A Novel Method for Visually Mapping Intellectual Property Risks and Uncertainties in Evolving Innovation Ecosystems: A Design Science Research Approach for the COVID-19 Pandemic

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***Abstract*—Prior management science literature proposes different visual methods for mapping ecosystems. These methods, however, largely lack an effective approach to visualising Intellectual Property (IP) related risks and uncertainties appearing among stakeholders as the innovation ecosystem evolves. Using the Design Science Research Methodology (DSRM), we develop a novel method that visualises loci of IP risks and uncertainties, as well as dynamics of IP ownership and usage in evolving innovation ecosystems.**

We demonstrate and evaluate the effectiveness of the new method in uncovering IP related risks and uncertainties by presenting results from applying the method to the innovation ecosystem for crisis-critical products during the COVID-19 pandemic. The currently ongoing pandemic has caused structural changes to that innovation ecosystem with new relationships being formed between incumbent manufacturers and new entrants that have rushed into that innovation ecosystem to support the upscaling of manufacturing capacities.

This paper contributes to the literature on visual methods for innovation ecosystems and provides a new method for researchers, practitioners, and policy makers to identify IP related risks and uncertainties that can arise when innovation ecosystems undergo structural changes. The method allows researchers to formulate and test new theories, as well as practitioners and policy makers to develop strategies to anticipate and mitigate IP risks and uncertainties.

***Index Terms*—Visual Mapping Methods, Innovation Ecosystems, Intellectual Property, Ecosystem Evolution, Industrial Organisation, Design Science Research Methodology, COVID-19**

I. Introduction

THE biological sciences have embraced visual mapping of ecosystems for a better understanding of dynamic processes and evolutions, as well as devising policies for their conservation. Highly cited articles in ecology point out several advantages of ecosystem visual mapping, such as the ability to predict vegetation patterns in ecosystems on the basis of mapped climate data as a driving force [1], the potential to investigate relationships and feedbacks in changing mangrove ecosystems [2], and the opportunity to reveal dynamic interrelationships between changes of human land use and ecosystem service capacity [3].

In the management and organisation sciences, several studies applied node-and-link network visualisations based on quantitative analysis and algorithms to capture complexity and temporal changes in business ecosystems [4], [5], while other research took a qualitative approach and used visual mapping methods as a means to identify boundaries and understand value exchanges in complex innovation and business ecosystems, respectively [6], [7]. Despite these efforts to analyse business and innovation ecosystems quantitatively and qualitatively, visualisation methods for effectively capturing ecosystem dynamics and evolution as a basis for theory formulation and testing, policy development and managerial advice still seem to lag behind their counterparts in the biological sciences. Moreover, considering the ever increasing prevalence of multi-technology products and the resulting need for managing inter-organisational innovation [8], [9], visual mapping methods for ecosystems in the management sciences require a particular focus on intellectual property (IP) and its governing role, such as in open innovation. To our knowledge, no visual mapping method exists to date that integrates capturing structural changes in industrial organisation and the role of IP in evolving innovation ecosystems.

In this study, we follow the nominal Design Science Research Methodology (DSRM) introduced by Peffers *et al.* [10] to develop a new visualisation method for the analysis of IP related risks and uncertainties of multiple stakeholders experiencing structural changes in industrial organisation in evolving innovation ecosystems. Our new method builds on existing innovation ecosystem research and addresses a gap in existing methods that fail to capture the intricacies of IP related dynamics in evolving innovation ecosystems. Furthermore, the new method builds on existing research in mapping business ecosystems [7] and represents an extension of a recently established Standardised Visual Ecosystem Language (SVEL) which enables the analysis of structural dynamics in evolving innovation ecosystems [11]. This paper contributes methodologically by providing researchers, practitioners, and policy makers with a new method to visually analyse IP related risks and uncertainties for stakeholders in evolving innovation ecosystems for the purposes of developing and testing new theory, formulating strategies and policy responses.

We demonstrate and evaluate the new method's utility and efficacy by applying it to visually map structural changes in industrial organisation and concomitant IP related dynamics in the rapidly evolving medical innovation ecosystem during the COVID-19 pandemic. The COVID-19 induced health crisis has caused major disruptions to ecosystems in many sectors on a global scale, including manufacturing, finance, transportation and healthcare [12]–[14]. The healthcare ecosystem is under particular pressure due to the surging demand for intensive care by the drastically increasing number of critically ill patients [15], [16] on one side and the shortage of Crisis-Critical (CC-) Products[1], that are needed by doctors, hospitals and publicly funded healthcare systems to treat patients and to protect its health care workers and intensive care capacities [17], [18] on the other side. Numerous industrial efforts to increase manufacturing capacities for CC-Products to meet the surging demand in the healthcare ecosystem emerged at the start of the pandemic[2] [19]. Tietze *et al.* [20] identify these early industrial efforts in the Crisis-Critical (CC-) Sector[3] in response to the COVID-19 induced health crisis as indicators of structural changes in industrial organisation and highlight resulting issues related to innovation governance and IP. Furthermore, they call for an IP focused analysis of the risks and uncertainties to key stakeholders during the different stages of the pandemic for the purpose of formulating appropriate innovation and IP policy responses [20]. In essence, visually mapping the rapidly evolving CC-Sector innovation ecosystem during the COVID-19 pandemic represents a highly appropriate testing environment for our new visual mapping method and particularly allows us to ascertain its efficacy in capturing IP related risks and uncertainties that accompany structural changes in industrial organisation.

In the remainder of this paper, we review the existing innovation ecosystem research of relevance, as well as visual methods for mapping business and innovation ecosystems (section II). Subsequently, we explain how we applied DSRM to design, demonstrate and evaluate our new method (section III) and describe its design elements and how they relate to its conceptual grounding (section IV). We continue with the demonstration of the new method, namely its application to map structural changes in industrial organisation and concomitant IP related risks and uncertainties in the CC-Sector innovation ecosystem during the COVID-19 pandemic that result from the entry strategy pursued by agile manufacturers with particular skills (section V). Furthermore, we discuss the evaluation of the new method based on the demonstration example against the objectives of this study (section V). Finally, we conclude with a summary of contributions, implications, and future research (section VI).

II. Background: Innovation Ecosystems and Visualisation Methods

The establishment of the ecosystem concept in the management sciences originated from Moore's [21] seminal work, which draws an analogy between the biological concepts of natural ecosystems and co-evolution of species, on one hand, and the organisation of business activities across industries and co-evolution of companies' capabilities around new innovations, on the other hand. Since then, it has gained increasing relevance in strategy, innovation and entrepreneurship research [22]–[25], and evolved from the earlier notion of business ecosystems to the more recent conceptualisation of innovation ecosystems [26].

A. *Innovation Ecosystems*

In a recent effort to add conceptual rigour to the ecosystem understanding in an innovation context, Granstrand and Holgersson [27] describe innovation ecosystems as the link between an actor's innovative performance and the evolving set of actors, activities and artefacts surrounding it, as well as the institutions and both complementary and substitute relations among them. Furthermore, Gomes *et al.* [26] emphasise a distinctive characteristic of innovation ecosystems, namely their focus on collaborative value creation, which is defined as the joint formulation and provision of innovation that represents a benefit or increased value compared to previous offerings to the consumer [28]. This typically requires the disclosure of ideas by first-generation innovators, as well as the provision of reuse or recombinative access to these ideas to second-generation innovators, coupled with some form of reward exchange between innovator generations in a process called cumulative innovation [29]. Viewing the CC-Sector as an innovation ecosystem thus provides us with an effective conceptual basis for the identification of the various actors and their respective activities, such as incumbent CC-Product manufactures and newly entering firms from outside the CC-Sector along with their respective supplier and customer networks, and the investigation of the nature of relationships among these actors and their respective activities. Furthermore, the additional conceptual consideration of artefacts in Granstrand and Holgersson's [27] most recent definition of the innovation ecosystem allows us to localise innovations by using respective underlying IP as a proxy and how they relate to actors and their activities in the ecosystem.

[1] In this paper we adopt Tietze *et al.*'s [20] definition for Crisis-Critical (CC) Products, namely the aggregate of scarce products that are relevant to the prevention, diagnosis and treatment of patients during the COVID-19 Pandemic, such as vaccines, personal protective equipment, ventilators and diagnostic test kits.

[2] Examples for these industrial efforts include GM and Ventec Life Systems jointly ramping up ventilator production [64], Dyson indigenously designing a ventilator in cooperation with the Technology Partnership [65], and 3D printer manufacturers and the maker community reverse-engineering ventilator components and face shields [56], [66].

[3] For the purposes of this study, we adopt Tietze *et al.*'s [20] definition of the Crisis-Critical (CC-) Sector, that is the collective of incumbent manufacturers of CC-Products along with actors in their respective ecosystems.

Another highly relevant property of the ecosystem conceptualisation is its ability to account for dynamic and evolving processes [27]. More specifically, Auerswald and Dani [30] conceptually derive the adaptive cycle of entrepreneurial ecosystems following their biological role model established by Holling [31], which highlights ecosystems' inherent ability to absorb strong stochastic shocks induced by agents of rapid disturbances, such as fire, storm or pest, by structural reorganisation. Adopting Auerswald and Dani's [30] analogy of the entrepreneurial ecosystem adaptive lifecycle to the innovation ecosystem concept enables us to observe how actor roles and relationships, loci of innovation and usage of underlying IP evolve as industrial organisation changes during the COVID-19 Pandemic [20].

B. *Visual Mapping of Ecosystems*

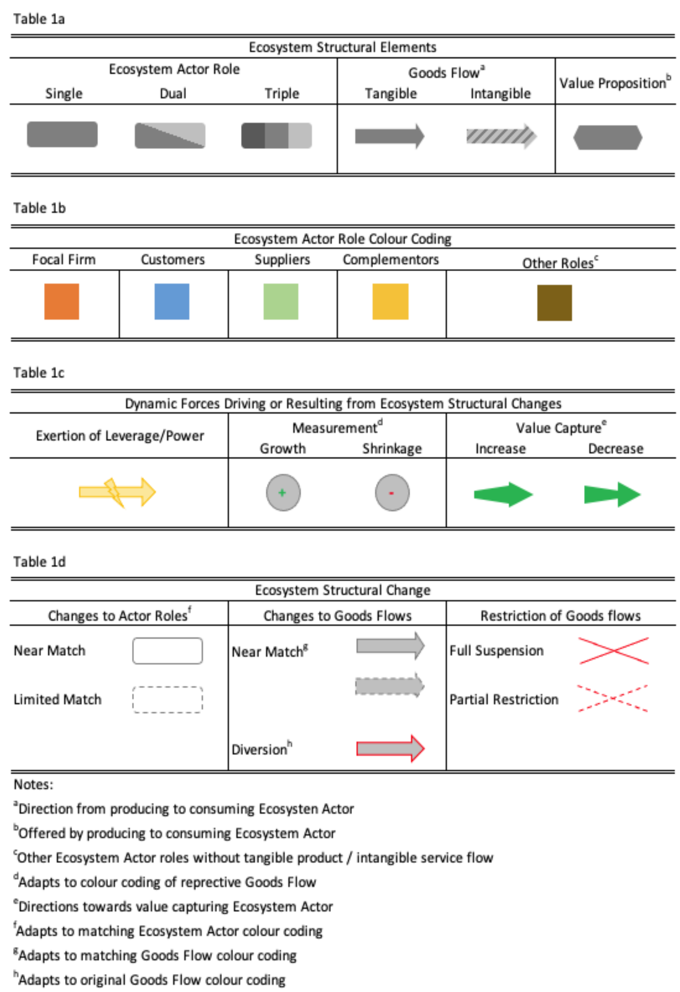
Visualisation has always played a key role in scientific progress [32] due to its ability to uncover information in empirical data that was otherwise not apparent [4]. In a recent example, So *et al.* [33] showed that network analysis and visualisation of COVID-19 cases represents a more real-time prediction method for pandemic risk than just relying on numbers daily confirmed cases alone. In innovation ecosystem related research, visual methods have enjoyed increasing popularity only recently. Examples of such recent efforts highlighting the feasibility and benefits of ecosystem visualisations for innovations and businesses include Phillips and Srai's [6] qualitative ecosystem mapping for the purpose of determining boundaries in emerging innovation ecosystems and Basole *et al.*'s [34] web-based, easy-to-use and adaptable tool providing triangulated insight into temporal ecosystem dynamics for corporate executives, respectively. Furthermore, Urmetzer *et al.* [7] conducted ecosystem value mapping to visualise value creation and capture in order to understand the complexity of a company's external value network. Due to the lack of standardisation in the emerging ecosystem visualisation methods, particularly for the qualitative analysis of innovation ecosystems, Moerchel *et al.* [11] built on Urmetzer *et al.*'s [7] ecosystem value mapping and developed a standardised visual mapping method for capturing dynamic co-evolutionary processes in evolving innovation ecosystems, namely the Standardised Visual Ecosystem Language (SVEL), which we briefly present in the next section.

Despite all previous efforts to develop visual approaches to the qualitative and quantitative analysis of ecosystems, a gap remains in the method 'toolbox' for capturing and analysing IP related risks and uncertainties that are concomitant with structural changes in industrial organisation in evolving innovation ecosystems. The rapidly changing CC-Sector innovation ecosystem during the COVID-19 pandemic is a topical case in point, in which researchers, practitioners and policy makers would benefit from an effective visual method that allows them to delineate the complexities of the rapidly unfolding structural changes in industrial organisation and the concomitant IP risks and uncertainties. This led us to pose the following research question: *How can loci of innovation, ownership and usage of the underlying IP be visually represented in order to capture innovation and IP related dynamics in conjunction with changing industrial organisation in evolving innovation ecosystems?* To address this methodological gap, we build on Moerchel *et al.* [11] standardised approach to visualising innovation ecosystems dynamics and extend their SVEL to additionally capture innovation and IP related dynamics.

C. *Standardised Visual Ecosystem Language*

Moerchel *et al.*'s [11] SVEL provides the methodological basis and enables researchers, practitioners and policy makers to visually map structural changes in evolving innovation ecosystems in a standardised fashion. At the top level SVEL consists of a defined set of symbols, labels and colour scheme, collectively denoted as external representations [35], which are grouped in three clusters (see Table 1): (i) structural elements, (ii) dynamic forces and effects and (iii) structural changes.

Table 1: Summary of the SVEL from Moerchel et al. [11]



1) Structural Elements

The formulation and external representation of structural elements in the ecosystem was informed by Adner and Kapoor's [24] generic ecosystem framework, which lists actors along with their roles and position, inputs/outputs among actors and value creation as essential ingredients. These are represented by the ecosystem actor role, goods flow and value proposition symbols in the SVEL (see Table 1a), respectively, whereas colour coding is used to distinguish among different actor roles (see Table 1b). Particularly inspired by Adner's [36] structuralist approach to ecosystems, SVEL is designed to focus only on those actors, roles and inputs/outputs that are essential for the formulation and delivery of a value proposition to customers, namely the focal firm, suppliers and complementors along with their respective products, component inputs and complementing offers. In addition, during SVEL development Moerchel *et al.* [11] determined that an ecosystem actor can occupy a combination of multiple roles concurrently. For example, an actor can be a supplier providing components and subassemblies for integration into a product by the focal firm in the innovation ecosystem, while at the same time providing complementary products and/or services directly to customers for downstream bundling with the focal firm's product for further value enhancement.

2) Dynamic Forces and Effects

Dynamic forces and effects are external representations devised by Moerchel *et al.* [11] in order to either capture endogenous dynamic effects on the relationships among actors that result from the ecosystem's evolution or to map the exogenous forces triggering phase changes in an ecosystem's adaptive life cycle [30]. The standardised SVEL representations of the dynamic forces and effects cluster (see Table 1c) contain exertion of leverage or power by one ecosystem actor on another, the measurement of goods flows (growth or shrinkage), and changes in economic value capture (increase or decrease) by one ecosystem actor resulting from another actor's change in valuation of the respective input [28].

3) Structural Changes

The external representations of ecosystem structural changes in Moerchel *et al.*'s [11] SVEL were inspired by Auerswald and Dani's [30] notion of the ecosystem adaptive cycle and particularly the phases of release and reorganisation that are typically triggered by exogenous forces, such as ecosystem external disturbance, and endogenous dynamics. Moerchel *et al.* [11] identified that these are best captured by changes to actor roles, changes to goods flows, and restriction of goods flows in an innovation ecosystem (see Table 1d). The changes to actor roles could be near match or limited match depending on the degree to which an existing or newly emerging/entering actor in the innovation ecosystem adopts the role of another incumbent actor. The symbols representing changes to goods flows indicate the emergence of new relationships by highlighting either new goods flows that match existing ones or diversions of existing goods flows as the innovation ecosystem evolves. Finally, the representations of goods flow restrictions highlight changes in established relationships between ecosystem actors that typically accompany changes to goods flows and are characterised as being either a full suspension or partial restriction of the existing goods flows.

III. Research Approach

We applied the Design Science Research Methodology (DSRM) in order to develop the new visualisation method for the sought purpose of capturing and mapping innovation and IP related dynamics in an evolving innovation ecosystem. The DSRM was deemed as a highly effective approach for the goals of this study because it focuses on the solution of relevant and identified problems, leads to the design and development of innovative and purposeful artefacts, including methods, that are founded in existing theory, and allows their evaluation against

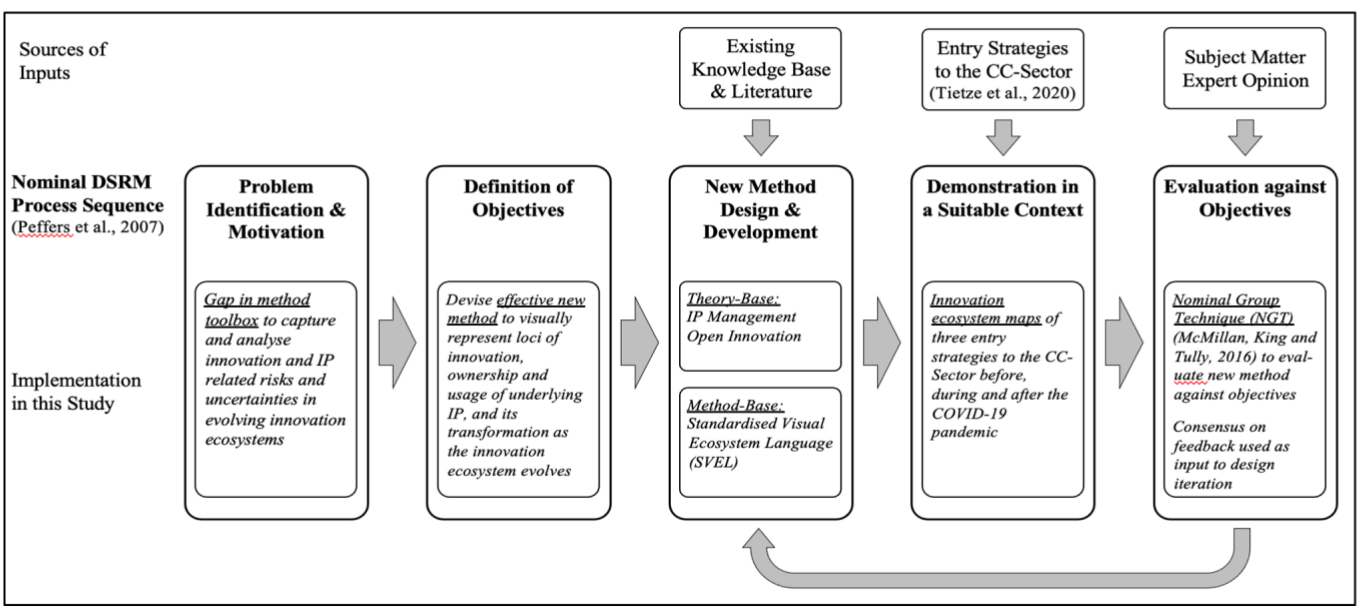


Figure 1 Overview of DSRM for the design, demonstration, and evaluation of the new method

appropriate metrics both quantitatively or qualitatively [37]. More specifically, we followed the nominal DSRM process model proposed by Peffers *et al.* [10], which is synthesised into six steps derived from literature in the design-science research paradigm: (i) problem identification and motivation, (ii) definition of objectives, (iii) artefact (i.e. method) design and development, (iv) demonstration in a suitable context, and (v) evaluation against appropriate performance metrics. In addition, the nominal DSRM process stipulates effective communication to the target audience at the end. Several studies highlight the effectiveness of DSRM in the design, development, and evaluation of new methods for researchers and practitioners in the fields of information systems and business process modelling [38]–[40].

As summarised in Figure 1, we accomplished each step of the nominal DSRM process model for our new method to capture and map innovation and IP related dynamics in an evolving innovation ecosystem:

1) Problem Identification and Motivation

The identification of and motivation for solving a relevant business or research problem [37] was already addressed in sections I and II and can be summarised as a gap in the method 'toolbox' of researchers, practitioners, and policy makers for capturing and analysing IP related risks and uncertainties in changing industrial contexts.

2) Definition of Objectives

The objectives were derived qualitatively in the form of the new method's desired functionality and architecture [10] in section II, namely to visually represent loci of innovation, to capture ownership and usage of underlying IP, and to map its transformation over time in evolving innovation ecosystems.

3) New Method Design and Development

The design and development of the new method was conceptually grounded in prior literature on visual mapping of ecosystems, open innovation, and strategic IP management. Using this existing knowledge base as a starting point ensured rigour in our new method's design and development process [37]. More specifically, we employed Moerchel *et al.*'s [11] previously described SVEL method for the standardised visual mapping of static structure, structural changes, and dynamic forces and effects in evolving innovation ecosystems as a basis and extended it with new external representations capturing established IP typologies [41], [42]. The integration of IP typologies with the existing SVEL innovation ecosystem terminology was informed by theory on the role of IP in collaborative and open innovation [43]–[45] and additionally guided by the notion that IP rights constitute a contractual infrastructure for the trade of ideas and inventions among actors engaged in open innovation [9].

4) Demonstration in a Suitable Context

To demonstrate the utility of our new visualisation method and to prove its efficacy in capturing IP related dynamics in an evolving innovation ecosystem, we applied it to visually map the changing innovation ecosystem and underlying IP dynamics in the CC-Sector during the unfolding COVID-19 pandemic. As stated previously, this context was deemed highly appropriate for demonstrating the new method's utility because the CC-Sector experiences structural changes in industrial organisation causing incumbent actors and new entrants to encounter risks and uncertainties related to innovation governance and IP [20]. The new visualisation method was applied to create innovation ecosystem maps of the CC-Sector covering a total three strategies pursued by industrial new entrants that were identified by Tietze *et al.* [20], as well as the three temporal phases of the COVID-19 pandemic, namely pre-pandemic, pandemic and post-pandemic [46].

For the purposes of fully demonstrating our new method and explicitly describing its functionality, we focus on one of the three entry strategy scenarios by an industrial new entrant identified by Tietze *et al.* [20] at the start of the COVID-19 pandemic, namely agile manufacturers with particular skills insouciantly adopting incumbent CC-Product designs and features. We chose this scenario as a demonstration example because it clearly exemplifies the new method's features that enable it to visualise loci of innovation, ownership and usage of the underlying IP and IP dynamics in conjunction with changing industrial organisation in evolving innovation ecosystems. At the same time, our choice of demonstration example avoids distractions caused by the more complex IP specific interdependencies and dynamic mechanisms that are inherent in the remaining entry strategy scenarios identified by Tietze *et al.* [20], but which our new method still was able to visualise as shown by Moerchel *et al.*'s [46] all-encompassing analysis of the medical innovation ecosystem during the COVID-19 pandemic.

Table 2: Composition of NGT panel including members' affiliation, areas of expertise and sector

NGT Member	1[a]	2	3	4	5	6
Affiliation[b]						
Academic	x	x	x	x	x	x
Industry	x					
Areas of Expertise						
Artificial intelligence				x	x	
Biotechnology and bioeconomic policy						x
Corportate strategy			x			
Economics of IP		x	x	x	x	
IP analytics and IP intelligence					x	
Negotation of purchasing and licensing contracts	x					
Open IP strategies and IP pledges		x	x	x		x
Strategic decision making					x	
Technology, Innovation and IP management	x	x	x	x	x	
Technology licensing		x	x			x
Sector						
Aerospace MRO	x					
Biotechnology and bioeconomy		x		x		x
Economics		x	x			
Manufacturing and management	x	x	x	x	x	

Notes:

[a] NGT Member 1 was nominated as the facilitator of the NGT process

[b] The table is arranged in alphabetical order of headings and sub-headings

5) Evaluation against Objectives

The evaluation of newly designed artefacts in the design-science research paradigm relies on established methodologies, whereas the construction of detailed scenarios for the collection of appropriate empirical evidence is recommended in the case of particularly innovative solutions [10], [37]. To this effect, we utilised the Nominal Group Technique (NGT)[4] to gather feedback from an interdisciplinary panel of subject matter experts (the NGT panel) on the demonstration of our new method in the creation of visual maps of the entry strategy scenario in the CC-Sector before, during and after the COVID-19 pandemic. The composition of the NGT panel, which is summarised in Table 2 along with affiliations, areas of expertise and sector of each NGT member, combines experts with relevant knowledge [47] in the analysis of IP related risks and uncertainties in the CC-Sector.

The scope of the qualitative evaluation by the NGT panel covered both evaluating the completeness of the innovation ecosystem maps generated by using our new method to capture each phase in the evolution of the CC-Sector innovation ecosystem of the selected demonstration example and the functionality as well as efficacy of the new method in visually representing IP related dynamics. The following questions served as the guideline for the qualitative review by the NGT panel: How well are loci of innovation visually represented? How accurately are ownership and usage of underlying IP captured? How intuitively is the transformation of IP ownership and usage visualised as the innovation ecosystem evolves during the COVID-19 pandemic? The feedback on which the NGT panel reached consensus was then used to iterate both the design and development step in order to improve the new method with respect to the documented objectives of visually representing loci of innovation and capturing IP related dynamics in an evolving innovation ecosystem [10] and the innovation ecosystem maps capturing the CC-Sector evolution in the demonstration example.

As indicated in the description of the evaluation step and as illustrated in Figure 1, we iterated the design of our new method based on the consensus reached by the NGT panel during the evaluation of the innovation ecosystem maps of the CC-Sector during the COVID-19 pandemic. Table 3 summarises the evolution of our new method from the initial design (i.e. Version 0), which was conceptually founded in SVEL and prior literature on IP typologies and its role in collaborative open innovation, to the final design (i.e. version 2), which was validated against qualitative performance metrics. To ensure internal validity [48] of our new method's demonstration and evaluation in the innovation ecosystem during the COVID-19 pandemic, the final versions of the innovation ecosystem maps, namely those that were created using the final design of the SVEL and IP specific extension, were ultimately verified with empirical evidence from the secondary data on actual examples of industrial new entrants and their respective strategies to enter the CC-Sector.

Table 3: Evolution of new method (SVEL and IP extension) during DSRM process

Version	Main / Added Features	Reasons for Changes
0	Method Basis: SVEL external representations consisting of - structural elements - dynamic forces and effects - structural changes Method Extension: new external representations for IP in open innovation: - formal/informal IP dichotomy [41, 42] - foreground/background IP [44] - 3rd party IP usage [50]	Version 0 represents the initial design of the IP specific extension of and integration with SVEL; it was designed to meet the objectives of the study: - to map loci of innovation - to capture ownership and usage of underlying IP - to visually represent IP dynamics concomitant with innovation ecosystem evolution
1	Added colour coding to higligt the mode of *Third Party IP* usage: [44, 50] - authorised - unauthorised - public access Added representation of *Sideground IP* as an existing IP type relevant in open innovation	Version 1 includes added features that specify whether the usage of *Third Party IP* by an ecosystem actor is authorised via a licensing contract between the owner and the user of the IP artefact Representation for *Sideground IP* was added as an IP type to fully capture the IP types already defined in received literature on IP in the open innovation paradigm [44]
2	Introduced representation of *Paraground IP* as a new IP type relevant in open innovation Introduced *IP Spatial* and *Temporal Identifiers* as additional lables for each IP symbol in the innovation ecosystem	Version 2 introduces *Paraground IP* as a new IP type because existing IP types in received literature on IP in open innovation were insufficient to address the emerging concept in the demonstration example in the CC-Sector innovation ecosystem during the COVID-19 pandemic; the addition of the new IP type was appraised and endorsed by the NGT panel The *IP Spatial* and *Temporal Identifiers* were deemed necessary to facilitate tracing the transformation of IP types and changes in IP ownership and usage as the innovation ecosystem evolves over time

IV. VISUALISATION METHOD FOR CAPTURING IP DYNAMICS

This section presents the new visualisation method for the analysis of IP related risks and uncertainties of multiple stakeholders experiencing structural changes in industrial organisation in evolving innovation ecosystems. It is a modular extension of the existing SVEL method by Moerchel *et al.* [11] and integrates a new set of external representations that specifically capture innovation and IP related dynamics. Our new visualisation method is appropriately informed by established IP typologies and their governing role in collaborative and open innovation as explained below. In summary, the new set of IP specific external representations can be grouped in three clusters (see Table 4): (i) types of IP, (ii) IP ownership and usage, and (iii) IP dynamics.

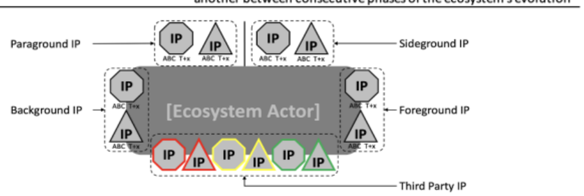
[4] NGT represents a highly structured, direct interaction, and consensus reaching procedure involving smaller groups of subject matter experts, which typically involves the following steps: silent generation, round-robin, clarification and voting [47], [67], [68]. It was chosen for evaluating our new method because of its proven capability to achieve more accurate judgement about future scenarios in the face of uncertainty, as is the case with the demonstration of our new method to the CC-Sector in the ongoing COVID-19 pandemic, compared to statistically aggregated independent judgement, such as questionnaires [69]. Furthermore, the NGT method has been shown to be capable of being integrated with other methods to solve relevant business problems [70] and has previously been applied as an evaluation tool in the education context [71].

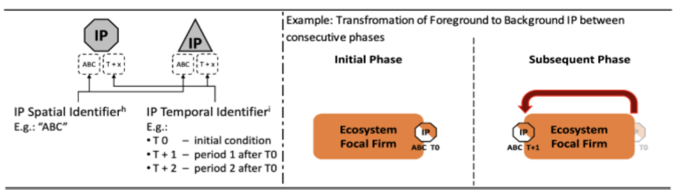
1) Types of IP

In order to devise new external representations for IP in the innovation ecosystem, first and foremost a distinction between two forms of IP is introduced, namely formal IP represented as octagons and informal IP depicted as triangles (see top section of Table 4). While formal IP is typically registered with governmental agencies and therefore public, legally protected and exclusive to the inventor, informal IP tends to be unobservable by other actors and protected by alternative means [42]. Examples of formal IP typically comprise patents, trademarks, design rights and copyrights, whereas informal IP typically consists of trade-secrets, complexity and lead-time [41]. While Hall *et al.* [41] uncovered empirically that firms prefer informal IP over formal IP to protect their innovations, Holgersson and Granstrand [49] confirmed on the basis of survey evidence that technology firms seek formal protection, and patents in particular, to protect their invention, to prevent competitors' access and to secure a freedom-to-operate.

Table 4: Details of IP Extension to SVEL showing IP specific external representations and their integration with SVEL

External Representation	Nomenclature[a]	Description
	Formal IP[b,c]	IP that is public and exclusive to the innovator (usually for a limited time)[d]
	Informal IP[b,c]	Intellectual Property that is not observable by other actors[e]
	Unauthorised IP Access	IP used by the actor to which it is attached without any licensing agreements in place with the legal IP owner
	Public Access to Expired IP	IP used by the actor to which it is attached and for which the exclusive rights of the legal owner have expired or underlying knowledge advantage has become public
	Authorised IP Access	IP used by the actor to which it is attached under a license agreement with the legal IP owner
	IP Access[f]	Provision of access to IP by the Ecosystem Actor owning the IP to another Ecosystem Actor through licensing
	IP Transformation[g]	Transformation of individual IP artefacts from one classification to another between consecutive phases of the ecosystem's evolution





Notes:

[a]IP stands for Intellectual Property

[b]The colour of the IP symbol adapts to the colour coding of the inventor Ecosystem Actor Role

[c]Dashed borders represent complementary IP invented outside of the innovation ecosystem being visualised

[d]List of formal IP includes patents, trademarks, design rights, copyrights (Bonakdar et al., 2017)

[e]List of informal IP includes trade secrets, complexity, lead-time (Bonakdar et al., 2017)

[f]Adapts shaded Colour Coding of origin Ecosystem Actor Role

[g]IP transfromation can involve a transfer of ownership

[h]Unique three-letter code label for individual IP artefact; does not change over time

[i]Counts the number of discrete intervals of each IP artefact's existence since conception

2) IP Ownership and Usage

In order to visually capture the spatial or organisational dimension of IP dynamics in evolving innovation ecosystems, namely transfer of IP ownership between actors and changes to usage (e.g., through licensing contracts) by actors of IP belonging to other (i.e., third party) actors, five groups of IP are distinguished, namely (a) Third Party IP, (b) Background IP, (c) Paraground IP, (d) Sideground IP and (e) Foreground IP. These IP groups are visually integrated with the existing SVEL by positioning IP symbols denoted by octagons for formal IP and triangles for informal IP, along the four edges of the external representation for the ecosystem actor role (see middle section of Table 4).

A. Third Party IP

Third Party IP is the IP owned by another actor (i.e. a third party). It is located along the bottom edge of the ecosystem actor role symbol representing the actor that is building on the IP during the temporal phase being visualised in the respective innovation ecosystem map. The colour-coded frames of the IP symbols indicate whether access to this IP is authorised through licensing (green), unauthorised due to lack of licensing (red) or publicly accessible due to an expired exclusive IP right, such as an invalidated patent [50] (yellow).

B. Background IP

Background IP represents IP that is either relevant (solid border) or complementary (dashed border) to the innovation ecosystem context being visually mapped and was previously developed by first-generation innovators in a temporal phase prior to the one that is visualised in the respective innovation ecosystem map [29], [44]. Background IP sits along the left edge of the ecosystem actor role symbol and is owned by the actor role to which it is attached.

C. Paraground IP

Paraground IP[5] denotes IP that is independently conceived by the ecosystem actor role to which it is attached, namely the second-generation innovator, during the temporal phase that is visualised in the respective innovation ecosystem map, while building on Third Party IP that was previously developed and is still owned by other non-collaborating ecosystem actor roles or first-generation innovators [29]. The fact that Paraground IP is conceived outside of any collaboration between first- and second-generation innovators also means that formal contractual arrangements, such as licensing agreements, ensuring authorised access to the respective Third Party IP are omitted and that proper freedom-to-operate is not established by the second-generation innovator [43]. Paraground IP is located on the left half of the top edge of the ecosystem actor role symbol and is owned by the actor role to which it is attached.

D. Sideground IP

Sideground IP is also independently developed by the ecosystem actor role to which it is attached, namely second-generation innovators, during the temporal phase that is visualised in the respective innovation ecosystem map, but it builds on Third Party IP that is owned by collaborating ecosystem actor roles or first-generation innovators. Thus, in contrast to Paraground IP, a collaboration agreement is in place

[5] Paraground IP is a new IP classification that resulted from the demonstration and evaluation of our new method in the CC-Sector innovation ecosystem. After close examination, consensus was reached by the NGT panel during the evaluation step of the DSRM process that existing IP classifications are not sufficient to capture this IP phenomenon. Further details are provided in the new method's evaluation in section V.

between first- and second-generation innovators meaning that formal contractual arrangements, such as licensing agreements, are typically in place and that proper freedom-to-operate is established by the second-generation innovator [29], [43] in contrast to Paraground IP. Sideground IP is positioned alongside Paraground IP along the top edge of the ecosystem actor role symbol, but on the right half, and is owned by the actor role to which it is attached.

E. Foreground IP

Foreground IP refers to IP that is jointly developed by at least two ecosystem actor roles in collaboration during the temporal phase that is visualised in the respective innovation ecosystem map [44] and, thus, could potentially be also jointly or co-owned by the collaborating ecosystem actor roles, particularly when the collaboration is informal and joint research is on a small scale [51], [52]. Foreground IP is positioned along the right edge of the ecosystem actor role symbol.

In addition to the classification of IP specific external representations above, a diagonally striped, red arrow (see top section of Table 4) represents the provision of access to IP owned by one ecosystem actor role to another by way of IP specific contractual infrastructure such as licensing [9].

3) IP Dynamics

Dynamics of IP refer to the emergence of newly conceived IP, transformations in the classification from one group of IP to another and changes in IP ownership or usage as structural changes in industrial organisation unfold in the innovation ecosystem over time. In order to effectively track and trace these IP dynamics, each IP symbol is equipped with a (a) Spatial Identifier and a (b) Temporal Identifier (see bottom section of Table 4). These external representations facilitate capturing the coevolution of IP artefacts and industrial organisation at discrete time intervals of the innovation ecosystem evolutionary process.

A. Spatial Identifier

The *Spatial Identifier* helps to trace the position of each IP artefact in the industrial organisation during the innovation ecosystem's evolutionary process. The Spatial Identifier is a label comprising a three-letter combination, which is unique to each IP artefact, does not change with time and is located just underneath the respective IP symbol (also see example in the right of bottom section of Table 4). By comparing the locations of an IP artefact with a specific three-letter combination, such as "ABC", in visual maps of subsequent discrete intervals (i.e. across a phase change), any transformation in its classification, or changes in ownership or usage of the IP artefact labelled "ABC" can be analysed.

B. Temporal Identifier

The *Temporal Identifier* counts the number of discrete time intervals of the ecosystem evolutionary process during which the respective IP artefact existed since conception, thus effectively measuring its age. It is a unique label comprising the letter "T" along with the symbol "+" and the respective numerical count "1, 2, 3, etc." representing the number of cumulative discrete intervals, whereas "T0" marks the interval of conception. It is placed alongside the Spatial Identifier just below the respective IP symbol (also see example on the right of bottom section of Table 4). For example, when an IP artefact is conceived in a given phase of the innovation ecosystem evolutionary process, it would be labelled using "T0" as the Temporal Identifier in the respective visual map. In the visual map of the subsequent phase the Temporal Identifier for the same IP artefact would change to "T+1".

In addition to the Spatial and Temporal Identifier, a U-shaped, dark-red arrow (see top section of Table 4) represents the transformation of a specific IP from one classification to another, such as the transformation of Foreground IP to Background IP when transitioning from one phase to a subsequent phase in the innovation ecosystem evolution [44] (also see example in the right of bottom section of Table 4). This IP classification transformation could additionally entail a transfer of ownership of IP from one ecosystem actor role to another depending on the specific scenario being visually mapped in the innovation ecosystem.

V. Demonstration and Evaluation

A. Demonstration of the Visualisation Method for IP Dynamics to the CC-Sector during the COVID-19 Pandemic

This section presents the demonstration of our new visualisation method. The goal is to validate its functionality in capturing and analysing loci of innovation and IP related risks and uncertainties that accompany structural changes in industrial organisation in evolving innovation ecosystems. For that purpose, we show and describe a selection of visual maps that were created using the new visualisation method [46] to capture entry strategies pursued by industrial firms entering the CC-Sector during the global health crisis identified by Tietze *et al.* [20]. More specifically, the entry strategy scenario serving as the demonstration example in this study was previously characterised by Tietze *et al.* [20] as agile manufacturers with particular and complementary skills to the CC-Sector insouciantly adopting features of incumbent firms' CC-Products by copying or reverse engineering without conducting a proper freedom-to-operate analysis. Furthermore, the new visualisation method was applied to all three phases of the COVID-19 induced health crisis, namely the pre-pandemic, pandemic, and post-pandemic phases, to particularly demonstrate its functionality in capturing IP related dynamics, such as transformation of IP ownership and usage, as the CC-Sector evolves. The consecutive phase changes among these temporally discrete intervals are marked by a dramatic surge in demand for CC-Products at the start of COVID-19 induced health crisis and a continuous drop at the end, both of which represent an exogenous force triggering changes in structural organisation within the CC-Sector innovation ecosystem.

Application of the new visualisation method to the pre-pandemic CC-Sector innovation ecosystem reveals the visual map shown in Figure 2. It represents *Incumbent CC-Product Manufacturers* as focal firms of the CC-Sector innovation ecosystem (see centre of Figure 2) because they bundle components into CC-Products [24] and highlights the representation of their endogenously developed innovations and IP in the form of the formal and informal IP symbols that are attached to the focal ecosystem actor role symbol and labelled "*INC T0*" (see centre of Figure 2). These IP external representations capture product specification and manufacturing process information, for which incumbent firms previously either sought legal rights, thus building a portfolio of formal IP, or used alternative means of protection in the form of informal IP [53]. As this IP was developed during the process of CC-Product development prior to the start of a COVID-19 induced crisis, this IP forms the background crisis-critical IP, or background IP in the terms of the new modular IP specific extension, that is owned by incumbent firms [20] and is therefore attached to the left-hand edge of the *Incumbent CC-Product Manufacturers*' actor role symbol. Furthermore, the right-hand half of Figure 2 illustrates that CC-Products, such as Personal Protective Equipment (PPE), ventilators or drugs [54], are offered to diverse customer groups, namely *Patients*, *Publicly Funded Healthcare Systems* or *Private Hospitals/Doctors*, by incumbent firms as a customised value proposition.

The visual map of the pandemic phase in Figure 3 captures the onset of structural changes in industrial organisation in the CC-Sector, namely the emergence of newly entering industrial firms represented by the new ecosystem actor role *Agile Manufacturers with Particular Skills* (see top centre of Figure 3), that is triggered by the surge in demand for CC-Products at the start of pandemic. These new entrant firms introduce and start manufacturing CC-Products that adopt only essential features of incumbent firms' CC-Product. This is due to their relatively small size and limited resources [20], whereas these limited matching CC-Products nevertheless meet minimally clinically acceptable specifications [55]. By offering this minimal viable CC-Product to *Patients*, as well as *Private Hospitals/Doctors* concurrently to original CC-Product by incumbent manufacturers, this group of new entrant firms supports the effort to meet the surge in demand at the start of the pandemic phase on a local or regional scale [56]. Furthermore, these new entrants potentially introduce frugal innovations to the CC-Sector, which is captured by the informal Paraground IP symbol labelled "*ADP T0*" at the top left of the new entrant ecosystem actor symbol (see enlarged view on the left-hand side of Figure 3). This newly conceived IP is classified as Paraground IP because contractual infrastructure, such as licensing, authorising new entrants to adopt incumbents' CC-Product features and granting access to inherent background IP owned by incumbent firms is missing. Enabled by our new visual method, this unauthorised access is captured by the Third Party IP symbol highlighted by a red frame and labelled "*INC T+1*" that is attached along the bottom edge of the newly entering *Agile Manufacturers with Particular Skills* ecosystem actor role symbol (see top of enlarged view in Figure 3).

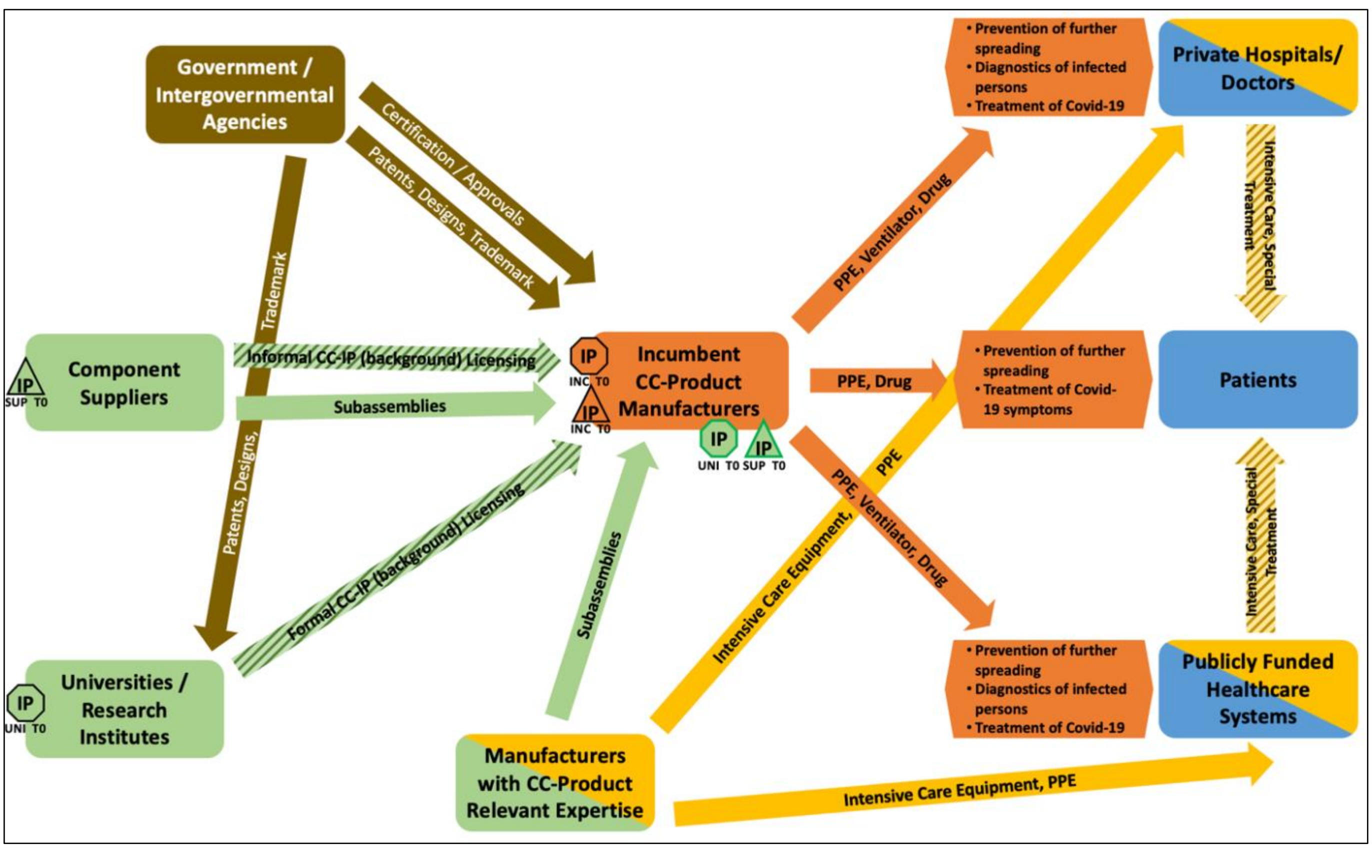


Figure 2 Innovation ecosystem map of pre-pandemic CC-Sector created using new visualisation method for capturing IP dynamics [46]

The map of the post-pandemic phase of the CC-Sector innovation ecosystem in Figure 4 highlights a potential response option by incumbent firms after the COVID-19 pandemic terminates and the demand for CC-Products decreases towards pre-pandemic levels. As highlighted in the enlarged view on the left side of Figure 4, *Incumbent CC-Product Manufacturers* could choose to respond adversely and aggressively by filing an infringement claim against newly entered *Agile Manufacturers with Particular Skills* that insouciantly adopted incumbent CC-Product features for unauthorised usage of its background IP. For example, volunteer engineers in Italy were threatened to be sued for reverse-engineering and 3D-printing of valve components, which can be vital for treating critically ill COVID-19 patients in hospitals but were in short supply, without permission by the incumbent manufacturer [57]. Furthermore, by not having conducted a proper freedom-to-operate analysis prior to reverse engineering incumbent firms' CC-Products at the start of the pandemic phase, new entrant firms could have exposed themselves to such litigation by incumbent firms, potentially resulting in having to compensate the latter for lost profits or reasonable royalties [58, p. 120]. Incumbent firms' option to additionally file an injunction could also stop new entrant firms from committing any further infringement permanently [58, p. 123], thus fully suspending their supply of minimal viable CC-Products to various customer groups and forcing their exit from the CC-Sector. This is captured by the omission of the Third-Party IP symbol labelled "*INC T+1*" from the *Agile Manufacturers with Particular Skills* ecosystem actor symbol see enlarged view in Figure 4), as well as the red crosses applied to the goods flow arrows pointing from the new entrant actor symbol to the *Patients* and *Private Hospitals/Doctors* actor symbols (see top right-hand section of Figure 4).

B. Evaluation of the New Visualisation Method for IP Dynamics

By demonstrating our new visualisation method by means of the CC-Sector during the COVID-19 pandemic, we show its functionality and effectiveness with regards to capturing innovation and IP dynamics that accompany structural changes in industrial organisation in an evolving innovation ecosystem. More specifically, the demonstration example focusing on agile manufacturers entering the CC-Sector and introducing frugal innovations in the form of minimal viable CC-Products exemplifies the ability of the new visualisation method to locate Background IP developed and owned by incumbent firms prior to the pandemic, to capture the emergence of Paraground IP developed by new entrant firms at the start of the pandemic, and to trace the involved unauthorised access to incumbents' background IP by new entrants, which acts as a proxy for insouciantly adopting features of incumbent CC-Products. On one hand, this visual mapping of IP related dynamics enables IP management and strategy practitioners at new entrant and incumbent firms to take appropriate action addressing the risk of litigation and the potential of gaining compensation or access to new entrants' paraground IP, respectively. On the other hand, policy makers can benefit from these insights by using them as a basis for the formulation of innovation and IP policies that

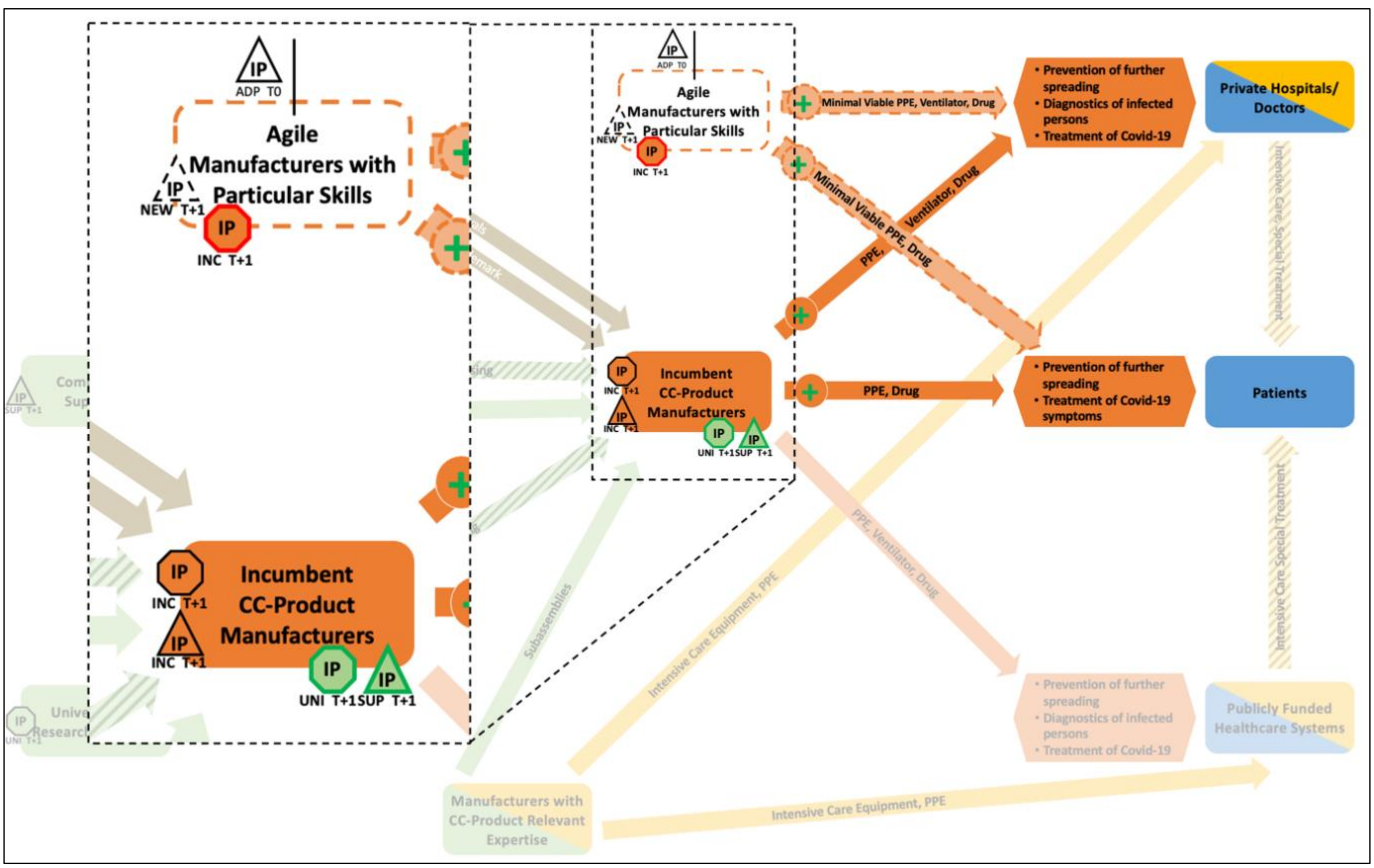


Figure 3 Innovation ecosystem map of pandemic CC-Sector created using new visualisation method for capturing IP dynamics. [46]

aim for incentivising incumbent firms to share and support new entrants to gain access to background IP underlying CC-Products, thus expediting concerted efforts in response to crises.

The demonstration example also shows that the application of the new visual method offers IP management practitioners with enhanced transparency of the loci of innovation, as well as ownership and usage of the underlying IP as the encompassing innovation ecosystem evolves. The NGT panel conducting the evaluation of the new method agreed that this enhanced transparency and awareness enables IP strategists, particularly at incumbent firms, to reflect on whether the potential value of gaining access to new entrants' frugal innovation, which is visually captured in the form of Paraground IP, outweighs the benefits of litigation, namely damage compensation by the infringing new entrant. The inherent characteristics of the frugal innovations introduced by new entrants in this scenario, namely minimised resource requirements, cost reductions and optimisation of product quality and performance [59], are relevant features in the post-pandemic phase due to an emerging general consensus on voluntary simplicity and affordability [60], as well as looming pressures on public and private sector R&D budgets [61]. Ultimately, the demonstration example emphasises that our new visualisation method for the capture and analysis of IP related dynamics not only permits the delineation of innovation and IP related risks and uncertainties that are relevant to incumbent firms and new entrants, but also the sensing and discovery of potential benefits and complementarities that were previously not apparent, which lies at the heart of the open innovation paradigm [62].

Scientific rigour, construct and internal validity in this study were underpinned by the adoption of the DSRM for the design of our new method, the correlation of our demonstration example to secondary empirical sources, and the consultation of the NGT panel consisting of interdisciplinary subject matter experts for the evaluation of our new method, respectively [10]. However, external validity, namely the generalisability of our new method to contexts other than the evolving CC-Sector innovation ecosystem[6] during the COVID-19 pandemic remains to be tested [10], [48, p. 400], [63, p. 45]. Demonstrating and evaluating the functionality of this new method for visually capturing IP related risks and uncertainties in evolving innovation ecosystems in other research, industrial or policy settings will further validate it as a tool for IP management practitioners to either analyse with hindsight or plan for the future when diversifying into new sectors and to identify and mitigate IP related conflicts and tensions among multiple stakeholders.

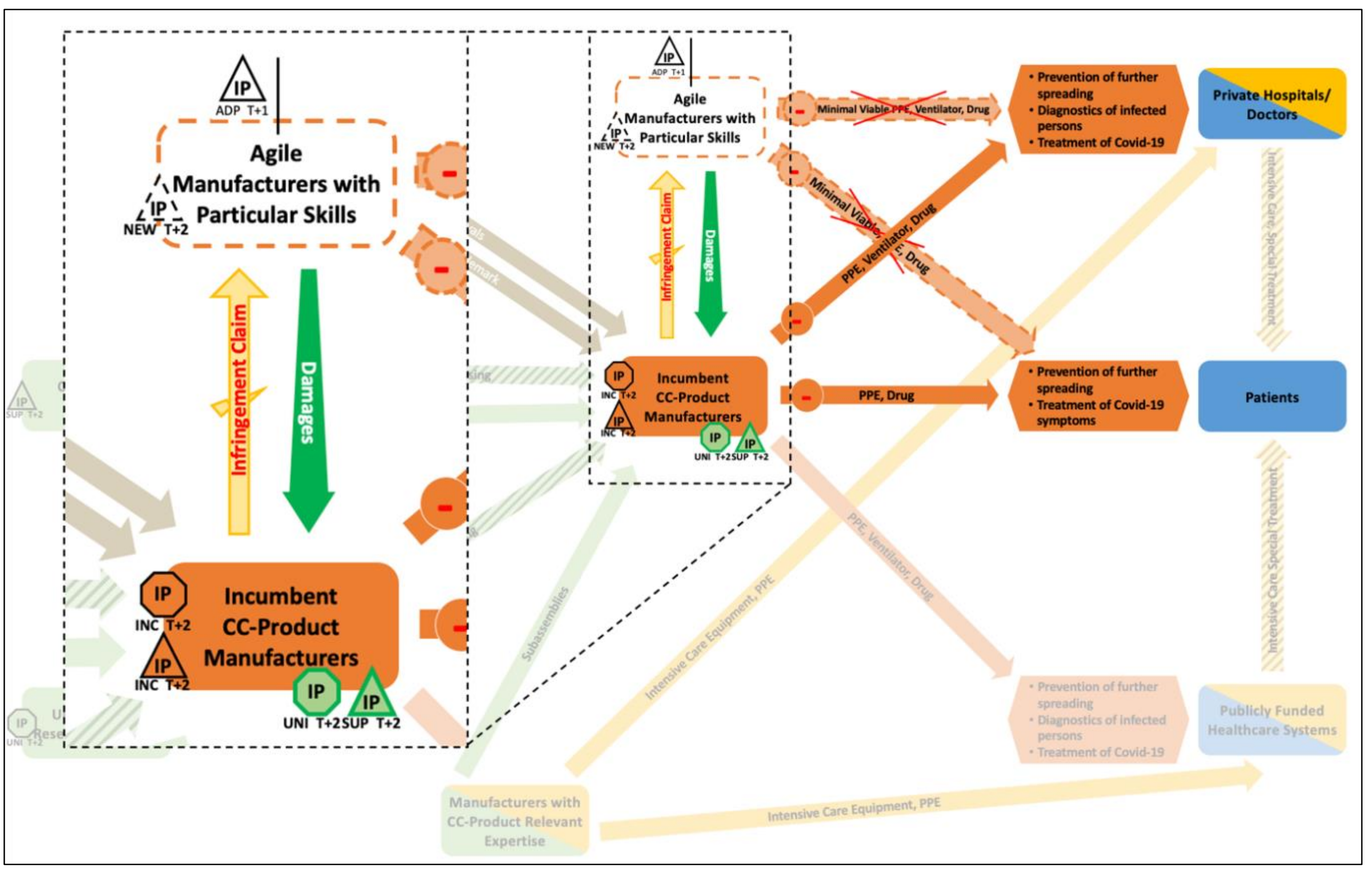


Figure 4 Innovation ecosystem map of post-pandemic CC-Sector, created using new visualisation method for capturing IP dynamics [46]

[6] The new method's generalisability across multiple firm strategies was however shown by Moerchel *et al.'s* [46] application to a set of three entry strategy scenarios pursued by industrial new entrants that were identified by Tietze *et al.* [20] at the start of the COVID-19 pandemic.

VI. Conclusion, Limitations and Future Research

The goal of this paper is to introduce a new visualisation method for the analysis of IP related risks and uncertainties of multiple stakeholders experiencing structural changes in industrial organisation in evolving innovation ecosystems. To address this objective, we applied Peffers *et al.*'s [10] DSRM to design and develop the new method on the basis of Granstrand and Holgersson's [27] state-of-the-art innovation ecosystem conceptualisation and building on recent methodological advances in the visualisation of structural dynamics in innovation ecosystems, namely Moerchel *et al.*'s [11] SVEL. Furthermore, we provide a detailed description of our new visualisation method and its external representations (i.e. symbols, shapes and colours) for capturing loci of innovation, ownership and usage of underlying IP, as well as its transformation over time, and also explain its conceptual grounding in literature on IP management and strategy and the role of IP in open innovation. Subsequently, we demonstrate our new visualisation method by applying it to map the entry strategy scenario pursued by agile manufacturers with particular skills in the evolving CC-Sector innovation ecosystem during the COVID-19 induced health crisis. We finally discuss the evaluation of our new method using the NGT process including an interdisciplinary panel of subject matter experts.

This paper advances the current state-of-the-art in visual analysis of innovation and IP related dynamics in evolving innovation ecosystems. More specifically, we contribute to the method 'toolbox' of innovation, IP management and strategy practitioners, researchers and policy makers for the identification and analysis of future courses of action, phenomena and decision-making processes when encountering structural changes in industrial organisation in evolving innovation ecosystems, such as when firms diversify into new sectors.

Our proposed new method, however, lacks external validity and proof of generalisability. Therefore, we hope that future studies would apply this visualisation method to other contexts exhibiting structural changes in industrial organisation and innovation ecosystem evolution. Another area of interest is to integrate the new visualisation method with other visual mapping approaches in ecosystem research to test its modularity. Such future studies could also help to identify areas of improvement and lead to further enhancements of external representations and respective labels. Furthermore, this study is primarily qualitative in nature, wherefore future work might want to focus on integrating quantitative techniques and analyse measurable performance indicators in business and innovation ecosystems.

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