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Scientometric exploration of responsible innovation: mapping the knowledge landscape

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Abstract

While research into responsible innovation is not new, there have been recent calls to explore responsible product development, across different development stages and pillars of responsible innovation. In this paper, we use scientometric analysis to explore how the responsible innovation knowledge structure has evolved over the past 50 years. Our aim is to explore the relevance of the topic and propose future research orientations. Findings show that responsible innovation is an emerging topic warranting further investigation.

Keywords: responsible innovation, product development, innovation management, scientometrics

1. Introduction

The accelerated development of technology in recent years has put sustainability, social impact, and ethics at the forefront of economic development, growth, and innovation (Haefner *et al.*, 2021; Mariani, Machado and Nambisan, 2023; Mariani, Machado, Magrelli, *et al.*, 2023). While innovation is often considered as the key driver of progress, the concerns related to rapidly developing AI technologies have put great emphasis on responsible innovation (Voegtlin et al., 2022). As a result, practitioners and academics are focusing more on how responsible innovation is defined, studied and integrated, particularly in the field of new product and service development. While businesses have been traditionally driven by commercialization and profits, the push from customers and the wider society has seen an increased shift towards sustainable, ethical, and responsible innovation (Montiel et al., 2021).

Responsible innovation can be described as a process wherein stakeholders work collectively to ensure that innovation processes and outcomes are ethically acceptable, sustainable, and socially desirable (Von Schomberg, 2013). Responsible innovation is defined through 4 pillars/dimensions: *inclusion*, *anticipation*, *reflexivity*, and *responsiveness* (Stilgoe et al., 2013). While these pillars have been considered separately, an integrated approach to responsible innovation within the product development field is yet to be developed. Most recently, academics have developed measurement scales for the four pillars and provided the baseline for responsible innovation measures (Zhang *et al.*, 2023), but these measures are considered at one point in time and at a company rather than individual project, product or service level.

Despite this important work on responsible innovation, there is currently a gap in the literature in two respects. First, we seem to lack a clear definition and differentiation between sustainability, responsibility, and ethics within innovation. While these terms have been conceptualized differently across academic work, there are overlaps in research and practitioners and academics would benefit from a clear differentiation and definition of these important constructs. Second, there is limited exploration of how these concepts impact product development. This study explores the interplay between responsible innovation, sustainability, and ethics, offering practical insights for both academics and industry professionals in product development processes.

We approach this exploration through a scientometric examination of responsible innovation and, more specifically, responsible product development. In this paper, we present our analysis of the evolution and interrelations of scientific literature related to responsible innovation in product development, focusing on the period between 1951 and 2023. We focus on identifying key themes in responsible innovation within the past few years to develop a potential research agenda. In the next section we briefly discuss the boundary conditions of our research, related to responsible innovation and responsible product development. This is followed by the methodology overview, followed by findings and analysis. We conclude by highlighting the major research topics from this domain and the guidelines set for future work.

2. Theoretical background

2.1. Responsible innovation and responsible product development

The landscape of responsible product development is gaining importance and interest in today's rapidly changing business environment. Organizations across various industries recognize the importance of responsible practices for ethical reasons, long-term sustainability, and market competitiveness (Adomako and Nguyen, 2023; Adomako and Tran, 2022; Asante *et al.*, 2014; Voegtlin *et al.*, 2022). Furthermore, there is growing awareness of the need to integrate responsibility into each stage of the product development process. Various reports and studies underscored the global shift towards responsible product development (European Commission, 2013; Matthews et al., 2021; UN Global Compact, 2022). The consequences of irresponsible product development can range from environmental degradation and social harm to reputational damage and legal liabilities.

A multi-stakeholder perspective is critical in understanding and addressing the challenges of responsible innovation and product development. This includes key actors, such as product developers, regulators, consumers, and sustainability advocates (Hart *et al.*, 2003; Lozano, 2015a, 2015b; Subramaniam *et al.*, 2023). These stakeholders have a shared interest in ensuring that products are designed, produced, and marketed to minimize negative impacts on society and the environment. Historically, the private sector has played a pivotal role in shaping product development practices (Cooper, 2011; Eppinger and Chitkara, 2009; Porter *et al.*, 2012). Private organizations have collaborated with governments and industry bodies to establish standards, guidelines, and best practices. However, the contemporary landscape introduces new complexities, including evolving regulations, heightened consumer expectations, and emerging technologies. Key questions arise in this context: Are private sector entities fully embracing responsible innovation, or are they resistant to change? To what extent do short-term financial considerations, fragmented internal management structures, shifting market dynamics, and resource constraints impact responsible innovation (Schaltegger *et al.*, 2019)? Are organizations prioritizing risk mitigation in product development due to the potential financial consequences, or are they driven by a genuine commitment to societal and environmental well-being? This calls for academic input to identify objective approaches to responsible innovation.

2.2. Scientometric exploration and mapping the knowledge landscape

Scientometrics is a broad term for various approaches which are used to analyse and illustrate relations and structures among researchers, institutions, or scientific knowledge, and to identify and track the dynamics of scientific publications through published ideas, concepts, citations, and keywords (Fortunato et al., 2018).

The scientometric analyses of scientific works resulted in many influential works within the research community, including those by Börner et al., (2003), Clauset et al., (2017), Garfield, (1970), Lotka, (1926), Merton, (1968), Price, (1965), Uzzi et al., (2013), Wang et al., (2013), Wu et al., (2022) and Zipf, (1949). One of the most used tools in the scientometric literature are science maps, which spatially and/or temporally represent individual authors, their research groups, or the knowledge concepts they have written about.

Seminal research, which explored the organization of scientific knowledge, studied citation networks, identifying and analysing common patterns of citation links among articles in a collection of scientific literature (Klavans and Boyack, 2017). The studies resulted in several renowned scientific works which exposed concealed structural features, including the famous small-world phenomenon (Newman, 2005; Watts, 2003) rich-get-richer mechanism (Barabási and Albert, 1999), and hierarchical organization of scientific knowledge (Ravasz and Barabási, 2003). Further details are nicely presented in monograph by Wang and Barabási, (2021).

Scientific knowledge structures can also be explored using keywords and key phrases as basic knowledge elements (Yi and Choi, 2012). They can be either harvested from the title and/or abstract of each article using natural language processing algorithms or collected from a list of descriptors already provided by the authors.

3. Methodology

This study utilized a scientometric approach to analyse and characterise the structure and dynamics of the responsible innovation knowledge domain. The next subsection, the process of compiling the dataset from a bibliographic database is elaborated upon. The method for extracting keywords is presented in the following subsections, including the procedure to construct a co-word network. Lastly, we detail a technique for identifying and interpreting research topics detected in the co-word network.

3.1. Data collection

Bibliographic records of interest were retrieved from the Web of Science Core Collection, restricted to the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts and Humanities Citation Index. The search query consisted of three statements:

1. TS=("responsible innovation" OR "sustainable product development" OR "engineering design" OR "product innovation" OR "product development" OR "data driven design" OR "regenerative innovation" OR "eco-innovation" OR "implications of innovation")
2. TS=("ethical acceptability" OR "societal desirability" OR "anticipation" OR "reflexivity" OR "inclusion" OR "forecasting" OR "value-based" OR "responsible future" OR "open communication" OR "transparency" OR "social impact" OR "stakeholder involvement" OR "collective input" OR "responsiveness" OR "responsibility" OR "collective stewardship" OR "complexity" OR "foresight" OR "assessment of impact")
3. #1 AND #2

where the TS tag was used to query records containing a specific key term in its topic (i.e., in the title, abstract, author keywords, or KeyWords Plus® fields). The retrieved set of publications was further refined to select only records published in English. The last query update was performed on November 2nd, 2023. The three statements allowed for a search to explore a broader field of responsible innovation, including product development and engineering design and ethical and sustainable innovation. We included subtopics related to responsible innovation to identify relevant literature that may have explored only a part of the responsible innovation construct.

3.2. Keywords extraction

Approximately 30% of the retrieved bibliographic records had empty abstract fields; therefore, we relied on the titles for further analysis. We pre-processed the titles using a standard text mining protocol, including lowercasing, stopword removal, and stemming (Chai, 2023). After the cleaning step, we performed a n-gram extraction step in which we parsed out significant unigrams ($n = 1$) and bigrams ($n = 2$). A unigram or bigram was considered significant if it occurred in at least five titles.

3.3. Co-word network

Next step is to perform the co-word analysis. Its goal is to detect clusters of keywords, which frequently occur in conceptually similar papers. Analysis starts with creation of co-occurrence network from a list of keywords that were extracted from all harvested documents. When two keywords occur together in a particular document, we say that a relationship between two nodes is established. The next step is to weight the co-occurrence network according to the number of observed pairs of keywords. E.g., if keyword *i* and keyword *j* are both found in 150 papers, their co-occurrence weight is set to 150. The last step is to normalize the raw edge weights to account for the unbalanced number of keywords in the papers. This was done by using an association measure defined as (Equation 1):

$$e_{ij} = \frac{c_{ij}^2}{c_i c_j}, \tag{1}$$

where c_{ij} is the number of co-occurrences of keywords *i* and *j*, while c_i and c_j are the frequencies of keywords *i* and *j*, respectively (Callon *et al.*, 1983). The normalized value is zero if the keyword pair is not associated at all, and is equal to one if a given pair occurs together in each paper.

3.4. Identification of research topics

To identify clusters of homogeneous keywords we ran Louvain's community detection algorithm on a co-occurrence network prepared as described in the previous section (Blondel *et al.*, 2008). Each of the detected clusters groups together several contextually similar keywords and represents one specific research topic.

The interpretation of the research topics followed the procedure described by Callon *et al.* (1983). We calculated two measures, centrality and density, to represent a particular research topic in a two-dimensional plot called a strategic diagram. Centrality represents the relatedness of an observed research topic to other topics in a strategic diagram. The stronger this relatedness is, the more central the topic is in the observed network. In practice, we interpret centrality as the strength of a research topic in the examined scientific domain. The centrality of a topic is defined by Equation 2:

$$c = 10 \times \sum e_{kh}, \tag{2}$$

where *k* is a keyword from the observed topic, *h* is a keyword belonging to other topics, and e_{kh} is the normalized co-occurrence frequency of the pair of keywords *k* and *h* according to Equation 1.

Density, on the other hand, represents internal cohesion, and indicates how strongly an observed research topic is conceptually developed. Density is defined by Equation 3:

$$d = 100 \times \frac{\sum e_{ij}}{w} \pi r^2, \tag{3}$$

where *i* and *j* are keywords associated with a cluster, and e_{ij} is the normalized frequency of co-occurrence of the two keywords. The *w* in denominator represents the total number of keywords in a given research topic.

Centrality and density can be graphically represented in a strategic diagram to illustrate the structural landscape of knowledge. The chart is centred by medians of both axes, which divide the plot area into four quadrants, which indicate different levels of maturity and elaboration of observed research topics.

A particular topic can be assigned a unique qualitative description based on its position in the diagram as follows (see Figure 1):

1. Quadrant I is home to the motor research topics, which are characterized by high centrality and high density. Usually, that means they have been worked on over a long period of time by already well-developed research groups and are thus well-defined and mature.
2. Quadrant II hosts niche topics (i.e., specialized and peripheral topics), which have low centrality but high density. They have strong internal links within the clusters (are very homogeneous), but they have weak linkages to other research topics. They are of only marginal importance for the field.
3. Quadrant III contains topics which are defined by both low centrality and low density and refer to either new (i.e., emerging) or declining research topics. Such topics are both weakly developed and marginal in the observed period.
4. Quadrant IV hosts basic research topics with high centrality but low density. This indicates that the topics are well interconnected to others but not well developed. Such topics might be of significant value to narrow research communities but are too general for broader interest.

For qualitative labelling, we used the top-*n* most cited papers in each cluster. The threshold was empirically set to $n = 5$ to balance the trade-off between topic interpretability and topic specificity.

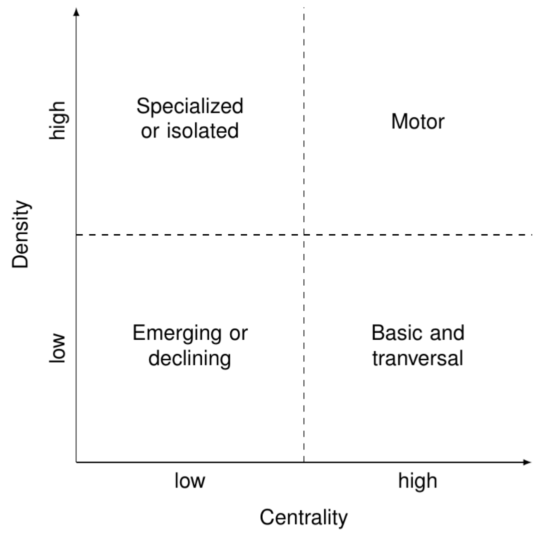


Figure 1. Strategic diagram

4. Results

A total of $N = 3438$ documents, published between 1951 and 2023 were included in the analysis. We extracted 319 keywords from the list of titles. Almost all documents ($n = 3432$) were published after 1990. Therefore, we partitioned the time interval from 1990 to 2023 into three equal-width (i.e., 10 years) time slices (TS_1–TS_3). Six documents published before 1991 were included in TS_1, whereas documents published after 2020 generated a separate slice (TS_4). Figure 2 shows constant growth in the annual volume of publications over the past 30 years.
We performed a co-word analysis for each of the four periods and provided a brief explanation of the corresponding strategic diagrams for each period in the following sections.

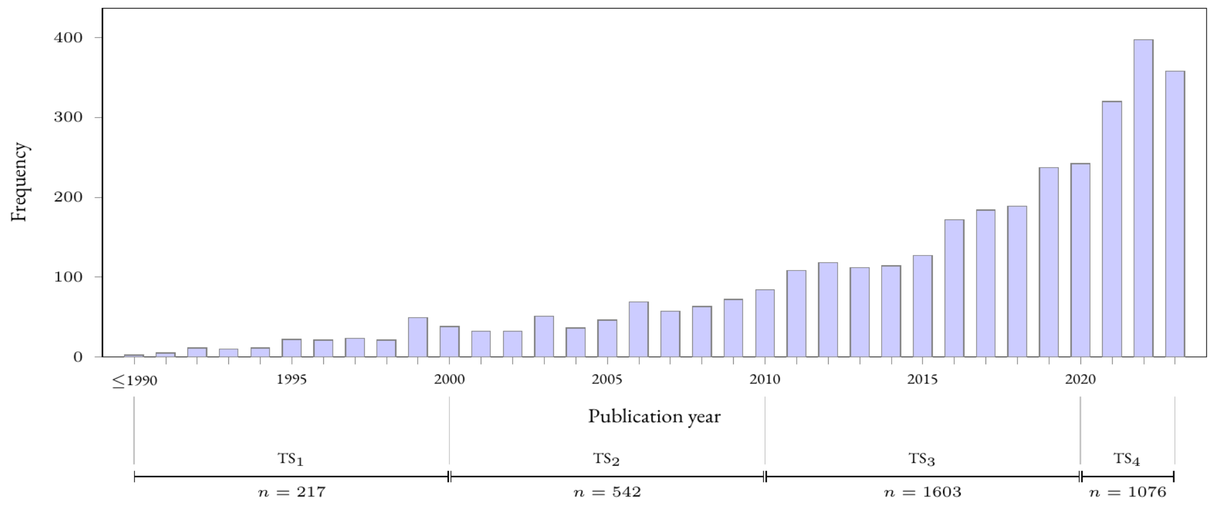
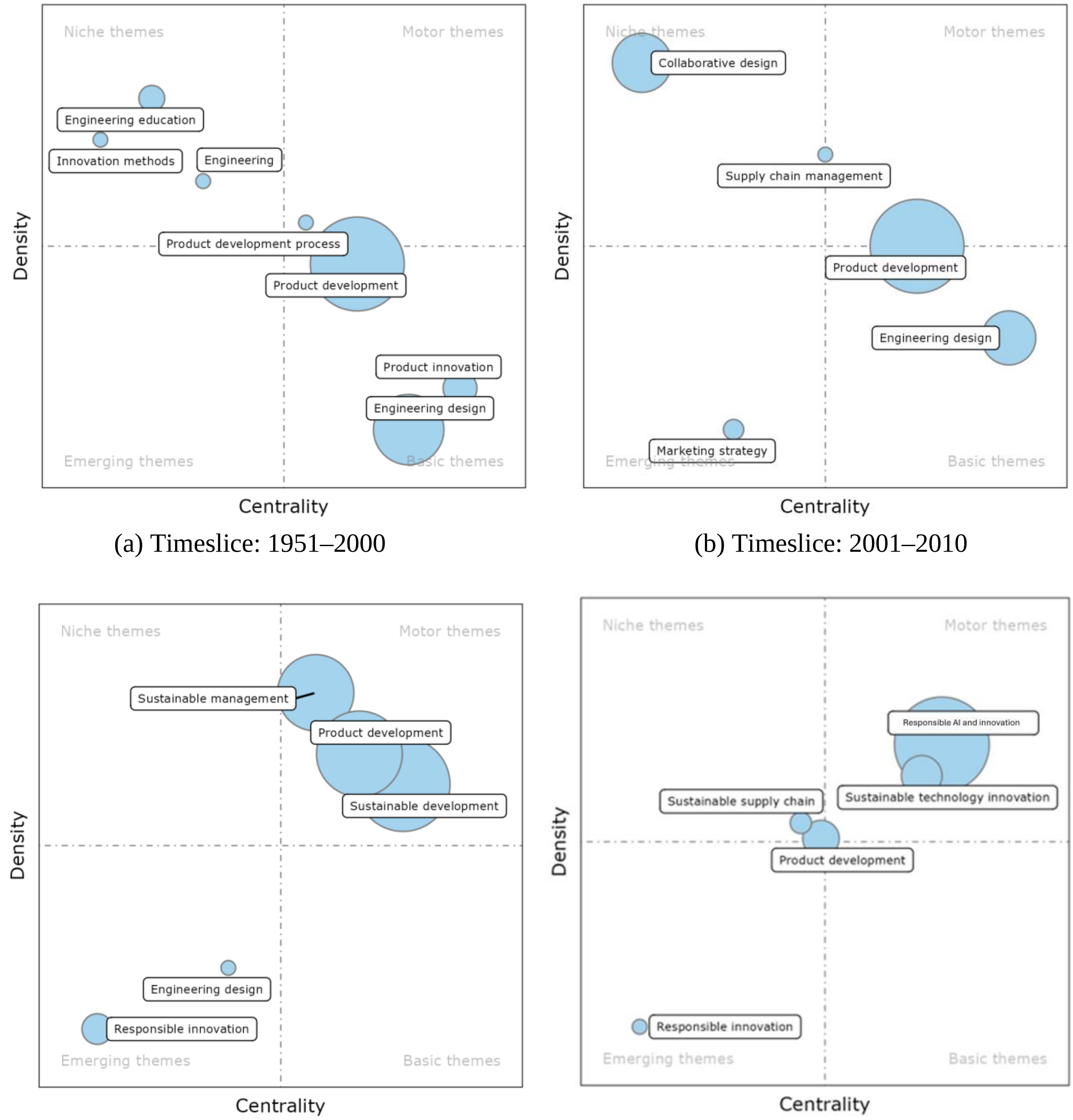


Figure 2. Scientific publications per year

4.1. Period: 1951 - 2000

During this period 7 clusters emerge in the strategic diagram (Figure 3a). Only product development, as the largest cluster, is partially positioned in quadrant 1, emerging as a cluster with close internal connections and connections to other clusters as well.

In this time period, engineering education, innovation methods and engineering were regarded as specialized themes with high conceptual development but weak external interconnection with other themes. Interestingly, product innovation and engineering design were considered more general research topics during this period.



(a) Timeslice: 1951–2000

(b) Timeslice: 2001–2010

(c) Timeslice: 2010–2020

(d) Timeslice: 2021–2023

Figure 3. Clusters for different periods

4.2. Period: 2001 - 2010

In this period (Figure 3b), 5 clusters are evident, with three new themes appearing in the diagram. Product development is still considered the largest theme within the responsible innovation research, increasing both in density and documents associated with the theme. Engineering design shows an increase in density but fewer documents compared to the previous period. It is still considered a more general theme.

Two new more specialized themes emerge in this period, collaborative design, and supply chain management. While both have a smaller number of documents associated with them, supply chain management is sitting at medium centrality, showing potential to emerge as a motor theme in the future. Marketing strategy further appears as an emerging research theme in this period.

4.3. Period 2011 - 2020

In this period, three motor themes overlap: product development, sustainable management, and sustainable development. While product development was the theme with the largest number of documents in previous periods, sustainable development took over as the motor theme in this period, showcasing increased interest in sustainable practices.

While the product development cluster has increased density in this period, a smaller percentage of documents was associated with it in this period (Figure 3c). External connections between the three themes are evident in this period. Engineering design has decreased both in centrality and percentage of documents associated with the cluster and was relocated to the lower left quadrant, suggesting that it is either a disappearing or emerging theme. Responsible innovation appears as a theme for the first time in the lower left quadrant as a potentially emerging theme. Collaborative design disappears from the top left quadrant, where it was positioned as a specialized theme in the previous period.

4.4. Period 2021-2023

While previous periods included a 10-year time slice, this final period only considered the most recent 3 years (Figure 3d). Interestingly, the motor theme has shifted from product development and sustainable development towards responsible use of AI and technology management. Product development as a theme has decreased both in centrality and density, slowly moving towards a niche or disappearing theme. Sustainable supply chain emerges as a niche theme in this period and responsible innovation maintains its position in the emerging or disappearing themes.

Thematic analysis revealed that the focus in the product development cluster is on additive manufacturing (AM), investigating AM adoption, and emphasizing inter-organizational collaboration (Luomaranta and Martinsuo, 2022), the need for balanced approaches to optimize creativity and efficiency (Blosch-Paidosh and Shea, 2021; Prabhu *et al.*, 2021), and highlighting sustainability concerns related to environmental impacts (Gopal *et al.*, 2023) and competitiveness (Turkcan *et al.*, 2022). Such focus supports the shift towards a more specialized view of product development, positioning it in the more niche theme quadrant.

The new motoring theme identifies a distinct new cluster, focusing on artificial intelligence (AI) and its implications for responsible development. Buhmann and Fieseler (2021) introduce a deliberative framework for responsible AI innovation, emphasizing public engagement, inclusiveness, and informed discourse to address autonomy, agency, fairness, and justice concerns. Stahl (2022) extends the discourse to innovation ecosystems, proposing the concept of responsible innovation systems and integrating ethical and social considerations into the innovation pathways. Grover *et al.* (2022) further investigate the feasibility of AI utilization in operations management, offering guidelines for managers based on expert insights from Twitter and academic literature. Together, this cluster contributes perspectives on responsible innovation, addressing transparency, ethics, collaboration, and responsible governance in the context of AI development.

The small new motoring cluster represented here as sustainable technology innovation highlights papers related to eco-friendly technology adoption, energy security implications, renewable energy, economic complexity, and environmental control technology on environmental quality, underscoring the importance of pollution metrics and policy strategies for sustainability. It is interesting to note, that responsible innovation papers, representing an emerging cluster in this time slice focus on the impacts of corporate social responsibility and fostering sustainability within such governance.

5. Discussion and conclusion

The premise of this paper was to explore the knowledge structure related to product development and responsible innovation in the past 73 years. The results reveal that almost 78% of the total body of literature was published in the last 14 years, with over 40% of those documents published in the last three years. While the first time slice considered a longer period, it was interesting to note that no prevailing themes were evident within this context. Product development emerged as a well-researched and explored cluster, establishing the motor position in the 2011-2020 time slice. While it maintained this position for the next period, in the past 3 years, the focus has shifted from product development to responsible innovation related to new technologies, which aligns with calls to action in terms of sustainability and responsibility in innovation ((Fitjar *et al.*, 2019; Jakobsen *et al.*, 2019).

Innovation as a keyword appears as a theme for the first time in the 2011-2020 period. This indicates two attractive research opportunities: (1) while product development was a cluster present throughout the researched period as a keyword, responsible innovation has been prevailing lately, both in terms of specialized research and motoring themes, which presents a question of whether the definition of the two keywords has shifted or are considerations now focusing on the broader innovation as a topic, and (2) how product development relates to the broader topic of responsibility.

While in this paper, we only focus on in-depth thematic analysis of the last time slice, the findings of the scientometric analysis show that the examination of additive manufacturing, artificial intelligence, and environmental practices across diverse sectors has yielded valuable insights into how responsible and sustainable practices can be integrated into technological advancements. Due to time limitations, this paper does not provide enough depth for redefining and fully distinguishing between responsible and sustainable in the context of innovation; while responsible innovation in its core indicates sustainability, identifying the relationship and hierarchy between the two themes may be helpful to support researchers and practitioners in establishing more robust constructs and research outcomes.

The number of themes has mostly stayed the same over the different periods. This suggests that the main fields related to responsible innovation in the context of product development have not shifted toward specific specializations. Themes seem to emerge and disappear, but specialization as such has decreased in recent decades. This may be for various reasons, one of them being naming conventions. As mentioned previously, various definitions exist on the themes identified and the overlap between clusters indicate, naming conventions may have influenced the driving themes related to the field of knowledge.

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