smart cities

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Review

The Making of Responsible Innovation and Technology: An Overview and Framework

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Abstract: In an era in which technological advancements have a profound impact on our cities and societies, it is crucial to ensure that digital technology is not only driven by technological progress with economic goals but that it can also fulfill moral and social responsibilities. Hence, it is needed to advocate for 'Responsible Innovation and Technology' (RIT) to ensure cities and societies can harness the potential of technological progress and prosperity while safeguarding the well-being of individuals and communities. This study conducts a PRISMA review to explore and understand RIT concepts and its characteristics. In this study, we emphasize that RIT should deliver acceptable, accessible, trustworthy, and well governed technological outcomes, while ensuring these outcomes are aligned with societal desirability and human values, and should also be responsibly integrated into our cities and societies. The main contribution of this study is to identify and clarify the key characteristics of RIT, which has not been performed in such detail so far. The study, reported in this paper, also broadens the understanding of responsible research and innovation in the technosphere, particularly from a bottom-up perspective. Furthermore, the paper develops an RIT conceptual framework outlining its possible design procedures, which could be used by governments, companies, practitioners, researchers, and other stakeholders as a tool to address the grand challenges that accompany technological and scientific progress. The framework also informs science, technology, and innovation policy.

Keywords: responsible research and innovation; responsible innovation and technology; social responsibility; research and development; artificial intelligence; robotics; science; technology and innovation policy; smart city

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1. Introduction

Driven by advancements in science and technology, emerging innovations have offered significant societal benefits and new commercial opportunities for our societies and cities, especially offering invaluable disruptive technology prospects in agriculture, biological, medical, and urban domains [1–7]. Nevertheless, these disruptive technologies may also raise significant ethical, social, and regulatory challenges, such as the technological and digital divide, inequality and disruption, the misuse of data and information, and others [8–10].

In the context of 'responsible research and innovation (RRI)', which has become a popular concept during the last decade, the terms responsible innovation and responsible technology (collectively referred to as 'responsible innovation and technology (RIT)' in this paper) have been increasingly mentioned and practiced in academia, industrial circles, and public sectors. They were recognized as having strong potential to address the grand societal challenges associated with innovations and contribute to shaping our (smart) cities—creating pleasant places to live [11–13]. RIT is conceptually regarded as a socially

desired/expected technological outcome in the agenda of RRI, which represents innovation and technology's ability to fulfill moral and social responsibilities while achieving socially desirable goals in a responsible manner [14]. To a certain extent, RIT can be called the carrier of the RRI concept, reflecting the practical results of the RRI theory in our cities and societies—particularly in the context of smart cities and societies [15–18].

Initial discussions of the concepts of 'responsible' or 'responsibility' in science and technology can be traced back to the developments in research integrity and ethics beginning in the early 20th century [17,19,20]. Via the broader philosophical and sociological analysis of this concept, it has become gradually recognized that scientific research could be governed in socially responsible ways via multiple and overlapping methods to overcome the concomitant challenges [11,21]. With the increasing attention on the notions of the social responsibility of science and technology, the term RRI has emerged over the past decade, and since then, it has been an integral part of European research and innovation policies [11,22,23].

RRI has often been described as an forward-looking and comprehensive approach to innovation and research activities, which aims to prudently manage innovations to allow them to be properly embedded in our society [22–24]. With the growing interest in RRI, the number of relevant academic articles has been rapidly increasing over recent years [24]. For instance, Burget et al. [22] reviewed over 200 relevant articles to provide a discussion on the definitions and conceptual dimensions of RRI; Thapa et al. [13] investigated applications of RRI to regional studies; Wiarda et al. [24] identified the commonalities of RI and RRI and expounded on the accumulation of their knowledge; Liu et al. [25] discovered the landscape and evolution of RRI and provided an understanding of existing research.

Although the number of publications with an RRI focus is steadily growing, the research on the topic is still relatively limited. Existing research tends to expound the concepts of RRI in a top-down manner to formulate standardized principles or frameworks guiding innovation towards producing the 'right impacts' during the creation and implementation process [14,26–28]. Nonetheless, the intended outcomes of RRI remain unclear and lack attention—i.e., what kind of innovation or technology can be considered responsible in the context of RRI? [22,23].

Hence, additional investigations and reviews are needed to capture the growing knowledge on this topic and to bridge the research gap. The difference from previous studies is that the paper at hand focuses on investigating the expected outcomes in the existing RRI practices, i.e., responsible innovation and technology (RIT), that attempt to broaden the understanding of responsible research from a bottom-up perspective. Accordingly, the following research question was posed in the paper: what are the key characteristics of responsible innovation and technology (RIT)?

To tackle this question, the rest of this paper is organized as follows: Following this introduction, Section 2 presents the practices of RIT. Then, Section 3 outlines the research methodology. Next, Section 4 presents the results of the analysis. Afterwards, Section 5 discusses the study findings. Lastly, Section 6 concludes the paper.

2. Literature Background

Since the term RRI emerged in the European research and innovation (R&I) policy discourse, increasing industries and scenarios have advocated and attempted to incorporate or embed the concept into the innovation creation and implementation process in emerging technological fields, especially those that are potentially controversial. Today, this concept is moving from the early theoretical stages to one in which it is embedded in specific practices [25,29]. Guided by the RRI framework, a growing number of actors are exploring the characteristics of RIT, that is, establishing what kind of innovations and technologies can meet both social expectations and ethical standards and are able to embed into our cities and societies responsibly [23,30].

For instance, in the field of urban transport, Singh et al. [31] analyzed the implementation case of electrical rickshaws (e-rickshaw)—also known as e-tuk-tuks—in India using

the RRI framework. The authors pointed out that some key dimensions of the RRI concept have been evidently deployed in this case, i.e., deliberation and participation dimensions, which is the critical factor facilitating the successful implementation of responsible mobility and transport innovation in India. In addition, the authors mentioned that imparting universal and culture-specific values in the technical product to increase its acceptability has acquired significance for shaping responsible innovation and technology. The e-rickshaw case imparted these values during its deliberation and participation process, which made this innovation acceptable in India, providing a brilliant example of responsible innovation and technology implementation in a developing country.

To provide another example, in the agriculture field, Eastwood et al. [4] denoted that accessibility, both technical and financial, is one of the core challenges associated with robotics and automation adoption in agricultural systems. To improve existing agricultural technology design and innovation practices, the authors proposed a design guide for responsible robotic applications in pasture-grazed dairy farming based on the concepts of RRI, systems thinking, and co-design. The guide identified the critical design factors for responsible robotics and automation in smart farming, which involved broader considerations of the impacts on work design, worker well-being and safety, changes to farming systems, and the influences of market and regulatory constraints. Based on the guide, the authors stated that the focus of the further development of robotics and automation in smart farming should be on improving their technical adaptability and financial feasibility, aiming to provide wider accessibility for innovation to meet the market needs adequately.

Similarly, Hussain et al. [32] employed a 'responsible thinking' case study design to investigate software practitioners' perceptions of human values in software engineering. The survey results demonstrated that almost all participants agreed that human values, such as privacy, transparency, integrity, social justice, diversity, and so on, need to be explicitly addressed during software development. However, software companies tend to consider values mainly in the early phases of a project. The authors emphasized that the value issues need to be considered throughout the whole software development lifecycle because stakeholder values may conflict at different phases. These conflicts may be due to the different prioritization of values chosen by stakeholders, such as some prioritizing climate change while others prioritize economic equality. The authors indicated that resolving tensions between different values and embedding values in software design contributes to ensuring that technological outcomes meet social expectations, i.e., that they are aligned with universal human values.

Moreover, in the medical science field, Sujan et al. [6] investigated stakeholders' perceptions of AI-based applications in healthcare. The authors hold that, although most existing healthcare AI applications have been evaluated retrospectively, they are still not sufficient to ensure that the use of AI in healthcare settings is safe and free from any subsequent sociotechnical concerns, such as trust, skill erosion, and ethical issues around fairness. The authors suggested embedding the notion of RRI in the healthcare innovation process, especially embedding the debate about societal concerns to ensure the diversity of views from actors and stakeholders. Such inclusive dialogue can ensure the meaningful and safe integration of AI into healthcare systems, which contributes to providing trustworthy healthcare innovation and technology for users and increasing their willingness to accept care.

Concerning market regulation in food and agricultural commodities, Merck et al. [33] stated that traditional regulatory regimes may be insufficient to deal with the more complex ethical, legal, and social implications of novel products produced using nanotechnology. For example, although nanotechnology has the potential to improve the sustainability, safety, and availability of agri-food products, in many cases, there remain uncertainties in assessing the potential risks they may pose, which present not readily addressed challenges to existing regulatory frameworks. The authors suggested implementing the principle of RRI to improve existing regulatory regimes, allowing innovators and policymakers to prospectively evaluate the associated influences and be more responsive to

the public's needs and concerns. Appropriate and adequate regulations contribute to shaping responsible innovation in nano-agri-foods and promote the future development of agricultural innovation.

In addition to the above cases, an increasing number of studies have been exploring the specific practices of RIT in various technospheres, such as gene drive technology in biology [5], deep synthesis application in digital media [30], information and communication technologies (ICT) in tourism [34], community energy storage (CES) in the energy field [35], and others. The participants from various industries are attempting to shape emerging innovations and technologies to be more 'responsible' by embedding the RRI concept, aiming to address the grand challenges accompanied by technological and scientific progress.

Against this backdrop, the key characteristics of RIT, based on previous research efforts, could in a nutshell be categorized as follows: (a) acceptable; (b) accessible; (c) aligned; (d) trustworthy; and (e) well governed. The summary descriptions of these key characteristics are provided in Table 1.

Table 1. Key characteristics of responsible innovation and technology.

Characteristic	Description	Exemplar Reference
Acceptable	Publicly acceptable, ethically unproblematic, and harmless, including being free of bias and deception. Devoted to delivering equitable products and encouraging fair technology use for achieving an overall state of well-being and the common good.	[31]
Accessible	Broaden the notions of accessibility to deliver culturally inclusive, technically adaptable, and financially affordable products. Devoted to spreading the benefits of digitization across societies and cities without barriers.	[4]
Aligned	Deliberate in decision-making practices and aligned with societal desirability and human values. Devoted to achieving meaningful, positive, and sustainable outcomes to solve the accompanied challenges and improve the well-being of life on Earth.	[32]
Trustworthy	Handle greater informational transparency and technical security within designing, producing, implementing, and operating processes. Devoted to delivering human-understandable explanations of decisions to increase public understanding, trust, and confidence robustly.	[6]
Well governed	Adhere to statutory regulations and governance requirements and can be well governed by the broader stakeholder groups. Devoted to ensuring its dependability and accountability to maintain public support and trust, which leads to higher acceptance and further implementation.	[33]

3. Methodology

This paper adopts a systematic literature review method with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to address the following research question: 'What are the key characteristics of responsible innovation and technology (RIT)?' This paper applied a three-stage procedure as the methodology, i.e., Stage 1 (planning), Stage 2 (review), and Stage 3 (reporting), which has been proven to be feasible and reliable by previously conducted systematic literature reviews—e.g., Li et al. [36] and Li et al. [37].

The task of the planning stage (Stage 1) is to form a feasible research plan, including setting up a research objective to address the abovementioned research question, selecting search keywords for relevant article searching, and developing the criteria of exclusion and inclusion for article screening. The research objective was framed to conceptualize the key characteristics of RIT. Therefore, the keywords were confirmed as 'responsible innovation' and 'responsible technology', which were used to search across the titles, abstracts, and keywords of available articles. The search task was conducted via an academic search engine, which covered approximately 400 different bibliographic repositories, including Directory of Open Access Journals, Web of Science, Wiley Online Library, Scopus, and ScienceDirect. The inclusion and exclusion criteria were developed to improve the efficiency

of screening tasks (Table 2), which can assist in selecting suitable articles and reduce unnecessary efforts.

Table 2. Inclusion and exclusion criteria.

Primary Criteria		Secondary Criteria	
Inclusionary	**Exclusionary**	**Inclusionary**	**Exclusionary**
Academic journal articles	Duplicate records	Responsible innovation and technology-related	Not responsible innovation or technology-related
Peer-reviewed	Books and chapters		
Full-text available online	Industry reports	Relevance to the research objective	Irrelevant to the research objective
Published in English	Government reports		

In the review stage (Stage 2), the reviewing task followed the PRISMA 2020 statement to ensure transparency, integrity, and accuracy of the article selecting and reviewing process. The search task was conducted in August 2022. The initial search did not include any restrictions for publication year so that we could inspect the suitability of all time periods covered by the academic search engine. However, in consideration of 'responsible innovation and technology' as an emerging concept that has grown rapidly during the last decade, most of the highly relevant articles were published in this period [38,39]. Therefore, the final search task developed a literature database with a limited publishing period, covering the articles published between January 2010 and August 2022. Additionally, a fuzzy format—'*'—was included in the query string to ensure the comprehensiveness of the obtained data.

The final query string of the search task was determined as follows: TITLE-ABS-KEY ("Responsible innovation" OR "Responsible technolog*") AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")). The result of the initial search returned a total of 1201 articles based on the primary criteria. After removing duplicates, the records went down to 1008 articles. Based on the secondary criteria (reviewing article titles and abstracts), the result of the second-round review recorded a total of 178 articles. In the third screening task, a full-text review of 178 articles was undertaken to evaluate the relevance, consistency, and reliability of these articles. The result of the third-round review returned a total of 51 articles.

In addition, the repetitive screening test and the snowballing strategy were used in this stage to ensure the comprehensiveness and validity of the final article selection, which additionally recorded 14 articles. Snowballing is a literature retrieval strategy that identifies additional relevant papers by tracking the reference list of articles, which is adopted in the complementary search task of this paper, aiming to expand candidate articles at the specific themes to discover additional insights [40,41]. Finally, a total of 65 articles included in the qualitative analysis were recorded (Figure 1).

In the reporting and dissemination stage (Stage 3), the insights were captured from recorded articles and sorted into specific themes via a qualitative analytical approach, focusing on understanding the characteristics of responsible innovation or technology. In this stage, the eye-balling technique was adopted to identify the commonalities and disparities of recorded articles, which helped in the categorization of themes [36,42]. Lastly, the insights of articles were finally classified under five themes: 'aligned', 'accessible', 'acceptable', 'trustworthy', and 'well governed'. The detailed criteria for this categorization work were developed and are shown in Table 3. The completed reporting table is presented in Appendix A Table A1.

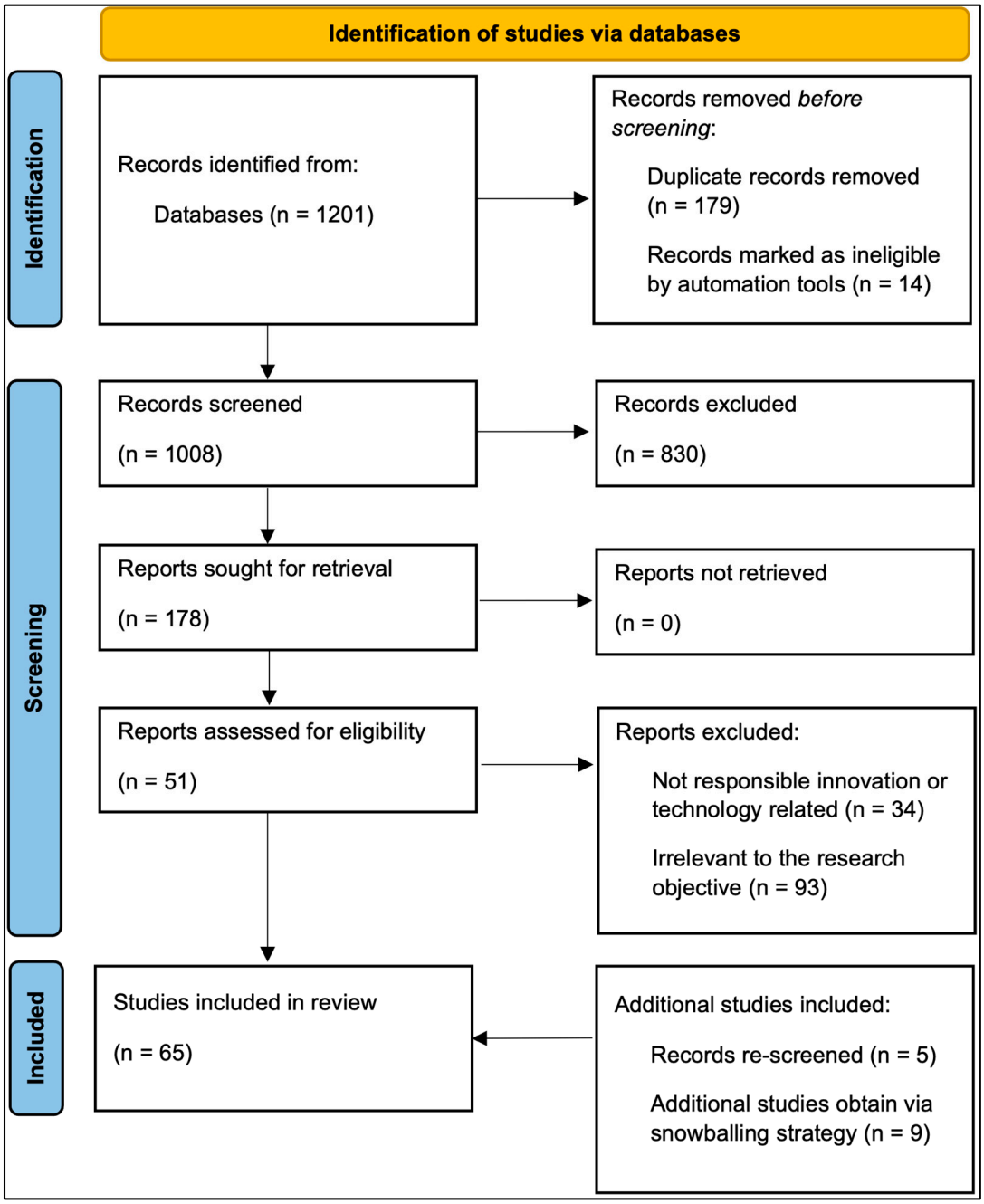

Figure 1. Literature selection procedure.

Table 3. Categorization criteria.

Criteria
1. Identify the themes and contents associated with responsible innovation or technology in the articles;
2. Determine the domain of existing practices relevant to responsible innovation or technology in the selected articles;
3. Capture the insights about responsible innovation or technology in the selected articles;
4. Conceptualize the key characteristics of responsible innovation or technology;
5. Narrow down themes and crosscheck the consistency and reliability of themes against other published literature;
6. Conduct a final review of the selected and reviewed literature and reconsider the refined themes.

4. Results

4.1. General Observations

Based on the statistical data extracted from the reviewed articles (n = 65), the number of RIT studies has increased over time, reflecting the growing interest in this topic over the past decade. Since the European Union (EU) mainstreamed the notion of 'responsible' in the EU's research and innovation (R&I) policy, it has evoked extensive discussion and reflection regarding the 'responsibility' of innovation and technology among various participators, including researchers, practitioners, and policymakers. This discussion and reflection recently gained momentum, especially in the emerging technological fields that are potentially controversial, such as artificial intelligence (AI), gene technology, and nanotechnology [43–45]. The reason might be the growing concerns over uncertainty about the potential consequences and opportunities presented by these promising but potentially disruptive technological advances. Figure 2 shows the publication trend of RIT studies during the last decade.

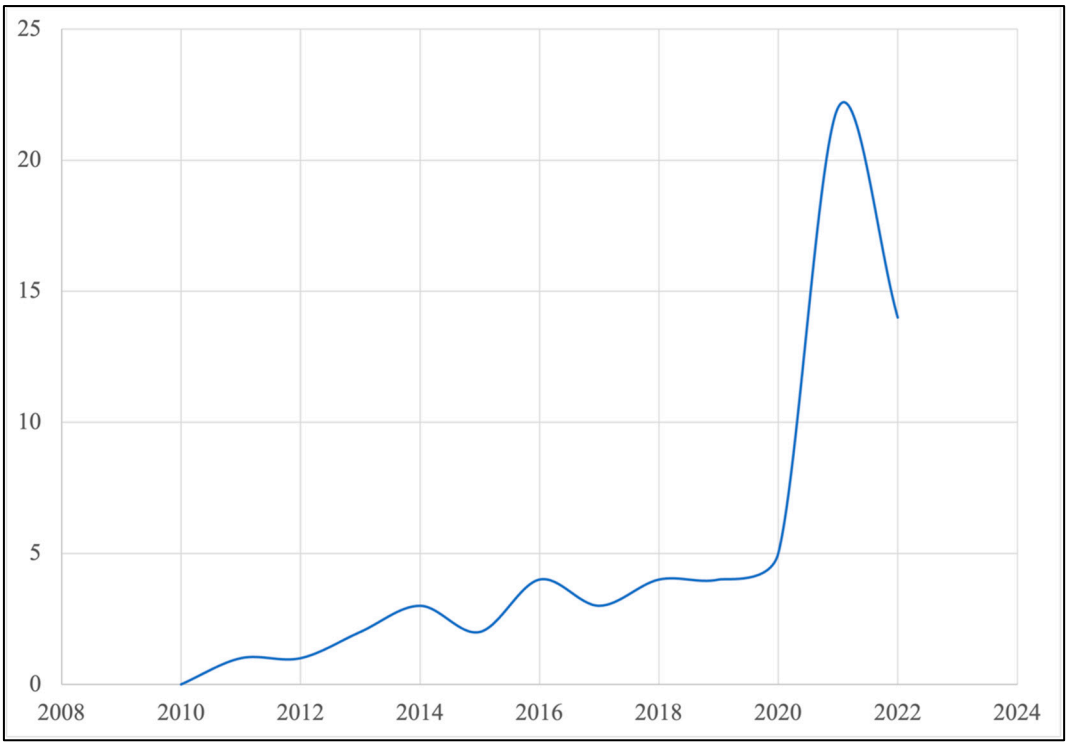

Figure 2. Publication trend of RIT studies.

In addition, the statistical data indicated that RIT studies mainly focus on AI (n = 10), healthcare technology (n = 6), robotics (n = 4), nanotechnology (n = 4), information and communications technology (ICT) (n = 4), and gene technology (n = 4). The technology categories of articles were classified based on the keywords or explicit statements in the paper. The pieces without specific statements about technology were classified into the category of 'non-specific'. The articles that had less than two pieces but had specific statements about technology were classified into the category of 'others'. The result shows that RIT-related articles had a great interest in AI technology (over 15% of the total reviewed articles). The reason might be that the global proliferation and societal penetration of AI have raised widespread concerns regarding human autonomy, agency, fairness, and justice, and relevant sectors are attempting to introduce the concept of RIT in AI practices, aiming to offset these concerns and promote the development of responsible AI innovations [43,46]. Figure 3 shows the technology categories of RIT studies during the last decade.

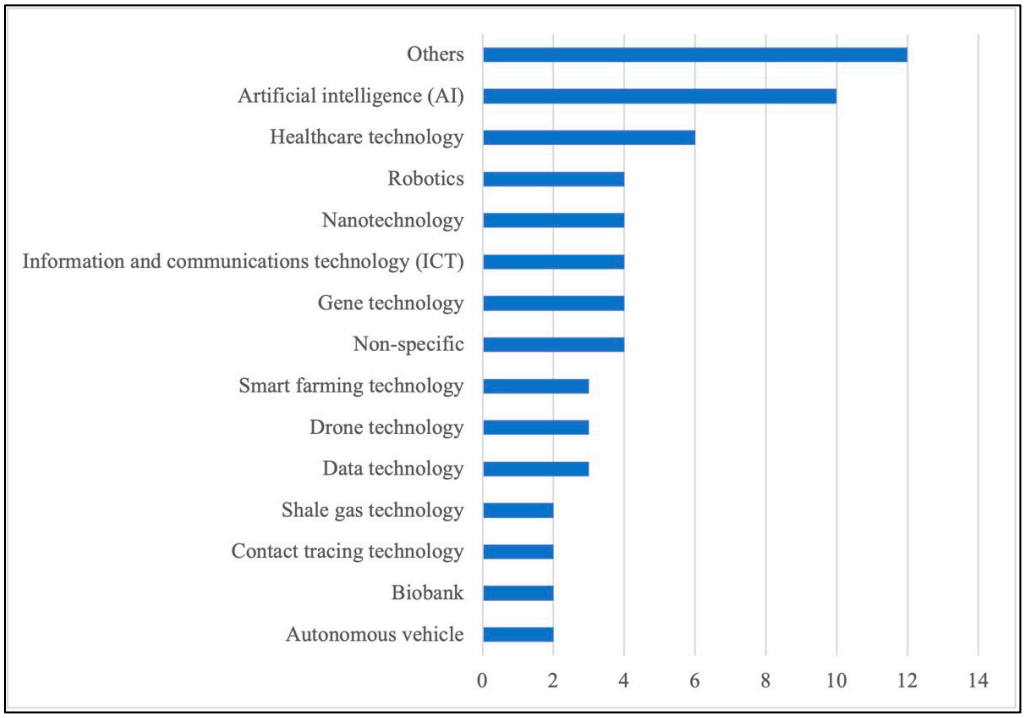

Figure 3. Technology categories of RIT studies.

Furthermore, the most mentioned characteristic of RIT is 'well governed', occupying 34% of the recorded articles (n = 46, 65 articles in total). The proportion of remaining characteristics are relatively average, namely 'trustworthy' (20%, n = 28), 'acceptable' (17%, n = 23), 'accessible' (15%, n = 21), and 'aligned' (14%, n = 19). The reason might be that existing research tends to formulate standardized principles or frameworks in a top-down fashion to guide the development of innovation and technology towards a responsible direction [14,26–28]. Figure 4 shows the proportion of RIT characteristics mentioned in the recorded articles. The following five sub-sections will provide a detailed analysis of these characteristics.

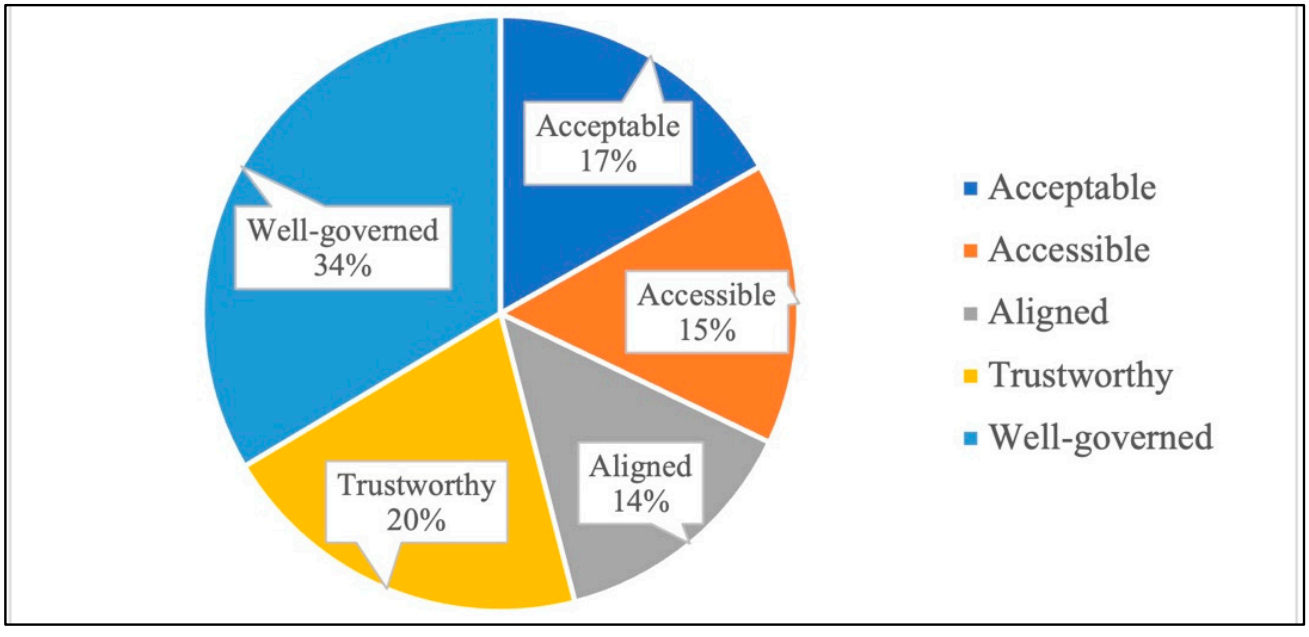

Figure 4. Proportion of characteristics mentioned in RIT studies.

4.2. Acceptable Innovation and Technology

The *acceptability of innovation and technology* has been often mentioned in studies on the topic, such as Owen et al. [47], Stilgoe & Guston [48], Bacq & Aguilera [49]. Based on the reviewed articles, the 'acceptable' characteristics of RIT can be interpreted as follows.

Innovation and technology should be publicly acceptable, ethically unproblematic, and harmless, including being free of bias and deception, while ensuring they will not disrupt the existing social orders. Marketable products and services should be bound by the inherently safe design and meaningful control approach to ensure they do not harm human beings and the environment. The design principles should eliminate systematic stereotyping, encouraging more equitable innovation implementation for achieving overall well-being and the common good.

Based on the above description, the RIT characteristic of 'acceptable' comprises three keywords, namely ethical, harmless, and equitable. Table 4 lists the keywords of this RIT characteristic and provides their summary descriptions.

Table 4. Keywords of RIT's acceptable characteristic.

Keyword	Description	Exemplar Reference
Ethical	Afford and respect human rights and freedoms, including dignity and privacy, while ensuring innovations and technologies do not reinforce social orders that subjugate human beings, promoting autonomy and ethical acceptability to avoid unethical consequences.	[50–52]
Equitable	Eliminate systematic stereotyping to reduce the potential risks and impacts of perpetuated and/or increased inequalities between individuals and groups in society while encouraging more broad, democratic, and equitable innovation implementation.	[52–54]
Harmless	Ensure products do not harm human health (including physical and psychological) and/or the environment while reducing or eliminating the harmful effects of technology use by appropriate safeguards, e.g., inherently safe design, meaningful human control approach, and so on.	[3,4,55]

From an ethical point of view, innovation and technology should follow the principle of people-centered development and use to be compatible with respect for freedoms and human rights, including autonomy, dignity, privacy, and so on, ensuring they are ethically acceptable [30,50,51,56]. Additionally, Foley et al. [52] stated that technological innovation should afford people freedom of expression and freedom from oppression while not reinforcing social orders that subjugate human beings but aiming to achieve the overarching aspirations of human flourishing. Therefore, broader and more open discussions regarding moral and societal values and potential ethical issues are needed to incorporate into the innovation process to make technological outcomes more ethical and democratic [53,57]. In addition, innovators and adopters should be especially prudent in considering potential ethical problems in highly sensitive settings to either avoid or fuel controversy. For example, in Europe, there is a highly valued animal health and welfare context, so it has a long historical arc of concerns about animal food safety [58].

The planning objective and design principle of innovation and technology should encourage a broad, democratic, and equitable implementation approach to avoid disadvantaging specific groups or individuals [52–54]. Li et al. [30] stated that innovation and technology should ensure fairness and justice during their entire lifecycle to avoid prejudice and discrimination. Li et al. [30] and Bunnik and Bolt [51] suggested applying a non-discriminatory and more inclusive design approach to eliminate systematic stereotyping during the innovation process, which may contribute to reducing the risks of perpetuated and/or increased inequalities between individuals and groups in society, such as marginalization towards minority groups. Additionally, Brandao et al. [59] indicated that innovation and technology would face many unforeseen challenges regarding equity issues during real-world implementation, such as indirect discrimination, social inequalities produced by fairness-unrelated decision-making, and others. The authors suggested including realistic fairness models in the early stage of the innovation process, which are

important to anticipate potential fairness conflicts or issues and optimize equity in realistic contexts [59].

Furthermore, Li et al. [30] stated that being harmless is one of the core conditions for the high acceptance of innovation and technology. Innovation and technology must do no harm to human beings' physical and psychological health, which is also considered to be the bottom line for enabling technological innovation attempts [3,4,30]. The specific practices and marketable products must not damage human abilities and must not subvert human statuses, such as disrupting interpersonal relationships or replacing human roles [4,6]. Additionally, technological practices and outcomes should avoid causing irreversible social or environmental damage to ensure the sustainability of society and the environment [3,30,60].

However, Boden et al. [61] highlighted that technological products are "just tools designed to achieve goals and desires that humans specify"; all the participants, including users, are responsible for ensuring their actions obey the rules humans have made. This is partly because users may make these products do things their designer did not foresee [61]. Therefore, the appropriate safeguards should be embedded in the design process, such as inherently safe design, meaningful human control approaches, eco-friendly design, and so on. These measurements are crucial to ensuring the right and proper human control over life and the surrounding environment and to reducing or eliminating the harmful effects during practice and use as far as possible [3,55,62].

4.3. Accessible Innovation and Technology

The second key RIT characteristic relates to the *accessibility of innovation and technology*, which numerous studies on the topic have mentioned [13,22,26]. Based on the reviewed articles, the 'accessible' characteristics of RIT can be interpreted as discussed below.

Innovation and technology should actively incorporate diversified considerations into the design and practice strategies to broaden the notions of accessibility. To create better conditions for widespread availability, marketable products and services should be technically adaptable, financially affordable, and culturally inclusive. The design principles should overcome technological and ideological lock-ins to minimize the digital divide's potential impacts, aiming to spread digitization benefits across societies and cities without barriers.

Based on the above description, the RIT characteristic of 'accessible' comprises three keywords, namely inclusive, adaptable, and affordable. Table 5 lists the keywords of this characteristic and provides their summary descriptions.

Table 5. Keywords of RIT's accessible characteristic.

Keyword	Description	Exemplar Reference
Adaptable	Produce valid and reliable products adaptable to existing technologies and complex operating environments, ensuring they are easy to train, use, and maintain to increase the flexibility for application scenarios and the useability for a broader range of people.	[4,63,64]
Affordable	Ensure the delivery of high-value outputs while maintaining economic viability; alternatively, leverage resources in economic ways to avoid any negative financial implications for users, which creates better conditions for wider implementation scenarios.	[38,65,66]
Inclusive	Incorporate diversified cultures, knowledge, and values to align innovation more responsibly with practical societal contexts, aiming to overcome technological and ideological lock-ins and make technological trajectories more responsive to the needs of society.	[67–69]

Technically, innovation and technology should be able to integrate with existing technologies and leverage new opportunities to capture all the potential benefits, such as increased work flexibility, productivity gains, and so on [4]. Marketable products must be reliable and robust to deal with complex operating environments under real-world conditions [63,64]. Additionally, it is essential to ensure that innovations and technology, as well as their marketable products and services, are easy to train, use, and maintain, which reduces the technical difficulty for adoption to provide more extensive adaptability for a broader range of people [4].

Economically, innovations and technology and their marketable products and services should ensure avoiding negative financial implications for individuals or users [65]. The design principles should ensure innovation and technology can deliver effective and efficient outcomes while balancing their technical performance and economic viability [38]. Alternatively, other solutions should be provided so as not to jeopardize the delivery of high-value outputs, such as improving the ways resources are leveraged and so on [66]. Some studies stated that improving the financial accessibility of innovation and technology is expected to create better conditions for wider implementation scenarios, which is one of the essential aspects of achieving sustainability outcomes [35,38,70].

Culturally, innovation and technology should adopt more inclusive strategies to incorporate diversified cultural considerations and social impacts into the technological design [68,69]. In some cross-cultural settings, the design and operational criteria should actively respect and include local values, needs, and preferences, aiming to ensure that the marketable products are able to recognize local knowledge and governance [35,69]. Additionally, the interdisciplinary dialogue between fields should be supported during the innovation process because it is essential for adding the richness of understanding to possible cultural impacts and ensuring an accommodation between public values and technological outcomes [54,71].

4.4. Aligned Innovation and Technology

The third characteristic of RIT responds to the initiative stated by former EU Research and Innovation Commissioner Máire Geoghegan-Quinn in supporting the Horizon 2020 Strategy for European research and innovation. Her opinion is that "innovation must respond to the needs and ambitions of society, reflect its values and be responsible" [72]. In other words, innovation and technology must be *aligned with the social desirability* that responds to public needs and/or preferences. Based on the reviewed articles, the 'aligned' characteristics of RIT can be interpreted as follows.

Innovation and technology should always be thoughtful and careful in decision-making practices throughout their entire lifecycle to minimize irreversible social, health, and environmental consequences. Marketable products and services need to achieve a better alignment with societal desirability and/or preferences and human values of freedom, justice, privacy, and so on. The design principles should be devoted to delivering meaningful, positive, and sustainable outcomes to solve the challenges that accompany technological and scientific progress and improve the well-being of life on Earth.

Based on the above description, the RIT characteristic of 'aligned' comprises three keywords, namely deliberate, meaningful, and sustainable. Table 6 lists the keywords of this characteristic and provides their summary descriptions.

Table 6. Keywords of RIT's aligned characteristic.

Keyword	Description	Exemplar Reference
Deliberate	Carefully anticipate and assess the associated consequences and opportunities and exercise deliberation in decision-making practices to mitigate actual and potential negative impacts for life on earth to the extent feasible.	[44,63,73]
Meaningful	Achieve a better alignment between people's needs and/or preferences and innovative technologies and social practices to create expected and meaningful outcomes; e.g., address significant problems or societal needs and improve human well-being.	[60,74,75]
Sustainable	Taking the environment into consideration is part of the innovation to treat resources with respect and in the most responsible way throughout the entire lifecycle of innovation, which ensures broad sustainability outcomes while avoiding large and irreversible consequences for the earth.	[52,60,76]

As mentioned in multitudinous articles, the practices of innovation and technology could have various unforeseen consequences for society, the environment, and the economy due to the inevitable entry of provided products and services into the complex scenarios

of human use [58,63,73]. Given this, the context and uses of innovation should be clearly investigated as early as possible, aiming to provide sufficient knowledge and information for participators to comprehensively anticipate and consider the future scenarios of innovation and technology practices, including the actual and potential near-term and longer-term risks and benefits [44,63,74]. Innovation and technology need to keep care and moderation in decision-making practices throughout their entire lifecycles to reduce unforeseen and undesirable consequences to the extent feasible, such as significant or irreversible consequences for life on Earth [73,74]. Therefore, they require stakeholders, including innovators, actors, and researchers, to keep humility, avoid easy judgment, and learn to hesitate during the innovation and practice processes [58,77].

In addition to minimizing the undesirable consequences, Van den Hove et al. [67] stated that innovation and technology should be re-targeted, focusing not just on their technical characters or the potential for economic growth but also more directly on their roles in improving human or social well-being. Innovation and technology should be "designed to truly meet people's needs and to put the user at the center of service provision, with all the associated benefits" [78]. Therefore, innovation and technology should actively seek to align their processes and expected outcomes with societal needs and/or preferences, aiming to create effective and efficient products to address significant problems or societal needs and positively impact social well-being [60,70,75]. Some studies suggested that embedding human values, including universal and culture-specific values, throughout the innovation process would contribute to achieving a better alignment between technological advancements and societal desirability and acceptability [31,32,71].

Moreover, innovation and technology should commit to achieving broader sustainability outcomes, which not only concentrate on social and economic sustainability but should incorporate environmental considerations as a critical part of the innovation process [4,76]. During the designing and practice process, the resources should be treated and used in a respectful and non-wasteful manner to foster the development of environmentally friendly innovation and technology [52,60,76]. Additionally, Eastwood et al. [4] and Middelveld and Macnaghten [58] posed an interesting point: innovation and technology should ensure not merely human well-being but should also take care of the welfare of other creatures on this planet. The implication for other creatures on this planet during the technical practices is one of the key considerations to ensure broad sustainability outcomes of innovation and technology [4].

4.5. Trustworthy Innovation and Technology

The fourth RIT characteristic relates to the *public trustworthiness in innovation and technology*. Asveld et al. [79] stated that RRI is a way to stimulate public trustworthiness in technological outcomes. Trustworthiness in innovation and technology is one of the desirable outcomes of RRI practices and is also a prerequisite for the successful adoption of technological achievements in our societies and cities [65,79,80]. Based on the reviewed articles, the 'trustworthy' characteristics of RIT can be interpreted as outlined below.

Innovation and technology should foster greater informational transparency throughout their entire lifecycle, especially if information and data are related to matters that affect human beings. Any decisions or acts made by participators or technology itself should be understandable and explainable. Marketable products and services should be physically and digitally secure to minimize the risks of harm or adverse consequences. The design principles should be devoted to enhancing public understanding, trust, and confidence in innovation and technology to increase public acceptance.

Based on the above description, the RIT characteristic of 'trustworthy' comprises three keywords, namely transparent, secure, and explainable. Table 7 lists the keywords of this characteristic and provides their summary descriptions.

Table 7. Keywords of RIT's trustworthy characteristic.

Keyword	Description	Exemplar Reference
Explainable	Make explicit the reason or standard for any decisions or acts made and be able to justify these choices to provide not just the experts but also the public with adequate understanding and trust, which is essential for effective implementation and management.	[3,50,78]
Secure	Assure the safety and security of innovation in society, both physically and digitally, to minimize the risks of harm or the adverse consequences these technologies may cause as possible, aiming to build the public's trust and confidence in them.	[61,66,81]
Transparent	Information and data regarding the design, production, implementation, operating processes, and future planning of innovation should be transparently disclosed to increase public understanding of innovation, including its opportunities, benefits, risks, and consequences.	[33,59,82]

According to Samuel et al. [56], the practice of innovation and technology should take place in contexts where public trust in relevant sectors is established and robust. Given this, the decisions or acts made by participators or technology itself during innovation practices should be understandable and explainable, which is essential for establishing solid public trust in technological outcomes [34,77]. Whether in the innovation process or in specific practice, the reason or standard for choosing any options in the decision process should be clearly made explicit and be able to be justified [50,83]. Professionals and participators should be able to explain the rationale and the strengths and weaknesses of innovation and technology to relevant audiences in an interpretable, intuitive, and human-understandable way [34,51,55]. Additionally, in addition to providing sufficient explanations, there need to be clear responses to audiences' suggestions and concerns [43]. Santoni de Sio [3] noted the need to create adequate social and legal spaces in which professionals and participators can provide the required explanations to audiences, and the audiences can be able to require further explanations and share their opinions with professionals and participators.

In addition, innovation and technology should ensure that the promise of safety and security is delivered to users in practical scenarios, thereby building and enhancing their trust and confidence [61,66,70]. Digitally, innovation and technology should minimize the inherent risks of algorithmic processing, including bias, privacy violation, and cybersecurity vulnerabilities, to reassure users that technological outcomes will not be misused, used to discriminate, or used to unjustifiably target any individual in any way [82,84]. The privacy-assuring methods should be applied in the personal information collection process for heightened data protection and processing while promoting the measures of informed consent and user control over data [3,59].

Physically, innovation and technology should provide greater stability and accuracy to reduce error and risk in practical applications, creating products that are safer than their conventional counterparts [6,44]. Given this, sufficient safeguards, rigorous safety studies, and assiduous protection mechanisms should be adopted in the designing process to increase safety and security and reduce the created risks or adverse consequences as possible [6,77,81]. Additionally, Sujan et al. [6] and Merck et al. [33] underlined that adopting independent oversight and third-party testing to provide sound safety evidence is vital to assure the safety and security of innovation and technology. Bunnik and Bolt [51] pointed out that security is a crucial condition that responsible innovation must provide in its practical application scenarios.

Furthermore, greater transparency during the entire lifecycle of innovation and technology should be implemented to increase people's understanding, which was deemed important to build people's trust in innovation and technology [85,86]. Greater transparency gives stakeholders as much information as possible about the matter involved to increase their understanding of innovation practices. Stakeholders can evaluate the issues from all possible viewpoints based on adequate information and communicate all their concerns [43,60,87]. This informed discourse may assist decision makers in fully considering all relevant matters, especially the uncertainties and limitations that may be relevant

for various stakeholders, to direct technological developments towards more responsible goals [63,65,88]. In addition, with the growing public concerns about digital privacy, there is a growing call for transparency in information and data processing. Merck et al. [33], Akintoye et al. [84], and Ienca et al. [82] suggested that innovation and technology should contain a range of measures or processes to disclose how and for what purpose the information and data will be collected, managed, and used. Chamuah and Singh [70] stated that ensuring greater data transparency not only helps to build trust among the users but also would further make innovation and technology responsible.

4.6. Well Governed Innovation and Technology

The last RIT characteristic relates to the *governance of innovation and technology*. According to Stilgoe et al. [14], RIT should "take care of the future through collective stewardship of science and innovation in the present" [14]. Innovation and technology, thus, should be well governed to ensure the desired outcomes can be delivered for our cities and society. Based on the reviewed articles, the 'well governed' characteristics of RIT can be interpreted as follows.

Innovation and technology must adhere to statutory regulations and governance requirements during the entire lifecycle while providing explicit accountability mechanisms to make participators consider and act upon the values of responsibility. Participatory governance approaches should be adopted to ensure innovation and technology can be well governed by a broader range of stakeholders, including the public and private sectors, communities, and other relevant entities. The design principles should be devoted to maintaining and strengthening public support and trust in innovation practices and ensuring that the desirable technological outcomes can be delivered to our cities and societies.

Based on the above description, the RIT characteristic of 'well governed' comprises three keywords, namely regulated, accountable, and participatory. Table 8 lists the keywords of this characteristic and provides their summary descriptions.

Table 8. Keywords of the RIT characteristic well governed.

Keyword	Description	Exemplar Reference
Accountable	The entities with legal responsibility for any decisions and acts made or other failures are identifiable, traceable, and held accountable, aiming to embed the values of responsibility in the overall innovation processes.	[50,57,82]
Participatory	Widen stakeholder groups, enhance participation level, and support mutually responsive relations to bring diversified public views and values into innovation, which maintains public support and trust, while embedding innovation successfully in the complex and dynamic societal context via participatory and responsive governance.	[65,89,90]
Regulated	Operated as far as is practicable to comply with existing regulations, fundamental rights, and freedoms, which helps address the complex challenges and reach a consensus that fosters and facilitates innovation and improves the wider implications to society.	[61,91,92]

According to Hemphill [93], three basic methods can be taken to support the governance of innovation and technology—i.e., government regulation, self-regulation, and public regulation. The authors indicated that self-regulation and public regulation are promising supplementary approaches to improve the traditional regulatory method (government regulation), which may solve the shortcomings of traditional regulatory regimes in dealing with the more complex implications carried by rapid scientific and technological progress.

From the self-regulation perspective, innovation and technology should be auditable and accountable while ensuring that the locus of responsibility remains with the human participators, e.g., designer, operator, or other legal entity [30,50,94]. The intelligent system should provide traceable historical records of every action to identify specific responsibility ascriptions, which contribute to facilitating the clear incident investigation process [6,57]. Additionally, the participators responsible for different stages throughout the lifecycle of

innovation practice should be identifiable and accountable for the results of decisions and acts made [55,61,83]. Mecacci and Santoni de Sio [94] indicated that "only humans can be held responsible for unwanted actions or mistakes of a technical system". The authors suggested deploying the concept of meaningful human control (MHC) in the decisional chain of intelligent systems to promote a strong and clear connection between human agents and intelligent devices, thereby resulting in more transparent accountability [94].

From the public regulation perspective, an increasing number of studies have stated that the regulation of innovation and technology must include efforts to engage with the public, which makes it "a more inclusive, participatory, reflexive and responsive heralding responsible governance" [89,90,93]. According to Russell et al. [5] and MacDonald et al. [87], the decision maker and key participator of innovation should focus more on finding creative ways for public engagement, such as allowing for the bottom-up approach that considers the voices of wider stakeholder groups [54,95,96]; interaction with stakeholders in the early stage of the innovation process [33,60,97]; applying interdisciplinary approaches to embed public values and cultures into innovation [64,91,98]; and others. Similarly, Stemerding et al. [92] advocated that public engagement enhanced reflexivity about the different needs and that the interests of stakeholders should be considered in shaping the responsible innovation agenda.

Additionally, considering that some implications of innovation practices may be controversial, innovators, decision makers, and regulators should carefully consider the relevant audience's concerns, insights, and feedback to shape, modify, and restrain innovation, which supports mutually responsive relations in the innovation practices [65,99]. This responsive relationship would assist different stakeholders in reaching a consensus on potential conflicts in the context of the complex and dynamic embedding of technology in society [57,100,101]. The enhanced participation level allows wider stakeholder groups to establish a common ground of innovation practices, which can, along with other positives, increase user acceptance of technological outcomes and maintain public support and trust [31,35,56].

Consequently, a formal and inclusive cooperative mechanism needs to be established that allows wider stakeholders institutionalized access to deliberative settings and provides them with sustained engagement in innovation practices, which ensures they can identify their respective obligations and can voice opinions throughout the innovation process [3,43,74]. Hemphill [93] stated that "participatory public regulation might be a far more thoughtful, efficient, and effective approach to ensuring responsible innovation and technology, which could act as an alternative, complementary, or hybrid form to improve traditional regulation mechanisms".

Lastly, from the traditional regulatory perspective (government regulation), the entire lifecycle of innovation and technology must adhere to existing laws and statutory regulations, while ensuring technological outcomes align with academic discipline, research integrity, and ethics [44,61,102]. On that point, Samanta and Samanta [88] stated that the combination of ethicolegal principles and statutory regulations would enable innovation and technology to maximize its benefits in a responsible way in practical applications. Hence, professionals and legislature should cooperatively establish a more sound and clearer regulatory framework or guideline to address the emerging challenges of defining ethics and reaching a consensus [57,69,91]. Meanwhile, the comprehensive and explicit legislation would contribute to addressing increasing concerns of privacy and safety, while helping to facilitate public acceptance and foster future innovative development [84,92,93].

Yet, Merck et al. [33] indicated that relevant legislation should not appear as a regulatory barrier to innovation. The innovation trajectories should be flexibly steered within a highly regulated environment without generating potential safety or efficacy issues [74]. Given this, regulators should appropriately balance the technological viability (what can be done), statutory permissibility (what may be done), and ethical acceptance (what should be done) during the development of relevant provisions to ensure the appropriateness of regulations [81]. Moreover, Koirala et al. [35] and Leenes et al. [103] suggested that the leg-

islature can adopt socio-technical models specific to local, social, and physical conditions to develop flexible and adaptive legislation programs better suited to specific circumstances.

5. Findings and Discussion

5.1. Key Findings

This paper reviewed studies (n = 65) with a focus on RIT, which were published between January 2010 and August 2022 and aimed to conceptualize the key characteristics of RIT and to broaden the understanding of responsible research in the technosphere, particularly from a bottom-up perspective. The findings of this review disclosed the following: (a) the number of RIT studies has increased over time, reflecting the growing interest in this topic over the past decade; (b) RIT studies mainly focus on AI, healthcare technology, robotics, nanotechnology, ICT, and gene technology; (c) RIT is characterized as acceptable, accessible, aligned, trustworthy, and well governed; (d) these characteristics may be shaped and influenced by cultures, values, social norms, and virtues. The key findings of this paper are summarized and presented in Tables 1 and 4–8. In accordance with the above efforts, we conceptualize and define RIT in this paper as follows:

> *"Responsible innovation and technology is an approach to deliver acceptable, accessible, trustworthy, and well governed technological outcomes, while ensuring these outcomes are aligned with societal desirability and human values and can be responsibly integrated into our cities and societies."*

In other words, technological advancements should be developed and integrated into cities and societies in a way that is aligned with societal needs, values, cultures, and ethics. The technological outcomes and practices should ensure accessibility, acceptability, and trustworthiness for relevant audiences and be appropriately managed to ensure its 'right' impact on society. The goal of RIT should pursue a balance between the promising opportunities of technology and its potentially negative consequences, ensuring that it can spread the benefits of technological progress across our societies and cities in a responsible manner.

In terms of practical design and practices, a first suggestion is that decision makers and key participators of innovation should apply a series of formal and evidence-based procedures to evaluate the impacts in different phases of the innovation process, e.g., impact prediction, assessment, and monitoring. Impact prediction helps to identify the potential risks, unintended consequences, and negative impacts of the technology before it is developed and implemented. It allows for early consideration and provides participators with first-mover advantages to take proactive steps to deal with, mitigate, or solve problems; minimize harm; and maximize benefit.

Impact assessment can assist innovators in balancing the opportunities and consequences of innovation and technology, ensuring that technological outcomes deliver the desired outcomes and positively impact society. Additionally, regular impact monitoring should be incorporated into the entire process and make improvements continuously to the technological product as needed to ensure innovation and technology progresses towards more responsible outcomes. The decision makers and key participators of innovation should maintain 'long-term thinking' in the whole evaluation process to consider the long-term implications of innovation and technology and ensure that improved results are resilient and sustainable. A thorough impact evaluation procedure contributes to promoting RIT development.

Our second suggestion is that a broader and clearer ethical framework should be adopted to guide decision making, ensuring that innovation and technology are developed and deployed in line with ethical considerations. The framework should involve two key components. The first involves core and common ethical principles, such as respect for human rights and dignity, ensuring fairness and non-discrimination and being harmless to human beings and the environment. The second component is being flexible depending on specific cultures, values, and industries, such as geo-cultural characteristics and values, different industry standards, and requirements for sensitive industries. Additionally,

industry-specific ethical guidelines can be incorporated into the framework to improve its completeness, such as the EU's *Ethical Framework for Trustworthy AI* and the IEEE's *Ethically Aligned Design* for autonomous and intelligent systems. Incorporating a comprehensive and adaptable ethical framework helps build public trust in innovation and technology, which can also promote their responsible implementation in our cities and societies.

Thirdly, the regulatory sector plays a crucial role in promoting responsible innovation and technology development by setting laws, policies, and regulations that ensure legal innovation practices. The regulatory sector should formulate a clear and effective regulatory framework to ensure that innovation practices are carried out under the constraints of the law. The framework can incentivize participators to prioritize responsible innovation by setting clear expectations and consequences for non-compliance. Additionally, effective regulation and governance also facilitates transparency and accountability in innovation practices, encouraging stakeholders to take responsibility for their decisions and actions. A well governed innovation practice can ensure that the technological outcomes are trustworthy and help to ensure that the outcomes are developed and used in a way that benefits society while avoiding severe consequences.

Lastly, an effective participation mechanism is critical in developing RIT. The desirable characteristics of RIT should be realized via active engagement with a broader range of stakeholders, such as policymakers, industry, civil society, academic communities, and underrepresented groups. The decision makers and key participators of innovation should actively consider the diverse perspectives of stakeholders to understand their concerns and opinions, ensuring that innovation and technology will deliver the best possible outcomes. The mechanism can be built by establishing interdisciplinary research programs, partnerships between industry and academia, and public engagement initiatives.

Additionally, a supportive environment for ongoing dialogue and collaboration should be created, including but not limited to providing practical funding and regulatory support. Incorporating participation mechanisms into the innovation process may contribute to broadening the perspectives and knowledge base of the innovation sector to help them make the right decision, such as acquiring more comprehensive background information regarding local cultures, values, and potential influences. Moreover, an effective participation approach can increase the transparency of the innovation process, which helps to enhance public trust and confidence in technology and increase their acceptance.

5.2. Conceptual Framework

Based on the systematic literature review, this section conceptualizes a broad framework outlining the fundamental results and key findings, aiming to explore the possible design procedure of RIT and assist its future research, development, and practices towards more responsible outcomes. The framework (Figure 5) is invaluable for governments, companies, practitioners, researchers, and other stakeholders as a tool to address the grand challenges that accompany technological and scientific progress—especially given the context of smart and sustainable cities. The framework also informs science, technology, and innovation policy.

The conceptual framework (Figure 5) indicates that ensuring a responsible innovation environment is essential to the delivery of a socially desirable technological outcome, i.e., RIT. Innovation practices should be conducted within the statutory regulatory framework and ensure it adheres to the core ethical principle, which should consider as the bottom line enabling technological innovation attempts. During the innovation process, the innovation sector should consider adopting the concept of RRI and applying specific RRI tools to ensure the technological outcomes can satisfy the 'responsible' characteristics. These characteristics are as follows: (a) acceptable; (b) accessible; (c) aligned; (d) trustworthy; and (e) well governed.

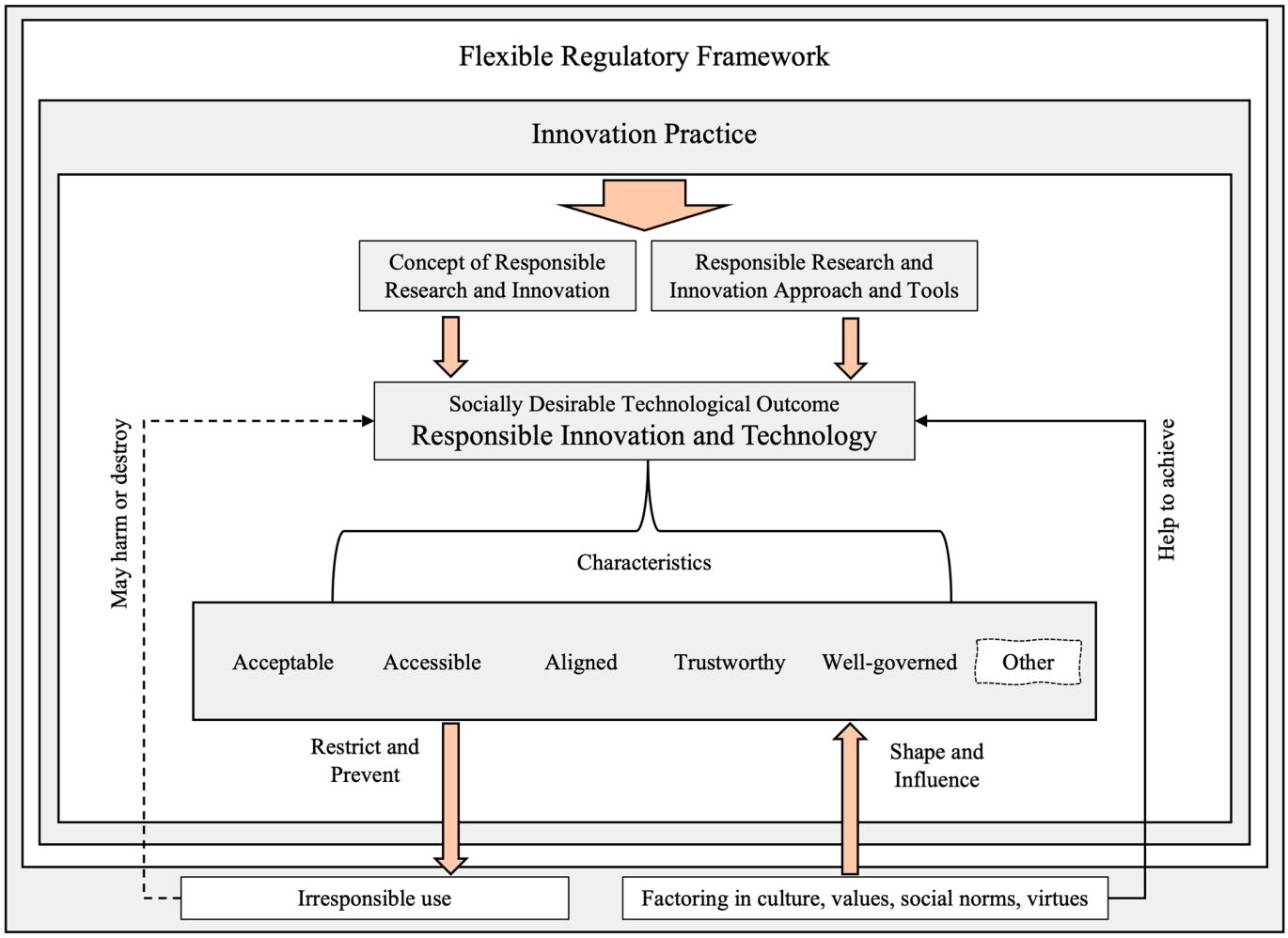

Figure 5. Conceptual framework of RIT design and implementation.

According to Stilgoe et al. [14] and Burget et al. [22], the RRI concept is an attempt to govern the process of emerging science and innovation by anticipating and discerning opportunities and consequences of innovation within a broader social context. The existing concept pays more attention to describing the processual elements required for a 'responsible' innovation process rather than certain outcomes—e.g., anticipation, reflexivity, inclusion, and responsiveness [22]. Thus, specific tools are needed in this process to achieve concrete results or outcomes. Thapa et al. [13] presented some of the most frequently applied RRI tools in practices, such as comprehensive and acceptability analysis, participatory appraisal, technology assessment, etc., which may assist the innovation sector in designing and developing responsible products to meet social expectations.

In addition, cultures, values, social norms, and virtues may exert significant influence in shaping the characteristics of RIT. According to Von Schomberg [15], the vision of RRI is to embed fundamental social values into the research and innovation process to ensure that technological outcomes are socially desirable. Nonetheless, culture is considered one of the important determinants in the innovation process [104–106]. Although certain core human values are universal but may be interpreted in different ways by different cultures, even within the same society, "the values appreciated by Western society or the developed part of the world may be disliked by developing parts of the world, and vice versa" [107]. Therefore, the social perceptions and expectations of 'responsible' outcomes might exhibit differences in different cultural contexts, assuming that 'one size fits all' is unwise. RIT should respect and recognize 'other' (as shown in Figure 5) possible characteristics shaped

by specific cultural settings, e.g., local social norms and virtues, and approach sensitively when values from different societies and cultures conflict with each other.

Finally, irresponsible use may remove some of the characteristics of RIT, making it unable to meet social expectations. As Boden et al. [61] underlined, innovation and technology are "just tools designed to achieve goals and desires that humans specify". Although RIT is expected to provide certain safeguards to restrict or prevent irresponsible use, the awareness of 'responsible use' still needs to be promoted, especially in practical application scenarios. The 'responsible' notion in innovation and technology requires a collective effort to sustain, not only by innovators but also by users.

6. Conclusions

This paper investigated the reported practices of the RRI concept in our societies and cities and conceptualized the key characteristics of its expected outcomes—i.e., RIT. Additionally, a focused discussion has been provided on possible solutions for realizing these characteristics. The conceptual framework has been developed, and the possible design procedure of RIT has been outlined, which will broaden the understanding of responsible research from a bottom-up perspective, especially regarding its application to specific practices. It sheds light on the overall design principles of RIT that assure emerging innovations and technologies to be more 'responsible' by embedding the RRI concept. The framework could be used by the government, practitioners, researchers, and other stakeholders as a tool to address the grand challenges accompanied by technological and scientific progress and ensure innovation and technology can be responsibly embedded into our cities and societies.

Although the interest in the theme of 'being responsible' in technospheres is growing, specific ways to achieve desired outcomes still need further research. Given this, this section underlines some issues to be further explored/studied, which may pave the way for a new research agenda concerning achieving the development and practices of responsible technological outcomes in our cities and societies. The following issues/questions are important for prospective research to focus on and address:

- How can we decide if innovation and technology contain the responsible characteristics, and what are the specific evaluation criteria?
- What are the specific scales in defining responsible characteristics in innovation and technology? For example, when a technological innovation contains many characteristics of RIT but is missing some, should it still be considered 'responsible'?
- How should RIT be compatible with specific values in complex cultural contexts, and how should innovation and technology sectors balance the possible conflict of values from different levels of cultural contexts, such as individual, collective, community, and national levels?
- How can we define the social desirability of innovation and technology that may vary with different values or specific innovation purposes, and how can we make choices when different social expectations or needs conflict?

Lastly, this paper offers invaluable insights into responsible research in the technosphere—particularly from a bottom-up perspective. However, it is essential to acknowledge several limitations that may influence the interpretation of the findings. Firstly, the paper did not apply any automated analysis tools or techniques to conduct the qualitative analysis. Secondly, the selected search keywords may not cover all studies relevant to the research objective. Thirdly, the literature selection only records available online and peer-reviewed academic journal articles, which may omit some additional insights from other forms of studies. Fourthly, the findings may be influenced by the unconscious biases of the authors.

Despite these limitations, our research lays the groundwork for future investigations in this area. The topic of responsible research in the technosphere is relatively new, and there are still significant research gaps that need to be bridged, especially the uncertain pathway between theoretical study and practical applications. This paper advocates that

future research should open new discussions on responsible research in the context of specific practices and scenarios, with the aim of making the concept more responsive to specific settings—e.g., innovation and technology. On that very point, our prospective studies will concentrate on providing more clarity and measurability to RIT.

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Appendix A

Table A1. Summary of the reviewed literature.

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
1	Sujan et al.	*Safety Science*	Stakeholder perceptions of the safety and assurance of artificial intelligence in healthcare.	2022	Healthcare	Artificial intelligence	Acceptable	Harmless	1. The use of innovations should not disrupt the relationship between patients and clinicians.
							Trustworthy	Secure	1. Innovation should provide greater efficiency and accuracy to reduce error and to make care safer. 2. Need for rigorous approaches, sound safety evidence, and independent oversight.
							Well governed	Participatory	1. Diversity of views can support responsible innovation.
								Accountable	1. Provide auditable and traceable history of every action that the AI did to facilitate the incident investigation process.
2	Li et al.	*Computers in Human Behavior*	What drives the ethical acceptance of deep synthesis applications? A fuzzy set qualitative comparative analysis.	2022	Digital media	Artificial intelligence	Aligned	Meaningful	1. Should promote the progress of society and human civilization, create a more intelligent way of work and life, improve people's well-being, and benefit all humanity, including future generations.
							Acceptable	Ethical	1. Should follow the principle of people-centered development and use, based on the principle of respecting human autonomy.
								Harmless	1. Well-being and the common good, justice, and a lack of harm are the core conditions of high ethical acceptance.
								Equitable	1. Should ensure fairness and justice, avoid prejudice and discrimination against specific groups or individuals, and avoid disadvantaging vulnerable groups.
							Trustworthy	Transparent	1. Accountability and transparency are the most important guiding principles in AI development.
							Well governed	Accountable	1. AI should be auditable and accountable. The people responsible for different stages of the life cycle of an AI system should be identifiable and responsible for the results of the AI system.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
3	Eastwood et al.	*Frontiers in Robotics and AI*	Responsible robotics design–A systems approach to developing design guides for robotics in pasture-grazed dairy farming.	2022	Agriculture	Robotics	Aligned	Meaningful	1. Robotics should provide positive impacts on social well-being.
								Sustainable	1. To ensure broad sustainability outcomes with milking robotics. A key consideration is the implications for animal well-being using robots.
							Accessible	Adaptable	1. Should be able to integrate with existing technologies and leverage new opportunities for productivity gains. 2. Must be robust to deal with complex operating environments. 3. Must be easy to train, use, and maintain to increase job flexibility and ability for a wider range of people.
								Affordable	1. High-throughput robotics may be using high-cost technology to perform low-cost jobs.
							Acceptable	Harmless	1. Robotics should reduce injuries and physical demands on people and avoid negative psychological impacts, such as changes to the self-identity of staff if robotics replaces their roles.
							Well governed	Regulated	1. Potential regulatory barriers also need to be assessed in robotics development.
4	Ienca et al.	*Neuroethics*	Towards a Governance Framework for Brain Data.	2022	Medical science	Data technology	Trustworthy	Secure	1. Brain data should be considered a special category of personal data that warrants heightened protection during collection and processing. 2. Usage of brain data should consider and prevent inherent risks of algorithmic processing including bias, privacy violation, and cybersecurity vulnerabilities.
								Transparent	1. The process of collecting, managing, and/or processing identifiable brain data should be transparently disclosed.
							Well governed	Accountable	1. Legal entities responsible for data breaches and other regulatory failures should be identifiable and held accountable.
5	Bao et al.	*Computers in Human Behavior*	Whose AI? How different publics think about AI and its social impacts.	2022	Technology	Artificial intelligence	Well governed	Participatory	1. AI development and regulation must include efforts to engage with the public in order to account for the varied perspectives that different social groups hold concerning the risks and benefits of AI.
6	Townsend and Noble	*Sociologia Ruralis*	Variable rate precision farming and advisory services in Scotland: Supporting responsible digital innovation?	2022	Agriculture	Smart farming technology	Well governed	Participatory	1. Design and implementation of innovation should allow for a more bottom-up approach that considers the voices of a broader stakeholder group.
7	Stahl	*International Journal of Information Management*	Responsible innovation ecosystems: Ethical implications of the application of the ecosystem concept to artificial intelligence.	2022	Technology	Artificial intelligence	Aligned	Meaningful	1. Innovations should actively seek to align their processes and expected outcomes with societal needs and/or preferences.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
8	Middelveld et al.	*Public Understanding of Science*	Imagined futures for livestock gene editing: Public engagement in the Netherlands.	2022	Agriculture	Gene technology	Aligned	Deliberate	1. We need to exercise care (and moderation) in decision-making practices of innovation to avoid large and irreversible consequences for life on Earth.
								Sustainable	
9	Merck et al.	*Bulletin of Science, Technology & Society*	What Role Does Regulation Play in Responsible Innovation of Nanotechnology in Food and Agriculture? Insights and Framings from US Stakeholders.	2022	Agriculture	Nanotechnology	Trustworthy	Transparent	1. Should provide a range of processes to ensure transparency (via processes, safety studies, and assessments), requiring disclosure, and changing the use of confidential business information.
								Secure	1. Should conduct more safety studies to strengthen safety and ensure independent third-party testing.
							Well governed	Regulated	1. Require basic and appropriate regulations to ensure safety and efficacy but ensure that they do not appear as a barrier to innovation or a guardrail against the risks of novel products.
								Participatory	1. Should interact with stakeholders early in innovation processes, involving the public and engaging stakeholders, to strengthen community and stakeholder engagement.
10	Russell et al.	*Journal of Responsible Innovation*	Opening up, closing down, or leaving ajar? How applications are used in engaging with publics about gene drive.	2022	Biology	Gene technology	Well governed	Participatory	1. Should devote more attention to finding creative ways for public engagement, which can create fresh perspectives, engagements, and collective actions.
11	Foley et al.	*Journal of Responsible Innovation*	Innovation and equality: an approach to constructing a community governed network commons.	2022	Technology	Information and communication technologies	Well governed	Participatory	1. Apply more interdisciplinary approaches to bring the public's values into innovation, aiming to align technological and societal research for equitable outcomes.
12	Donnelly et al.	*AI & Society*	Born digital or fossilized digitally? How born digital data systems continue the legacy of social violence towards LGBTQI+ communities: a case study of experiences in the Republic of Ireland.	2022	Technology	Data technology	Acceptable	Equitable	1. Developers should eliminate systematic stereotyping during the innovation process and take a more inclusive approach within the original software design to reduce marginalization towards minority groups in society.
13	Samuel et al.	*Critical Public Health*	COVID-19 contact tracing apps: UK public perceptions.	2022	Healthcare	Contact tracing technology	Acceptable	Ethical	1. New health innovation practices should be compatible with respect to personal privacy and autonomy.
							Trustworthy	Explainable	1. Innovation practices should be within contexts where public trust in government and institutions is established and robust.
							Well governed	Participatory	1. Effective communication and engagement are helpful in maintaining public support and trust.
14	MacDonald et al.	*Journal of the Royal Society of New Zealand*	Conservation pest control with new technologies: public perceptions.	2022	Biology	Gene technology	Trustworthy	Transparent	1. Innovation design and processes need to involve and communicate/be transparent with the public.
							Well governed	Participatory	

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
15	Bunnik and Bolt	*Epigenetics Insights*	Exploring the Ethics of Implementation of Epigenomics Technologies in Cancer Screening: A Focus Group Study.	2021	Medical science	Epigenomics technology	Acceptable	Ethical	1. From an ethical point of view, innovation and its implementation should be respected for autonomy and ethically acceptable.
								Equitable	1. Should grant all categories of road users the same level of protection, which aims to redress inequalities in vulnerability among road users. 2. Should adopt non-discriminatory and more inclusive designs to reduce the risks of perpetuated and increased inequalities between individuals and groups in society. 3. Should avoid blaming the victim, stigmatization, and discrimination.
							Trustworthy	Transparent	1. Informed consent was deemed important because people need to understand 'the whole chain' of events or decisions they may be confronted with based on the possible outcomes of screening.
								Explainable	1. Professionals should be able to explain what epigenomic screening entails and what the results might mean.
								Secure	1. The security of data and samples and the protection of the privacy of screening participants were crucial conditions for the responsible implementation of epigenomics technologies in public health settings.
16	Santoni de Sio	*Ethics and Information Technology*	The European Commission report on ethics of connected and automated vehicles and the future of ethics of transportation.	2021	Urbanology	Autonomous vehicle	Acceptable	Harmless	1. CAVs should prevent unsafe use by inherently safe design and meaningful human control approaches. 2. Products do not harm human health and/or the environment.
							Trustworthy	Secure	1. The first and most obvious is the safeguard of informational privacy, in line with some basic principles of GDPR such as data minimization, storage limitation, and strict necessity requirements, as well as the promotion of informed consent practices and user control over data.
								Explainable	1. Create adequate social and legal spaces where questions about the design and use choices of CAVs can be posed and answered, making the relevant people aware, willing, and able to provide the required explanations to the relevant audience and the relevant audiences able and willing to require and understand the explanations.
							Well governed	Participatory	1. Create the institutional, social, and educational environment to ensure that all key stakeholders can discuss, identify, decide, and accept their respective obligations.
								Accountable	1. Should address the following often-posed question: who is to blame (and held legally culpable) for accidents involving CAVs?

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
17	Kokotovich et al.	*NanoEthics*	Responsible innovation definitions, practices, and motivations from nanotechnology researchers in food and agriculture.	2021	Agriculture	Nanotechnology	Aligned	Meaningful	1. Create effective and efficient products to improve human well-being and solve societal problems.
								Deliberate	1. Should carefully and comprehensively consider the potential social, health, and environmental impacts associated with the innovation and ensure that actual and potential near-term and longer-term negative impacts are mitigated to the extent feasible.
							Acceptable	Harmless	1. Develop products that are publicly acceptable because of their potential to impact the uptake of technology.
							Trustworthy	Secure	1. Use nanotechnologies and/or engineered nanomaterials to create agrifood products that were more safe than conventional counterparts.
							Well governed	Regulated	1. Adhere to regulations to ensure agrifood products align with the mission of academic discipline and research integrity and ethics.
								Participatory	1. Engage stakeholders and collaborate interdisciplinarily to determine what specific products to pursue.
18	Grieger et al.	*NanoImpact*	Responsible innovation of nano-agrifoods: Insights and views from US stakeholders.	2021	Agriculture	Nanotechnology	Aligned	Meaningful	1. Create effective and efficient products to address a significant problem or societal need and improve the world.
								Sustainable	1. Should treat resources with respect and in the most responsible way and use the resource in a non-wasteful manner.
							Acceptable	Harmless	1. Do nothing that could cause irreversible harm to public health or the environment.
							Trustworthy	Transparent	1. Improve transparency and communication.
							Well governed	Participatory	1. Consider the impacts of an innovative development on the different stakeholders and engage them in the early stage of innovation process.
								Regulated	1. Adhere to regulations.
19	Laursen and Meijboom	*Journal of Agricultural and Environmental Ethics*	Between Food and Respect for Nature: On the Moral Ambiguity of Norwegian Stakeholder Opinions on Fish and Their Welfare in Technological Innovations in Fisheries.	2021	Agriculture	Fishery technology	Well governed	Regulated	1. Governance regulation becomes a key outcome of the innovation process to make innovation acceptable in India.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
20	Singh et al.	*Technological Forecasting and Social Change*	Analysing acceptability of E-rickshaw as a public transport innovation in Delhi: A responsible innovation perspective.	2021	Urbanology	E-rickshaw	Aligned	Sustainable	1. Universal and culture-specific values should be embedded in innovation, which can make the product socially, economically, and environmentally sustainable.
							Accessible	Inclusive	
							Well governed	Participatory	1. Engage stakeholders via a representative and inclusive process to establish common ground or consensus, which can, along with other positives, make innovation acceptable and workable. 2. Some implications of technological innovation may be controversial, and thus, public research and development must reconcile the possible repercussions of participating in their development.
21	Stitzlein et al.	*Sustainability*	Reputational risk associated with big data research and development: an interdisciplinary perspective.	2021	Agriculture	Data technology	Acceptable	Equitable	1. Encourage fairer and more equitable technology use.
								Ethical	1. Incorporate moral and societal values into the design processes for making emerging technologies more ethical and more democratic.
							Trustworthy	Transparent	1. Handle greater transparency about data collection, reuse, consent, and custodianship.
22	Christodoulou and Iordanou	*Frontiers in Political Science*	Democracy under attack: challenges of addressing ethical issues of AI and big data for more democratic digital media and societies.	2021	Digital media	Artificial intelligence	Well governed	Participatory	1. Should involve even more stakeholders (public) to identify common ground across countries and regions, as well as cultural-specific challenges that need to be addressed.
						Data technology		Regulated	1. Legislation should help to address the challenge of defining ethics and reaching a consensus that improves the wider implications to society.
23	Middelveld and Macnaghten	*Elem Sci Anth*	Gene editing of livestock: Sociotechnical imaginaries of scientists and breeding companies in the Netherlands.	2021	Agriculture	Gene technology	Aligned	Deliberate	1. Require stakeholders—including agricultural scientists—to exercise humility, avoid easy judgment, and learn to hesitate.
								Meaningful	1. The purpose of livestock gene editing applications is represented as that of producing "better" animals, with "improved" animal welfare and "increased" disease resistance, that contribute a vital role to play in "solving" the global food challenge.
							Acceptable	Ethical	1. Highly valued animal health and welfare and the long historical arc of concerns about animal food safety in unison create a high ethical sensitivity to animals in Europe. Innovation should be particularly careful to avoid or fuel future controversy.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
24	Mladenović and Haavisto	*Case Studies on Transport Policy*	Interpretative flexibility and conflicts in the emergence of Mobility as a Service: Finnish public sector actor perspectives.	2021	Urbanology	Mobility-as-a-Service	Aligned	Meaningful	1. Mobility as a Service (MaaS) should be designed to truly meet people's needs and to put the user at the center of transport service provision, with all the associated benefits.
								Sustainable	1. MaaS would reduce the percentage of car use, by freeing people from car dependency to increase the share of sustainable modes.
							Accessible	Inclusive	1. Embrace the inherent conflict in the value-laden mobility domain, which paves the way for a culture of technological innovation.
							Well governed	Participatory	1. The public and private sectors need to find a way to cooperate and begin dialogue, and information sharing are important in a fast-moving field.
25	Rochel and Evéquoz	*AI & Society*	Getting into the engine room: a blueprint to investigate the shadowy steps of AI ethics.	2021	Technology	Artificial intelligence	Trustworthy	Explainable	1.Innovator should be able to make explicit their reasons or standard for choosing option A over other existing options and be able to justify these choices.
26	Pickering	*Future Internet*	Trust, but Verify: Informed Consent, AI Technologies, and Public Health Emergencies.	2021	Healthcare	Artificial intelligence	Acceptable	Harmless	1. Reduce or eliminate the harmful effects of technology use and achieve an overall state of well-being.
							Trustworthy	Explainable	1. Should explain the rationale to users, characterize the strengths and weaknesses, and convey an understanding of how they will behave in the future.
							Well governed	Accountable	1. Understand the actors who will often be regulated with specific obligations. These actors would all influence the trust context.
27	Stankov and Gretzel	*Information Technology & Tourism*	Digital well-being in the tourism domain: mapping new roles and responsibilities.	2021	Tourism	Information and communication technologies	Trustworthy	Explainable	1. Generating high-quality interpretable, intuitive, human-understandable explanations of AI decisions is essential for operators and users to understand, trust, and effectively manage local government AI systems.
28	Yigitcanlar et al.	*Journal of Open Innovation: Technology, Market, and Complexity*	Responsible urban innovation with local government artificial intelligence (AI): A conceptual framework and research agenda.	2021	Urbanology	Artificial intelligence	Acceptable	Ethical	1. The ethical considerations made by the designers and adopters of AI systems are critical when it comes to avoiding the unethical consequences of AI systems.
							Accessible	Affordable	1. AI systems should be accessible and affordable. Alternatively, the resources can be leveraged in new ways, or other solutions can be found that do not jeopardize the delivery of high-value outputs.
							Trustworthy	Transparent	1. Reduce the created risks or adverse consequences as much as possible and build users' trust and confidence via increasing transparency and security of the system.
								Secure	
29	Iakovleva et al.	*Sustainability*	Changing Role of Users—Innovating Responsibly in Digital Health.	2021	Healthcare	Healthcare technology	Well governed	Participatory	1. Should carefully consider the ability and willingness of users to get involved and contribute their insights and absorb this type of feedback to shape and modify innovation in response to their insights.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
30	Buhmann and Fieseler	*Technology in Society*	Towards a deliberative framework for responsible innovation in artificial intelligence.	2021	Technology	Artificial intelligence	Accessible	Inclusive	1. The inclusion of all arguments constitutes the main precondition of the rationality of the process of deliberation.
							Trustworthy	Transparent	1. Stakeholders need to have as much information as possible about the issues at stake, the various suggestions for their solution, and the ramifications of these proposed solutions.
								Explainable	1. Needs to be clearly responsive to stakeholders' suggestions and concerns.
							Well governed	Participatory	1. Stakeholders need institutionalized access to deliberative settings to ensure they have a chance to voice their concerns, opinions, and arguments.
31	Lehoux et al.	*Health Services Management Research*	Responsible innovation in health and health system sustainability: Insights from health innovators' views and practices.	2021	Healthcare	Healthcare technology	Accessible	Affordable	1. Address specific system-level benefits but often struggle with the positioning of their solution within the health system.
							Acceptable	Ethical	1. Increase general practitioners' capacity or patients and informal caregivers' autonomy.
							Well governed	Participatory	1. Engage stakeholders at an early ideation stage using context-specific methods combining both formal and informal strategies.
32	Akintoye et al.	*Journal of Information, Communication and Ethics in Society*	Understanding the perceptions of UK COVID-19 contact tracing app in the BAME community in Leicester.	2021	Healthcare	Contact tracing technology	Acceptable	Ethical	1. Reassure users that this technology will not target them and will not be misused in any way. The collected data will securely be processed and will not be used in any way to discriminate against them or unjustifiably target them.
							Trustworthy	Secure	
								Transparent	1. Commit to full transparency in the implementation of the technology to provide clear information on how and what the data will be used for in the future.
							Well governed	Regulated	1. Clear regulation or policy to prevent misuse or dual use of concern.
33	Ten Holter et al.	*Technology Analysis & Strategic Management*	Reading the road: challenges and opportunities on the path to responsible innovation in quantum computing.	2021	Technology	Quantum computing	Accessible	Inclusive	1. Support interdisciplinary dialogue between fields to empower researchers, which is essential to add richness of understanding to possible impacts.
							Acceptable	Equitable	1. Ensure wide, democratic access to technologies.
							Well governed	Participatory	1. Generate more frequent, more detailed conversations with society to increase public understanding of quantum technologies. 2. Widen the pool of stakeholders consulted to incorporate the views of wider groups of stakeholders.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
34	Macdonald et al.	*Journal of Responsible Innovation*	Indigenous-led responsible innovation: lessons from co-developed protocols to guide the use of drones to monitor a biocultural landscape in Kakadu National Park, Australia.	2021	Urbanology	Drone technology	Accessible	Inclusive	1. Incorporate diversified ethical considerations and social impacts into the technological design, especially in some cross-cultural settings, to ensure products match local users' needs and preferences and recognize local knowledge and governance.
							Well governed	Regulated	1. Establish guidelines for technological systems to remain human-centric, serving humanity's values and ethical principles, including ensuring humans remain in the loop about drone development and use.
35	Chamuah and Singh	*Aircraft Engineering and Aerospace Technology*	Responsibly regulating the civilian unmanned aerial vehicle deployment in India and Japan.	2021	Urbanology	Drone technology	Well governed	Participatory	1. Participation of both internal and external stakeholders in regulations would make it more inclusive, participatory, reflexive, and responsive, heralding responsible governance that is suitable for robust policymaking.
								Regulated	
								Accountable	1. Have to keep a strategy and plan and identify essential values to ensure the accountability of new and emerging technology.
36	Rose et al.	*Land use policy*	Agriculture 4.0: Making it work for people, production, and the planet.	2021	Agriculture	Smart farming technology	Accessible	Inclusive	1. Having open conversations about the future of agriculture should include the crucial views of marginalized individuals who might possess differing opinions.
							Well governed	Participatory	
								Regulated	1. Require updates to legislation, guidelines, and possible support for various technologies in the form of skills training, improved infrastructure, or perhaps funding.
37	Hussain et al.	*IEEE Transactions on Software Engineering*	Human values in software engineering: Contrasting case studies of practice.	2020	Technology	Software engineering	Aligned	Meaningful	1. Technology should be socially desirable and aligned with human values of freedom, justice, privacy, and so on.
38	Lockwood	*IET Smart Cities*	Bristol's smart city agenda: vision, strategy, challenges and implementation.	2020	Urbanology	Smart city technology	Accessible	Inclusive	1. Reduce the impacts of the digital divide on the most deprived areas or more vulnerable groups to spread the benefits of digitization spreading across the city.
							Trustworthy	Secure	1. It is vital that smart technologies are developed with sufficient safeguards to minimize the risk of harm these technologies may cause, be that data protection and privacy breaches or biased, discriminatory outcomes.
							Well governed	Regulated	1. Regulators in developing relevant policy frameworks, regulations, and standards should appropriately balance what can be done (what is technologically viable), what may be done (from a legal perspective), and what should be done (what is ethical and acceptable).
39	Mecacci and Santoni de Sio	*Ethics and Information Technology*	Meaningful human control as reason-responsiveness: the case of dual-mode vehicles.	2020	Urbanology	Autonomous vehicle	Trustworthy	Secure	1. Promote a strong and clear connection between human agents and intelligent systems, thereby resulting in better safety and clearer accountability.
							Well governed	Accountable	

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
40	Brandao et al.	*Artificial Intelligence*	Fair navigation planning: A resource for characterizing and designing fairness in mobile robots.	2020	Urbanology	Robotics	Acceptable	Equitable	1. Include realistic fairness models within the planning objectives of innovation.
							Trustworthy	Transparent	1. Provide transparency to let users understand and control the impact of the technology in terms of the values of interest.
								Secure	1. Require data collection to go together with privacy-assuring methods.
41	Chamuah and Singh	*SN Applied Sciences*	Securing sustainability in Indian agriculture through civilian UAV: a responsible innovation perspective.	2020	Agriculture	Drone technology	Aligned	Meaningful	1. Have the ability or power to address existing problems or societal needs.
							Accessible	Affordable	1. The economic viability is one of the essential aspects of sustainability for civilian UAVs in India.
							Trustworthy	Secure	1. Should maintain the safety, security and privacy rights of the people while deploying the drone.
								Transparent	1. The transparency and traceability of data provided by civil UAVs further make them accountable and entwine the values of responsibility in the overall civilian UAV innovations.
							Well governed	Accountable	
42	Rivard et al.	*BMJ Innovations*	Double burden or single duty to care? Health innovators' perspectives on environmental considerations in health innovation design.	2019	Healthcare	Healthcare technology	Aligned	Sustainable	1. Taking the environment into consideration is part of responsible practice in health innovation to foster environmentally friendly health innovations, which realize supporting patient care while reducing environmental impacts.
43	Hemphill	*Journal of Responsible Innovation*	'Techlash', responsible innovation, and the self-regulatory organization.	2019	Digital media	Information and communication technologies	Well governed	Regulated	1. Implement a regulatory regime to address policy concerns of privacy, public safety, and national security. 2. Except for the traditional approach (government regulation), self-regulation and public regulation can be well-reasoned alternatives.
44	Stemerding et al.	*Futures*	Future making and responsible governance of innovation in synthetic biology.	2019	Biology	Synthetic technology	Well governed	Regulated	1. Need to foster and facilitate innovation via more generic institutional, regulatory, and pricing measures.
								Participatory	1. Stakeholder engagement enhanced reflexivity about the different needs and interests that should be considered in shaping the innovation agenda.
45	Samuel and Prainsack	*New Genetics and Society*	Forensic DNA phenotyping in Europe: Views "on the ground" from those who have a professional stake in the technology.	2019	Medical science	DNA phenotyping	Accessible	Adaptable	1. Had to meet two criteria: be valid and reliable; be ethically unproblematic. 2. It is important only to use tests that are deemed ethically "safe".
							Acceptable	Ethical	
							Well governed	Participatory	1. Must engage both professional and public stakeholder views regarding future policy decisions.
46	Rose and Chilvers	*Frontiers in Sustainable Food Systems*	Agriculture 4.0: Broadening responsible innovation in an era of smart farming.	2018	Agriculture	Smart farming technology	Accessible	Inclusive	1. Broadening notions of 'inclusion' that open up to wider "ecologies of participation", which change public opinion to accept technologies rather than making technological trajectories more responsive to the needs of society.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
47	Koirala, et al.	*Applied Energy*	Community energy storage: A responsible innovation towards a sustainable energy system?	2018	Energy	Community energy storage	Aligned	Meaningful	1. Provide higher flexibility as well as accommodate the needs and expectations of citizens and local communities.
								Sustainable	1. Guarantee socially and technologically acceptable transformation towards an inclusive and sustainable energy system.
							Accessible	Inclusive	1. Allow stakeholders to express their values and design operational criteria to respect and include them.
								Affordable	1. Decentralized markets for flexibility, ease of market participation, and community empowerment are expected to create better conditions for its implementation.
							Well governed	Participatory	1. Enhance participation level to allow local communities to provide important feedback to the technology providers, which leads to higher acceptance and further technological innovation.
								Regulated	1. Flexible legislation program for the experimentation and development of socio-technical models specific to the local, social, and physical conditions.
48	Winfield and Jirotka	*Physical and Engineering Sciences*	Ethical governance is essential to building trust in robotics and artificial intelligence systems.	2018	Technology	Artificial intelligence	Acceptable	Harmless	1. Do no harm, including being free of bias and deception.
								Ethical	1. Respect human rights and freedoms, including dignity and privacy, while promoting well-being.
							Trustworthy	Explainable	1. Should be explainable or even capable of explaining their own actions (to non-experts) and being transparent (to experts).
								Transparent	1. Be transparent and dependable while ensuring that the locus of responsibility and accountability remains with their human designers or operators.
							Well governed	Accountable	
49	Pacifico Silva et al.	*Health Research Policy and Systems*	Introducing responsible innovation in health: a policy-oriented framework.	2018	Healthcare	Healthcare technology	Aligned	Sustainable	1. Need to reduce, as much as possible, the negative environmental impacts of health innovations throughout their entire lifecycle.
							Accessible	Affordable	1. Deliver both high-performing products as well as affordable ones to support equity and sustainability.
							Acceptable	Equitable	1. Increase our ability to attend to collective needs whilst tackling health inequalities.
50	Sonck et al.	*Life Sciences, Society and Policy*	Creative tensions: mutual responsiveness adapted to private sector research and development.	2017	Business	Non-specific	Well governed	Participatory	1. Support mutually responsive relations in the innovation process, which assist innovators and stakeholders reach some form of joint understanding about how the innovation is shaped and eventually applied.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
51	Boden et al.	*Connection Science*	Principles of robotics: regulating robots in the real world.	2017	Technology	Robotics	Acceptable	Harmless	1. Robots should not be designed solely or primarily to kill or harm humans, except for national security interests.
							Trustworthy	Secure	1. Robots should be designed using processes that assure their safety and security and make sure that the safety and security of robots in society are assured so that people can trust and have confidence in them.
								Transparent	1. Robots should not be designed in a deceptive way to exploit vulnerable users; instead, their machine nature should be transparent.
							Well governed	Regulated	1. Robots should be designed and operated as far as is practicable to comply with existing laws, fundamental rights, and freedoms, including privacy.
								Accountable	1. The person with legal responsibility for a robot should be attributed.
52	Leenes et al.	*Law, Innovation and Technology*	Regulatory challenges of robotics: some guidelines for addressing legal and ethical issues.	2017	Technology	Robotics	Well governed	Regulated	1. Develop a method, a framework, or guidelines that can be used to make innovation in a certain context more responsible. 2. Develop self-learning procedures that can be used to make innovation in a certain context more responsible.
53	Demers-Payette et al.	*Journal of Responsible Innovation*	Responsible research and innovation: a productive model for the future of medical innovation.	2016	Medical science	Healthcare technology	Aligned	Deliberate	1. Carefully anticipate the consequences and opportunities associated with medical innovations to generate a clear understanding of the uses of medical innovation and of its context.
								Meaningful	1. Ensure potential innovations align with clinical and healthcare system challenges and needs to achieve a better alignment between health and innovation value systems and social practices.
							Well governed	Participatory	1. Use formal deliberative mechanisms to provide a sustained engagement way for stakeholders in the innovation process.
								Regulated	1. Flexible steering of innovation trajectories within a highly regulated environment without compromising the safety of new products.
54	Foley et al.	*Journal of Responsible Innovation*	Towards an alignment of activities, aspirations and stakeholders for responsible innovation.	2016	Technology	Non-specific	Aligned	Meaningful	1. Support the creation of technologies that contribute to the stewardship of planetary systems identified.
								Sustainable	1. Does not interfere with access to basic resources critical to a healthy human life.
							Acceptable	Ethical	1. Affords people freedom of expression and freedom from oppression and does not reinforce social orders that subjugate human beings.
								Equitable	1. Ensure that select groups of people are not inequitably burdened by negative impacts.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
55	Dignum et al.	*Science and engineering Ethics*	Contested technologies and design for values: The case of shale gas.	2016	Energy	Shale gas technology	Well governed	Participatory	1. To create and implement a technological design, we must look beyond technology itself and iteratively include institutions and stakeholder interactions to acknowledge the complex and dynamic embedding of a (new) technology in a societal context.
56	Arentshorst et al.	*Technology in Society*	Exploring responsible innovation: Dutch public perceptions of the future of medical neuroimaging technology.	2016	Medical science	Neuroimaging technology	Accessible	Affordable	1. Should never result in negative social or economic implications for individuals/patients.
							Trustworthy	Transparent	1. Freedom of choice, guaranteed privacy, the right to know or to be kept in ignorance, and informed consent should be self-evident prerequisites. 2. The acts, competencies, and knowledge of experts developing and working with neuroimaging can be trusted in terms of doing good and determining the correct treatment plan.
							Well governed	Participatory	1. Relevant actors need to become mutually responsive, and participants' concerns should be taken seriously in order to promote responsible embedding of neuroimaging.
57	Fisher et al.	*Journal of Responsible Innovation*	Mapping the integrative field: Taking stock of socio-technical collaborations.	2015	Technology	Non-specific	Accessible	Inclusive	1. Adopt more inclusive strategies to integrate wider stakeholders to align science, technology, and innovation more responsibly with their broader societal contexts.
58	Samanta and Samanta	*Journal of Medical Ethics*	Quackery or quality: the ethicolegal basis for a legislative framework for medical innovation.	2015	Healthcare	Healthcare technology	Trustworthy	Transparent Accountable	1. At the heart of the regulation of medical innovation is care delivered by a process that is accountable and transparent and that allows full consideration of all relevant matters.
							Well governed	Regulated	1. A combination of ethicolegal principles and statutory regulations would permit responsible medical innovation and maximize benefits in terms of therapy and patient-centered care.
59	Toft et al.	*Applied Energy*	Responsible technology acceptance: Model development and application to consumer acceptance of Smart Grid technology.	2014	Energy	Smart grid technology	Accessible	Adaptable	1. Acceptance of a new technology depends on believing that the technology is easy to use and useful for achieving a personal goal.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
60	Wickson and Carew	*Journal of Responsible Innovation*	Quality criteria and indicators for responsible research and innovation: Learning from transdisciplinarity.	2014	Environment conservation	Nanotechnology	Aligned	Meaningful	1. Addressing a grand social challenge.
								Deliberate	1. Generating a range of positive and negative future scenarios and identifying and assessing associated risks and benefits of these for social, environmental, and economic sustainability.
								Sustainable	
							Accessible	Inclusive	1. Openly and actively seeking ongoing critical input, feedback, and feed-forward from a range of stakeholders.
								Adaptable	1. Outcomes work reliably under real-world conditions. 2. Resources are carefully considered and allocated to efficiently achieve maximum utility and impact.
							Trustworthy	Transparent	1. Transparent identification of a range of uncertainties and limitations that may be relevant for various stakeholders.
								Explainable	1. Openly communicated lines of delegation and ownership able to respond to process dynamics and contextual change.
							Well governed	Regulated	1. Documented compliance with highest-level governance requirements, research ethics, and voluntary codes of conduct, which are all actively monitored throughout.
								Accountable	1. Preparedness to accept accountability for both potentially positive and negative impacts.
61	Taebi et al.	*Journal of Responsible Innovation*	Responsible innovation as an endorsement of public values: The need for interdisciplinary research.	2014	Energy	Shale gas technology	Accessible	Inclusive	1. Responsible innovation as an accommodation of public values, which requires undertaking interdisciplinary research and interaction between innovators and other stakeholders in conjunction with the early assessment of ethical and societal desirability.
62	Lauss et al.	*Biopreservation and Biobanking*	Towards biobank privacy regimes in responsible innovation societies: ESBB conference in Granada 2012.	2013	Biology	Biobank	Trustworthy	Secure	1. Biobank privacy regimes presuppose knowledge of and compliance with legal rules, professional standards of the biomedical community, and state-of-the-art data safety and security measures.
							Well governed	Regulated	
63	Gaskell et al.	*European Journal of Human Genetics*	Publics and biobanks: Pan-European diversity and the challenge of responsible innovation.	2013	Biology	Biobank	Aligned	Deliberate	1. Lying behind European diversity is a number of common problems, issues, and concerns—many of which are not set in stone and can be addressed by informed and prudent actions on the part of biobank developers and researchers.
							Trustworthy	Secure	1. Assiduous mechanisms for the protection of privacy and personal data should be given careful consideration.
								Explainable	1. Need to consider how to explain to the public the rationale for cooperation with other actors that can help to increase people's trust.
							Well governed	Participatory	1. Stakeholder engagement relates to readiness to participate in biobank research and to agree to broad consent.

Table A1. *Cont.*

No	Author	Journal	Title	Year	Aspect	Innovation	Characteristic	Keyword	Finding
64	Van den Hove et al.	*Environmental Science & Policy*	The Innovation Union: a perfect means to confused ends?	2012	Technology	Non-specific	Aligned	Meaningful	1. Innovation should be re-targeted to deliver better health and well-being, improved quality of life, and sustainability.
							Accessible	Inclusive	1. A broader concept of innovation must be deployed, aiming to overcome technological and ideological lock-ins.
65	Stahl	*Journal of Information, Communication and Ethics in Society*	IT for a better future: how to integrate ethics, politics and innovation.	2011	Technology	Information and communication technologies	Acceptable	Ethical	1. Incorporate ethics into ICT research and development to engage in discussion of what constitutes ethical issues and be open to incorporation of gender, environmental, and other issues.
							Well governed	Regulated	1. Provide a regulatory framework that will support ethical impact assessment for ICTs to proactively consider solutions to foreseeable problems that will likely arise from the application of future and emerging technologies.
								Participatory	1. To allow and encourage stakeholders to exchange ideas, to express their views, and to reach a consensus concerning good practices in the area of ethics and ICT.
								Accountable	1. Ensure that specific responsibility ascriptions are realized within technical work and further sensitize possible subjects of responsibility to some of the difficulties of discharging their responsibilities.

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