the focus might be on recommendations. At a later stage of the project, the implementation of mitigation measures might be leading. At the very least, input is required during the design phase and when the technology is prototyped.

## 4. Conclusion and recommendations

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The HOLDEN project developed a responsible design approach for RF sensing technologies that aimed to integrate ethical and societal reflection directly into the design and development process. To do so, the project combined Value Sensitive Design, Guidance Ethics, Techno moral Scenarios, Technological Mediation Theory, Technological Gaze Theory, stakeholder engagement activities, appropriation studies, and qualitative empirical research. Together, these approaches enabled the project to examine not only questions of privacy and data protection, but also broader transformations in human technology relations, experiences of visibility, technologically mediated environments, and emerging forms of ambient sensing.

One important finding is that responsible design approaches for RF sensing technologies require multiple complementary methodologies rather than a single ethical framework. RF sensing technologies are highly context-dependent and can operate across very different environments, including smart living environments, gesture recognition systems, localization systems, and care-related settings. Ethical analysis therefore needs to move continuously between technical design choices, stakeholder concerns, application contexts, and broader societal implications.

The project also demonstrated that ethically relevant recommendations can already be developed before fully operational prototypes are available. Through workshops, exhibitions, interviews, appropriation studies, and interaction with technical partners, the project identified recurring concerns surrounding autonomy, privacy, transparency, fairness, responsibility, trustworthiness, and sustainability. These concerns informed recommendations regarding data minimization, selective sensing scope, local and split processing, informed consent, transparency mechanisms, confidence awareness, fairness metrics, privacy preserving sensing representations, and decentralized processing architectures.

Several of these recommendations were reflected in the technical work carried out by consortium partners. Depending on the use case and technical architecture, partners implemented measures such as local or split processing, reduced data retention, selective sensing, constrained sensing scope, point cloud abstractions, confidence aware inference, beam steering, and privacy preserving sensing representations. In several cases, the project also demonstrated that ethical concerns and technical design choices could reinforce one another. For example, reducing sensing scope or limiting retained information could simultaneously contribute to privacy protection, contextual integrity, and more targeted sensing performance. At the same time, the project showed that the implementation of ethical recommendations depends strongly on the maturity of the use case, the availability of demonstrators, and the technical constraints of the systems under development.

Another important lesson concerns the evolving nature of ethical analysis itself. Throughout the project, ethical reflection developed alongside the technical work and was repeatedly refined through interaction with technical details, stakeholder responses, exhibitions, and changing application contexts. Ethical inquiry in projects such as HOLDEN therefore does not consist simply of applying predefined ethical principles to technological systems. Ethical researchers also continuously reinterpret and refine their own concerns and conceptual frameworks while engaging with emerging technologies and interdisciplinary collaboration.

Several recommendations can be formulated for future projects working on RF sensing technologies and related AI-driven systems.

First, future projects would benefit from defining use cases earlier in the research process. Within HOLDEN, considerable time passed before some use cases became sufficiently stable for more

focused ethical analysis. In retrospect, it would have been beneficial to begin ethical investigations earlier around plausible application domains, particularly in areas such as healthcare and care environments where ethical sensitivities and socially relevant risks are already foreseeable even before technical implementations are finalized.

Second, early use case exploration should be combined with Guidance Ethics workshops and related anticipatory methods. The HOLDEN exhibitions and appropriation studies demonstrated that these approaches can generate valuable insights even in situations where prototypes are still limited or absent. This is particularly important for technologies such as RF sensing, where many ethically and socially relevant implications only become visible when participants are encouraged to imagine how sensing technologies may become embedded in everyday environments and practices.

Third, future projects should consider more flexible and continuously updated forms of ethical documentation. Several ethical concerns, technical capabilities, use case definitions, and mitigation strategies evolved substantially during the project. In this respect, more dynamic “living documents” may be better suited to interdisciplinary innovation projects than highly fixed deliverable structures that are defined early and updated only periodically. Jointly written papers could be complementary means to secure what has been established at a certain point of the project. At the same time, such dynamic approaches may not always align easily with existing European funding and reporting structures (see, section 3.3).

Fourth, future projects on RF sensing technologies should not underestimate the importance of continuous interaction between ethical researchers and technical experts throughout the development process. In the case of RF sensing, many ethically relevant characteristics of the technology, such as sensing range, wall penetration, localization precision, data granularity, beam steering, environmental sensitivity, network architecture, and possibilities for local or distributed processing, are highly dependent on technical design choices that may change during development. Especially in the absence of mature demonstrators or fully operational prototypes, ethical analysis therefore depends strongly on continuous access to technical expertise and detailed understanding of how specific sensing configurations function in practice. The HOLDEN project demonstrated that responsible design approaches are most productive when ethical reflection remains closely connected to ongoing technical experimentation and implementation choices throughout the project, rather than functioning as a separate layer of evaluation after technical decisions have already stabilized.

Fifth, future projects on RF sensing technologies should combine more top down ethical frameworks with more bottom up and anticipatory methodologies throughout the development process. The HOLDEN project demonstrated that approaches such as Value Sensitive Design and Mediation Theory are valuable for identifying broader normative concerns and transformations in human technology relations, while bottom up approaches such as Guidance Ethics, exhibitions, appropriation studies, and stakeholder workshops are essential for identifying context specific concerns, ambivalences, and socially emerging tensions that cannot easily be anticipated through abstract ethical analysis alone. Importantly, the bottom up activities not only revealed concerns surrounding surveillance, privacy, and autonomy, but also showed that participants sometimes perceived RF sensing positively, particularly as a potentially less intrusive and more privacy preserving alternative to cameras in contexts such as healthcare or emergency response. The HOLDEN methodology therefore demonstrated that neither abstract ethical analysis nor bottom up engagement is sufficient on its own: ethical frameworks help structure and interpret emerging societal responses, while bottom up approaches reveal context specific tensions, expectations, and forms of acceptance that abstract theory alone would likely overlook.

Finally, future projects on RF sensing technologies should continuously reflect on and clarify the precise form of ethical engagement guiding the project, since different forms of responsible innovation in this domain imply different ambitions and expectations. One possible orientation is highly ambitious and starts from the assumption that RF sensing technologies may help address ethical and societal problems associated with existing sensing and surveillance technologies, such as cameras or other highly intrusive monitoring systems. In this case, the focus lies not only on identifying ethical risks, but also on exploring whether alternative sensing architectures, privacy preserving representations, selective sensing, or reduced identifiability can contribute to technologically and socially preferable forms of sensing. A second, more modest orientation focuses less on solving broader surveillance problems and more on contributing to the ongoing development of RF sensing technologies themselves in ethically responsible ways. Here, the aim is not necessarily to resolve the societal tensions surrounding sensing infrastructures as such, but to help ensure that emerging RF sensing systems are developed with greater attention to privacy, transparency, autonomy, fairness, and context sensitive deployment. A third orientation operates at the methodological level by developing approaches for how emerging sensing technologies can be investigated ethically under conditions of uncertainty, evolving use cases, and incomplete prototypes, while also generating insights that may be extrapolated to future sensing applications and related technological domains. HOLDEN operated across these orientations simultaneously. Future projects would therefore benefit from periodically re-articulating which orientation primarily guides the project at different stages of development, since these orientations imply partly different expectations regarding technological development, societal impact, and criteria for success.

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