FORGING

INDUSTRY-ACADEMIA FORUM
TO UNCOVER THE POTENTIAL OF
EMERGING ENABLING TECHNOLOGIES

FORGING Value Sensitive Innovation Journey

D1.4 Innovation Journey Map – Shaping the way towards sustainable technologies

VTT

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Deliverable abstract

In this deliverable, the FORGING Value Sensitive Innovation Journey is introduced. The Value Sensitive Innovation Journey is defined for six distinct technology frameworks and offers a starting point for responsible development and implementation of emerging enabling technologies. The values highlighted in the journeys are divided in two categories: environmental and societal considerations.

There are several innovation models documented in the literature, each offering a distinctive perspective on how innovation unfolds within organizations. For sustainable and socially responsible innovation processes, equally rich research documentation exists. The FORGING Value Sensitive Innovation Journey does not aim to establish itself as a new standalone innovation model. Instead, its ambition lies in serving as a value-sensitive layer that can be overlaid onto the common steps shared by existing models, whether they follow a more linear or interactive trajectory. These universal steps encompass: 1) Research, 2) Development of concepts and products, 3) Introduction and early implementation, and 4) Scaling-up and fine-tuning established technologies.

The Innovation Journey can be used as a reflection tool to identify themes that are important in different phases of the life cycle of emerging enabling technologies, as it contains considerations that could aid in coming up with more responsible and socially desirable technological solutions. In the coming years, the FORGING project will continue to develop the journey to add more concrete tools to help in developing and implementing technology responsibly.

Keywords

Innovation, technology development, sustainability, responsibility, value sensitive

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1. Introduction

Being value sensitive and promoting sustainable development and implementation of emerging technologies is in the core of FORGING. As we take up new technologies as a part of our everyday environments and habits, understanding their social implications and sustainability aspects is vital. These implications are shaped in the development process of the technologies, as well as in the implementation decisions of new technologies. Therefore, the FORGING project wants to present this journey and offer perspectives for consideration of these value sensitive aspects.

The Industry 5.0 framing encompasses the work presented in this report. Industry 5.0 is a concept that highlights the changes to European Industry, envisioning a way towards industrial practices that support the social and environmental goals of European Union. The approach has three pillars, namely human-centricity, sustainability and resilience. Building on these three aspects, the European industrial sector is envisioned to work for the greater good of the society, including creating better conditions for industrial workers, as well as remaining competitive in longer timescales. The Industry 5.0 approach is thus central to the renewal of European industrial sector to better answer the needs of changing societal and environmental landscapes (European Commission 2022).

This deliverable builds on Industry 5.0 enabling technologies representing a complex system of combining technologies that are divided in the following six technological frameworks:

1) Human-centric solutions and human-machine-interaction
2) Bio-inspired technologies and smart materials
3) Real time-based digital twins and simulation
4) Cyber safe data transmission, storage, and analysis technologies
5) Artificial Intelligence
6) Technologies for energy efficiency and trustworthy autonomy.

These technology frameworks represent the technological enablers of the industrial shift towards the goals of Industry 5.0 (European Commission 2020). The division makes it possible to consider values in a more context specific manner. Thus, the considerations relevant to all technology development are present in the journeys but complemented by sector-specific concerns enabled by the differentiation into technology frameworks.

For each technology framework, insights from several experts are integrated into the journey, as well as desk research results. The journey builds on the previous activities of the FORGING project, especially on the Scenario Workshops conducted in 2023. In addition, an interview round with eight social sciences experts with expertise from each of the six technology frameworks was conducted and their feedback on the journey was gathered. Based on the expert evaluations and desk research, innovation journeys for each technology framework were defined, depicting a selection of value-sensitive considerations from environmental and societal perspectives that are important to be taken into account for the processes of technology development and implementation.

The FORGING Value Sensitive Innovation journey depicted in this report is meant as a starting point for technology developers, users and distributors to think about the sustainability and value alignment of their operations. From this reflexive starting point, concrete methodologies of evaluation, engagement and improvement can be envisioned. The journeys might be particularly useful for industrial agents with the aim of utilizing the enabling technologies of Industry 5.0.

In this report, the theoretical background for the value sensitive innovation journey is first introduced in chapter 2. Here, the focus is on overall understanding of sustainability, on the one hand, and on approaches for responsible technology development, on the other. In chapter 3, the building process and the structure of the journey is first introduced, followed by the Value Sensitive Innovation Journeys for each of the six technology frameworks. Finally, in chapter 4, future steps are drawn, especially regarding the building of FORGING Playbook and Toolbox with concrete examples and tools for responsible technology practices.

2. Value sensitivity and sustainability

2.1 Value sensitivity: what does it mean?

Technology impacts societies and the world around us in multiple ways, both positive and negative. Often the same exact technologies have diverse impacts depending on the perspective and the application of the technology. For example, mobile phones have immense and wide-reaching positive impacts, as they connect people across distances, offer new possibilities in an inclusive manner and bring the internet to vast masses of humanity. At the same time, the excess use of mobile phones has led to a number of quite serious negative effects, including mental health struggles in young adults (Thomee 2018) and hindering the psychosocial development of young children (Pratiwi et al. 2022). The example illustrates the intricate nature of technology impacts that need to be considered.

The struggle with designing technology with an aim towards positive impacts and the avoidance of negative impacts is the difficulty of predicting the impacts of new, emerging technologies (Brey 2017). When releasing something completely novel, often only guesses can be made of the long-term impacts it will have on society, people and the environment. During the development phase, predictions of potential impacts and adjustments based on those can still be made. Methodological choices, like diversifying the human perspectives accounted for and engaging potential user groups early on, can also steer towards more responsible innovations. Similarly, while taking up new or emerging technologies, the initial impacts can be monitored and adjustments made where needed.

Human and environmental values are not typically at the center of technological innovation processes. Yet, considerable efforts have been made in recent years to apply the concepts of ethics and sustainability in technological domain. Technology ethics has risen as a research field with strong practical embedding (see e.g. Van de Poel & Royakkers 2023; Leikas et al. 2019). Numerous practical tools have also been developed to help tackle the difficult ethical questions of technology development (see e.g. Vakkuri et al 2021; FCAI Ethics Advisory Board; Ethical Stack).

Taking a value sensitive approach, in our definition, means taking both societal and environmental concerns seriously and working towards technologies that are not only well-functioning and technologically advanced, but also account for human values and the environment, holistically improving conditions rather than harming them. Values accounted for can be multiple and various, and to define the most important ones for a certain case the FORGING Value Sensitive Innovation Journey offers starting points.

2.2 Concept of sustainability

When deciding to aim for a more sustainable future, the need to define the most important aspects of sustainability arises. Sustainability is a wide-reaching concept that entails practically all aspects of human action, from social and cultural to economic activities. One of the most frequently used definitions of sustainability is the Brundtland's committee's definition of three pillars of sustainability (Brundtland 1987). There, sustainability is conceived as comprising of three equal pillars, each of which needs to be in sustainable level for holistic sustainability to be achieved. The three pillars are *ecological, social* and *economic sustainability.* Sometimes a fourth pillar, *cultural sustainability*, is added to highlight the importance of being sensitive to the multiplicity of human cultures.

Corporations have recently made intensifying efforts to build sustainable business practices, and a distinct line of literature on corporate sustainability has been growing exponentially. In corporate sustainability and sustainability reporting, the aspects of sustainability have often been divided into three aspects that give it the widely used acronym *ESG reporting*: *ecological, social* and *governance.* Economic aspects are typically well covered with traditional business reporting, and thus ESG reporting focuses instead on fair, well defined and ethical governance practices (Dorfleitner et al. 2015).

The three pillars of sustainability are also the principle behind widely used United Nations Sustainable Development Goals (SDGs) (see https://sdgs.un.org/). The SDGs cover all three pillars of sustainability with their 17 goals and 169 targets, that are set for the year 2030. These goals and targets have the commitment of all 191 UN member states. This makes the SDG framework a powerful common language of sustainability shared by the majority of the world.

The idea of having three equal pillars has also been criticised. As the three pillars approach does not elevate any of the aspects above another, it often also leads to the conclusion that trade-offs between the aspects can be made. This can lead to the idea of compensating ecological damage with economic compensations, for example. Many critics have, however, noted that the idea of all three pillars being equal and replaceable with each other does not depict reality. Instead, ecology should be seen as the foundation for the other aspects, as without sustainable ecology, sustainable society or economics are not possible. Similarly, economy should also be seen as nested in the society, as the economy cannot exist without society (Giddings et al. 2002).

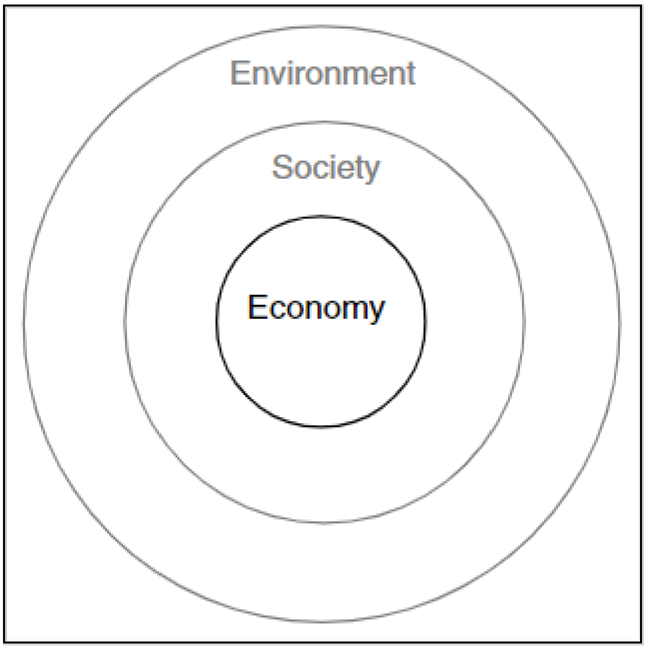

Figure 1. Three spheres of sustainability, nested in each other, as depicted by Giddings et al. (2002).

In FORGING Value Sensitive Innovation Journey, two types of concerns are highlighted. These are *societal* and *environmental considerations.* These two sustainability aspects are brought to the front because they are often not the focus on technology development yet considering them is crucial for achieving the goals of SDGs as well as the Industry 5.0 objectives. Instead of sustainability and responsibility considerations, economic values tend to be very central in technology development processes. When economic values drive the processes, wider impacts towards society and the environment can be overlooked, either purposefully or unconsciously.

2.3 Approaches to sustainable technology development and design

The need for developing technological innovations that account for human values has been long recognised. As technologies have transformed our societies in an unpreceded pace it has become clear that technologies are not ethically neutral but have strong moral implications that need to be taken seriously (Miller 2021). In contemporary societies, technologies often mediate human interactions and provide for many human needs.

Value sensitive design is one framework for designing technologies bearing in mind human values. In value sensitive design, ethical values such as privacy, autonomy and security are often highlighted. Value sensitive design offers a framework for conceptual value considerations as well as concrete technological and empirical considerations (Friedman et al. 2013). The approach also recognises the problem of often conflicting values and the need for trade-offs and compromises between different human values.

Human-centred design is another, well established and influential strain of thought, emphasising the importance of designing technology with human characteristics in mind. Human-centred design therefore departs from the user, tracing the experience and behavioural implications of different technical solutions (Boy 2017). Often the motivation for using human-centred design practices stems from the promise of enhancing human well-being as a result.

As value-based design and human-centric design practices have developed, new branches have emerged. Inclusive Design, for example, is a branch of design practices that emphasises the importance of designing technologies from the beginning to be usable for people with different abilities (Coleman et al. 2013). This covers people with disabilities as well as elderly people with limited eyesight, for example. Post-human design, on the other hand, is an interaction design framework that explores what it means to design to actors other than only humans. It accounts the growing role of AI applications as actors in networks, for example (Forlano 2017).

Another vast initiative that has brought the human values to technological pursuits has been RRI (Responsible Research and Innovation). Under the theme of RRI numerous technology projects that account for the inclusiveness, responsiveness and anticipated impacts of their projects have been conducted (Liu et al. 2022). New European Bauhaus, on the other hand, is a multidisciplinary programme that has brought technology together with human-centric design and designing for desirable societies. In the initiative, environmental values have been taken up together with more human-centered values, emphasising that to build societies that support human flourishing, harmony with the natural environment also must be achieved (New European Bauhaus 2023).

Sustainable design has emerged as an umbrella term for different types of design practices aiming for environmental sustainability. In the intellectual outset for exploring sustainability in design, the negative, concurrently with positive, effects of human design stemming from domains of engineering have been recognised. From this outset, the necessity of designing the human environments with a different mindset arises (Vallero & Brasier 2008; Baldassarre et al. 2020).

Taking the sustainability potential of design even further, regenerative design has emerged. The approach emphasises the potential of design practices for not only minimising harm but also generating benefits for the natural systems. It aims to create more sustainable relationships between humans and our natural surroundings through sustainable, regenerative design practices (Cole 2012). Design practices that consider the perspectives of other species and the natural world, the more-than-human, have also arisen (Clarke et al. 2019).

All of these different approaches emphasise different dimensions of values and offer different tools for the technology design and development process. The common idea behind all of these is that technology is not neutral but ultimately holds great meanings in terms of human values and environmental conditions. In the FORGING Value Sensitive Innovation Journey, we do not follow any single approach to implementing values, but rather aim to offer a holistic picture of the implications human and environmental values have on technology development.

2.4 Societal concerns

With societal concerns, we refer to concerns about the effects of emerging technologies towards human well-being, fairness, health, equality, and other human values. Technological innovations have significant implications towards human values such as equal opportunity for all, health and safety, social belonging, freedom of thought as well as ability to make choices about one's life. By the design of technology, solutions and applications that either support or hinder fulfilment of human needs and values can be created. The importance of socially responsible technological practices has been widely recognised in recent decades.

For any organisation working with technology, the first social concern should be the well-being of the organisation's own employees as well as employees in its value chains. Here, important aspects to consider include working conditions, equal treatment and enabling of a healthy work-life balance. These concerns apply to all sectors, regardless of the technology intensity of operations. With emerging technologies, new questions also arise, as the workers have to adapt to new practices in their job, learn to use new systems and navigate a changing cognitive environment (see e.g. Sweller 2020).

When it comes to the employees in the value chains of companies and technology developers, there persists to be constant human rights challenges in the value chains of many industry sectors (Clarke & Boersma 2015; Parella 2019). Typically, most of these violations happen in the countries of the Global South, and often in the initial stages of the value chains, such as raw material extraction and production. There are widely recognised human rights issues in, for example, the extraction of many minerals necessary for digitalisation (Church & Crawford 2020). As many of these violations happen in the earlier phases of the value chain and outside of Europe, there has long been a common mindset that these issues could not be solved in Europe. Now, however, the European Union is placing strong laws against human rights violations anywhere in the world at any stage of a value chain (European Parliament 2023), and responsibility must be taken by European actors.

In addition to violent violations of human rights, the more subtle impacts of technologies in the social structure of societies should be recognised and considered. Technological advancements have already radically changed most aspects of human life, from communication to work to healthcare. The way technologies are designed, has deep-cutting consequences to the quality of communication, inclusion of different groups as well as our time use and ability to use our capacities. As a response to technology development that has not always taken seriously the human factor, new schools of thought, such as human centric design introduced above, have arose.

When developing and implementing emerging technologies, social and societal issues cannot be ignored. In many stages along the development and implementation journey there are possibilities to choose differently, either supporting or eradicating human rights and social values. In the FORGING value sensitive innovation journey, examples of such choices will be given. The aim is to help technology developers and implementers think about societal and social values in a more comprehensive way in their work.

2.5 Ecological concerns

From the point of view of ecological systems, contemporary patterns of production and consumption, including but not limited to technology, are unsustainable. This is illustrated by the nine planetary boundaries, six of which have already been exceeded (Richardson et al. 2023). This means that the current amount of resource use and waste production can't be maintained without destroying the ecological systems of the Earth. As we as humans are part of these ecological systems, the implications are dire also to human populations across the globe.

One line of responses to the ecological crisis we are facing is the expectation that new technologies will emerge and help turn the tide. Green technologies, such as electric cars, solar panels and plant-based plastics, have been celebrated for this reason. They are technological responses to the constant consumption demands that have become problematic with the degradation of environment. These new technologies help reduce environmental footprint of human activities by decreasing the need for fossil fuel-based energy and materials, for example. Green technology is not environmentally neutral, but it has a moderate effect on environmental footprint of technology (Du & Li 2019). As contemporary societies are dependent on many essentially unsustainable technologies, such as private cars, green technologies can give us time to reconsider our patterns of consumption as they enable cutting emissions without major changes in human behaviour and societal structures.

Another widely celebrated, ecologically motivated model that has strong implications for technology development is circular economy. Circular economy aims at using the materials already at use as long and efficiently as possible. Therefore, concepts like recycling and reusing are central to the idea (Kirchherr et al. 2017). This idea has far-reaching consequences to the ways technology should be designed and utilized. For example, designing technologies in a way that allows for replacement of critical parts and recycling of components after disposal are practices that can be associated with circular economy (van den Berg & Bakker 2015).

Digitalisation has sometimes been celebrated as a green practice, where the use of materials can be reduced since more things can be possessed and more activities conducted virtually. Signals of even fashion turning increasingly virtual have been seen (see Vogue Business 2023). However, in recent years, more researchers have started to point out the material reality of digitalisation; that is, the increased energy demand, computing power and battery capacities needed (Gensch et al. 2017). The production in ever higher volume of these goods while pivoting back towards the planetary boundaries is not a simple task. When developing emerging digital technologies, in addition to considering the material reality of the hardware, the software can also be designed using methods that account for environmental sustainability (Heithoff et al. 2023).

As ecological concerns with technology are multiple and often difficult by nature, carefully assessing the current and potential future impacts of any technology is important. It is highly recommendable to use systematic methods, such as Life Cycle Assessment (LCA) and Biodiversity Impact Assessment, as much as possible, to truly map and calculate the possible environmental impacts. The FORGING Value Sensitive Innovation Journey offers a starting point to evaluating and deciding which actions should be taken and which methods utilised.

3. FORGING Value Sensitive Innovation Journey step-by-step

3.1 Methodological notes of building the Value Sensitive Innovation Journey

Next, we will present the FORGING Value Sensitive innovation journey step-by-step. Nevertheless, as described in chapter 3.3, the journey is not designed to be implemented in a chronological step-by-step manner. Rather, the journey is to be picked up from any phase relevant for practitioners and used to an extent that is useful in any particular situation.

The Value Sensitive Innovation Journey has been built using multiple sources and rounds of iteration. First, the building blocks for the innovation journey derive from previous approaches to responsible and sustainable innovation, described in chapter 2.

Secondly, for technology specific value considerations, the material produced in the Future Scenarios Workshops was utilised as a starting point (described in detail in D3.1). In these workshops, technology experts were invited to imagine a future where the technologies have unfolded further, setting the target year to 2050. Wide societal perspectives were encouraged, using PESTEC framework (political, ecological, social, technological, economic, cultural). The workshops produced a rich material with both hopes and fears related to each of the six technological frameworks.

Thirdly, the innovation journey was replenished with important societal and environmental considerations by desk research. In this phase, literature concerning sustainable business practices and sustainable technology development was utilised.

Finally, the Value Sensitive Innovation Journey was piloted with a set of eight social sciences and humanities experts, representing expertise of all the six technology frameworks. The experts were offered an opportunity to comment on all of the aspects of the journey, as well as encouraged to talk about these issues more widely based on their expertise. In this phase, some of the contents were modified and new concerns were added. Generally, the experts confirmed that the journey contained legitimate concerns related to all the six technological frameworks that really should be considered in technological practices.

3.2 The four phases of the journey

The Forging Value Sensitive Innovation journey has four key stages, which will be introduced in detail in next chapter and are named as follows: 1) Research, 2) Development of concepts and products, 3) Introduction and early implementation and 4) Scaling up and fine-tuning established technologies. In technology development and implementation, these phases don't typically follow each other in a chronological order. Instead, there are usually many feedback loops and the evolving technologies move through different stages multiple times in a non-linear manner (Muller 2013).

There are numerous previous presentations of innovation and technology implementation processes in the form of different phases. A concept of technology readiness level (TRL) is a widely used scale, where technologies are rated based on how close to an actual operational system they are (see Mankins 1995). Other descriptions of innovation phases also exist, such as the five-stage model of Auerswald and Branscomb (2003), where technologies are depicted to develop through the stages of 1) research, 2) concept or invention, 3) early-stage technology development, 4) product development and 5) production and marketing. Yet another model, focusing on the capacities needed for innovation activities and recognising continuous feedback loops between different stages comes from, proposes four important phases that lead to diffusion and growth of innovations: 1) idea creation, 2) idea selection, 3) implementation and 4) routinisation (Boukamel et al. 2019).

Different models also exist for the introduction, implementation and diffusion of technologies. One commonly used model is the hype cycle. It depicts the technology's journey from introduction through inflated expectations and following disappointment to its maturity and recovery of reasonable expectations (Dedehayir & Steinert 2016). Another common depiction is the Technology Adoption Curve that describes how new technologies are taken up by different consumer groups at different times (Lai 2017).

In the FORGING Value Sensitive Innovation Journey, we have taken inspiration from various previous depictions of technology development and implementation summarising the phases to the four key stages mentioned above. The FORGING innovation journey thus maps the way from scientific basic research to the diffusion to wider user groups in the four phases. The journey recognises that there are usually many overlaps with the stages and feedback loops that together form the overall evolution of technological innovations. There is fluctuance between the different phases and instances of returning to a previous phase.

Additionally, as technological innovations move through the different phases of the journey, they typically do not stay in one person's desk. Instead, it is common that research is committed in one unit, and the development of a product takes place in a different unit. For one person working with technological innovation, the journey does not typically start from research and end with commercial scaling-up. Instead, one person or working group might handle one or two of the phases, and the technology might then disappear from their work desks to perhaps reappear in an evolved state later.

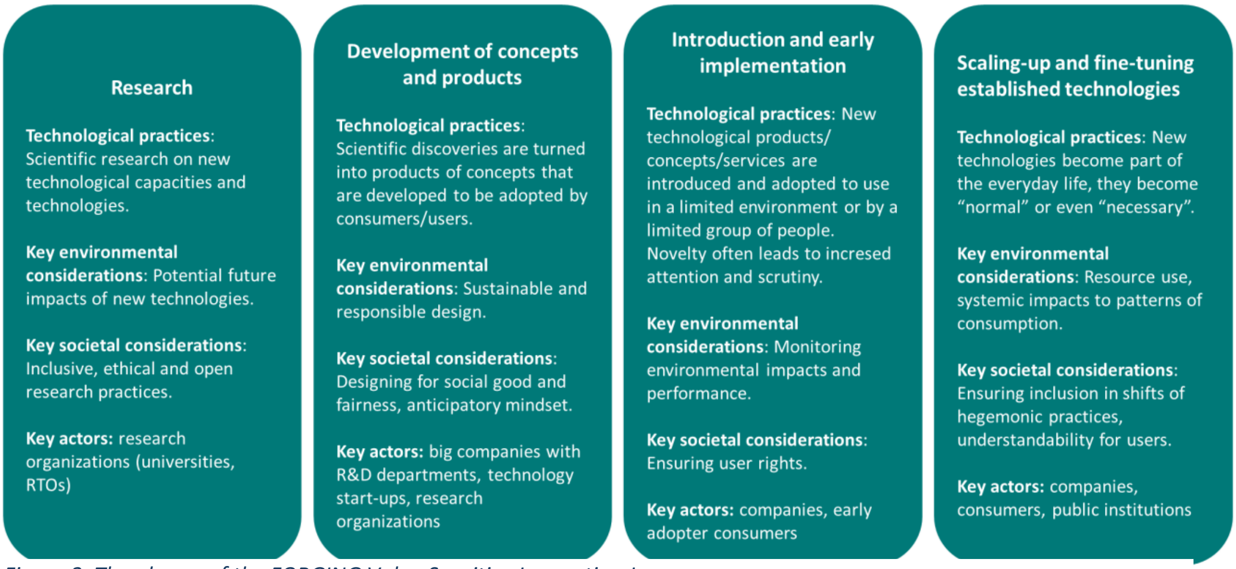

Figure 2. The phases of the FORGING Value Sensitive Innovation Journey.

For these reasons, the Forging Value Sensitive Innovation Journey is built in a way that allows starting from any of the four phases and only using the parts that are relevant for a certain project, unit or person. We recognize the multiple trajectories of the realities of innovative technological work. The separation of different stages is considered useful because the sustainability and responsibility questions that need to be considered vary between the stages of technology development, even though the borders between the stages and thus also the relevant responsibility questions are not clear-cut.

3.3 Utilising the Journey: general guidelines

As a technology developer or user wishing to make use of the journey, we want to offer you a few general guidelines for utilising the journey. The journey consists of considerations, both ecological and social, that could be relevant to different actors working with emerging technologies. Especially the journey is envisioned to be useful for industrial companies looking to make a transition towards integrating Industry 5.0 principles. The Industry 5.0 framework describes the next step of European industrial sector, with a goal of bringing prosperity to European citizens through industrial practices that have positive impacts for the whole society and nature around us. The Industry 5.0 approach can be summarised in three key principles, that are human-centricity, sustainability and resilience (European Commission 2021).

In the FORGING Value Sensitive Innovation Journey, these principles are translated into considerations about the environmental impact of technologies as well as the societal and social consequences these emerging technologies might have. In addition to industrial companies, the journey is drafted in a way that could also be useful for other organisations working with emerging technologies, such as research teams or public organisations.

To utilise the FORGING Value Sensitive Innovation Journey in the quest for more sustainable and human-centric technology use, start from the technology frameworks that your organisation is currently using or planning to use in the near future. Utilising multiple frameworks can offer the best reflection point for the unique situations of different organisations. Keep an open mind, as companies and other organisations usually have impacts that reach wider than the organisation structure, even though the impacts for surrounding society, customers or ecosystems are not always visible with the measurement practices currently utilised.

Start from the phase of the Innovation Journey that best describes the current practices in your organisation. Keep in mind, that the journey phases do not always chronologically align in a consecutive manner, but movement between different phases happens in all directions. Therefore, it might be useful to go through the whole journey for the relevant technology framework before picking out the considerations most relevant to your case.

When going through the Innovation journey, to truly identify the aspects that could be important to work with in your organisation, a reflective mindset is crucial. Some of the considerations might sound either self-evident or too distant to the concrete work with technologies, but with closer reflection they might reveal important aspects that are easily overlooked in the everyday technological practices. Therefore, to help utilising the journey in a truly fruitful manner, we offer a few reflective questions that can be asked when reading through different considerations of the journey. These questions work as a critical interrogation tool for technology practices of organisations, whatever phase they are currently tackling.

Some questions to ask yourself while going through the journey:

- **Are the considerations of the FORGING Value Sensitive Innovation Journey already considered in your work?**

- **How could you (individually and as an organization) take the considerations of the Innovation Journey into account better?**
- **Who´s help would you need to better integrate the considerations to your technological practices? Who should you discuss, ideate and reflect with?**
- **Do your project’s KPIs or other evaluation measures track the integration of the considerations of the Innovation Journey? Should new KPIs or data points be introduced to better track the impacts related to these considerations?**
- **How could you evaluate the responsibility of the technological practices in your organisation? Remember that evaluating ethical performance can call for qualitative as well as numeric evaluation data.**

3.4 The FORGING Value Sensitive Innovation Journeys

Artificial intelligence

Intro

Responsibility of AI has recently been widely discussed in the scientific community. We see AI taking over at the moment in a quick pace that makes even keeping up with AI developments almost impossible for experts, and even more so for consumers.

Potentials:

•AI has the potential to transform many aspects of human lives, such as working life, consumption and learning. AI can make many mundane tasks easier.

•If used wisely, AI applications hold the power to aid in making better decisions, and navigating complexities of the modern world.

•AI might be able to share some ethical values with humans in the future.

•AI can interact with human intelligence in ways that enrich our capacities.

•AI is learning to create also culture and art, traditionally believed to be exclusive to humans.

Risks:

•AI might reduce need for human workforce in many areas, possibly leading to unemployment.

•If not understood and regulated well enough, AI might also hold the power to steer societal discussions and political realities in directions that might enforce divisions.

•Developments in AI and language generation that leaves invisible the original (human) sources of information hold risks for eradicating trust in society, as facts and fabrications become more difficult to differentiate.

•AI technologies might become so good at interaction that they will be impossible to differentiate from real humans. This might also have implications to how we treat our fellow humans.

•AI might contribute to creating technology-driven bubbles that can lead to increasing amounts of loneliness and isolation.

1: Research

- New capacities for AI are being researched all the time.
- In AI development, this phase includes basic research on technological capabilities and the limits of possibilities of artificial intelligence, increasing computing power and innovating new enabling hardware solutions.

Ecological considerations

•Developing more ecological hardware solutions: Exploring new, ecological materials or recycling solutions.

•Developing efficient software solutions: Developing solutions that require relatively less computing power. Is it possible to move towards use of representative data instead of large data masses?

Societal considerations

•Licensing and open-source: Purposefully balancing between open science and protecting intellectual property rights. Preventing potential misuse of data or technologies should be considered when making these decisions, as well as the use purposes that might require licensing.

•Inclusiveness of research practices: When research groups are diverse in composition, and different citizen groups are engaged in the research project whenever possible, the results are more likely to be usable and beneficial for larger groups of people.

2: Development of concepts and products

- AI develops at an unprecedented pace right now, new innovations and application areas appearing.
- With AI, this phase includes the translation of technological capabilities into concrete AI applications. In this phase, different application areas and opportunities of utilizing AI are considered.

Ecological considerations

• Environmental data for AI: when AI is applied to an area that can have ecologically impactful outcomes (e.g. industry), adequate attention should be paid to using enough high-quality environmental data in the AI modelling, optimizing the outcomes as ecologically as possible.

• AI working in a way that helps make processes more ecological: AI technologies such as environmental modeling and AI aided optimization hold significant potential for environmental performance of technologies.

Societal considerations

• Future considerations: Often the future implications of technologies that are developed now can seem irrelevant, but the first applications can be important in creating path dependencies that either preserve or harm human values in the future.

• Considering public perceptions of AI technologies: the research should be conducted in a societally acceptable and ethical way, taking into account and mapping public perceptions of AI use. When necessary, the decision to not develop AI applications for certain functions should be taken.

• Privacy: AI applications are often data intensive. When planning the data use, privacy of individuals should be taken seriously, considering the implications using their data in training AI can have.

3: Introduction and early implementation

- New AI applications are introduced to consumers all the time. As they are new and unlike anything before, they can receive high level of public interest on their release. For example, generative AI is discussed widely right now, and the opportunities offered by it are being actively explored by many users. On the other hand, novelty makes new applications hard to understand.
- Research on the application of AI for e.g. autonomous vehicles is right now aiming for commercialization in the coming years.

Ecological considerations

• Monitoring impacts: as new AI applications are taken up, is their environmental impact being monitored? Especially important might be with environmentally sensitive application areas, e.g. in industry.

Societal considerations

• Target groups: Vulnerable groups, such as children and elderly, should be protected from harmful use of AI. They should have a chance of understanding that they are using AI (as opposed to e.g. chatting with a human) and what that means for them, e.g. through gathering data about them.

• Differentiation of humans and artificial intelligence: New AI applications can resemble human interaction and thought patterns in a believable manner. If we start treating artificial intelligence as we would humans, this can lead to deep issues and have implications to even human rights.

• Preventing biased decision making: AI models trained using data describing the existing society tend to omit human biases. When taking up new AI applications, it is therefore crucial to ensure the data used for training is unbiased or the biases are corrected as much as possible.

4: Scaling-up and fine-tuning established technologies

- As technologies become normalized part of our everyday practices, their basic premises are usually not questioned so much anymore. However, it remains important to stay aware of the ethical, ecological and societal impacts of technologies. For example, the algorithms used by all big social media sites at the moment use AI that shapes our perceptions of the world in a powerful way, even though they are often unnoticeable in everyday use.

Ecological considerations

• Energy use: AI can sometimes be energy intensive as opposed to e.g. using human decision making. The use of AI - compared to other technologies - should be considered, choosing the most efficient and purposeful technology that can be used.

Societal considerations

• Autonomy: AI should be applied in a way that allows users to preserve their autonomy. One part of this is that users can opt out from the use of AI applications that could potentially be harmful for them.

• Explainability: The AI systems that are widely used should be also publicly explained in a manner that allows users to understand their function and implications.

• Human connections: even when the use of AI applications is booming, it should be ensured they don't isolate people in technological bubbles but human connections remain.

Real-time based digital twins and simulation

Intro

Simulations, modelling and digital twins are taking huge leaps at the moment, both in early development and practical applications. Computing power and lack of good quality data form barriers to what can be currently modelled, but quantum computing is expected to help solve these problems.

Potentials:

• Improved data use and new digital tools can produce better predictions and help in making better decisions.

• Virtual spaces can complement mobility, replace much of travelling and create new connections without place-dependency.

• Modelling of complex systems (even ecosystems and societies) with quantum computing can help

Risks:

• Living in digital worlds more and more can lead to physical loneliness, as people will likely still crave and need physical closeness.

• Care might become more digital, as it is too expensive to keep human workforce –based system running, yet digital twins and virtual environments might not be as good in answering to human needs.

in achieving environmental sustainability and social fairness.
• Digital avatars and working spaces might allow active life to people who can't move and be active in the physical world.
• Visualisation of alternative futures through modelling holds potential for e.g. involving citizens in urban planning.

• As data use is amplified, taking care of individuals privacy might become challenging.
• There is a risk of big tech companies attaining monopoly of digital twin and simulation technologies
• The systemic implications of e.g. modeling human activities in industrial settings might ultimately be harmful to humans.

1: Research

- Simulations and digital twins are based on on-going vast research efforts, and the potential complexity of modelled entities gets greater all the time.
- Related to digital twins and simulations, research phase includes development of computing potential for ever more complex systems and researching on new immersive simulation technologies, for example, as well as sensor development to enable information collection and developing a digital twin of a physical system.

Ecological considerations

• Computing power and electricity use: digital twins and simulations use computing power intensively. Even in the basic research phase the question of energy use and needed computing power should be kept in mind, possibly developing solutions that are less intensive or not developing solutions that could replace more efficient practices.

Societal considerations

• Data privacy: At all points in the development of digital modelling solutions, individuals' right to privacy should be respected, even if this puts limitations to the research.
• Inclusion: As new immersive and interactive solutions are developed, usability, functionality and affordability to all groups should be ensured as well as possible.
• Purpose: There should be more consideration of the fundamental motivations behind technology development, and discussion in order to define shared visions for the society.

2: Development of concepts and products

- As new capabilities emerge, new application areas are developed all the time. At the moment, digital twin based solutions for industrial environments are visioned, for example.
- The challenge is how to bridge the gap between the virtual and real worlds, recognising the economic, social, political, psychological etc. constraints.

Ecological considerations

Societal considerations

• Modelling environmental impacts: when developing models for application areas that have impact on the environment (e.g. industry), building in environmental optimization with high quality data and enough variables can lead to considerably more eco-friendly results.
• Energy use considerations: Sometimes using modelling and AI applications can be more energy intensive than using human labour. If this seems to be the case, the distribution of work between automation and human workforce is good to consider also from this perspective.

• Licensing and openness: when developing new products based on modelling or digital twin technologies, it is good to consider the level of openness regarding the data used and the functioning of the application. Generally, openness is considered to lead to more democratic technology environment as consumers can get information about the technology they use.

3: Introduction and early implementation

- Digital twin and simulation technologies are currently entering many new fronts. They are tested e.g. in forerunner companies of manufacturing industry.
- There is a strong need for multidisciplinary foresight units in both business and the public sector to understand the implications of new technologies, using e.g. science fiction prototyping.

Ecological considerations
• Environmental data quality and comprehensiveness: as environmental modelling is taken up, it should be ensured that enough high quality environmental data covering all important environmental issues is used. If a system is optimised only for its carbon balance, for example, it may still end up producing other type of environmental damage.

Societal considerations
• Inclusivity: when testing new solutions with users and starting a scale up, it is important to remember that a solution that works well with some groups might be completely inaccessible for others. Therefore, care should be taken to account for the needs of different groups.
• Fairness in using test-phase technology: when new solutions are first introduced, they should be treated as experimental and older, alternative back-up systems should be kept up long enough. A complex modelling technology might reveal some unintended features only when used in large scale.
• Privacy and data security: as data intensive applications are taken up in new sectors and environments, the privacy of users as well as companies should be carefully ensured.

4: Scaling-up and fine-tuning established technologies

- As new technologies become mainstream solutions, they reach more people and have more impacts than before. They can also become invisible and unnoticed, yet there are many important responsibility factors to consider.

Ecological considerations

- Replacing mobility: digital twin and simulation technology enables conducting many tasks without physical presence. As these established solutions emerge, many businesses can consider using them instead of travelling.

Societal considerations

• Physical needs: as virtual solutions are scaled up it should be carefully ensured they don't replace important physical services and leave people lacking in their physical needs. In some domains it might be better to not have a virtual solution at all, and in other domains it might be good only as supplementing the physical work.

• Reality +: novel ways of being in the augmented world have broad based implications for societies.

Cyber safe data transmission, storage, and analysis technologies

Intro

More and more data, including personal data about people, is generated and analyzed all the time. As the amount of data is increasing rapidly data security is becoming even more important. Responsible data processing protects people and their privacy. At the same time, it ensures responsible data use and utilization.

Potentials:

• Strong regulations about data safety and privacy are needed, as life moves more and more into the digital realm. Well justified, strong regulation is likely to be widely accepted.

• Data ownership could be decentralized to distribute it more widely. Potential for new, more distributed data economy where more people would benefit also exists.

• With adequate education, individuals could be more active in taking care of their own privacy and data security.

Risks:

• With data accumulation, huge power is centralizing to few big players. People might not realise what this means for them and possibly can't protect themselves.

• Societies are becoming dependent on a few critical virtual infrastructures, and cyber-attacks to those systems could cause enormous harms. Cyber-attacks can even be used as a weapon in warfare.

• If code efficiency is not carefully planned for, this could lead to excessive energy use.

• Safe online environments ultimately enable digitalization and new, virtual realities that are emerging.

• With increasing data available for powerful players, dissident voices may be more and more at risk.

1: Research

- Cyber security and data management form large research fields. As the pace of development is very high, even keeping up with criminals and hackers can sometimes be a challenge. As digital systems are vital to modern societies, cutting-edge research holds enormous importance.

Ecological considerations

• Code efficiency and energy use: cyber security as well as data management are often heavy processes that can use plenty of electricity. When developing the solutions, there is room to influence the amount of energy used by e.g. improving code efficiency.

Societal considerations

• Licensing and openness: Open science usually aids in taking up novel technologies in different sectors and can lead to faster development. However, openness needs to be balanced with concerns of security, ownership and financial utilisation in many cases.

• Safety: Security solutions should be based on the principle that the mechanism is so good that even if it is known to the other party, the counterparty still cannot violate it.

2: Development of concepts and products

- As new breakthroughs are made, they still need to be turned into practical products. Packaging the new solutions in a responsible manner can sometimes be a challenge when talking about data intensive products.

Ecological considerations

• Material reality of digital solutions: Even digital solutions always require a material basis that consists of computers, batteries, wires… As new digital software solutions are developed, their effect on the need for this material basis can be considered through e.g. capacity needed and suitability of software to existing (and old) hardware.

Societal considerations

• Data ownership models: many apps and companies collect data about individuals and sell it further. These models are likely to be restricted in the future as legislation evolves. Models for individual data ownership are still developing, and should be developed in a fair and inclusive way that offers opportunities for real agency for users.

• Anticipatory approach: Developers should move beyond identifying and fixing security vulnerabilities as they are discovered and embrace more proactively a risk modeling approach that identifies and address risks before they can be exploited.

3: Introduction and early implementation

- With digital services and products, the pace of development is fast, and there are always many new things entering the digital markets. Consumers can't always keep up on the newest trends in data management and digital solutions, even when they are directly affected.

Ecological considerations

• Environmental data: As new data intensive solutions are taken up the role and protection of environmental data should be considered along with more human-centric values. Data about the environment should be gathered carefully and the security and truthfulness always ensured.

Societal considerations

• Creating opportunities for autonomy: Data management can often be built in ways that offer people opportunities for agency regarding their own data. Note that asking for consent is often not enough, as this does not usually give users a real chance to choose.

• Privacy legislation: there is already a rather strict data privacy legislation in the EU. When launching anything new to users, it should be double checked the data handling follows these laws and rules, or even goes beyond the mandatory levels.

4: Scaling-up and fine-tuning established technologies

- Digital and data intensive solutions have become essential for daily lives in modern societies. As these solutions are scaled and more people are using them, they start also having different impacts.

Ecological considerations

• Energy use: Digitalization consumes a significant portion of all electricity used in current societies, and data handling is often quite intensive in terms of processing power needed. When making decisions of which solutions to take up, efficiency should be used as a criteria. Minimizing energy waste by e.g. using the heat generated by data centers can be a good solution.

Societal considerations

• User education: Understanding data use and management is a complex and rapidly evolving field. Users of digital tools and services need easily accessible and understandable education to keep up with the ever-changing field and protect themselves online.

• Strongly protecting important digital infrastructures beyond the current concept of critical infrastructures: Digital spaces often play very important role in satisfying the very basic human needs on daily basis. Important infrastructures need strong protection, that is

frequently updated and resilient against cyberwarfare threats.
• Understandability: People should have a real chance to give their consent for transferring data. Should be independent of literacy, internationally understandable, e.g. icon based solution that is easy to understand.

Bio-inspired technologies and smart materials

Intro

The material world build by humans is evolving with advances in synthetic biology and material sciences. Sustainability can be a driving force in developing new materials, but new materials do not come without risks as well.

Potentials:
• Taking inspiration for innovation from natural ecosystems we can harness human resources for the good of the planet while simultaneously gaining better technologies for us.
• New materials with active (sensing, responding) and passive (antibacterial) functionalities can enhance the quality of life for many.
• With new materials, new solutions to persistent issues can be found, such as buildings functioning as batteries.
• New, emerging materials can play a role in replacing crude oil and moving towards use of recycled and reusable items.
• New materials and bio-sensing provide possibilities for health care.
• Utilising materials that are currently treated as waste or pollution might offer interesting business opportunities.

Risks:
• New materials require substantial investments to mature to usable solutions and to mitigate unintended consequences.
• Excessive use of raw materials needs to stop, and thus even new materials should not be excessively produced or used carelessly.
• New innovations lead to the surplus of the old, and old materials or technologies might end up as waste.

1: Research

- This phase includes scientific explorations with different raw material possibilities, material structures and properties. Research does stretch the limits of possibility, even if the usability might not be tested outside of lab environments yet.

Ecological considerations
• Combining different materials: Often, to make new materials last and enhance their

Societal considerations
• Research funding: As researching new materials is often based on trial-and-error

properties, artificial components are added. This can be a good solution, but the implications for e.g. recyclability or compostability should be carefully considered and communicated.

• Finding starting points from nature: Traditionally, research processes start from the needs of humans. When aiming for a better balance with natural ecosystems, starting points for research should also be found in the needs of nature. Waste materials or invasive species, for example, might offer interesting opportunities for material sciences.

type of testing, it requires grand amount of funding and the results of any one experimental branch can not be guaranteed. To move forward with material sciences, adequate funding is necessary, but prioritization of different research areas might be necessary.

• Ecological costs: when considering the costs of new materials, not only their current monetary value should be given priority, but emphasis should always be put to their whole costs to ecosystems and the society.

2: Development of concepts and products

- As new materials emerge from the scientific field, their application areas and use properties still need to be refined. As they are turned into products, they at the same time become parts of whole products and production chains, and their recycling properties, among many other factors, need to be refined.

Ecological considerations

• Recycling and promoting circular economy: As new materials and production methods are developed, it is good to always consider adding elements that promote circular economy, such as using recycled raw materials or ensuring the recyclability of the materials or changeability of product parts.

Societal considerations

• Licensing and growth: With new solutions, the pros and cons of licensing should be carefully considered. Licensing might enable attaining funding or selling the idea to bigger companies and thus scaling the solution. On the other hand, it might limit the use of the new solution as grass-roots hobbyists, for example, might not be able to experiment with the new material anymore.

• Considering wider impact: At this stage, new innovations are still in very small scales and not widely used. However, it is necessary to already consider the consequences of the innovation scaling up: how could it change every-day practices, for better or for worse?

3: Introduction and early implementation

- As the new materials mature, they will eventually reach the consumers. As the consumers encounter the new materials, their safety and rights need to be considered in a new way.

Ecological considerations

• Multi-criteria evaluation: Materials that make it to user testing phase usually have positive effects to at least some sustainability values. When considering taking up new technologies, their sustainability should be assessed from multiple perspectives, considering many different environmental values, such as climate change, biodiversity and toxicity.

• Benefits of new materials or solutions: Changing for more sustainable materials is usually a good decision from environmental perspective. However, even more sustainable materials have their environmental footprint, and if the use can be avoided altogether, it can be an even better alternative.

Societal considerations

• User rights and knowledge sharing: when testing with smart materials that have functionalities affecting the users or their direct environment, the user rights and privacy should be carefully ensured. Users should also have enough knowledge available for them about the products they are using in simple enough language.

• Considering time scales of use: If a solution is perfect for 5 minutes of use but harmful for long periods of time before and after, the actual benefit of the product might be questioned. In such situations, careful consideration of whether to introduce the new product or not is needed.

4: Scaling-up and fine-tuning established technologies

- If a new material or solution proves to be useful, it might enter the scaling phase. In this phase, the solution gains popularity and becomes more common. With larger production amounts and wider user base, new responsibility considerations also become relevant.

Ecological considerations

• Resource use: As new solutions are scaled up more resources are used. Thus, it is important to ensure that the raw materials of solutions that will be taken up in large scale can truly be produced sustainably in the locations of production, even at scale.

• Limiting overall consumption: Even as new materials might be less ecologically harmful than traditional materials, their use still consumes limited natural resources. Thus, even with new materials, the overall consumption of virgin raw materials should be decreasing to achieve true sustainability.

Societal considerations

• Inclusion and fairness: New materials can sometimes offer life-enhancing opportunities for people with disabilities, the elderly, or other special groups. From social fairness viewpoint, equally distributing the opportunity to benefit from these scientific advancements regardless of e.g. financial situation is important, especially in context of health care system.

4. Future steps

This report has introduced the FORGING Value Sensitive Innovation Journey, divided in six distinct technology frameworks based on the enabling emerging technologies relevant for Industry 5.0 framework. The innovation journey offers reflection points and gathers important values and sustainability questions for different phases of technology development. The journey operates as a starting point for reflecting on the responsibility and sustainability of emerging technologies.

Going forward, the FORGING value sensitive innovation journey will be further integrated into the project. Specifically, the Value Sensitive Innovation Journey will be integrated in the FORGING Playbook and Toolbox, informing in the responsibility work related to enabling emerging technologies. The Value Sensitive Innovation Journey will inform in selection of needed tools and methodologies for each technology framework. In the Playbook and Toolbox, concrete tools for improving responsibility aspects and monitoring impacts of emerging technologies will be offered.

In this way, we hope to build a continuum for not only the project but also the use of the value sensitive innovation journey. The version of the journey you are reading currently offers perspectives to consider when evaluating the importance of different sustainability and responsibility aspects to your research and technology development and implementation projects. In the Playbook and Toolbox, that will be released in their final form in 2025, additional concrete tools for implementing responsible, value sensitive processes will be offered.

Sources

Auerswald, P. E., & Branscomb, L. M. (2003). Valleys of death and Darwinian seas: Financing the invention to innovation transition in the United States. *The Journal of technology transfer, 28*(3-4), 227-239.

Baldassarre, B., Keskin, D., Diehl, J. C., Bocken, N., & Calabretta, G. (2020). Implementing sustainable design theory in business practice: A call to action. *Journal of cleaner production*, 273, 123113.

Boukamel, O., Emery, Y., & Gieske, H. (2019). Towards an integrative framework of innovation capacity. *The Innovation Journal*, 24(3).

Boy, G. A. (Ed.). (2017). *The handbook of human-machine interaction: a human-centered design approach*. CRC Press.

Brey, P. (2017). Ethics of emerging technology. In Hansson, S. O. (ed.) *The ethics of technology: Methods and approaches*, 175-191. Rowman & Littlefield Publishers.

Brundtland, G. H. (1987). Our common future—Call for action. *Environmental conservation*, 14(4), 291-294.

Church, C., & Crawford, A. (2020). Minerals and the metals for the energy transition: Exploring the conflict implications for mineral-rich, fragile states.In Hafner, M., & Tagliapietra, S. (eds.) *The geopolitics of the global energy transition*, 279-304. Springer Nature.

Clarke, R., Heitlinger, S., Light, A., Forlano, L., Foth, M. & DiSalvo, C. (2019). More-than-human participation: Design for sustainable smart city futures. *Interactions*, 26(3), 60-63.

Clarke, T., & Boersma, M. (2017). The governance of global value chains: Unresolved human rights, environmental and ethical dilemmas in the apple supply chain. *Journal of business ethics*, 143, 111-131.

Clarkson, P. J., Coleman, R., Keates, S., & Lebbon, C. (2013). *Inclusive design: Design for the whole population*. Springer.

Cole, R. J. (2012). Regenerative design and development: current theory and practice. *Building Research & Information*, 40(1), 1-6.

Dedehayir, O., & Steinert, M. (2016). The hype cycle model: A review and future directions. *Technological Forecasting and Social Change, 108*, 28-41.

Dorfleitner, G., Halbritter, G., & Nguyen, M. (2015). Measuring the level and risk of corporate responsibility–An empirical comparison of different ESG rating approaches. *Journal of Asset Management*, 16, 450-466.

Du, K., & Li, J. (2019). Towards a green world: How do green technology innovations affect total-factor carbon productivity. *Energy Policy*, 131, 240-250.

European Commission, Directorate-General for Research and Innovation, Breque, M., De Nul, L. & Petridis, A. (2022). *Industry 5.0 – Towards a sustainable, human-centric and resilient European industry.* Publications Office of the European Union. Available at: https://data.europa.eu/doi/10.2777/308407.

European Commission, Directorate-General for Research and Innovation, Müller, J. (2020). *Enabling Technologies for Industry 5.0 – Results of a workshop with Europe's technology leaders.* Publications Office of the European Union. Available at: https://data.europa.eu/doi/10.2777/082634.

European Parliament (2023). Corporate due diligence rules agreed to safeguard human rights and environment. Press release. Available at: https://www.europarl.europa.eu/news/en/press-room/20231205IPR15689/corporate-due-diligence-rules-agreed-to-safeguard-human-rights-and-environment.

Ethical Stack. Web page. Available at: https://ethicalstack.virteuproject.eu/index.html.

FCAI Ethics Advisory Board. *FCAI Ethics Exercise Tool*. Web page. Available at: https://fcai.fi/ethics-exercise.

Forlano, L. (2017). Posthumanism and design. *She Ji: The Journal of Design, Economics, and Innovation*, 3(1), 16-29.

Friedman, B., Kahn, P. H., Borning, A., & Huldtgren, A. (2013). Value sensitive design and information systems. In N. Doorn, D. Schuurbiers, I. van de Poel & M. E. Gorman (eds.) *Early engagement and new technologies: Opening up the laboratory*, 55-95, Springer.

Gensch, C. O., Prakash, S., & Hilbert, I. (2017). Is digitalisation a driver for sustainability?. In Osburg, T., & Lohrmann, C. (eds.) *Sustainability in a Digital World: New Opportunities Through New Technologies*, 117-129.

Giddings, B., Hopwood, B., & O'brien, G. (2002). Environment, economy and society: fitting them together into sustainable development. *Sustainable development*, 10(4), 187-196.

Heithoff, M., Hellwig, A., Michael, J., & Rumpe, B. (2023). Digital twins for sustainable software systems. In *2023 IEEE/ACM 7th International Workshop on Green And Sustainable Software (GREENS)*, 19-23.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, conservation and recycling*, 127, 221-232.

Lai, P. C. (2017). The literature review of technology adoption models and theories for the novelty technology. *JISTEM-Journal of Information Systems and Technology Management, 14*, 21-38.

Leikas, J., Koivisto, R., & Gotcheva, N. (2019). Ethical framework for designing autonomous intelligent systems. *Journal of Open Innovation: Technology, Market, and Complexity*, 5(1), 18.

Liu, J., Zhang, G., Lv, X., & Li, J. (2022). Discovering the Landscape and Evolution of Responsible Research and Innovation (RRI): Science Mapping Based on Bibliometric Analysis. *Sustainability,* 14(14), 8944.

Mankins, J. C. (1995). Technology readiness levels. White Paper, April, 6, 1995. Advanced Concepts Office, Office of Space Access and Technology, NASA.

Miller, B. (2021). Is technology value-neutral? *Science, Technology, & Human Values*, 46(1), 53-80.

New European Bauhaus (2023). About the initiative. Web page, available at: https://new-european-bauhaus.europa.eu/about/about-initiative_en.

Parella, K. (2019). Improving Human Rights Compliance in Supply Chains. *Notre Dame L. Rev.*, 95, 727.

Pratiwi, R. D., Handoyo, L., Romlah, S. N., & Rohaeti, T. (2022). Psychosocial Development of Children Addicted Versus Not Addicted to Smartphones. *KnE Life Sciences*, 354-361.

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S.E., Donges, J.F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., Petri, S., Porkka, M., Rahmstorf, S., Schaphoff, S., Thonicke, K., Tobian, A., Virkki, V., Weber, L. & Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances* 9, 37.

Sweller, J. (2020). Cognitive load theory and educational technology. *Educational Technology Research and Development*, 68(1), 1-16.

Thomée, S. (2018). Mobile phone use and mental health. A review of the research that takes a psychological perspective on exposure. *International journal of environmental research and public health*, 15(12), 2692.

Vakkuri, V., Kemell, K.-K., Jantunen, M., Halme, E., & Abrahamsson, P. (2021). ECCOLA : a method for implementing ethically aligned AI systems. *Journal of Systems and Software*, 182, Article 111067. Available at: https://doi.org/10.1016/j.jss.2021.111067.

Vallero, D. A., & Brasier, C. (2008*). Sustainable design: The science of sustainability and green engineering.* John Wiley & Sons.

Van de Poel, I., & Royakkers, L. (2023). *Ethics, technology, and engineering: An introduction*. John Wiley & Sons.

Van den Berg, M. R., & Bakker, C. A. (2015). A product design framework for a circular economy. *Product Lifetimes And The Environment*. *Conference proceedings, 17-19 June 2015 – Nottingham, UK*, 365-379.

Vogue Business (2023). Virtual Clothing. Web page. Available at: https://www.voguebusiness.com/tag/virtual-clothing.