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Observing autonomous product development: A grounded theoretical analysis of product innovation outside the boundaries of firms

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ABSTRACT

The development of tools or products has always been fundamental to human progress, societal evolution and thereby a sustainable future. Thanks to the decreasing cost of 3D printing technology, we can develop complex products in the comfort of our home – and with the help of online communities. Despite this phenomenon, personal product development is less represented in product innovation literature, where profit-driven outcomes are prioritised. This gap in literature led to the main research question of this paper: how do individuals autonomously innovate products within open community settings? In order to find out, we interviewed makers (autonomous developers) of personal woodworking, metalworking, robotics, and 3D printed products.

Through grounded theoretical discovery, we were able to answer the main question with three concepts – a range of product innovation, stages of autonomous product development and product innovation outcomes. The range of product innovation demonstrates three types of product development activities – copying, innovating and acquiring exclusivity. Four stages of autonomous product development were inferred motivations behind the range. Makers are motivated to evolve evolve a competence first. They then choose to innovate and finally increase individualistic development. These motivations result in product innovation outcomes during their development process. Product innovation outcomes are instances that lead to the introduction of something novel such as an idea, method or product. 16 outcomes are classified in this paper by the community and 13 by the individual developer.

Our findings on autonomous product development contribute to future research in circular economy and sustainability. They present a foundation to examine development activities and motivations to upcycle household waste and minimises packaging. In addition, our research supports diffusion of innovations theory and social learning theory. Identifying autonomous development activities, motivations and outcomes show that even personal product innovations can be created, enhanced and influenced by open community systems. By demonstrating that complex scientific products can be learned in communities through social learning methods such as copying, personalising and acquiring exclusivity, this research enhances social learning theory.

1. Introduction

Innovation is integral to sustainability [1–3]. As we innovate, we find new ways to conserve resources, contribute to the environment, and shift toward transformative sustainable consumption behavior [4]. Since the Stone Age, making tools is how humans build relationships with their environment and improve their quality of life [5–8]. Today, advanced technology can be replicated and adapted without specialised skills, in the comfort of our homes. Such autonomous product development is widespread with the availability of 3D printing technology and peer-supported communities. These innovations reduce overproduction and e-waste that is common in electronics manufacturing [9]. Online communities play an important role here. There are many 3D communities that encourage building and learning product development for individuals with no prior knowledge or skill [10–12]. They offer peer feedback, experiential learning and access to free resources [13]. Innovation literature acknowledges product innovation greatly when firms introduce new products and services to meet market demand [14–16,17]. In addition, community innovation is portrayed as contributory to firms from large external groups [18–23]. However,

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autonomous product development is an individualistic method of building objects, without a firm's involvement. Individuals have autonomy to drive product creation, independent decision making about resources and design. Autonomous product development influenced by open communities can lead to innovation outcomes for the developer and community. In particular, a product innovation outcome is an instance that can lead to the introduction of something novel such as an idea, method or product. It is an enhancement of the definition by Kahn, where product innovation outcomes are indicative of both an outcome and a process (2018). Autonomous product development is not regarded as a domain in product innovation phenomena. Without conceptual frameworks scholars of product innovation and experiential learning cannot compare studies across disciplines.

There are three impediments to scientific progress in community-driven product innovation. Firstly, there is limited research on autonomous development activities. A working paper on the worldwide aircraft industry describes autonomous product development as independent production by a firms [24]. Another article on new product development mentions the term autonomous product development team with reference to group autonomy within a company [25]. The widespread phenomenon of individuals autonomously developing products requires observation. Secondly, scientists and practitioners lack the foundation to hypothesise the effect of motivations to build under one's own terms. Innovation potential, economic implications and safety conditions determined by personal motivation lacks a foundation for future research. Thirdly, sustainability studies rely on contributions from firms and society. However, engineers, social scientists and innovation scholars cannot compare product innovation outcomes that are predominantly firm-driven [26]. The environmental impact of autonomous product development is neither compared nor measured. Thirdly, if innovation outcomes are not presented from the community and autonomous developers, relationships between variables - such as innovation outcomes, motivations to build products, and development activities - are lost. Community managers cannot provide sustainable solutions to autonomous developers due to their unfamiliarity with the impact of community design on innovation outcomes. The domain – product innovation in open communities – requires a theoretical framework that can be applied across disciplines. For a framework to support theory-building and the development of the domain as a scientific field, it should be applicable to real-world problems. Therefore, an exploratory method supported with data from real-life settings is crucial. It provides a structured approach to test hypotheses in the next stage of theory-building. The framework should present an understanding of potential relationships or variables in the new domain. Accordingly, the main research in this study is - how do individuals autonomously innovate products within open community settings? It is divided into three sub questions namely what type of product development activities can be observed in communities? what motivates individuals to develop products autonomously? and which community or individual outcomes are derived as a result?

An inductive, grounded theoretical framework addresses how individuals innovate products autonomously in communities. Its main contribution is foundation upon which, multiple disciplines can compare results that can contribute to improvements in the social wellbeing of individuals and groups. In the next section, we argue the importance of building products supported with literature throughout historical ages. In section 3, we describe how Gioia's methodology of grounded theoretical discovery was applied to answer the three research (sub) questions. First, we interviewed 17 makers of woodworking, metalworking, robotics, and 3D printed products. We acquired and analysed data from semi-structured interviews, grounded theoretical discovery, and theoretical sampling. Data analysis was modelled on the works of Nag & Gioia [27] and adapted with a multi-grounded theoretical approach [28]. In section 4, we introduce a framework of autonomous product development. This inductive framework answers the three sub questions. First, three types of product development activities were determined. Copying, innovating and acquiring exclusivity were placed across a range of product innovation. Second, inferred motivations demonstrated progression as four stages of autonomous product development. The stages evolving competence, innovating, intensifying personalisation and transcendence were further grounded in theory. We confirmed the necessity to evolve empirical findings with theoretical validation [29]. Finally, we linked product innovation outcomes from the community and the individual to their respective stages. We have summarized the results of this study in conclusion section 5. In the following section, we conclude with a discussion on how the findings support future research and key theories.

2. From stone age tool making to developing 3D printed products

The phenomenon of building and innovating products is most studied within the boundaries of firms. However, it is insufficient to rely on a single field of research when ethnographers have long determined the vital role of tool-making in the advancement of societies [30–34]. In Mesolithic Norway, bone tools and fishhooks were found to display refined craftsmanship. Leroi-Gourhan reconstructed tool development patterns of the Mesolithic era. At the time, tools were built in a logical sequence of actions as if they were a set of operations undertaken to transform raw material such as skeletal parts into tools [7,35–37]. Neolithic artefacts include axes, chisels and adzes for woodworking and farming [38]. Ethnographic literature describes Neolithic tools as instrumental in the transition from foraging societies to fixed village life based on horticulture tools [39]. The Bronze age not only marks the discovery of copper it is considered significant by technological, social and archaeological scientists. This period highlights a relationship between technology and society [6,8,40]. Awls, casting cakes and smaller household tools such as vessels, clips and pins increased productivity and social wellbeing [41,42]. Tools discovered in India between 1192 and 1206 AD included glassmaking and textile technology. Glass flasks were found to aid in pharmaceutical processes and bow strings were used to separate seeds from cotton for textile production [43,44]. From around 800 – 1400 AD vessels that were lead and tin glazed, and ceramic were discovered to be significant in the Mesopotamia and Persian region [45]. During the industrial age, tool-making shifted from being individually handcrafted to becoming industrialised to produce goods and services [46,47].

Cognitive archeologists have linked high-level cognitive development in early humans to co-evolution of tool-making [48–50]. Humans copy actions from each other's tool-making methods, which other species cannot [51–53]. Paleocognition researchers posit that tool-making is the outcome of intelligence interacting with the environment [54–56]. The brain's ability to retain and manipulate information determines its development, even in children [57]. Even today, building or making is associated with learning complex problem solving [58,59]. Constructivist learning theories emphasise the act of making as constructing material models to understand complexity [60]. Autonomous development practices are critical to educational, ethnographic and societal literature – particularly for scientific, technological, engineering and mathematical objects [61,62]. Developing products involves interdependent steps that need to be done effectively. One such step is copying or imitating, where makers take inspiration from existing designs and modify them to create their own products. In maker communities, copying is a form of "remixing" or "recombining" existing knowledge and resources to create something new [63]. With autonomy, developers are free to decide how they develop products even if it includes methods avoided by firms.

During the pandemic, medical equipment shortages were rapidly addressed by maker communities [64–67]. The open availability of product designs in maker communities continues to increase social welfare. Consider the case of a 3D modeler who develops a prosthetic limb using advanced modeling software and 3D printing technology

[68]. The outcome is a prosthesis that can improves the quality of life for an amputee. The process leading to this innovation is significant. The modeler's journey involves research, design iterations, and mastery of 3D printing techniques, contributing to their personal growth and expertise. When the modeler uploads their design files and assembly instructions in a 3D printing community, they share their knowledge with 3D enthusiasts, makers and healthcare professionals. This dissemination can fulfil a modeler's motivation and contribute to collective innovation in prosthetics, potentially sparking further innovations.

Studies on product development and innovation are confined to management literature. As the definition of a product is limited to those produced for markets, this comes as no surprise [69–73]. In a study by Roberts, Palmer, and Hughes [74], they looked at how organisations seek new resources for product development by looking beyond their usual boundaries. They found that consumers who were initially selected for their potential in innovation were later excluded if they did not fit the company's target market. This shows that even if consumers have great potential for contributing to new products, their relevance to the company's target audience is a key factor in whether they are involved in the development process. Many similar studies are limited by firms' boundaries and determined by markets and buyers [14–16,17]. Sometimes these boundaries exclude product innovation that benefit society at large. Some examples are products developed individualistically for the purpose of personal household or healthcare [75–81].

3. Research Methodology

The study of product innovation in open communities is is an interdisciplinary subject across phenomena. We adopted a methodology that contributes to conceptual definitions across disciplines. Given the exploratory nature of the main research question, we selected a qualitative methodology for its ability to explore social processes in a new domain [82]. We applied Gioia's methodology of grounded theoretical analyses because as an approach, it supports discoveries in social, complex, real-life inductive methods. The study of individuals building products privately includes complex learning and developing processes. In the case of scientific, technological and engineering products, these processes often begin without prior knowledge.

Grounded theory is an inductive research method to discover new theories. The purpose of the grounded theoretical method is to let data guide the researcher's analysis or theory creation instead of creating a hypothesis to be validated. The applicability of grounded theory lies in its systematic qualitative technique to new concept development and grounded theory articulation [27]. We applied overarching guidelines in structured empirical research for 'good theory building' [83]. Contributions from the Gioia method are significant to theory-building, particularly within the context of grounded theory. Grounded theory is a methodology that focuses on generating theory from data rather than testing pre-existing hypotheses, creating theories that are rooted in empirical evidence [82]. The Gioia method, a structured approach within this framework, is instrumental in providing a systematic process for interpreting qualitative data and advancing theory-building [84].

As Wacker [83] posits, "Theory-building provides a framework for analysis. It facilitates the efficient development of the field, and is needed for the applicability to practical real-world problems," such as understanding product development within open communities. In line with this, Wacker's [83] research guidelines have adhered to for different theory-building methods, which stresses the importance of rigorous analytical procedures. There are four criteria that contribute to 'good' theory building', [83]. They are in the order of: i. conceptual definitions, ii. domain limitations, iii. relationship-building, and iv. predictions. The scope of this article is exclusive to a part of the first criteria i. conceptual definitions. Due to the broad scope involved in exploring a new domain thoroughlythe focus of this article is on conceptual definitions or 'defining who and what is included in the domain' [83].

3.1. Research approach

We modelled this analytical approach on Nag & Gioia's study of how knowledge becomes a strategic resource for firms, who developed an inductive process model [27]. Utilising these methods of analysis, we developed a framework that provided answers to the research sub-questions. Nag & Gioia's framework is based on interpretative research, so concepts were derived from the data rather than prior theory [82,85]. The method included a "theoretical overview, to preview major findings and grounded model" instead of elaborating on a "complex data presentation before revealing the major theoretical dimension" [27]. However, emerging concepts were further studied in literature on present theories.

Grounded theoretical discovery is a research approach that supports conceptual definitions in a new domain based on its social processes. At the same time, it was important to select the right open communities. So, we identified communities where individuals had open access to resources, and where real-world experiences could be openly observed. We selected communities where online access to an account was at no financial cost, where access to product development resources were openly available, and where the community supported the learning curve for product development. We found four communities that met these criteria. They specialised in physical technical products, particularly in 3D printing, wood working, machine- and robotics engineering. These communities specialised in products that were highly complex. In terms of product development, we labelled them in the category of scientific, technological, engineering and mathematical communities. Above all, the combination with autonomy, access and social purpose, all four communities fostered an environment to build from scratch. This was important because, it offered a sense of autonomy to makers.

Website content in the four maker communities were divided into four sections - i. product showcasing, ii. learning and education, iii. developing or creating and iv. member services and administration. The first section showcased products that were presented by makers. It included product files, details about remixing or innovating, and a comment section. In this section, any contributor could comment and discuss details about the product posted. The second section consisted of resources to learn how to build. Tutorials and courses were grouped by subject matter such as engineering, science, technology and robotics. Many online courses included lesson plans and activities for individuals wanting to teach other people how to build products. The third section was focused on building products, and makers could access this section to upload technical product files, with design files and documentation. They could also download other design and development files, to customize or recreate. All in all, it was visible that maker communities foster autonomous creation and rapid prototyping of products [86]. Without boundaries of hierarchies and controlled resources, we selected maker communities as open communities, and accordingly sources of product innovation [18–23].

3.2. Sampling

Over 120 makers and were evaluated from the showcase section of four online communities. We scanned makers with specialisms in products in 3D printing, wood working and robotics engineering. They were evaluated for their engagement and the products they showcased in the community. We excluded contributors, who did not engage frequently in the community, or who did not post regular updates about their products. Some communities offered a status badge for heavy to low participation in the community, which was considered, when present. We excluded products that were like those developed by makers already on the shortlist. So, if we shortlisted a maker, who produced model auto parts, then we did not consider interviewing a maker with a similar choice of product. We did this to seek maximum variation by including general population trends and contrasting cases [27,87–89]. Later we revisited communities and product showcase sections for new instances, often to support emerging relationships or to explore differing instances.

Out of the 120 makers screened and approached, 17 were interviewed. 8 were 3D modelers, 4 were woodworkers, 2 CNC makers and metalists, 2 were robotics machinists, 1 was a scale modeler and another a DIY salvager. The 3D modelers work on designing, developing and printing three-dimensional products, through a process of 3D rendering and computational production. The woodworkers were individuals, who design and develop wooden products that can range from household furniture to musical instruments. CNC stands for computer numerical control. CNC makers are machinists, who designed, developed and assembled industrial, metal products such as engines. They do this using automated CNC machines that need to be pre-programmed and adjusted during the product development process. A robotic machinist develops roboticised machinery and instruments, designed and developed through robotics engineering methods. A scale modeler recreates physical prototypes on a generally smaller scale than original, real-life objects. A Do-It-Yourself salvager recycles artifacts to create new products or recreates the original version of the product through significant restoration. We approached the informants through community chat and described my intentions from the study, which was to understand the range of innovation present to autonomous product developers in open communities.

3.3. Interviews

Interviews took place from December 2018 until June, 2019. They were conducted asynchronously, online, and through community chat, video calls and emails. We used community messenger for shorter conversations, or until an informant was conversant with us. We used emails for formal communication, such as reviewing the transcript, or to request and receive consent. As the dominant language in the community was English, we could interview informants from different parts of the world. After an introduction to the project and permission to proceed, questioning began with the informant's perspective on building products and innovation. We found that mentioning the antithesis of copying products created a realistic context for a range between building products and innovating them. Most responses demonstrated a trajectory, from learning to building products towards creating novelty. Informants shared personal details about their interactions and support in the community. They often referred to other makers or community incidents during the follow-up that we cross-checked for relevance.

During the interviews, we summarized my understandings with the informant, and often sought feedback later, when we developed findings. This iterative process was critical to determine second-order themes. We also addressed follow-up questions to all the informants. This allowed me to check my assumptions when we structured the data later. In addition to the interviews, we spent significant time observing makers interact in online communities in general. We observed the journeys of many, who posted products, who commented in support of another maker's progress, and who openly shared designs and even material. Before the interviews, we evaluated the four communities for their design and ease of access to information and resources. It helped us get a better understanding of the environment that maker communities offer, and the innovation that exists in them.

We conducted semi-structured interviews with ten main questions (Appendix A). The semi-structured format allowed me to model questions based on the informants' responses [90]. We began with introductory questions about the informant's perspective of copying, and innovation or novelty. We included questions about their perceptions of what could lie between the two. If it were mentioned, we asked after what learnings they needed to move towards innovation. Finally, we enquired about their decisions to build from scratch, why they copied a design or product in the community, and the influence of the community on their work.

3.4. Data analysis method

As we received responses from the informants, we began analysing data, following the Gioia methodology of grounded theoretical analysis [91]. It comprised of data collection through interviews, data analysis through coding responses, and concluded with structuring data into an inductive theoretical framework with second-order themes and aggregate dimensions. Gioia methodology has three levels of abstraction that we used to develop inductive grounded theory framework. The first level was a listing of first-order categories that were grouped from 709 excerpts. Each excerpt consisted of an individual sentiment or message, which was extracted from the interview transcripts, amounting to 11, 863 words in total. We used the language of the informants for first-order categories. These are centred around real-world experiences of the informants. The second level of abstraction has two levels. These are main second-order themes and their respective sub-categories or sub-themes. The sub-categories are concepts that we derived from first-order categories. They demonstrated a common pattern. Second-order subcategories were developed from common interpretations of first-order categories. In other words, we interpreted concepts, such as the acceptance of copying products, and copying to develop a competence as sub-categories from first-order categories. These concepts were then clustered as main second-order themes. All the main second-order themes were interpreted as product development activities performed by the informants.

Finally, the last level of abstraction included grouping second-order themes into aggregated dimensions [92]. Much like the model of analysis utilized by Nag & Gioa [27], we grouped aggregate dimensions. Then, we scanned literature and emerging theories about the aggregated dimensions. By analyzing the grouped dimensions and literature, we identified connections between the data and established theoretical concepts. In some cases, we adjusted aggregate dimensions to new subcategories in second-order themes. It allowed us to expand on concepts that were also grounded in theory. Accordingly, we included references to theoretical concepts in the results.

In further detail, we coded interview responses separately and based on *in vivo* terms used directly by the informants. The direct language of the informants was presented throughout the analysis, and in this article as much as possible. We coded excerpts from responses into first order codes. Interviews were coded until no more distinctions in shared patterns were present. Then, these codes were analysed for theoretical categories, which we rechecked across all the first-order coding [85]. Once theoretical themes emerged, we looked for patterns or second-order categories. We determined six sub-categories that we could assign to three main second-order themes – copying, innovating and acquiring exclusivity. At this point, we reconnected with the informants to check my assumptions about a range of product innovation. With additional follow-up questions, we were able to detect patterns, and cluster second-order themes into aggregate dimensions. We established three aggregate dimensions – evolving competence, intensifying personalisation and transcendence. The three levels of abstraction contribute to the data structure demonstrated in Fig. 1 in the following section. The results from the iterative data collection and analysis process include first-order categories of prominence in the informants' voices and second-order themes derived from our research interpretations that led to aggregate dimensions. Appendix B references prominent first-order data linking to the second-order themes and aggregate dimensions in further detail. There are three conceptual outcomes of this analysis– namely, a range of product innovation, stages of autonomous product development, and product innovation outcomes.

The informants' personal data was pseudonymized throughout the analysis. Table 1 is a list of informants from 4 communities with the attributes collected during interviews. Some conversations took place through video calls, and we received consent to pseudonymise

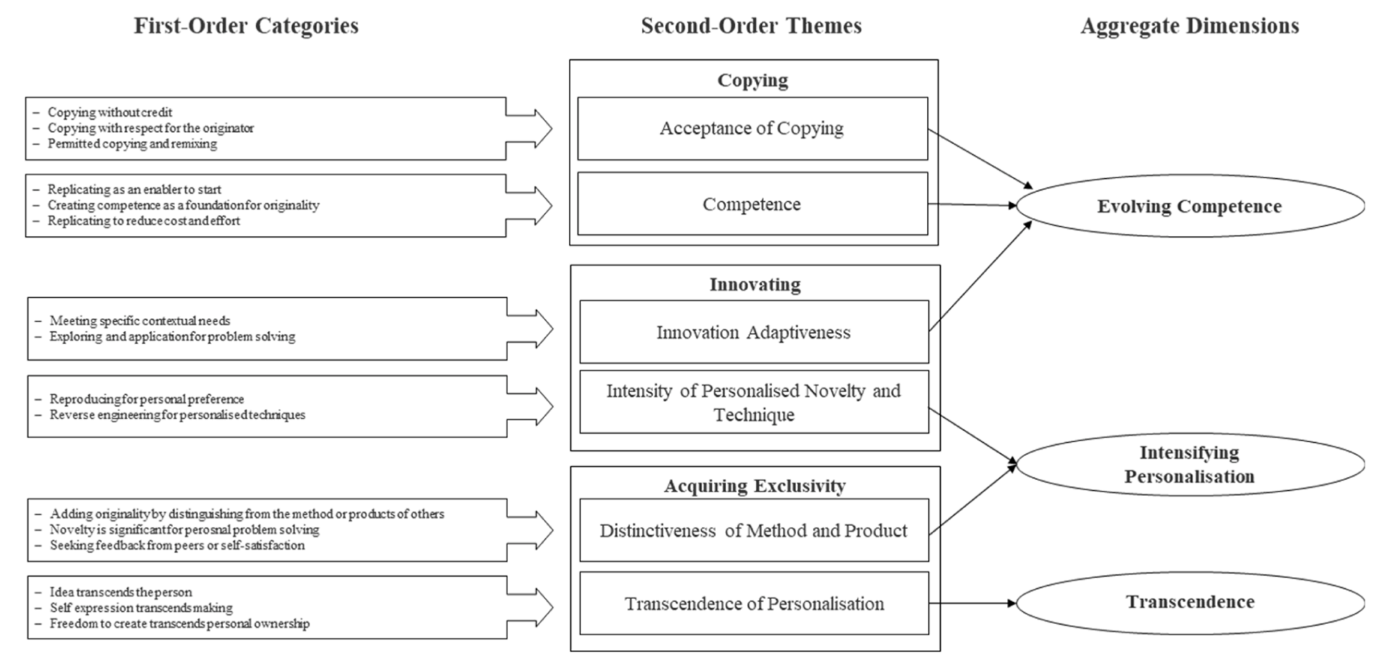

Fig. 1. A Grounded Theoretical Data Structure: A data structure of first-order categories linked to second-order themes (development activities) and grouped by aggregate dimensions (motivations).

Table 1
17 informants from 4 communities and their respective attributes. Interviews took place using community messenger, emails and one skype call.

Informant ID	Informant Type	Community ID	Mode
A-1	3-D Modeler	A	Community Messenger | Email
A-2	3-D Modeler	A	Community Messenger | Email
A-3	3-D Modeler	A	Community Messenger | Email
A-4	3-D Modeler CNC Maker	A	Community Messenger | Email
B-1	CNC Maker	B	Web phone | Email
C-1	Wookworker Metalist	C	Community Messenger | Email
C-2	Wookworker Metalist	C	Community Messenger | Email
A-5	3-D Modeler	A	Community Messenger | Email
A-6	3-D Modeler	A	Community Messenger | Email
A-7	3-D Modeler	A	Community Messenger | Email
A-8	3-D Modeler	A	Community Messenger | Email
C-3	Woodworker	C	Community Messenger
C-4	Scale Modeler (Miniature Trains)	C	Community Messenger | Email
C-5	DIY Salvaging	C	Community Messenger
C-6	Woodwork Restorer	C	Community Messenger
D-1	Robotics Machinist	D	Community Messenger
D-2	Robotics Engineer	D	Community Messenger

usernames of the informants into pseudonyms or IDs. The first column is an ID consisting of one of four community IDs from A to D, and the serial number of the community informant from 1 to 8. Owing to this level of anonymity, we could not share the names and shortlisting specifics of the small list of communities. Still, the second column includes the type of product developer they are, and the last column includes the interview mode. Interviews were transcribed and sent to the informants for validation, and consent to analyse.

4. Results

4.1. An overview

The response to the main research question is depicted in the framework of autonomous development (see Fig. 1). This grounded theoretical data framework comprises the responses to three research sub-questions. The analysis reveals that the concept of a range of product innovation is associated with the second concept - stages of autonomous product development, and both contributed to innovation outcomes. Two out of three levels in the data structure illustrated associative connections. For instance, the three second-order themes are conceptualised as a range, and the sequence of aggregate dimensions corresponded to four stages of autonomous product development. We finally developed the concept of product innovation outcomes as factors influencing the autonomous product development stages. The results section is organised as follows: it begins with the data structure, followed by second-order themes or product development activities in a range of product innovation. This answers the first sub-question. Next, we present the aggregate dimensions that are motivations for product development and introduce stages of autonomous product development. After grounding the analysis in theory, we incorporated innovation as an additional stage. Innovation, a distinct phenomenon in literature, serves both as a product development activity and as motivation. Given the exploratory nature of the grounded discovery process, we applied it to the emerging concept of product innovation outcomes. The expanded representation of the data structure allowed for a detailed listing of product innovation outcomes, which concludes the results section.

4.2. The framework of autonomous development: A grounded theoretical data structure

The first outcome of the data analysis unfolds three levels of abstraction (see Fig. 1). From left to right, the first level is first-order categories in the language of the informants. Groupings of first-order categories are linked to sub-categories of second-order themes. These are then clustered into my interpretations of main second-order themes. The main second-order themes (development activities) were arranged by theoretical aggregate dimensions (motivations). They are individually connected to subcategories in second-order themes, based on findings in literature.

First-order categories represent real-world experiences around product development in the context of open communities. We experienced enthusiasm about copying in the community, especially when it was without giving credit to the originator. Some informants were indifferent to copying products, and others frowned upon the act. However, copying, innovating and remixing was embraced by all the informants if it was to learn, and with credit to the originator. Most informants mentioned personal preferences and problem solving as subjects related to building performantly. As their competence grew, in some cases with confidence, so did the intensity to create personal versions of products, along with personal ways to build them. This created a unique experimental, learning experience that they expressed was rewarding and expressive of their originality. Further, first-order categories involved desires to exclude characteristics of common products and development methods. Finally, connections to spirituality increased in the responses, where the informants preferred novel ideas and idea generation to exceed their own limits.

There are three main second-order themes – copying, innovating and acquiring exclusivity. The main categories were coded based on the first-order categories and my interpretations of the subcategories. In other words, we interpreted concepts, such as the acceptance of copying products, and copying to develop a competence - as sub-categories from first-order categories. These concepts were grouped by main second-order themes, which we interpreted as product development activities. They demonstrate a range of product innovation. Second-order themes are my interpretations of the activities that makers undertake in the context of building products, on their own terms and with their own resources. These interpretations of second-order themes are set in the context of the community. In other words, the theme copying involves the acceptance of the act, and the motivation to develop a competence. Innovating includes developing a competence to build and adapt the product. In addition, innovation includes the act of increasing or intensifying personal definitions of product novelty, and their own personal technique to develop. The theme – acquiring exclusivity, is interpreted as an exercise, involving the exclusion of other methods and products, which are common in the community. Finally, transcendence is a sub-category, while acquiring exclusivity. It involves exceeding personal limits, standards, and those of the community.

Aggregate dimensions are divided into 3 groups of motivation behind corresponding product development activities in the range. Evolving competence is the motivation behind copying and innovating products, to adapt them to personal needs. Intensifying personalisation is the drive behind building novel ideas in novel ways. It is comprised of activities that distinguish the product or development method, from other products and methods in the community. Finally, transcendence is a motivational state that is triggered by a desire to exceed on many levels, including spiritually.

4.3. A range of product innovation and stages of autonomous product development

There is a range of product innovation that can be observed in communities. Our analysis shows that second-order themes in the range are product development activities (see Fig. 2). The range starts with copying on one end and acquiring exclusivity on the other. So, on one hand, when a maker copies a product to learn how to build it, there is no innovation involved. On the other, after many personal alterations, and no similarity to other products, the outcome can be completely unique. Acquiring exclusivity is the other extreme in the range. After copying a product, it can be remixed, adapted or altered. Thereby beginning the act of innovating, which is we positioned in the middle of the range.

Aggregate dimensions are motivations to develop a product through autonomous means. These motivations answer the second sub question - what motivates individuals to develop products autonomously? Results show that the dimensions are stages of autonomous product development. Corresponding second-order themes are activities motivated by aggregate dimensions. To evolve a competence, a maker will first copy, and later innovate and adapt the copied product. The more their personal needs increase, the higher the product novelty. Finally, a desire to distinguish their product from any other motivates them to transcend limitations.

4.4. The range of product innovation

In this section, we describe the results of the first sub-question - what product development activities can be observed in communities? The second-order themes line up as a range of product innovation. They consist of product development and innovation activities, undertaken by makers. Fig. 3.

4.4.1. Copying

All informants had strong opinions about copying other products, ideas and designs. Some felt copying in any form was unacceptable, and not worth posting. Oth/ers believed that nothing was built completely from scratch, and that ideas should be free. Many reflected on their relationship with the act, considering when they would choose to copy over building from scratch. Copying anything for the purpose of personal learning was interpreted as permitted copying and remixing. This was considered acceptable. Using copying as a starting point in a project was familiar to them. Replicating the design of an expensive part of a product, or copying another product to find out how it was made. In literature, we observed that copying products is a catalyst, that advances firms towards a new idea or concept, albeit through counterfeit processes. Research on aesthetic product innovation validates that imitation and reverse engineering is a prominent start of the product innovation process, even though firms need to decide, whether they want to fight or co-operate with counterfeiters [93,94].

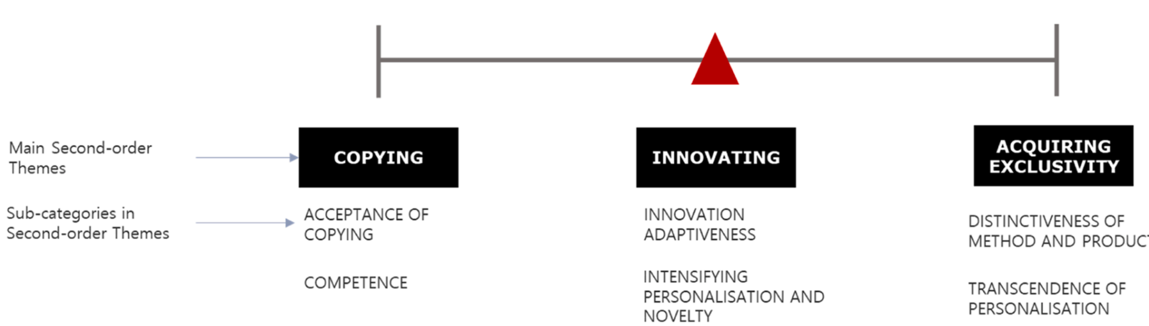

Fig. 2. The range of product innovation derived from main second-order themes (development activities).

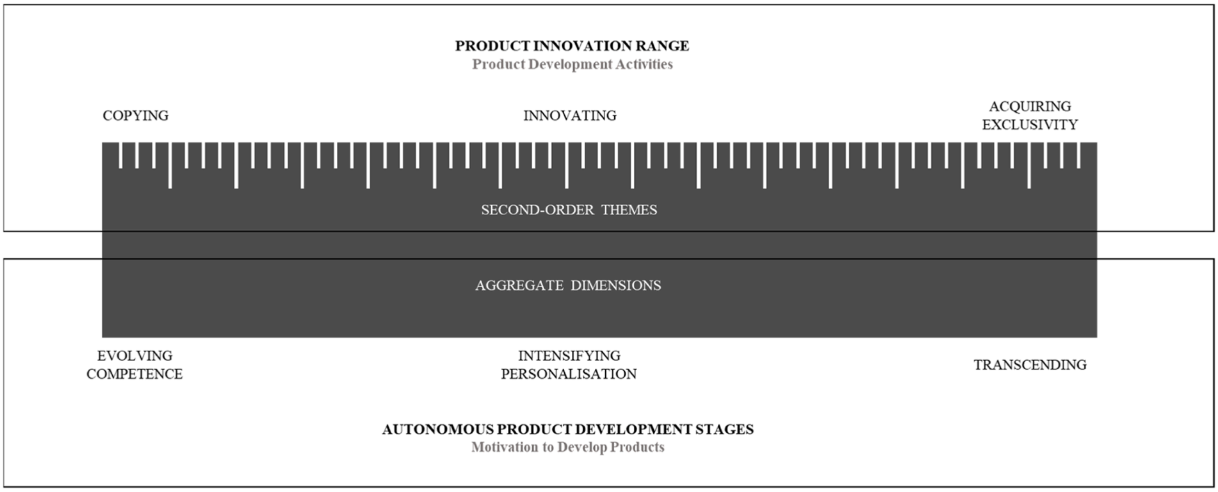

Fig. 3. Second-order themes are product development activities, and aggregate dimensions are motivation to develop products autonomously.

The two subcategories that contributed to this second-order theme, were *acceptance of copying* and *evolving competence*.

4.4.1.1. Acceptance of copying. This subcategory – acceptance of copying represents degrees of acceptance. Some degrees of acceptance are (i) copying without offering credit to the originator, or (ii) referencing the point of origin and (iii) respecting permitted levels of remixing. Makers differed in their preference for copying as a starting point to create and to innovate. Some believed that copying should only be permitted when credit was given to the original maker, whereas others referenced respecting the terms and conditions of the creative commons license especially for firms copying individual products.

A 3D modeler in community A commented on the importance of a creative commons license to protect the ideas of the individual from commercialization of borrowed products by firms:

The only reason I don't publish under full creative commons permissions, is that I feel that a for-profit company should have the funds to pay someone to make models for them and not rely on free models.

In another vein, CNC maker from community B frowns on copying entirely, and rejected the idea that copying might include inspiration from the original creator:

Some might rationalize it with "Oh I was inspired by the maker or artist and that's why I copied their work.". The informant doesn't believe this is inspiration but copying, especially if it is a direct translation.

4.4.1.2. Competence. The second subtheme – competence, connected with the second-order theme - copying is linked to the aggregated dimension - evolving competence. Here, copying was directly recognized as a starting point and foundation to innovate. A broad understanding was established from most makers about copying for personal advancement, and for familiarity, with methods to innovate or create new products. Moreover, innovators recognize the community as a platform that celebrates copying to be able to encourage newcomers to begin and develop a passion to build, as commented by CNC maker from community B:

[Community B] is built around sharing ideas and copying is celebrated. Products are posted to be copied and for people, who like the design to recreate it. Makers typically enjoy enough to make alone – not necessarily wanting to profit from the exercise.

The first theme in the range of innovation demonstrates an antithesis of novelty. Makers described novelty as creating new products and discovering new methods to develop products. However, their context of copying was interpreted as an act of replicating a product, design or idea with contrasting purpose to eventually create something new.

4.4.2. Innovating

This second-order theme was a departure from the act of coping. It was developed as a starting point of emerging novelty. We interpreted this theme as innovating in the range, as it was described by informants, as the next product development activity after copying. First order categories that referred to innovating, mentioned remixing what had been copied or building over it, until it no longer resembled the original. Accordingly, this second-order theme comprised of two subcategories – *innovation adaptiveness* and *intensity of personalised novelty and technique*.

4.4.2.1. Innovation adaptiveness. The aggregated dimension evolving competence also includes a subtheme from the innovating second-order theme, namely innovation adaptiveness. This second-order subtheme of innovation is motivated by the aggregate dimension – evolving competence because the maker begins by altering a copied or replicated product to meet their personal needs. Here's how woodworker and metal worker from community C shares an interpretation of the relationship between copying and adapting innovativeness:

…usually my projects are a combination of "copying" some other projects and making it my own—tweaking something someone else did to make it a little more original. It is rare that things are exact clones of something else. Creations may have had inspirations and parallels, and that doesn't mean it's just a copy.

4.4.2.2. Intensity of personalised novelty and technique. Where the first three second-order subthemes focus on evolving competence, the next set of second-order subthemes transform into a phase, where the individual contributes more of themselves through novelty and personal technique. This third element established clear novelty outcomes in method and output and based on the individual's problem-solving process. 3D modeler in community A had the following to say about the significance of personal novelty and technique (problem solving) when building:

In problem solving function it [personal novelty] is key above all. Aesthetics is a fair second but novelty of the product is not. In exploration novelty is first but even so, one person's findings is just the tiniest bump standing on shoulders of giants.

This second-order theme is driven by the aggregate dimension intensifying personalisation especially since the context of the maker in the community begins to close in on individual ideas and methods. Some makers have gone so far as to reverse engineer an existing product, only to infuse their own context. Others associate novel techniques of other makers as an introduction to personal advantages in reducing cost and effort.

4.4.3. Acquiring exclusivity

The last second-order theme consists of two final subthemes (1) distinctiveness of method and product, and (2) transcendence from personalisation. The former associates itself more with the aggregate dimension intensifying personalisation. Due to the dependency in the informants' linkage to increasing intensity of personalised novelty and technique, the latter has motivation of its own – transcendence. This aggregate dimension represents contribution to the community, particularly after a maker rises above mediocrity with novelty. 3D modeler from community A projects a connection and sequence between the aggregate dimensions of copying for evolving competence, intensifying personalisation and then the urge to "nurture gifts of talent" emerging as an extrinsic value for the greater good.

Maybe ego, it feels a bit degrading to my self-esteem to just replicate something without adding any part myself. But also a feeling of obligation or maybe a mission to nurture gifts of talent and inspiration to good.

4.4.3.1. Distinctiveness of method and product. The aggregate dimension - intensifying personalisation borrows from the subtheme distinctiveness of method and product from the second-order theme acquiring exclusiveness. In acquiring exclusiveness, makers and innovators display an opposing reaction to community influence – of going against the trend and creating novelty. In order to do so, they represent distinctiveness in method or product. A growing intensity of personalisation was observed in this subtheme and resulting distance to the community. These observations are best represented by scale modeler from community C.

I am somewhat unique in that I create my layouts entirely from scratch and without "reference images". See above (some people attempt to replicate real-life scenes). I do not attempt to replicate real life scenes. So on the scale of "copying" to "create from scratch" I am very much on the create from scratch side, more so than most other modelers. I don't know why I do it this way. It would be way easier to just copy a reference image. In this project the waterfall/river scene is entirely from imagination/scratch. I don't really know if rivers and waterfalls actually look like that. I almost actively avoid reference images in cases like that. Seems odd but that's just how I do it.

4.4.3.2. Transcendence from personalisation. The orientation of this subtheme depicts the maker as rising above oneself and towards increasing novelty in the community. Common associations with "ideas" and a separation from "self" led to an emphasis on ideas being a part of more than the maker and transcending above personalised creation. 3D modeler from community A references ideas as superior, external source that present fluidity to innovation in the community of makers:

When I create a new thing, my idea (how-to-make) is more important than the thing itself…

…Patents are not my way, I believe in free information flow. One of my goals could be to prevent patents by first publishing in cc license…

…Innovation is a free flowing [fluid] in the universe. Sometimes it comes to me, sometimes not. If stress on the job, it will not come. If I'm riding my bicycle, or (countryside) skiing in the forest, sometimes it will come. If the previous idea is unrealized, it will not come with new ideas. I have to write down the previous idea to paper to be free for new ideas…

The range of product innovation represents a spectrum of product development activities undertaken by makers in open communities. At one end lies copying, which involves replicating existing products with little to no modification. This activity can be observed in maker communities, where reverse engineering and imitation are prevalent. In the middle of the spectrum is innovating, characterised by creating novel products or significantly improving existing ones. This process often requires creativity, experimentation, and the ability to solve complex problems. At the other end of the spectrum is acquiring exclusivity, which involves securing uniqueness for specific products, thereby limiting similarities to existing products. Each of these activities plays a distinct role in the product development process and contributes to the broader landscape of innovation in communities. The range of product innovation is vital to understand dynamics of innovation within maker communities. These communities often operate outside traditional corporate structures, relying on informal networks and peer-to-peer collaboration. By examining the diverse product development activities within maker communities, we gain insights into how product innovations are triggered in non-traditional settings.

4.5. Autonomous product development stages

The aggregate dimensions identified in our analysis are fundamental motivations and stages of autonomous product development. It answers the second research question - what motivates individuals to develop products autonomously? These motivations can include factors such as the desire for competence, the need for personalization, and the pursuit of transcendence. Each dimension represents a different aspect of motivation, compelling makers to engage in the process of autonomous product development. We were also able to ground these findings in theory. In other words, after the analysis, we screened literature for existing theories about the relationship of product innovation and competence, personalisation and transcendence. We confirmed that the range of copying, innovating or acquiring exclusivity is motivated by the following aggregate dimensions.

4.5.1. Evolving competence

The following second-order subthemes contributes to the aggregate dimension - evolving competence. These are acceptance of copying, competence and innovation adaptiveness. Acceptance of copying is the activity of copying and giving credit to the originator. In order to learn to build, makers will struggle with how much of copying is considered acceptable before posting their results on the forum for feedback. Competence is the makers urge to develop skills in order to build something new. Innovation adaptiveness is the desire to alter the copied product and meet an individual need. Each of these subcategories were motivated by the individual determination to develop skills and build products.

4.5.2. Competence theories

In the research project on the theory of motivation, Robert White examined the individual's willingness to leave an enduring impact on the environment through competency. He called competence motivation "effectance". According to White, effectance satisfied an intrinsic need to cope with the environment, and the concept of competence is described as "the result of gradual learning by organism-environment interaction" [95]. Susan Harter further elaborated on this theory to create a framework called competence motivational theory (1978). In it, she emphasises the internalisation of self-regulated skill development. The aggregate dimension evolving competence represents individual ways, in which makers increase their competence to build and alter products. Copying products, ideas or designs played a significant role in this first aggregate dimension, where makers reflected on their relationship with the act of copying including their own interpretation of terms of acceptance and benefits. We interpreted that the stages of autonomous product development begin with developing competence in method and output.

4.5.3. Intensifying personalisation

The results of our analysis begin to focus on the independent and individual nature in which makers create and innovate in this aggregate dimension. A typical stage, after developing competence to create - is the emergence of personal aesthetic and past reflection, shown in a transcript from a call with CNC maker from community B.

The informant uses a sort of death-clock format to drive motivation. With the pressure of time, the informant finds the right opportunity and uses it to make it an expression of his personality and uniqueness. Another influencer is from this maker's childhood, where as a child of missionary parents, relatively fewer toys left a lasting impression and memories. The informant needs to care about the products they sell. This maker is also influenced by free flow and there are always a few ideas on his mind for the future. These ideas are often connected to how they can be successful to the people who might buy them.

As the title for an aggregate dimension - intensifying personalisation implies more novelty for the maker and their identity for themselves, and their past. This choice of term was interpreted from the informants' repeated references to the words "personal preference" or "because I want to" and common use of "I" compared to the earlier aggregate dimension that elaborated more on "learning".

4.5.4. *Emerging concepts in product personalisation*

Although few theories have been established around personalisation of products, we refer to Grant et. al., [96], who describe product personalisation as a process of "injecting meaning into products" and thereby "displaying a piece of themselves through that product". Grant et. al., [96] further explain that "the reasons why participants felt connected to their products include strong emotions/memories, the amount of time and effort invested into the personalisation, a sense of achievement". Our findings show that makers are motivated by intensifying personalisation in the second aggregate dimension. They seek personal product novelty and individual distinction in technique. Finally, this intensity leads to a desire to achieve a higher personal sense of originality. The second stage of autonomous product development is defined by the individual developing products that increases their sense of self and distinguishes itself from other products.

4.5.5. *Transcendence*

The motivation transcendence has a tight connection with the main second order subcategory transcendence from personalisation. For some makers, the necessity to contribute to a greater purpose connects closely to their originality – almost to a spiritual extent. In fact, makers in this stage of transcendence express it as being motivated by exceed limitations or rising through originality beyond something common. A 3D modeler from community A shares the attribution of unoriginal ideas to automation by machines, abstracting and projects "humanity's" and the informant's value as novelty of innovation:

These machines and software's can sometimes deliver very impressive work that really appears human made. But they also seems to be limited to rehash or just slightly expand on whatever prior art they are fed as instructions. Whenever they are made to produce new, never seen before, content the result is usually oceans and oceans of random nonsense. This lead me to a kind of view on where value possibly hides, what make means, and the point of making an effort. Maybe true novelty that carries a sense of purpose or curious intent still is, for the moment, a uniquely human trait. In a time when remixing almost can be reduced to machine work, I'm drawn to express myself in the niche remaining outside.

In this context, the 3D modeler refers to the outside as the greater macro and purpose of the maker, implying rising above an opposing view of mass improvements and remixing (mediocrity). This abstraction reflects a willingness to contribute to a greater purpose of humanity, with novelty that offers freedom from mediocrity and mass production.

4.5.6. *The role of transcendence in new product development*

In their article, Takeuchi and Nonaka [97] introduce self-transcendence as an important sub-characteristic to develop new products in an ever-changing environment. Through multiple observations, they describe this team characteristic as "elevating their own goals through the development process" and "overriding the status quo". Above all, the authors of the article The New Product Development Game believe transcendence to be a contributory factor in self-organising new product development. Makers develop a need to transcend common techniques and products, especially in the community. The motivation - transcendence constitutes rising above common products, mediocrity and even ideas. Makers are motivated to acquire exclusivity in order to contribute to the greater good of the community by raising the bar themselves.

4.5.7. *Innovation: The motivation to drive competence towards intensifying personalisation*

Product innovation is a phenomenon. The act of innovating consists of the development of foundational skills because innovating relies on a solid base of knowledge and expertise. Without this foundational knowledge, it is challenging to identify areas for improvement or innovation. Innovation is emphasised as a new stage in autonomous product development, particularly because it serves as both a product development activity and motivation to develop products [98–100]. Amabile and Pratt's dynamic componential model of creativity and innovation posits that both intrinsic motivation (e.g., enjoyment of the task) and extrinsic motivators (e.g., rewards and recognition of a finished product) increase product development [101]. We observed that once a maker obtains the necessary skills to build autonomously, they are motivated to innovate. Without altering the data structure, we singled out first-order categories related to innovation. In this stage, we interpreted makers as having competences that did not require them to copy or reverse engineer designs. We also represented this step prior to a desire to personalize products and methods. As a development activity, innovation is the act of adapting a product or design for the needs of the maker. As a stage of autonomous product development, we recorded new linkages as a concept called product innovation outcomes.

Once matched against the four stages in the journey, first-order categories described potential outcomes from the individual makers and the community that we extracted and highlighted in Table 2. During the act of copying (second-order theme and product development activity), a maker might trigger an outcome to reduce the effort of building something new. At the same time community participants benefit from the outcome of fair copying practices, when they respond about copying and giving credit to the originator. In the context of new product development in open communities, we inferred that these motivations were novel outcomes of autonomous product development. Kahn defines innovation outcomes 'as the introduction of something novel such as an idea, method or product' [102]. Furthermore, we also consider his definition of innovation outcomes as both an outcome and a process [102]. At the same time, we detected that there is an overlap between the outcomes and motivations. When a maker develops new skills, and posts about it, they may share a new competence, which is an individual motivation, and an outcome. Similarly, the community benefits from the post with access to new ideas, which is also motivation and an outcome to the community.

4.5.8. *Product innovation outcomes*

First order categories that were linked to aggregate dimensions, describe innovation outcomes in the context of autonomous and community product development. Above all, the outcomes portray that creators exhibit high levels of proficiency and self-regulation, whereas the community offers structure, governance and support. Table 2 portrays motivations and outcomes for both individuals and communities at each stage of the autonomous product development. Column 1 is a list of the aggregate dimensions that are stages in autonomous product development. The next column to the right called Individual Outcomes is a listing of first-order categories, where outcomes were individualistic or from the individual as a source. The last column on the right is titled Community Outcomes. It contains a list of second-order categories, where outcomes are from the community. Furthermore, categorizing first-order categories as motivations and innovation outcomes points as

Table 2
Individual and community product innovation outcomes.

Autonomous Product Development Stage (Aggregate Dimensions)	Individual Outcomes (First-order Categories)	Community Outcomes (First-order Categories)
1.Evolving Competence	Reducing cost and effort	Copying and giving credit
	Starting point	Copying with respect for the originator
	Learning experience	Permitted remixing
	New competence	Access to new ideas
	Meeting individual needs	
2. Innovating	Confidence in competence	New ideas and products
	Exploring and application for problem-solving	New technique and content
	Celebrated copying	Interacting and sharing innovation experiences
3.Intensifying Personalisation	Reproduction for personal preference	Community recognition of ideas and outcomes
	Personalised technique and aesthetics	Novelty of products
	Commonly used techniques	
	Trendy products	
	Expressing personal desires	
	Ideas that transcend the maker	Self-expression transcends creating
4. Transcendence	Ideas that transcend the community	Peer-comparison with trend setters
	Confidence in originality and ideation transcends copying	Community recognition transcends intrinsic value
		Creating imitations and foundations to remix novelty

possible interrelationships among stages, the community, and the maker. Ultimately, this categorisation informs our final research subquestion regarding specific, community or individual product innovation outcomes that may emerge as a result of our analysis.

Stage 1. Innovation outcomes in the evolving competence stage are learning outcomes for individuals, and governance outcomes for the community. They are outcomes that are subsequent to innovation. Makers copy an existing product to learn, and also reduce the cost and effort of product development. Subsequently, they speed up product innovation in their next build. Another outcome when using copying as a method to evolve competence, is the development of a foundational starting point that has worked for another product or innovation. Finally, the learning experience of product development is an innovation outcome. As individuals gain new competencies, they increase their potential to build novel products in novel ways. Innovation outcomes that benefit the community during this stage will promote an open innovation culture and foster open product development. For instance, governance, such as ensuring credit is given to original creators is an innovation outcome because it allows creators to publish their work without concerns about their products being counterfeited. So, outcomes such as copying and giving credit, copying with respect to the originator, permitted remixing and access to ideas are outcomes that are essential for a collective to offer fair innovation practices.

Stage 2. There are six individual and community innovation outcomes in the innovating stage. First, there is confidence in a maker's competence to build, because it increases their potential to find new ways to build new products. Products are built as a way to fill a need or solve a problem. In their article on Individual Innovation Competence, the authors establish that self-confidence in a competence are indicative of autonomy, which is core to the concept of ADP [103,104]. Second, makers will use the innovation process to explore and apply new ideas and solve problems, which is an outcome that leads to innovative processes and solutions. Third, when copying is celebrated during the innovating stage, it contributes to innovation due to the openness to build and share even copied products. This promotes further product development and eventually product innovation. Communities benefit from outcomes such as new ideas and products that increases the relevance of the community to its participants. New techniques and content are also introduced, and lead to new perspectives. Above all, the interaction and sharing of innovation experiences during this stage helps participants engage in collective creativity.

Stage 3. There are five individual outcomes and two community outcomes in the stage intensifying personalisation. Individuals will reproduce products for personal purposes creating innovations of their own preference. Another product innovation outcome is personal techniques and aesthetics, which when applied will allow makers to test a new method or personal aesthetics. The identification of commonly used techniques and trendy products indicates that they will adapt commonly used techniques, and trendy products in order to personalise them, often changing products significantly as a result. A maker's need to express personal desires through making individual products triggers an inherent need for novelty that leads to product innovations. The outcome benefits the community, when this novelty is posted and discussed with other makers. Similarly, the product innovation outcome community recognition of ideas and reinforces further product development, and thereby innovations.

Stage 4. Transcendence is a stage, where exceeding limits includes increasing openness. The first individual outcome in this stage is ideas that transcend the maker, where makers believe their ideas are of greater importance to the community than themselves (anyone in the community can copy my ideas). In some cases, thy believe their ideas are of greater importance to the world, when their ideas transcend the community. The next individual product innovation outcome arises when they describe their ideas as open enough to be copied. Their confidence in their own originality and ideation allows them to exceed any previous uncertainty from other people copying their products. There are four community innovation outcomes, which when present results in the creation of novelty. Self-expression that transcends creation is an outcome, where makers value self-expression through product creation as more important than the creation or product itself. When this takes place the openness to create products for the purpose of learning and innovating is at the forefront. Peer-comparisons with trend-setters is when a maker's peers compare them to trend-setters, whose products create popularity because of the individual building them and not necessarily due to the product themselves. When the volume of resonance in the community is higher than the personal cost to the makers then community recognition transcends intrinsic value.

5. Conclusion

With this study, we explore how individuals innovate products within open community settings. Using Gioia's methodology of grounded theoretical discovery, the following three subquestions were answered - what type of product development activities can be observed in communities?, what motivates individuals to develop products autonomously? and which community or individual outcomes are derived as a result? For the first answer, we established three types of product development activities – copying, innovating and acquiring exclusivity. We placed them across a range of product innovation. The range shows that makers copy products in communities to learn how to build them. They innovate and adapt products, and finally they look to acquire exclusivity in order to distinguish what they've built from the original design, or any other product.

The second subquestion is what motivates individuals to develop products autonomously? We present inferred motivations behind the range based on the data structure. These resulted in conceptual stages of autonomous product development. We learned that when makers are motivated to evolve a competence, they copy products and designs from the community. They also evolve competences by innovating, where innovating a product is often motivation in itself. When makers personalise products, they are motivated by increasing personal novelty and intensifying personal techniques. They develop a desire to exceed their own limits of originality, and the limits of the community. In isolation, autonomous stages of product development are in the form of a journey of personal product development. The stages were grounded in theory, confirming the necessity to evolve the empirical findings with theoretical validation [29].

The third and final subquestion was which community or individual outcomes are derived as a result? The concept of product innovation outcomes answers this question. First order categories that could result in product innovation outcomes were assigned to each of the four stages of autonomous product development. 29 outcomes were classified by the community and the individual resulting in 16 and 13 respectively. The three subquestions were created to answer 'what is included' in the definition of variables in a new domain product innovation in open communities. 'Who and what is included' is a part of the first step in the framework that applies Wacker's general procedure for 'good' theory building'. Based on real-world experiences and the selection of informants, we introduced makers and autonomous product development to management literature. The introduction of makers expands a conceptual definition of 'what is included in the domain' of product innovation with aspects of in open community literature. Each of the three concepts introduce a set of variables that help define the domain. The range of product innovation contains product development activities as variables. It describes what activities are done to develop and innovate products. The autonomous product development process has demonstrates progression in stages as characteristics that can be monitored. Finally, product innovation outcomes from individuals and communties are variables that can be observed as factors influencing product innovation.

6. Discussion

The framework of autonomous development supports two theories: diffusion of innovations theory and social learning theory. The framework answers the main research question by introducing a multidisciplinary domain and three product innovation concepts. The range of innovation, stages of autonomous product development and product innovation outcomes are the foundation for future product research in open communities. Diffusion of innovations theory is expanded with autonomous development and innovations in an open and free social system [105]. Many of the products in this study had a focus on complex, Scientific, Engineering, Technological and Mathematical (STEM) developments. The conceptualisation of how individuals and groups learn from observing autonomous development supports social learning theory and thereby education in complex subjects such as STEM [106,107]. The stages of autonomous product development illustrate makers on a journey of personal development within social learning systems [106].

With the framework of autonomous development, researchers across multiple disciplines have a baseline to compare the methods of individuals building and innovating. Majority of research on product innovation is conducted based on the introduction of a firm's products to meet market demand [108–110]. In similar vein, community innovation is portrayed as contributory to firms from large external groups [18–23]. Product development methods in firms can be compared to those in the household by being placed across the range of product innovation. Innovation scholars, community researchers and educational scientists can now record factors that influence development according to the three types of development activities. The influence of peer feedback from the community can be modelled and measured in future research. Studies on the role of copying in tool-making, learning-by-making and product development can be contrasted across cognitive archaeology, sustainability and product innovation fields. For instance, what effect does community feedback, group decisions or personal motivations have on the type of activity. Based on a long history of building and adapting tools to benefit society, firms can reconsider their role and restrictions to adapting their products freely. Community managers can design communities that cater to a makers development activity or stage of autonomous product development. For instance, if a developer is learning, they might need a safe virtual space, sufficient tools and permissions to copy. Community moderators can offer experienced peers benefits based on their motivations in order to support beginners. R&D departments can increase skills and experience in transverse scientific, technological, engineering and mathematic product development in product communities.

The common set of motivations that trigger autonomous product development can be assessed in across disciplines. Motivations to develop products autonomously are in stages. First contributors are motivated to evolve a competence, then innovate, then intensify personalised development, and finally transcend mediocrity. The relationship between motivations of the maker and the economic implications and innovation potential require future investigation particularly in the context of sustainability. Researchers can evaluate the use of resources in each stage. Similarly, technology researchers can measure the impact of advancing technologies in each stage. For instance, can personalisation technology increase learning and product development outcomes for 3D printing developers? The environmental impact of autonomous product development can be compared or measured across 13 individual innovation outcomes and 16 community driven ones. Sustainability studies rely on contributions from firms and society. Relationships between development activities and motivations can be modelled for several hypotheses related to environmental impact. Scientists can investigate when environmental impact changes based on innovation outcome. Similarly, social scientists can evaluate the influence of community influences on individualistic outcomes.

The rigour in continuous data collection and analysis in the Gioia methodology reduces the risk of subjectivism and advances combined phenomenology for empirical research especially in the areas of theoretical sensitivity, sampling, continuous coding and categorizing data. However, given the qualitative nature of this small data set, our analysis lacks clear, causal connections between the individual and community, and/or the product innovation outcomes. We suggest proponents of grounded theory reflect on inductivist approaches towards empirical analysis and the benefits of a structure in deductive, theory-driven analysis that includes quantitative grounding of the concepts [29]. The importance of integrating deductive, theory-driven analysis with inductive empirical research enriches the understanding of concepts, ensures they are grounded in established research, and enhance the overall quality and impact of the results. By preserving the identities of the informants, we ensure ethical standards and participant trust. Pseudonymisation ensures privacy by replacing usernames with coded identifiers and by minimising any risk of re-identification. At the same time, additional characteristics can illustrate a comprehensive picture of the individuals building products under their own terms. We encourage researchers to consider attributes such as profession, hobby, educational background and skills in interviews that protect the identities of the informants. Ultimately, we hope the open ethos of maker communities transcends profit-driven boundaries of product innovation and offers a network of sustainable techniques and future technology to a circular economy.

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Glossary of Terms

Term	Description in the context of the article
Autonomous Product Development (APD)	Autonomous product development is a process, where individuals have autonomy to drive product creation, making independent decisions about resources, design and development methods.
New Product Development (NPD)	New product development is the process of increasing novelty in a product, by either improving its use, or solving different problems with the product.
Product	A product is an item that serves a corresponding need, particularly as the solution to a problem. With the growth of a commons-based economy, products do not necessarily need to have commercial selling value.
Product Development	In the context of this article, it is the process of designing, creating, enhancing or rebuilding complex products.
Product Innovation	Product innovation is the phenomenon of introducing novelty in the design and creation a product.
Product Innovation Outcomes (PIO)	A product innovation outcome is an instance that can lead to the introduction of something novel such as an idea, method or product. It is an enhancement of the definition as both an outcome and a process by Kahn (2018)

Ethical Statement

The research only includes interactions involving survey and interview procedures, the information obtained is recorded by the investigators in such a manner that the identity of the human subjects cannot readily be ascertained, directly or indirectly through identifiers linked to the subjects, and no children are involved in the study. Therefore, the research is exempt from ethical review according to HHS regulation 45 CFR 46.104(b)(3), and the Natural Sciences & Engineering Sciences Ethics Committee of University of Twente has issued a waiver (application nr. 251289).

CRediT authorship contribution statement

Carrielle Somers: Writing – original draft, Project administration, Methodology, Formal analysis, Data curation. **Jörg Henseler:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors hereby declare that they have no competing interests.

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Appendix A

Interview Protocol
Introductory Information

i. Personal introduction.
ii. Introduction of their products – their experience building products, experience in their specialism, experience in the community. Introduction to this Research: we are exploring the concept of product innovation in open communities. It would be helpful to get your understanding of what the span of innovation is in this community, and how the community influences how you innovate.
iii. As a maker, what specific meaning does the act of creating have for you? or what does the act of innovating mean to you?
iv. How would you describe novelty, with regards to building products? How would you describe copying, with regards to building products?
v. What would influence your choice to copy a product or build it from scratch? Are you usually faced with this choice?
vi. What is your perspective when a community member reproduces a product or project that is not original, but copied? Have you observed any specific excitement on the forum when a product is copied? What are your thoughts about this?
vii. What is your perspective when a community member reproduces a product or project that is novel, and gaining popularity? Have you observed any specific excitement? What are your thoughts about this?
viii. Can you recollect a response or reaction on the forum that changed the way you create or build the next time? Can you share an experience?
ix. How have other people's opinions (in the community) influenced how you create new products?
x. Is there work you would not share in the community? Why? Is there work you definitely share in the community? Why?

Appendix B

Prominent Quotes on Three Levels of Abstraction

First-Order Categories	Second-Order Themes	Aggregate Dimensions
	Copying **Acceptance of**	
Giving credit, where credit is due. [Accredited Copying]	I have on occasion contacted those who copy (without any modification) to complain. Taking credit for others work or not acknowledging prior work if making modifications is not good. *3D Modeler, Community A* Oh I was inspired by the maker or artist and that's why I copied their work.". …doesn't believe this is inspiration but copying, especially if it is a direct translation. *CNC Maker, Community B*	
Posting despite the maker's terms. [Copying with respect for the originator]	If they aren't making any modifications to it, I think it's in poor taste to 100% re-post it and credit the original creator. If they don't credit the original creator, that is straight up stealing and is illegal a lot of the time. *3D Modeler, Community A* If they have specified 'no derivatives' then it disappoints / annoys me that the person copying this did not respect the originators wishes. That doesn't mean they can't make a derivative themselves for their own purposes but they shouldn't post it if they goes against the creator's terms that they applied when sharing the design. *3D Modeler, Community A* As long as the community member is following the terms of the license that the original author distributed the design under that is perfectly fine with me. *3D Modeler, Community A*	
Copying for self and learning and not to be published. [Permitted copying and remixing]	If I can copy and do it better or cheaper then I will. I've never had the intent to sell anything so it's just for me. DIY Salvager, Community C Copying is not commonly frowned upon as far as i noticed but sometimes larger uncredited work gets called out. *3D Modeler, Community A* As long as they aren't claiming it as their original idea, I will commend them on their work and effort. I look at it as though they have made their own version of the original. *Woodworker, Metalist, Community C*	
	CopyingCompetence	Evolving Competence
Being able to start somewhere. [Copying as a starting point]	Initially, being able to make anything was important – especially since, he did not start with too many tools and then when he got a new place, he also had a workshop and CNC helped create art out of wood. *CNC Maker, Community B* With woodworking for example, I like to consider that what we do is already something almost 99% of people will never do or experience in any way. If you got into it by copying a design or using plans from someone, more power to them! *Woodworker, Community C* I like to see people reproduce products. Ultimately, they are doing something that a large percentage of our global population is incapable of. They are learning how the product works in order to replicate it and furthering their understanding which will in turn lead to a more rounded skill set on future projects. *DIY Salvaging, Community C*	
Experimenting with new tools and exploring the complexity [Creating competence as a foundation for originality]	Copying allows people to iterate ideas, to put their own unique spin on a product, to experiment and to learn by following a guide. I would not have gotten anywhere in life if I confined my creation to something I thought was original. *Woodworker, Metalist, Community C* I must be familar in the tools to be used. I cannot innovate in a new design software. First projects will be copies (spare parts). I must have a design goal and make some first tests. Then I need a time between (maybe working other projects). A great idea will come itself. 3D Modeler, Community A To me, remixing a preexisting model is like taking someone else's photo or digital art and modifying it. You are adding your own flare to it and learning about how to use the program at the same time. Eventually if you find you enjoy doing this, you'll likely level up and start creating from scratch. *3D Modeler, Community A*	
Copying complex or expensive work [Replicating to reduce cost and effort]	I do things for practical and cost savings reasons. If I think something can be bettered I'd look into making it. Then I determine if it's in my skillset and decide if it's worth my time to build it or just find an item similar and buy it. … I may look at making a simple copy of a very expensive industrial device. The path of least resistance is my goal. *DIY Salvaging, Community C* Often it makes sense to follow instructions, copy and do what someone else did because it requires less time, effort and planning. *Woodworker, Metalist, Community C* Do I spend a lot of time and effort trying to re-invent the way a table is most stable or sturdy? I wouldn't. I would look up the tried-and-true methods on how to build a table and see which things I would have to follow step-by-step to gain some knowledge and experience on the method of building a table. *Woodworker, Community C*	
	Innovating **Innovation Adaptiveness**	
Modifying the existing to suit a specific purpose [Meeting specific contextual needs]	I have models that serve little purpose and I have models that are supposed to be functional. The latter I create because I need something functional (like a coat hanger) but want something that also is interesting to look at. If I need something and there's no need or desire to customize it to my own tastes, I'll go out and buy it or download the already-existing model and print it. *3D Modeler, Community A* Yes, typically I like to search for other works to use as is, or modify them to meet my requirements as its easier to modify an existing design rather than start from scratch. *3D Modeler, Community A* But you can be sure I'll customize it to my own liking. Thing such as height, materials, colours, finish. Those are things I would experiment with as much as I can. *Woodworker, Community C*	
Remixing to solve problems and explore [Exploring and application for problem solving]	A large part of making things is the problem solving that comes with the task. The problem-solving opportunities are at every turn, not only how you will make something as in what steps do you need to take to make the item but also the tools you have available or lack thereof in some cases. *Woodworker, Metalist, Community C*	

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	I like some novelty, but not just for novelty's sake. I like novelty that opens up the solution space to different ways of approaching a problem. *3D Modeler and CNC Maker, Community A*	
	My 3d printer I have bought as kit (K8200). Function was been very bad, so I have changed part per part. Some materials are re-used, but it is not the same printer as before. If I would buy a perfect machine, I will not have freedom to change what I like to change. And, I have got knowledge to make more tests. *3D Modeler, Community A*	
	Innovating	Intensifying Personalisation
	Intensifying Personalised Novelty and Technique	
Starting with replicating, finishing with personalisation [Reproducing for personal preferences]	I appreciate good craftsmanship, so if someone does a really nice job of reproducing something already designed, I'm impressed. If someone does a mediocre job of reproducing something, they may have learned something or may be happy with their product, but I'm not so interested myself. *3D Modeler and CNC Maker, Community A*	
	usually my projects are a combination of "copying" some other projects and making it my own—tweaking something someone else did to make it a little more original. It is rare that thinks are exact clones of something else. *Woodworker, Metalist, Community C*	
	Personal preference, I do not want to be just copying other folk's models. I have on occasion used a model as a starting point, but the changes are drastic enough to not merit giving credit. example I used a model of a dog to make a wolf sculpt but the final was not remotely recognizable as having been derived. *3D Modeler, Community A*	
Reverse-engineering to develop personal methods [Reverse engineering for personalised techniques]	So I have reverse engineered and then tried to design my own. By doing this, I have found out a computational system to generate this in an easy way. My series …are simple derivates of this idea. *3D Modeler, Community A*	
	Before the informant was about to design the key fob for example, she looked at the gaming industry (game controllers) instead of observing the work of a key smith. That way, his own vision isn't polluted. The informant perceives that most people don't think this way, when they copy, they copy from the individual instead of being inspired by broader ideas. *CNC Maker, Community B*	
	I gather many information from communities, scientific publications, YouTube etc… but I want to design my own solutions. My purpose is to learn and build-up experience. *Robotics Machinist, Community D*	
	Acquiring Exclusivity Distinctiveness of Method and Product	
Looking around so that no one else has done this before [Adding originality by distinguishing from the method or products of others]	It feels a bit degrading to my self-esteem to just replicate something without adding any part myself. But also a feeling of obligation or maybe a mission to nurture gifts of talent and inspiration to good fruition. *3D Modeler, Community A*	
	I always like to create from scratch. Occasionally I check before starting on a design that there is nothing similar already available. If there is I seldom create my own version. I prefer to focus on new and novel things. *3D Modeler, Community A*	
	While creating he tries to avoid observing other people's work and believes that when you isolate yourself, you can come up with something cool and original. Today, novelty is almost the most important thing. *CNC Maker, Community B*	
Novelty is significant for perosnal problem solving [Personalising problem solving and creating novelty]	Everything that ever gets built can use improvements and most of these improvements are pretty straightforward and incremental. That's not a level of innovation that interests me to a great degree. I'm interested in exploring different approaches, which may not end up being practical, but the process opens up the solution space. *3D Modeler and CNC Maker, Community A*	
	In those instances, they often feature something clever that is innovative / unique in the way it has been done. That provides a sense of satisfaction that you have succeeded at creating something new and different to overcome challenges. *3D Modeler, Community A*	
	In problem solving function it (personal novelty) is key above all. Aesthetics is a fair second but novelty of the product is not. In exploration novelty is first but even so, one person's findings is just the tiniest bump standing on shoulders of giants. *3D Modeler, Community A*	
	I go for approximations that line up with my sense of taste. A lot of what I do is trial and error. Rolling with errors during the creative process is part of what makes something unique. *Woodwork Restorer, Community C*	
	Novel things are the product of replication, reflection, reproduction, revision, iteration, variation, slight modification, slight adjustments and continuous developments. *Woodworker, Metalist, Community C*	
Interest in opinion versus peer feedback [Seeking feedback from peers or self-satisfaction]	There is always a bunch of awe from inexperienced users who don't recognize that my contribution is trivial. I delete those. Others are more inspirational and subtle encouragement from peers. That's what keeps me going. *3D Modeler, Community A*	
	If I were creating a product that was intended for an audience, I would care about the audience's opinion. But I create for myself, so I don't listen to their opinions; I listen to myself. *Woodworker, Metalist, Community C*	
	but I can't remember a time when someone's reaction changed the way that I create. I know there are many people who change their process and what they build based on what will gain them more attention or will be more popular, but I don't really focus on what other people think. *Woodworker, Metalist, Community C*	
	(Other user opinions …) They're not. If I lost all my followers and nobody was liking or collecting any of my models anymore, I doubt I would change my behavior. *3D Modeler, Community A*	
	Acquiring Exclusivity - Transcendence from Personalisation	**Transcendence**
The idea transcends the maker [Idea transcends the person]	I have this fantasy that I'll design and post something that will catch people's imagination, any it'll take off with a life of its own. This pretty much never happens. *3D Modeler and CNC Maker, Community A*	

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	It's more important to see through an idea I feel is genuine to myself. Having the picture in my mind come to life. *Woodwork Restorer, Community C* Innovation is a free flowing fluidum in the universe. Sometimes it comes to me, sometimes not. If stress on the job, it will not come. If I'm riding my bicycle, or (countryside)skiing in the forest, sometimes it will come. If the previous idea is unrealized, it will not come with new ideas. I have to write down the previous idea to paper to be free for new ideas. *3D Modeler, Community A* It's not possible to create something in a vacuum, it's always a product of what you've seen and what you're influenced by. That, and there's only so many ways to make a 3DOF hexapod, so they're bound to be similar structurally no matter what. But it's less about the end result of that, they are predestined from the outset to be similar, but in the design approach, specific goals, and implementations of those ideas that can be unique and creative. *Robotics Engineer, Community D*
Novelty as an exclusive form of self-expression [Self-expression transcends making]	This led me to a kind of view on where value possibly hides, what make means, and the point of making an effort. Maybe true novelty that carries a sense of purpose or curious intent still is, for the moment, a uniquely human trait. In a time when remixing almost can be reduced to machine work, I'm drawn to express myself in the niche remaining outside. *3D Modeler, Community A* (Novelty) to create a space I want to spend time in and around. Self-expression. *Woodwork Restorer, Community C* For me the act of creating is a combination of art and invention. I find displaying and sharing my creations with others gives me gratification and inspiration to create more works. *3D Modeler, Community A*
Sharing with the community as freedom to create [Freedom to create transcends personal ownership]	It's important to me, to stay anonymous. Patents are not my way, I believe in free information flow. One of my goals could be to prevent patents by first publishing in cc license. *3D Modeler, Community A* Yes, my preference is to share all my works under an non-commercial open source license. I come from a software development background and feel that myself, and society in general has benefited significantly from idea of freely sharing information freely via open source licensing of software. By releasing my own works under open source licensing, I feel I am giving back to the community that I have benefited from as well. *3D Modeler, Community A* I would be delighted if someone asked me to reproduce my robot, providing they do not claim it as his own design. Even if I design my own robot I have many sources of inspiration and many solutions to problem were found on communities. Is-it copy or is-it the purpose of Community to share experience? *Robotics Machinist, Community D* I believe ideas never appear by a single mind, but rater is fished out of a collective pond of influences. In this view the notion to owning the rights to ideas is appalling. Things that contribute to a world that works for everyone is the reward in itself. Replicate them as needed and then go fish for more ideas to spread. *3D Modeler, Community A*

Data availability

The authors do not have permission to share data.

References

[1] E. Johnson, Rationalizing the importance of business models for sustainability transitions, in: New Business Models Conference Proceedings 2023, Maastricht University Press, 2023.

[2] A. Llorca-Ponce, G. Rius-Sorolla, F.J. Ferreiro-Seoane, Is innovation a driver of sustainability? An analysis from a spanish region, Sustainability. 13 (16) (2021) 9286.

[3] D. Maier, A. Maier, I. Aşchilean, L. Anastasiu, O. Gavriş, The relationship between innovation and sustainability: A bibliometric review of the literature, Sustainability. 12 (10) (2020) 4083.

[4] W.A. Srisathan, P. Naruetharadhol, The paradox of consumer-level open innovation collaborators in sustainable consumption transformation, Sustain. Fut. (2025), https://doi.org/10.1016/j.sftr.2025.100662.

[5] G. Adamson. *Thinking through craft*, Bloomsbury Publishing, 2019.

[6] R. Lee, *Made to remake the world: The Bronze Age tool and the 'Idea of Craft'*, in: C. Burke, S.M. Spencer-Wood (Eds.), Crafting in the World, Springer, Cham, 2019 https://doi.org/10.1007/978-3-319-65088-3_2.

[7] A. Leroi-Gourhan, La Geste et la Parole I. *Technique et Langage*, Albin Michel (1988).

[8] M.B. Schiffer. *Anthropological perspectives on technology*, University of Mexico Press, 2001.

[9] A. Singh, A. Goel, A. Chauhan, S.K. Singh, Sustainability of electronic product manufacturing through E-waste management and reverse logistics, Sustain. Fut. (2025) 100490.

[10] D. Dougherty, The maker movement, *Innov.: Technol., Govern., Globaliz.* 7 (3) (2012) 11–14.

[11] E.R. Halverson, K. Sheridan, The maker movement in education, Harv. Educ. Rev. 84 (4) (2014) 495–504.

[12] S. Willis, The maker revolution, Computer. (Long. Beach. Calif) 51 (3) (2018) 62–65.

[13] R.E. Browder, Learning in collectives: How maker spaces encourage entrepreneurship and innovation, Acad. Manag. Proc. 1 (2020) 21636, https://doi.org/10.5465/AMBPP.2020.245.

[14] T. Cooper, Slower consumption reflections on product life spans and the "throwaway society, J. Ind. Ecol. 9 (1-2) (2005) 51–67, https://doi.org/10.1162/1088198054084671.

[15] R.G. Cooper, E.J. Kleinschmidt, New products: what separates winners from losers? J. Prod. Innov. Manage. 4 (3) (1987) 169–184, https://doi.org/10.1016/0737-6782(87)90002-6.

[16] E. Danneels, The dynamics of product innovation and firm competences, Strateg. Manage J. 23 (12) (2002) 1095–1121, https://doi.org/10.1002/smj.275.

[17] K. Fursov, J. Linton, Social innovation: integrating product and user innovation, Technol. Forecast. Soc. Change 174 (2022) 121224, https://doi.org/10.1016/j.techfore.2021.121224.

[18] K Boudreau, K Lakhani, How to manage outside innovation: Competitive markets or collaborative communities? MIT Sloan Manag. Rev. 50 (4) (2009) 69–75.

[19] H. Chesbrough. *Open business models: How to thrive in the new innovation landscape*, Harvard Business Press, 2006.

[20] O. Gassmann, Opening up the innovation process: towards an agenda, R&D Manage 36 (3) (2006) 223–228.

[21] J.C. Linder, S. Jarvenpaa, T.H. Davenport, Toward an innovation sourcing strategy, MIT. Sloan. Manage Rev. (2003).

[22] M. Sawhney, E. Prandelli, Communities of creation: managing distributed innovation in turbulent markets, Calif. Manage. Rev. 42 (4) (2000) 24–54, https://doi.org/10.4018/978-1-930708-65-5.CH014.

[23] J. West, M. Bogers, Leveraging external sources of innovation: A review of research on open innovation, J. Prod. Innov. Manage. 31 (4) (2014) 814–831, https://doi.org/10.1111/jpim.12125.

[24] B. Garrette, X. Castañer, P. Dussauge, *Collaborative versus Autonomous New Product Development in the WorldWide Aircraft Industry, HEC School of Management, Paris.*

[25] A. Khurana, S.R. Rosenthal, Integrating the fuzzy front end of new product development, IEEE *Eng. Manage. Rev.* 25 (4) (1997) 35–49.

[26] H. Moon, J.L. Johnson, B.J. Mariadoss, J.B. Cullen, Supplier and customer involvement in new product development stages: implications for new product innovation outcomes, Int. J. Innov. Technol. Manage. 15 (01) (2018) 1850004.

[27] R. Nag, D.A. Gioia, From common to uncommon knowledge: foundations of firm-specific use of knowledge as a resource, Acad. Manage. J. 55 (2) (2012) 421–457, https://doi.org/10.5465/amj.2008.0352.

[28] G. Goldkuhl, S. Cronholm, Adding theoretical grounding to grounded theory: toward multi-grounded theory, Int. J. Qual. Methods 9 (2) (2010) 187–205, https://doi.org/10.1177/160940691000900205.

[29] G. Goldkuhl, S. Cronholm, M. Lind, Multi-grounded action research, Inf. Syst. e-*Bus. Manag.* 18 (2) (2020) 121–156, https://doi.org/10.1007/s10257-020-00469-1.

[30] L. Grinin, D. Baker, E. Quaedackers, A. Korotayev. *Teaching & Researching Big History: Exploring A New Scholarly Field*, Uchitel Publishing House, 2014.

[31] M. Ilyin, Emergence and advancement of basic human capacities, Linguistic Front. 3 (2) (2020) 3–20, https://doi.org/10.2478/lf-2020-0010.

[32] A. Nowell, I. Davidson. *Stone tools and the evolution of human cognition*, University Press of Colorado, 2010.

[33] V. Seow, A tradition of invention: The paradox of glorifying past technological breakthroughs, East Asian Sci. Technol. Soc.: Int. J. 16 (3) (2022) 349–366, https://doi.org/10.1080/18752160.2022.2095103.

[34] J.J. Shea. *Stone tools in the Paleolithic and Neolithic Near East: A guide*, Cambridge University Press, 2013.

[35] K.A. Bergsvik, É. David, Crafting bone tools in Mesolithic Norway: A regional eastern-related know-how, Eur. J. Archaeol. 18 (2) (2015) 190–221, https://doi.org/10.1179/1461957114Y.0000000073.

[36] A. Leroi-Gourhan, *La Geste et la Parole II. Memoire et les Rythmes*, Albin Michel (1988).

[37] J. Pelegrin, C. Karlin, P. Bodu, Chaînes opératoires: un outil pour le préhistorien, Technologie préhistorique 25 (1988) 55–62.

[38] C. D'Amico, G. Nenzioni, S. Fabris, S. Ronchi, F. Lenzi, Neolithic tools in S. Lazzaro di Savena (Bologna): a petro-archaeometric study, Rendiconti Lincei 24 (1) (2013) 23–38, https://doi.org/10.1007/s12210-012-0208-y.

[39] C. Harman. *A people's history of the world: from the Stone Age to the New Millennium*, Verso Books, 2008.

[40] B. Sass, Pre-Bronze Age and Bronze Age artefacts, in: D. Ussishkin (Ed.), The Renewed Archaeological Excavations at Lachish (1973–1994), Vol. III, Emery and Clair Yass Publications in Archaeology, Tel Aviv, 2004, pp. 1450–1524.

[41] M. Lochner, Bestattungssitten auf Gräberfeldern der mitteldonauländischen Urnenfelderkultur, Vol. 448, Verlag der Österreichischen Akademie der Wissenschaften, 2013, pp. 11–32.

[42] M. Mödlinger, P. Trebsche, Work on the cutting edge: metallographic investigation of Late Bronze Age tools in southeastern Lower Austria, Archaeol. Anthropol. Sci. 13 (7) (2021) 125, https://doi.org/10.1007/s12520-021-01378-1.

[43] M. Chaudhuri, The technique of glass making in India (1400–1800 AD), Indian J. Hist. Sci. 18 (2) (1983) 206–219.

[44] A.M. Khan, Science and technology in early medieval India, Erdem 9 (26) (1996) 717–728.

[45] G. Fehérvár, Islamic pottery 800-1400 A.D, Kunst des Orients 7 (1) (1970) 80–82.

[46] R. Volti. *Society and Technological Change*, Worth Publishers, 2009.

[47] A. Yoshio, The formation of heavy industry: One of the processes of industrialization in the Meiji Period, Dev. Econ. 3 (4) (1965) 450–470.

[48] F. Osiurak, C. Crétel, N. Uomini, C. Bryche, M. Lesourd, E. Reynaud, On the neurocognitive co-evolution of tool behavior and language: Insights from the massive redeployment framework, Topics Cogni. Sci. 13 (4) (2021) 684–707, https://doi.org/10.1111/tops.12577.

[49] N. Rogers. *Stone tools, working memory and the brain: Investigating the cognitive and neural substrates of tool-use and tool-making,* Doctoral dissertation, University of New South Wales, Sydney, 2015. https://doi.org/10.26190/unsworks/19202.

[50] L. Vandervert, The evolution of theory of mind (ToM) within the evolution of cerebellar sequence detection in stone-tool making and language: Implications for studies of higher-level cognitive functions in degenerative cerebellar atrophy, Cerebellum & Ataxias 6 (2019) 1–7, https://doi.org/10.1186/s40673-019-0101-x.

[51] E.E. Hecht, L.E. Murphy, D.A. Gutman, J.R. Votaw, D.M. Schuster, T.M. Preuss, G. A. Orban, D. Stout, L.A. Parr, Differences in neural activation for object-directed grasping in chimpanzees and humans, J. Neurosci. 33 (35) (2013) 14117–14134, https://doi.org/10.1523/JNEUROSCI.2172-13.2013.

[52] A. Iriki, O. Sakura, The neuroscience of primate intellectual evolution: natural selection and passive and intentional niche construction, Philosophical Trans. Royal Soc. B: Biol. Sci. 363 (1500) (2008) 2229–2241, https://doi.org/10.1098/rstb.2008.2274.

[53] M.B. Schiffer. *The material life of human beings: artifacts, behavior and communication*, Routledge, 1999.

[54] K. R. Alarie (2014). Early stone tool use and the evolution of human cognition. University of Massachusetts Amherst Journal, 32 (2014).

[55] N. J. Griffith, Is cognition plus technology an unbounded system? Technology, representation and culture, In I. E. Dror (Ed.) Cognitive Technologies and the Pragmatics of Cognition (2008) 127–154, doi:10.1075/bct.12.10gri.

[56] L. Malafouris, How does thinking relate to tool making? Adapt. Behav. 29 (2) (2021) 107–121, https://doi.org/10.1177/1059712320950539.

[57] P.M. Greenfield, Language, tools and brain: The ontogeny and phylogeny of hierarchically organized sequential behavior, Behav. Brain Sci. 14 (4) (1991) 531–551, https://doi.org/10.1017/S0140525X00071235.

[58] J.A. Marshall, J.R. Harron, Making learners: A framework for evaluating making in STEM education, Interdisc. J. Problem-Based Learn. 12 (2) (2018) 3–18, https://doi.org/10.7771/1541-5015.1749.

[59] K. Taylor. *Collaborative robotics, more than just working in groups: Effects of student collaboration on learning motivation, collaborative problem solving, and science process skills in robotic activities*, Doctoral Dissertation, Boise State University, 2016.

[60] S. Papert, I. Harel. *Constructionism: research reports and essays*, 1985-1990, Ablex Publishing Corporation, 1991.

[61] K.M. Frias, D. Popovich, Bridging marketing and STEM education: cross-functional teamwork for new product development, in: A. Zimmerman (Ed.), *Preparing Students for Community-Engaged Scholarship in Higher Education*, IGI Global Scientific Publishing, 2020, pp. 284–305, https://doi.org/10.4018/978-1-7998-2208-0.ch014.

[62] T. Horie, A. Inuzuka, Y. Ikawa, Managing individual autonomy to increase intrinsic motivation within a new product development organization in Japan, in: PICMET'08-2008 Portland International Conference on Management of Engineering & Technology, IEEE, 2008, pp. 1905–1910, https://doi.org/10.1109/PICMET.2008.4599809.

[63] A.L. Toombs. *Care and the construction of hacker identities, communities, and society*, Doctoral dissertation, Indiana University, 2016.

[64] W. Abbassi, A. Harmel, W. Belkahla, H. Ben Rejeb, Maker movement contribution to fighting COVID-19 pandemic: insights from Tunisian FabLabs, R&D Manag. 52 (2) (2021) 343–355, https://doi.org/10.1111/radm.12503.

[65] V. Aryan, J. Bertling, C. Liedtke, Topology, typology, and dynamics of commons-based peer production: On platforms, actors, and innovation in the maker movement, Creativity Innov. Manag. 30 (1) (2021) 63–79, https://doi.org/10.1111/caim.12392.

[66] J. Millard, M.N. Sorivelle, S. Deljanin, E. Unterfrauner, C. Voigt, Is the maker movement contributing to sustainability? Sustainability 10 (7) (2018) 2212, https://doi.org/10.3390/su10072212.

[67] J. Profili, E.L. Dubois, D. Karakitsos, L.A. Hof, Overview of the user experience for snorkeling mask designs during the COVID-19 pandemic, Healthcare 9 (2) (2021) 204, https://doi.org/10.3390/healthcare9020204.

[68] G.M. Kim, J.E. Powell, S.A. Lacey, J.A. Butkus, D.G. Smith, Current and emerging prostheses for partial hand amputation: A narrative review, PM&R 15 (3) (2023) 392–401, https://doi.org/10.1002/pmrj.12764.

[69] C. Baldwin, C. Hienerth, E. Von Hippel, How user innovations become commercial products: A theoretical investigation and case study, Res. Policy. 35 (9) (2006) 1291–1313, https://doi.org/10.1016/j.respol.2006.04.012.

[70] N. Franke, E. Von Hippel, Satisfying heterogeneous user needs via innovation toolkits: the case of Apache security software, Res. Policy. 32 (7) (2003) 1199–1215, https://doi.org/10.1016/S0048-7333(03)00049-0.

[71] C. Herstatt, E. Von Hippel, From experience: developing new product concepts via the lead user method: A case study in a "low-tech" field, J. Prod. Innov. Manage. 9 (3) (1992) 213–221, https://doi.org/10.1016/0737-6782(92)90031-7.

[72] L.B. Jeppesen, L. Frederiksen, Why do users contribute to firm-hosted user communities? The case of computer-controlled music instruments, Organiz. Sci. 17 (1) (2006) 45–63, https://doi.org/10.1287/orsc.1050.0156.

[73] C. Lettl, C. Herstatt, H.G. Gemuenden, Users' contributions to radical innovation: evidence from four cases in the field of medical equipment technology, R&D Manage. 36 (3) (2006) 251–272, https://doi.org/10.1111/j.1467-9310.2006.00431.x.

[74] D.L. Roberts, R. Palmer, M. Hughes, Innovating the product innovation process to enable co-creation, R&D Manage. 52 (3) (2022) 484–497, https://doi.org/10.1111/radm.12492.

[75] H. Demonaco, P. Oliveira, A. Torrance, C. Von Hippel, E. Von Hippel, When patients become innovators, in: R. Tiwari, S. Buse (Eds.), *Managing Innovation in a Global and Digital World*, Springer Gabler, Wiesbaden, 2020, pp. 121–129, https://doi.org/10.1007/978-3-658-27241-8_9.

[76] M. Goeldner, C. Herstatt, Are patients and relatives the better innovators? The case of medical smartphone applications, Technol. Innov. Manage. (91) (2016), https://doi.org/10.2139/ssrn.2743314.

[77] H. Habicht, P. Oliveira, V. Shcherbatiuk, User innovators: when patients set out to help themselves and end up helping many, Die Unternehmung 66 (3) (2013) 277–294.

[78] E. Lakomaa, T. Sanandaji, Exploring collective consumer innovation in health care: cases and formal modeling, Res. Policy. 50 (8) (2021) 104210, https://doi.org/10.1016/j.respol.2021.104210.

[79] S.J. Savory, Digital coherent optical receivers: algorithms and subsystems, IEEE J. Selected Top. Quant. Electron. 16 (5) (2010) 1164–1179, https://doi.org/10.1109/JSTQE.2010.2044751.

[80] R. Tabarés, H. Kuittinen, A tale of two innovation cultures: bridging the gap between makers and manufacturers, Technol. Soc. 63 (2020) 101352, https://doi.org/10.1016/j.techsoc.2020.101352.

[81] A.M. Kanstrup, P. Bertelsen, C. Nøhr, Patient innovation: an analysis of patients' designs of digital technology support for everyday living with diabetes, Health Inform. Manag. J. 44 (1) (2015) 12–20, https://doi.org/10.1177/183335831504400102.

[82] B.G. Glaser, A.L. Strauss. *The discovery of*grounded theory*: strategies for qualitative research* (grounded theory), Taylor & Francis eBooks DRM Free Collection, 1967.

[83] J.G. Wacker, A definition of theory: research guidelines for different theory-building research methods in operations management, J. Oper. Manage. 16 (4) (1998) 361–385, https://doi.org/10.1016/S0272-6963(98)00019-9.

[84] D.A. Gioia, S.D. Patvardhan, A.L. Hamilton, K.G. Corley, Organizational identity formation and change, Acad. Manag. Ann. 7 (1) (2013) 123–193, https://doi.org/10.5465/19416520.2013.762225.

[85] A. Strauss, J. Corbin. *Basics of qualitative research*, Sage Publications, 1990.

[86] Foster, C. H., Lande, M., & Jordan, S. S. (2014). An ethos of sharing in the maker community. *2014 ASEE Annual Conference & Exposition* (24-4).
[87] F. Ciulli, A. Kolk, S. Boe-Lillegraven, Circularity brokers: digital platform organizations and waste recovery in food supply chains, J. Bus. Ethics 167 (2020) 299–331, https://doi.org/10.1007/s10551-019-04160-5.
[88] Y. S. Lincoln, E. G. Guba, Newberry Park, 1985.
[89] M.Q. Patton. *Qualitative Evaluation Methods*, Sage Publications, 1980.
[90] R. Mojtahed, M.B. Nunes, J.T. Martins, A. Peng, Equipping the constructivist researcher: the combined use of semistructured interviews and decisionmaking maps, Electron. J. Bus. Res. Methods 12 (2) (2014) 87–95.
[91] G. Magnani, D. Gioia, Using the Gioia Methodology in international business and entrepreneurship research, Int. Bus. Rev. 32 (2) (2023) 102097, https://doi.org/10.1016/j.ibusrev.2022.102097.
[92] J. Peuralinna, Data Lineage in the financial sector (2024).
[93] K. Ching, E. Forti, S. Katsampes, K. Mammous, Style and quality: aesthetic innovation strategy under weak appropriability, Res. Policy. 53 (3) (2024) 104947, https://doi.org/10.1016/j.respol.2023.104947.
[94] P. Trott, A. Hoecht, Product counterfeiting, non-consensual acquisition of technology and new product development: an innovation perspective, Eur. J. Innov. Manage. 10 (1) (2007) 126–143, https://doi.org/10.1108/14601060710720582.
[95] R.W. White, Motivation reconsidered: the concept of competence, Psychol. Rev. 66 (5) (1959) 297, https://doi.org/10.1037/h0040934.
[96] K. Grant, K. Straker, C. Muller, C. Wrigley, The search for individualism: self-expression through product personalisation, Int. J. Desig. Obj. 6 (1) (2013) 17–29.
[97] H. Takeuchi, I. Nonaka, The new new product development game, Harv. Bus. Rev. 64 (1) (1986) 137–146.
[98] T.M. Amabile, R. Conti, H. Coon, J. Lazenby, M. Herron, Assessing the work environment for creativity, Acad. Manage. J. 39 (5) (1996) 1154–1184, https://doi.org/10.5465/256995.
[99] T. Dewett, Linking intrinsic motivation, risk taking, and employee creativity in an R&D environment, R&D Manage. 37 (3) (2007) 197–208, https://doi.org/10.1111/j.1467-9310.2007.00469.x.
[100] S.L. Malek, S. Sarin, C. Haon, Extrinsic rewards, intrinsic motivation, and new product development performance, J. Prod. Innov. Manage. 37 (6) (2020) 528–551, https://doi.org/10.1111/jpim.12554.
[101] T.M. Amabile, M.G. Pratt, The dynamic componential model of creativity and innovation in organizations: making progress, making meaning, Res. Organ. Behav. 36 (2016) 157–183, https://doi.org/10.1016/j.riob.2016.10.001.
[102] K.B. Kahn, Understanding innovation, Business Horizons 61 (3) (2018) 453–460, https://doi.org/10.1016/j.bushor.2018.01.011.
[103] L.M. Hero, E. Lindfors, V. Taatila, Individual Innovation Competence: A systematic review and Future research agenda, Int. *J. High. Educ.* 6 (5) (2017) 103–121, https://doi.org/10.5430/ijhe.v6n5p103.
[104] C. Santandreu-Mascarell, D. Garzon, H. Knorr, Entrepreneurial and innovative competences, are they the same? Manage. Decis. 51 (5) (2013) 1084–1095, https://doi.org/10.1108/MD-11-2012-0792.
[105] E.M. Rogers. *Diffusion of innovations*, Free Press, New York, 1962.
[106] A. Bandura, Self-efficacy: toward a unifying theory of behavioral change, Psychol. Rev. 84 (2) (1977) 191–215, https://doi.org/10.1037/0033-295X.84.2.191.
[107] R. Williams, J. Stewart, R. Slack. *Social learning in technological innovation: Experimenting with information and communication technologies*, Edward Elgar Publishing, 2005.
[108] K. Aboulnasr, O. Narasimhan, E. Blair, R. Chandy, Competitive response to radical product innovations, J. Mark. 72 (3) (2008) 94–110, https://doi.org/10.1509/JMKG.72.3.094.
[109] L.F. Lages, G. Silva, C. Styles, Relationship capabilities, quality, and innovation as determinants of export performance, J. Int. Market. 17 (4) (2009) 47–70.
[110] J. Tung, A study of product innovation on firm performance, Int. J. Organiz. Innov. (Online) 4 (3) (2012) 84.

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