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Institutionalizing Responsible Research and Innovation in Complex Technology Networks

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Abstract: This paper develops a conceptual framework for understanding how Responsible Research and Innovation (RRI) becomes institutionalized within complex technological innovation networks. Focusing on additive manufacturing, the study draws on empirical evidence from multi-year European research projects and Delphi-inspired expert panels to examine how responsibility-oriented practices emerge, persist, and diffuse across organizations and innovation phases. Building on neo-institutional theory, the paper introduces the concept of RRI openings, defined as institutionalized points of intervention through which responsibility can influence innovation processes in situated ways. The analysis identifies key institutional carriers including regulation, incentives, standards, organizational knowledge and culture, and education, and shows how their relevance varies across phases of ideation, development, and diffusion. The findings demonstrate that responsibility does not become consequential through isolated project-level actions, but through institutional arrangements that stabilize learning and coordinate responsibility across time and organizational boundaries.

Keywords: responsible research and innovation; additive manufacturing; stakeholder involvement; innovation; responsible innovation.

1 Introduction

Technological innovations increasingly have consequences that extend beyond the organizations developing them. New products and technologies shape markets, societal practices, ethical debates, and environmental conditions, often in ways that are difficult to foresee at early stages of innovation. As innovation activities have become more distributed across organizational and sectoral boundaries, questions of who is responsible for innovation outcomes, and at what point responsibility should be addressed, have become increasingly complex.

Responsible Research and Innovation (RRI) has been and is promoted particularly through European innovation policy as a means to mainstream responsibility into research and innovation activities (European Commission, 2025). RRI as its original intention aims to align innovation processes with societal values and expectations (Von Schomberg, 2013; Owen et al., 2019). At its core, RRI emphasizes collective responsibility for both the intended impacts and unintended consequences of research and innovation. Rather than focusing only on end products, RRI draws attention to the

processes, decisions, and institutional contexts through which innovations are developed (Von Schomberg, 2013; Stilgoe et al., 2013; Owen et al., 2019).

The transition from Horizon 2020 to Horizon Europe reflects a change in the governance of Responsible Research and Innovation rather than a change in its substantive orientation (Gerber et al., 2020). Under Horizon 2020, RRI was articulated through explicit policy Keys, including public engagement, gender equality, ethics, and open access, which were intended to make responsibility more visible and actionable within research and innovation projects. In Horizon Europe, these same concerns are addressed through more integrated governance requirements such as open science practices, ethics review procedures, gender equality plans, responsible research assessment, and citizen engagement, without being grouped under a dedicated RRI framework (Papanagnou, 2023; ERA-LEARN, 2024). RRI is therefore increasingly reflected in institutional arrangements and routine governance practices rather than through clearly labelled policy instruments, providing an important context for analysing how responsibility is embedded and maintained in innovation systems.

From an innovation management perspective, however, there remains a persistent gap between RRI as a policy concept and RRI as an organizational practice. While responsibility is widely acknowledged as important, it often remains abstract or peripheral in day-to-day innovation work, especially in complex innovation networks involving multiple actors, competing interests, and long development cycles. This gap has been highlighted in recent research, which suggests that the main challenge is no longer defining responsibility, but understanding how responsibility-oriented practices can be embedded, stabilized, and diffused within organizations and innovation systems (Biegelbauer et al., 2025). Furthermore, RRI principles have been shown to apply differently across stages of innovation and venture development (Mulloth et al., 2025).

This paper addresses this topic through an empirical study of additive manufacturing (AM) innovation. Additive manufacturing provides a particularly rich context for examining responsibility in innovation. The technological development of AM spans more than six decades, involving successive waves of invention, commercialization, and diffusion (Su & Al'Aref, 2018). Innovation activities take place across universities, research institutes, start-ups, established firms, intermediaries, and user communities such as fablabs and makerspaces. At the same time, many AM applications, particularly in the biomedical field, raise ethical, regulatory, and societal questions that are directly relevant to RRI. Importantly, additive manufacturing has not yet reached full-scale diffusion. Innovation trajectories are still being shaped, standards are evolving, and new applications continue to emerge. This creates opportunities for responsibility-oriented steering but also raises questions about how such steering can realistically occur in fragmented and competitive innovation environments.

The study addresses the following research question: How is Responsible Research and Innovation institutionalized within complex innovation networks, and through which institutional mechanisms can responsibility-oriented steering occur across different stages of technological innovation?

Drawing on empirical data collected during a three-year European research project on additive manufacturing innovation, this study introduces the concept of RRI openings. RRI openings are defined as institutionalized points of intervention through which Responsible Research and Innovation principles can influence innovation processes within and across organizations. An RRI opening is characterized by the institutional mechanism involved, the actors participating, its position within the innovation value

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chain, and the RRI Key or responsibility domain it addresses. Conceptually, RRI openings link responsible innovation scholarship with neo-institutional theory by focusing attention on how responsibility becomes embedded through regulative, normative, and cultural-cognitive mechanisms (Scott, 2014).

By responding to this question, the paper seeks to contribute to innovation management research by (1) developing RRI openings as a conceptual construct that connects RRI with institutional theory, (2) providing empirically grounded insights into how responsibility is enacted within a complex technological innovation network, and (3) advancing theoretical integration between responsible innovation, innovation process research, and neo-institutional perspectives.

2 Literature review

Responsible research and innovation in innovation management

Responsible Research and Innovation (RRI) was introduced as a response to increasing societal concerns regarding the ethical, environmental, and social implications of scientific and technological progress. Initially articulated within science and technology studies and later institutionalized through European research and innovation policy (European Commission, 2025), RRI emphasizes collective responsibility for both intended and unintended consequences of innovation (Von Schomberg, 2013). From this perspective, responsibility is not an add-on to innovation outcomes but an integral part of how innovation is conducted, governed, and evaluated.

Much of the existing literature on responsible innovation has focused on normative process frameworks. The influential framework by Stilgoe et al. (2013), for example, conceptualizes responsible innovation through the dimensions of anticipation, reflexivity, inclusion, and responsiveness. These dimensions provide useful guidance for reflecting on innovation processes and broadening participation. However, they offer limited explanation of how such principles become institutionalized over time, or how they are carried across organizational boundaries as innovations move from research into development and diffusion.

However, while process-oriented approach clarifies what responsible innovation should aspire to, they provide limited insight into how responsibility-oriented practices become embedded within organizations and innovation systems over time. Innovation management scholars have thus increasingly questioned the practical enactment of responsible innovation beyond isolated project-level interventions (Biegelbauer et al., 2025). Existing frameworks do not sufficiently explain why responsibility considerations remain peripheral in many innovation contexts despite strong normative endorsement, nor how responsibility-related practices travel across organizational boundaries in networked innovation settings.

The second major approach to the RRI policy framework has been to attempt to operationalize responsibility through the introduction of six so-called RRI Keys: public engagement, gender equality, science education, open access, ethics, and governance. These keys reflect democratically negotiated societal priorities grounded in European treaties and broader sustainability agendas. At the same time, the RRI Keys have been

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criticized for fragmenting the broader concept of responsible innovation and for encouraging a checklist-like approach to responsibility (Owen & Pansera, 2019). Yet RRI can also be understood as a wicked problem, for which decomposition into more concrete domains may be necessary in order to make responsibility actionable in real innovation contexts (Schlaile et al., 2018).

What remains underdeveloped in innovation management research is an understanding of where responsibility-oriented interventions actually take place within innovation systems, through which mechanisms they operate, and which actors are able to convey them forward. Innovation processes are not uniform. Different phases of innovation involve different organizations, decision-making logics, and time horizons (Mulloth et al., 2025). As a result, the opportunities for addressing responsibility are unevenly distributed across innovation networks.

Innovation networks in the context of Additive Manufacturing

Additive manufacturing (AM) provides a relevant empirical context for examining questions of responsibility in innovation. Additive manufacturing is a growing manufacturing technology field in which multiple technological solutions enable "building up" a product using digital product designs and a process of joining and adding material, usually layer by layer (ASTM, 2012). Compared to traditional manufacturing methods of moulding, casting, and subtractive material removal, AM provides a different approach to manufacturing by enabling aspects that have not previously been feasible, such as the mass customization of complex geometries (Fontana et al., 2019).

However, what makes AM especially relevant is not only its potential to produce innovative products, but the complex network of actors involved in its development. The development of AM was preceded by advancements in semiconductor, laser, and material technologies (Su & Al'Aref, 2018), and ongoing progress in these fields continues to shape AM innovation.

Beyond the level of individual technologies and products, an additional source of complexity arises from the adoption of AM into production through process innovations. The adoption of AM can be understood as a systemic innovation, as it requires complementary innovations in company networks, design processes, and end-product production (Luomaranta & Martinsuo, 2020). Innovation management research conceptualizes innovation not as a single event, but as a multi-stage and multi-actor process. Classic models describe innovation as a sequence of interrelated phases of ideation, development, and diffusion (Hansen & Birkinshaw, 2007). These phases involve different actors, resources, and decision-making logics, and consequently create varying opportunities and constraints for responsibility-oriented interventions. Additive manufacturing thus provides a rich setting characterized by multiple overlapping technological innovations and heterogeneous organizations operating across different phases of the innovation process, where the introduction of Responsible (Research and) Innovation becomes particularly relevant.

Previous studies addressing responsibility in innovation have highlighted several issues related to AM. Sustainability has been linked to AM as a potential future pathway for manufacturing (Ford & Despeisse, 2016; Beltagui et al., 2020), alongside ethical concerns related to intellectual property (Neely, 2013) and the capability of AM to

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produce harmful products, such as weapons (Mattox, 2013). These studies demonstrate that AM raises multiple responsibility-related concerns with implications for Responsible Innovation (RI) and RRI. Another issue relevant to RRI in AM concerns the diversity of actors participating in AM innovation networks and the extent to which different stakeholders are able to influence responsibility-related outcomes. A previous study reported at ISPIM provides insights into secondary stakeholders in medical and automotive AM sectors whose interests and power positions shape responsibility considerations in AM innovation (Luomaranta, 2020). Despite these contributions, studies that explicitly integrate and advance RRI within the context of additive manufacturing remain limited.

What is characteristic of additive manufacturing in this respect is that innovation activities are distributed both temporally and organizationally in ways that make responsibility difficult to localize. Responsibility-related questions may emerge, disappear, and re-emerge across successive innovation cycles and across different organizational settings, ranging from publicly funded research projects to private commercialization and user-driven application development (Luomaranta et al., 2024). As a result, responsibility cannot be addressed solely through single project-level actions or isolated organizational practices. Instead, the AM context highlights the importance of institutional mechanisms through which responsibility-oriented practices can be embedded, stabilized, and conveyed across innovation networks over time. This makes additive manufacturing a particularly suitable empirical setting for examining how Responsible Research and Innovation becomes institutionalized in complex technology innovation systems.

Toward Institutionalized Intervention Points in Innovation Systems

Institutional theory offers a valuable lens for addressing the persistent gap between the ideals of Responsible Research and Innovation (RRI) and everyday innovation practice. Neo-institutional theory conceptualizes institutions as relatively durable systems of rules, norms, and shared meanings that shape organizational behaviour and stabilize social action (Scott, 2014). From this perspective, practices do not diffuse merely because they are efficient or normatively desirable, but because they gain legitimacy by aligning with regulative, normative, and cultural-cognitive structures.

Institutionalization refers to the process through which particular ways of acting become taken for granted and reproduced over time. Regulative mechanisms operate through formal rules, laws, and sanctions; normative mechanisms through values, professional standards, and moral obligations; and cultural-cognitive mechanisms through shared beliefs and interpretive frames that render practices meaningful (Scott, 2014). Organizations are embedded within these wider institutional environments and are influenced by policy frameworks, markets, professional communities, and societal expectations. In this sense, RRI can itself be understood as a form of social innovation seeking to re-orient prevailing innovation practices toward greater responsibility. However, as social reality is socially constructed and sustained through shared meaning (Giddens, 1984), the diffusion of RRI cannot rely solely on voluntary adoption or individual commitment. For RRI to shape innovation practices in a sustained manner, it must become institutionalized across the regulative, normative, and cultural-cognitive pillars.

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Existing research on the institutionalization of responsible innovation has identified a limited set of embedding mechanisms. Owen et al. (2021) emphasize doctoral education as an important institutional carrier, while Pansera et al. (2020) highlight micro-organisational influences such as peer dynamics and leadership, particularly when combined with open and collaborative innovation practices (see also Bercovitz & Feldman, 2008). Furthermore, the empirical studies identify multiple institutional carriers for responsible innovation, including regulation, public funding criteria, professional norms, standardization, organizational culture, and education and training (Pansera et al., 2020; Owen et al., 2021). Despite these insights, empirical studies on RI and RRI institutionalization remain scarce. To the author's knowledge, no studies have systematically examined institutional change mechanisms specifically in relation to the RRI Keys, by identifying concrete points through which EU-level RRI policy objectives could influence future innovation trajectories. Addressing this gap constitutes the central aim of this manuscript. Prior research in the additive manufacturing context indicates that policy-driven responsibility initiatives such as the RRI Keys tend to activate organisational learning and sensemaking processes, but only gain durability and influence when these processes are supported and stabilized by broader institutional arrangements rather than treated as stand-alone implementation tools (Sischarenco & Luomaranta, 2023).

The review literature on responsible innovation, institutional theory, and innovation management reveals a shared limitation: while responsibility is widely acknowledged as important, there is limited theoretical clarity regarding where and how responsibility-oriented interventions emerge within innovation systems. Responding to calls for more empirically grounded conceptual development of RRI (Biegelbauer et al., 2025; Mulloth et al., 2025), this study advances the concept of institutionalized intervention points within innovation networks. By integrating neo-institutional theory with an innovation process perspective, the concept directs attention to specific mechanisms, actors, and stages through which RRI becomes embedded in everyday innovation management practice.

3 Methods

This study adopts a theory-building research design aimed at developing a conceptual understanding of how RRI becomes institutionalized within complex technological innovation networks. The empirical context is a three-year EU-funded research project focusing on additive manufacturing (AM), which provided sustained access to innovation actors across research, industry, and intermediary organizations. This longitudinal and embedded research setting enabled examination of institutional dynamics shaping responsibility-oriented innovation practices across different stages of technological development.

Rather than aiming at prediction or evaluation, the research adopts an abductive, theory-building approach suited to emerging technology contexts and institutional analysis (van Aken & Romme, 2009). The study does not seek to prescribe normative solutions or assess compliance with predefined RRI criteria. Instead, it focuses on identifying recurring institutional mechanisms through which responsibility becomes embedded, stabilized, and diffused within innovation networks.

Empirical material was collected through three complementary sources. First, thirteen retrospective case studies of additive manufacturing innovation trajectories were conducted using semi-structured interviews with key organizational actors (Creswell, 2009). These cases were used to reconstruct innovation phases, actor constellations, and governance arrangements over extended time spans. In the results section one case was selected as representative of recurring institutional dynamics observed across the full set of cases. Second, six Delphi-inspired expert panels involving industry and research specialists in AM were organized as structured expert elicitation exercises (Avella, 2016). Rather than forecasting, the panels served to surface shared expectations, perceived intervention points, and institutional constraints related to responsibility in innovation processes.

Third, iterative analytical discussions within the research project and with external scholars supported theory development through systematic reflection on emerging empirical patterns. Notes from these discussions were treated as analytical memos rather than primary data sources. Data analysis proceeded iteratively by relating empirical observations to concepts from neo-institutional theory, particularly Scott's (2014) regulative, normative, and cultural-cognitive pillars. Through this abductive process, the concept of RRI openings emerged as an analytical construct capturing institutionalized points of intervention through which RRI principles influence innovation processes within and across organizations.

4 Findings

Additive manufacturing innovations and networks – illustrative example case

To illustrate the time span and complexity of AM innovations and innovation networks one example from retrospective case studies is presented first. Back in 2006 a European technical university started to study the technology of AM ceramics as a promising new stream of AM technologies. The preceding technical inventions enabling this were in the fields of mechanics, lasers, ceramics powders and binding materials. In 2007 a joint project with dental implant manufacturer was started, which lasted for three years and resulted a proof-of-concept ceramics AM machine. At this point the focus was solely on the AM technology, and aim was to develop the machine to produce ceramics feasibly. The idea came from the research done in the university and dental implants were chosen to be the application area, since it provided a medical ceramics application area without having the issues from certificates and regulatory point of view.

After a year in 2011 university spin-off company was founded, which started the commercialization of the ceramics AM machine and AM compatible ceramics material. In 2012 the first machine was sold. After this the development of the machine, material and application areas have been constantly on-going projects. The informant from that company estimated that approximately 50% of their development work has been conducted with funding from EU or local national research funding and the rest 50% have been funded by their customer cases. During the research project (during which the data for this manuscript was collected) a few use cases were conducted, which revealed that after the AM machine has been successfully commercialized, further ideas for

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development are coming from their customers who buy the machine to produce medical implants. This starts another cycle of material and process innovations to enable the produced end products to be certified and follow the standards of medical devices.

This illustrative case example provided insights of how the new technology is benefitting from several other technologies, how the development has happened trough several phases and with different setting and different partner and stakeholders. The other cases conducted (not reported here due length restrictions) further exemplify the long timespan of AM development, its cyclical nature, where one innovation initiates another innovation cycle, where research organizations and universities are actors that enable larger development leaps, where public research funding is an important source of funding for development. On the other hand, commercialization and finding of customers is also important, the development seems to continue in with the customers, which again may initiate another innovation cycle. These cycles can be defined as ideation, development and diffusion following Hansen and Birkinshaw's (2007) definition of innovation process.

Responsible research and innovation openings for additive manufacturing innovations to address RRI Keys

Drawing on neo-institutional theory, the findings indicate that responsibility-oriented innovation practices are most effectively diffused when they become institutionalized through regulative, normative, and cultural-cognitive mechanisms. Based on the empirical analysis of additive manufacturing innovation trajectories and expert elicitation, this study introduces the concept of RRI openings, defined as:

"RRI openings are analytically operationalized through institutional carriers; carriers are the mechanisms, openings are the situated points where they become actionable."

An RRI opening consists of four interrelated elements: (1) a specific institutional mechanism, (2) the actors involved, (3) the position in the innovation value chain, and (4) the RRI dimension addressed. Rather than representing isolated actions or policy instruments, RRI openings capture the ways in which institutional arrangements shape how responsibility becomes embedded in ongoing innovation activities.

The analysis identified five empirically grounded institutional carriers through which RRI openings operate in additive manufacturing innovation networks: incentives, regulatory arrangements, standards, organizational knowledge and culture, and education and skills development. These carriers draw on different institutional pillars and become salient at different stages of the innovation process. For example, funding incentives and regulatory requirements exert stronger influence during early-stage research and development, whereas organizational culture, standards, and education play a more prominent role during diffusion, scaling, and longer-term stabilization of innovation practices. Taken together, these findings demonstrate that responsibility in innovation does not emerge spontaneously from individual project decisions but is shaped by institutional mechanisms that structure expectations, define acceptable practices, and distribute responsibilities across actors and innovation phases.

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Table 1 summarizes the five institutional carriers through which RRI openings operate and identifies the institutional pillars on which they primarily rely. The mechanisms are analytically distinct but often operate in combination within innovation networks. Table 1 further combines analytical categorization with illustrative empirical observations to enhance transparency regarding how institutional carriers were identified in the data and how they functioned as RRI openings in practice.

Table 1: RRI openings as institutional carriers

RRI opening	*Description*	*Institutional pillar*
Regulation:	Formal regulatory frameworks define baseline requirements that organizations must meet when conducting research and innovation activities. These include legal obligations related to governance, ethics, and equality that shape permissible innovation pathways and establish baseline responsibility standards across organizations. One way to create institutional change is to establish new regulations that force every organization to comply. Basically, certain organization (size or public status, like universities) are required to have for example gender equality plan. Other RRI specific regulations can be established.	Regulative
Incentives: (funding, rewards, societal acceptability)	Incentives function as indirect institutional carriers by conditioning access to resources, legitimacy, and visibility rather than mandating specific practices. *Funding:* Public research funding is a great possibility to fund pre-competitive research for both private companies and public research organization such as universities. There is a possibility restrict funding, so that in order to get funded and secure funding during the whole project certain RRI objectives have to be met before and during the project. Contrasting to regulations, an organization has to follow the requirements only if applying the research funding. *Rewards:* Well planned and executed innovation projects that address RRI can get rewards, and what those actually are (monetary, public image, etc.) can be decided later. *Societal acceptability:* Governments can establish indexes or indicators about aspects that are part of RRI keys or other RRI core aspects. Indexes provide transparency to society via media or other channels. This again will have influence for example what organizations people would prefer to work with, with which companies' cooperation is preferred and so on. This is however not a compulsory or official regulation set by governments or EC but forms a sort of societal pressure to work towards socially desirable way which is reflected in the indexes.	Normative – Regulative Normative Normative-Cultural-Cognitive

Standardization:	There is the possibility to create standards regarding responsible research and innovation (some already exist, such as ISO26000 – Social responsibility guidance standard). Standards translate responsibility principles into codified practices that guide technological development and organizational routines. A possibility is to embed RRI keys into technology specific standards, like transparency of AM raw material supply chain. Standards are not government or state initiated, but industry initiated, and trough standardization process, the actor participating to the standard formulation can create commitment to follow it (contrasting to regulation that forces to follow). Through this process, standards translate responsibility principles into shared expectations that stabilize responsibility-oriented practices across organizational boundaries.	Normative-Cultural-Cognitive
Internal knowledge and cultural commitment:	Organizational knowledge and culture operate as carriers by embedding responsibility-oriented interpretations into routines, strategies, and collective sensemaking. One partner, a competitive cluster, stated that after this research project they are now convinced of the value and applicability of RRI. They also involved themselves with another RRI specific project. They have now started to educate the companies in their ecosystem about RRI. They also created a long-term strategy where they are trying to establish services to help companies to adopt RRI. Also, one big part of their work is to form up a consortium and seek public funding for the consortium's research and innovation agenda.	Normative-Cultural-Cognitive
RRI integration to education:	If socially constructed and structured social reality ontology is accepted, it becomes evident that the upbringing of children forms basis of their world view and meaning making. Education then beginning from early stages until later stages is providing further pieces of social constructs for persons to interpret, enact and re-construct. This is the most fundamental requirement to create a future world where being responsible is agreed way of operating. Another way to think this mechanism, is to think that organisations in the AM innovation network are cooperating with education. This implies that new technologies can be addressed in education only after they are mature enough.	Normative-Cultural-Cognitive

Note: The examples presented are illustrative and drawn from multiple cases and expert discussions; they do not represent exhaustive or exclusive manifestations of each carrier.

Table 1 summarizes the five institutional carriers through which RRI openings operate and identifies the institutional pillars on which they primarily rely. The mechanisms are analytically distinct but often operate in combination within innovation networks. These institutional carriers do not operate in isolation but rather they become

consequential through situated RRI openings that emerge at specific phases of the innovation process and activate different actors within the innovation network.

What, however, is not evident from table 1 is which RRI keys of Public Engagement, Gender Equality, Science Education, Open Access, Ethics and Governance the mechanism is directing the institutional change. The analysis shows indications that basically each of the keys can be addressed within the mechanism with fine tuning the mechanism. For example, all the keys are possible to convey into regulation, but perhaps not appropriate.

However more interestingly, the findings further indicate that the relevance of institutional carriers varies across stages of the innovation process, particularly along the phases of ideation, development, and diffusion. Early innovation phases are more strongly influenced by funding arrangements, regulatory frameworks, and problem framing practices, whereas later phases depend increasingly on standards, organizational routines, and accumulated competencies. The analysis suggests that the applicability of specific RRI dimensions is shaped more by innovation phase than by the institutional mechanism itself.

Also, the RRI keys are not at all problematic to address since they seem to work in a very different spheres of innovation and for example RRI Key of Public engagement resembles closely of the Stilgoe et al. (2013) RI process framework component of inclusion. RRI Key of ethics on the other hand can be directly applied into consideration of product's ethicality (societal and environmental for example), but it can also be seen covering every RRI keys and the whole innovation cycle. RRI key of Gender equality can be addressed in the product level by assessing the suitability of the product to each individual, but to have as diverse and as equally representative persons developing the innovation is a problem stemming all the way from childhood upbringing and education in later stages.

In addition to institutional carriers of RRI, the network of innovative organizations developing AM technology spans from basic research into industry and all the way to entrepreneurial actors. The findings highlight differences in how organizations positioned within innovation networks are able to activate RRI openings. Publicly funded research organizations and universities typically operate within stronger regulative and normative frameworks related to ethics, openness, and equality, and they already have most of the RRI related issues covered, even though they might not be named with same terms.

When smaller private organizations (for whom legislation does not impose strong requirements) starts cooperating with an organization with RRI in place, these ways of thinking responsible (even though stemming from institutionalization) is "transferred" during the cooperation or at least these RRI related aspects are more easily becoming visible then. This mechanism supports the diffusion of responsibility across organizational boundaries, particularly within publicly funded innovation projects. Figure 1 attempts to synthesise these arguments from innovation cycles, different actors, institutional mechanisms (RRI openings) and possible RRI keys into one framework.

Insights from the Delphi-inspired expert panels indicate that RRI considerations rarely emerge explicitly in routine innovation problem-solving unless institutional mechanisms make responsibility salient. The experts from innovation work said that RRI does not emerge naturally in the innovation work, because to innovate (especially product innovate) the concentration is on the problem solving. Implications of this is that RRI should be taken into consideration in the very early phase of idea creation (or problem definition) as used in the discussions, and for example. And here the RRI embedded

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thinking "hopefully" seeks its way to the innovations. It was also recognized that even though the first impression was that during the innovation work the focus is on problem solving, not on RRI, there are multiple options to solve the problem and to decide which option to take involves RRI thinking. This seems to be valuable learning from the project, to bring these kinds of situations where the wideness of thinking or impact-oriented thinking – overall wider perspectives created such concepts as RRI will have an influence on the outcomes of innovation process. This discussion did not however concentrate on any single RRI key but was more general, which illustrates the problematics of the abstract and unrelated RRI keys. Therefore, rather than mapping one-to-one onto institutional carriers, RRI Keys become selectively salient through openings depending on innovation phase.

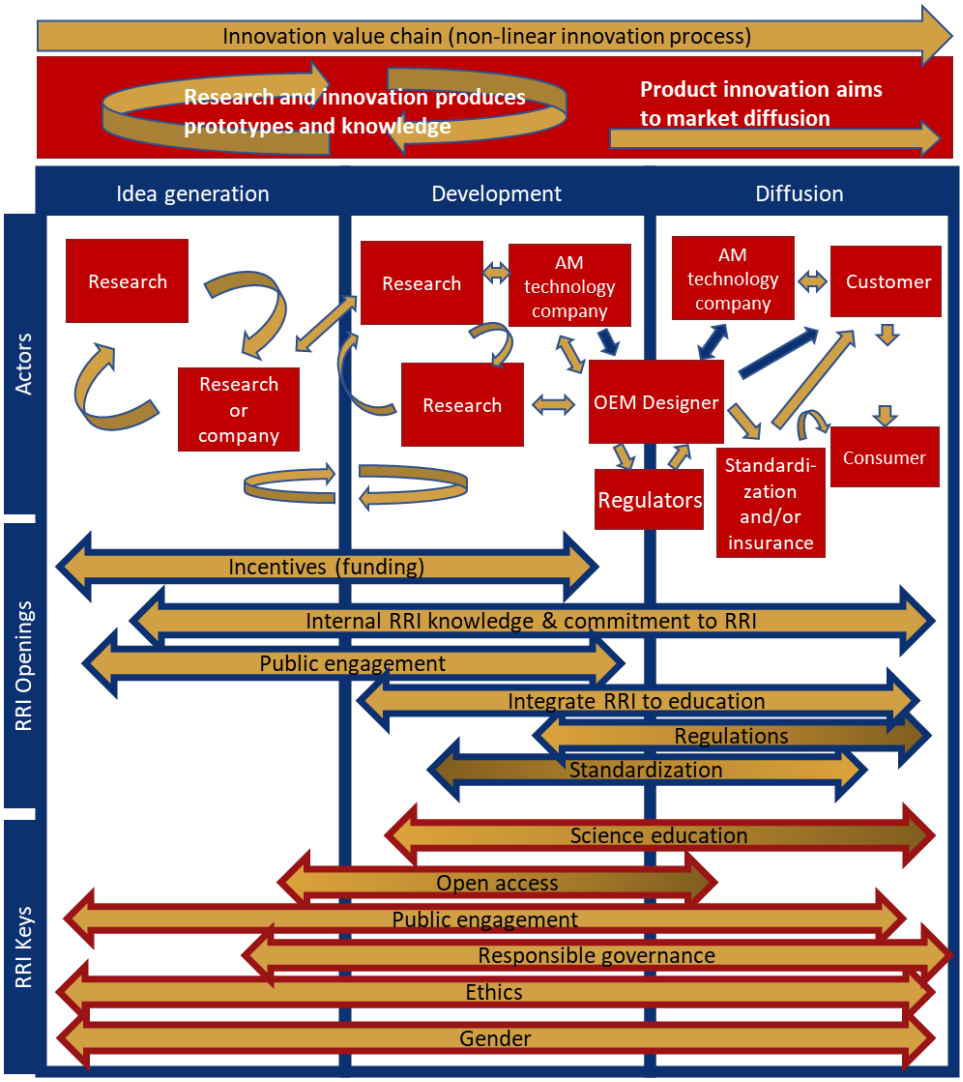

Figure 1: Framework RRI openings and medical AM innovation cycles.

Finally, worth noting would be the discussion about how the technology under study, additive manufacturing, can serve the societal need in a responsible way. Especially in the medical field where implant and prothesis customization is very valuable, it may help in making the whole industry to become more equal. Equal in a sense that now it is possible to get rid of one-size fits for all implants and prosthesis, resulting more equality in a purely medical scale. Of course, a whole another question is will everyone and how will everyone have equal access to these kinds of implants or prothesis. This adds to the complexity of innovations and RRI another layer is the focus of the RRI on the manufacturing technology innovations or product innovations produced with this new technology?

5 Conclusion

The study was set out to answer the research question: "How is Responsible Research and Innovation institutionalized within complex innovation networks, and through which institutional mechanisms can responsibility-oriented steering occur across different stages of technological innovation?" To answer this question, the study first illustrates the inherently distributed and phase-based nature of innovation networks in additive manufacturing as a technological context and shows that responsibility does not enter innovation processes at a single point. Instead, multiple potential influence points (theorized as RRI openings) emerge across innovation phases and organizational settings, each shaped by distinct institutional conditions.

Prior empirical research has shown that policy driven responsibility initiatives such as the RRI Keys are difficult to implement as concrete and measurable tools within industrial innovation projects, where they are often experienced as ambiguous, difficult to operationalize, and poorly aligned with the problem-solving logic of product innovation work. Rather than functioning as direct implementation instruments, these initiatives tend to trigger organisational learning processes, including reflection, dialogue, and sensemaking about responsibility among innovation actors (Sischarenco & Luomaranta, 2023). The findings of this study extend this insight by demonstrating that such learning-oriented effects do not persist or diffuse on their own but become consequential only when they are stabilized through institutional arrangements that embed, reinforce, and transmit responsibility-oriented practices across time, organizations, and innovation phases. This highlights the central role of institutional carriers in transforming episodic responsibility awareness into an enduring feature of innovation networks. At the same time, current European Union research and innovation policy increasingly emphasizes mission-oriented governance, cross sectoral coordination, and the alignment of technological development with clearly defined societal objectives over extended time horizons (European Parliament, 2023), shifting attention away from predefined instruments toward institutional structures and processes through which responsibility is enacted. In this policy context, the relevance of Responsible Research and Innovation lies less in the application of specific tools and more in understanding how responsibility becomes embedded within innovation systems, directly aligning with this study's focus on institutional carriers and phase based RRI openings in complex technology networks.

This paper contributes to innovation management research in three ways. First, it introduces the concept of RRI openings as a novel analytical construct linking

responsible research and innovation principles with neo-institutional theory. Rather than treating responsibility as a universal requirement, RRI openings conceptualize responsibility as emerging through specific institutionalized intervention points that enable collective stewardship of science and innovation in the present while shaping future innovation trajectories (Stilgoe et al., 2013). Second, the paper provides empirically grounded insights into how responsibility-oriented practices are enacted and diffused within complex innovation networks, responding to calls for organizational- and network-level RRI research (Biegelbauer et al., 2025). Third, it advances theoretical integration between responsible innovation, innovation process research, and institutional perspectives by showing how different institutional carriers shape responsibility in distinct ways across stages of technological innovation.

From a practical standpoint, the findings suggest that organizations and policymakers seeking to advance RRI should move beyond viewing responsibility as a generic policy requirement or a project-level compliance issue. Instead, responsibility-oriented steering requires attention to the institutional carriers through which innovation is governed, funded, standardized, learned, and legitimized. By identifying these carriers and their phase-specific relevance, the framework offers a more realistic pathway for embedding responsible innovation practices while preserving the problem-solving capacity and innovative momentum of complex technology networks (Mulloth et al., 2025).

This study has several limitations that also point toward promising avenues for future research. First, the empirical analysis is situated within the context of additive manufacturing innovation and a European policy environment where RRI is relatively well established. While this provides a rich setting for theory building, the transferability of the findings to other technological domains, institutional environments, or non-European innovation systems remains an open question.

Future research could examine whether similar responsibility openings and institutional carriers emerge in less regulated or more market-driven innovation ecosystems, or in technologies characterized by different risk profiles and societal expectations. Second, the study adopts an abductive, theory-building approach and does not evaluate the effectiveness or impact of specific institutional carriers in producing responsible innovation outcomes. Longitudinal studies could build on the proposed framework to assess how different institutional configurations influence innovation trajectories over time. Third, while the analysis foregrounds institutional mechanisms, it pays less attention to the role of individual and organizational agency. Examining how actors strategically activate, reinterpret, or contest RRI openings would further enrich understanding of responsibility in innovation systems.

Finally, reflecting the broader shift in European research and innovation governance under Horizon Europe, future research should move to examine how responsibility is shaped through evolving governance conditions at system level. Comparative studies are needed to investigate how funding logics, coordination arrangements, evaluation practices, standardization processes, and organizational capabilities interact to structure responsibility across innovation systems over time. Such research could explore how different governance configurations enable or constrain responsibility-oriented steering as technologies progress from research to diffusion and scaling, and how responsibility is distributed among actors within multi organizational innovation networks. By focusing on these institutional dynamics rather than on specific responsibility toolkits, future studies can advance understanding of how responsibility persists, adapts, and occasionally erodes within complex technological innovation systems.

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