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Complexity Mechanisms for Interaction to Foster Digital Innovation Processes: A Multiple Case Study

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Abstract: A digital innovation (DI) process with multiple stakeholder involvement is complex. While a reductionist approach might be occasionally favourable, embracing the complexity is more beneficial. In terms of researchers, it is social scientists' central task to study complex phenomena in society. For practitioners, complexity causes innovation due to heterogeneous actors and dynamic interactions (i.e., non-linearity). Thus, this paper aimed to unveil the complexity mechanisms in DI processes' structures and how interactions through these mechanisms foster DI. Two case studies of DI processes were conducted, where data was collected through interviews with project participants and through observing project meetings. The complexity mechanisms in DI processes' structures include open systems, nested systems, distributed control, and dependence on key stakeholders (i.e., hubs). This research offers a theoretical contribution to understanding DI process complexity by identifying how these mechanisms can foster and hinder innovation. The complex interplay of these mechanisms could also bring change in how the DI process works and its boundary definition. Research about the complexity of DI has focused on DI ecosystems. This paper shifts the focus to the complexity of DI processes that produce DIs and cause their ecosystems to come into existence and evolve, and even cause the ecosystem's extinction.

Keywords: digital innovation processes; stakeholder involvement; complexity; complex systems; digitalization; 5G; rural area

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1. Introduction

Innovation is a naturally collaborative process combining different know-how [1], resources [2], and skills. Traditionally, digital innovation (DI) has been a closed process involving the developers of the digital technology (DT) [3]. Users have only been engaged late in the innovation process for testing [4], causing the dominance of service providers [5]. Nowadays, DI is usually a more open process. With the convergence of DTs, meaning that DTs have the ability to be combined with other products [6,7], we now live in an era of smart products (e.g., smart shoes, buildings, phones, etc.) [6]. The needed know-how, resources, and skills might not necessarily exist within one stakeholder [1,3]. Especially if the DI spans multiple product categories (e.g., healthcare, ICT, and AI), having different stakeholders collaborate makes it possible to learn and use each other's skills, know-how, and resources without any dominating visions [5]. Moreover, the collaborating stakeholders could share the risk and cost, speed up commercialisation, and enable access to foreign markets [3]. This would, in turn, benefit the service provider, as an open DI process that involves its stakeholders as co-designers will have outcomes that better match the stakeholders'

preferences [8] and it will be possible to anticipate use before use through prototyping and testing [9]. The involved stakeholders will have a better understanding of the DI, thus increasing acceptance and minimising the failure of the DI [10].

On the other hand, additional stakeholders in the DI process increase its complexity [5,11]. Practitioners and researchers have adopted one of two pathways to "deal" with complexity. In the first pathway, practitioners reduce complexity through closed innovation or only involve stakeholders when testing starts [4]. This causes dominance by service providers on the DTs they developed and the DI process. This hinders the service provider and other stakeholders from detecting new opportunities away from the dominant vision [5]. It also makes the success of DI processes dependent on the dominant stakeholder's involvement [12], which causes DI lock-in. For researchers, reduction means adopting reductionist and simplification theories, e.g., hard system thinking (HST) [13], complex adaptive systems, actor-network theory (ANT), and simulation [14].

Alternatively, practitioners who embrace complexity adopt open innovation and involve "all" stakeholders who legitimately affect or are affected by the DI process [15,16], where the stakeholders have varying degrees of involvement and decision-making power [15]. For researchers, embracing complexity means attempting to understand a complex phenomenon in its entirety or, to be realistic, getting as close as possible to full complexity, e.g., using soft system thinking (SST) [17] or complexity theory [18,19].

While a reductionist approach might occasionally be favourable by focusing on existing structures and on details part by part, embracing complexity benefits practitioners as it offers a better possibility of creating radical change (i.e., innovation) [20]. Only through the heterogeneity of the actors and the non-linearity of their interactions (i.e., relations of difference) can innovation occur [21]. If the same predetermined participants have fixed interactions in a static (i.e., linear) process [22], it will garner the same outcome in every DI process. In contrast, heterogeneous actors with different backgrounds interacting dynamically and uniquely will garner different outcomes in every DI process. These outcomes, given the right conditions, could lead to change over time and evolution, or in other words, innovation [14,23]. We could look at what makes these interactions dynamic and unique as complex mechanisms where a combination of entities with their powers and liabilities trigger mechanisms in the form of structures and processes that cause particular outcomes [24,25]. In DI processes, complexity mechanisms exist, are triggered and are created by stakeholder interaction. Practitioners, particularly companies, need to find methods to exploit DI [26]. As such, they should exploit the complex mechanisms in DI processes to innovate. For researchers, it is the social scientists' central task to study complex phenomena in society [27,28], which could be understood in terms of structures, scales, and change processes [29]. Thus, to claim to understand a complex phenomenon like DI without studying its complexity is considered unethical [14]. However, reductionism is not irrelevant to understanding DI processes because analyses need the details of the elements and the underlying relationships. Balanay and Halog [30] stress that, on its own, reductionism can be paralysing, as it can create blind spots. Furthermore, the authors highlight that in development programmes, reductionism makes enormous contributions in terms of clarity of direction, purpose, actions, and inputs, but not in terms of the analysis of results and impacts, especially at the system level [30].

Thus far, research on the complexity of DI has focused on the complexity of DI ecosystems [6,7,11,31–33]. On the other hand, research on the complexity of the process of DI itself is lacking. According to a literature review conducted by Wang [11], there is a bias in research towards adopting a part (i.e., stakeholders) perspective instead of a whole (i.e., ecosystems and processes) perspective. One drawback to this bias is the lack of focus on the interactions across the levels [11]. Moreover, it ignores that the whole has properties greater

than the sum of its parts. Furthermore, DI ecosystems encompass the interdependence of the stakeholders, who co-exist and co-evolve to develop and implement DTs and, beyond implementation, exploit and reuse the DTs in further DIs [6,7,11,31–34]. For example, the smartphone ecosystem would encompass loosely coupled [11] stakeholders involved in various smartphone-related DIs, e.g., app development, phone camera development, device development, and their use and reuse in smartphone-related DIs. Research on the complexity of the DI process would focus instead on the complexity of the stakeholders and activities involved in innovating and developing collaboratively [5,35–37]. As such, the focus is on the DI processes that lead to (1) the first DI and that DI's ecosystem to come to be, through initial implementation and development, and (2) the further DI processes within DI ecosystems that can co-evolve the ecosystem through reuse. This includes the structure of the DI process, which is formed through stakeholders' interactions and how their interaction leads to change. Thus, in this paper, we conducted a multiple case study of two DI-focused research projects with the aim to unveil the complexity mechanisms in DI processes' structure that the stakeholders can interact through to enact change, including fostering DI. As such, the contribution of this paper is to describe how the complexity mechanisms can take shape in DI processes and how they foster innovation.

This paper is structured as follows: First, we lay the foundation for the phenomenon (i.e., DI processes) and the theories used as the basis for data collection (i.e., stakeholder theory) and analysis (i.e., complexity theory). Next, we explain the case study method used and the findings. Then, in the Discussion, we reflect on how the complexity mechanisms can foster or hinder DI.

2. Laying the Foundation

The following subsections lay the foundation for the case studies over three levels. First, they define DI processes. Second, they define the stakeholders of DI processes. Third, they define what complexity is, what phenomena we should attribute complexity to, and the complexity mechanisms in the structure of a complex phenomenon.

2.1. Digital Innovation Process

A DI process is the innovation of products, services, and/or processes that are digital or digitally enabled [5,35–37].

In the DI literature, the steps in the DI process differ from one source to another. Kohli & Melville [36] developed a framework for the DI process that includes initiation, development, implementation, and exploitation as activities. A slight variation defines the process's phases as discovery, development, diffusion, and impact [38]. In living labs (LL), an approach to open DI processes, the FormIT framework was defined, which starts with planning followed by three iterative cycles of user-centric design: concept design, prototype design, and final system design. Each cycle comprises an iterative process of need generation, design, and evaluation. Finally, the process ends with commercialisation [39].

However, in practice, DI processes do not follow a static input–process–output (IPO) format that we conventionally define as a process. In practice, the phases described in the literature could be iterated, skipped, and run in parallel, or the order could be different [40]; see examples [41,42]. Moreover, innovation is a product of chaos [43], be it an unorganised DI process or where the innovator might not have had the goal to innovate to begin with. This does not fit with a static process that implies a static output. Furthermore, the innovation process requires unpredictability in the organisation of the process to detect opportunities and innovation that cannot be confined to a rigid sequence of steps.

Accordingly, this paper assumes that DI processes are dynamic processes that do not have specific phases. Since the paper focuses on the interactions of the stakeholders, we

adopt a stakeholder lens when we look at DI processes. We focus on the DI process as a dynamic structural entity composed of stakeholders coming together to innovate, rather than a process with a set of steps.

2.2. Stakeholders of the DI Process

Based on stakeholder theory, stakeholders affect or are affected by the phenomena being studied. For DI processes, the common stakeholders include customers, governmental organisations, competitors, substitutes, and the media [44]. The DI process could also have researchers; end-users [45]; the customers' employees, managers, owners, and partners [46]; citizens [41]; crowdsources; service platform providers [47]; IT and industry service providers [48]; financers, LLs [49]; ethics committees [50]; DTs [2]; and the environment [51].

As previously mentioned, DI processes were traditionally closed. The service provider depended on internal R&D and held sole responsibility for the process from start to finish (i.e., held all the roles in the DI process). While this approach might have saved time for the service provider, as no time was consumed on collaborations, the drawback was that they were responsible for all the costs of the DI. They faced the risk of the DI's failure on their own [3], and they did not benefit from other stakeholders' knowledge, resources, and ideas. From the other stakeholders' perspective, the drawback was the dominance of the service provider's vision [5].

To have a more open and collaborative DI process, initially, the service provider involved the customers and end-users of the DI. However, this involvement was mainly in the later activities of the DI process (i.e., evaluation, implementation, and exploitation) rather than involving them in ideation and design [4]. This involvement was considered minimal; the customers and end-users were observed without their actual involvement, or they provided their opinion, with the service provider making the final decision [15]. To further improve their DI processes, the service providers started involving the customers and end-users in the earlier stages of the DI processes in various roles as need providers, co-designers, etc. In these roles, they could make decisions within certain boundaries or without any boundaries [15,40].

However, to further reap the benefits of open innovation, the service providers started to venture outside the customer and end-user for collaboration. This move was also triggered by the layered modular architecture of DTs, which is composed of layers of components (i.e., content, service, network, and device) connected through a standardised interface [37], which enables distributed and combinatorial innovation [5,36]. Furthermore, the DI process is no longer only initiated by the service provider; rather, other stakeholders have started taking the initiative in starting the DI process, e.g., customers, end-users, researchers, citizens, governmental organisations, etc. [35,47,48].

2.3. Theoretical Framework: Complexity

In complexity theory, complexity is seen as a property of systems, in which systems are "a set of interrelated elements and that a complex system is one in which, in plain English, the whole is greater than the sum of its parts" [52] (p. 12). Complex systems are the only systems capable of radical change (i.e., innovation) as they are the only systems with heterogeneous parts capable of non-linear relations [14].

The DI process became a complex system through the gradual move from a closed to an open innovation process [32,33]. First, the DI process has become the focal point of identifying stakeholders instead of a single service provider, where the stakeholders are those who affect or are affected by the DI process [53]. Second, the categorisation of primary and secondary stakeholders has become dynamic. It depends on the stakeholder's

role or lack thereof in the DI process, and it could even change from one activity to another. Third, a many-to-many relationship has emerged between the stakeholders and the roles. Instead of the service provider holding the sole responsibility for all roles, any stakeholder could adopt more than one role, and more than one stakeholder could adopt the same role in the same DI process. Fourth, within these roles, the different stakeholders have various degrees of involvement. Some stakeholders are observed as subjects or share their opinions, while others have decision-making power within certain boundaries or without boundaries [15].

In complexity theory, complex systems gain their "complex" title because they have complexity mechanisms in their structures (see Figure 1) [14,54]. A combination of entities with their powers and liabilities trigger mechanisms—structures and processes [24,25]—through unique and dynamic interactions [14,23] that cause particular outcomes [24,25], in which causality is contingent [24], as the same mechanism could cause different outcomes [25], the mechanisms could remain dormant [55], or the same outcome could be caused by other mechanisms, depending on the context [25]. These complexity mechanisms denote the affordances in the complex systems' structure that enable the interactions and influences between the whole, the part, and the environment of the complex systems, which, in turn, recursively inform its structure [52,54]. The complexity mechanisms are nested systems, open systems, distributed control, and hubs (see Figure 1) [14,54].

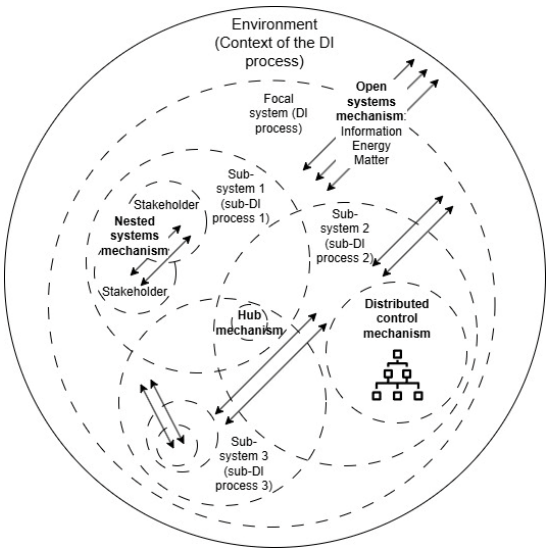


Figure 1. Illustration of the complexity mechanisms.

2.3.1. Nested Systems

Complex systems are systems of systems (SoS) where each system belongs to one or more wider systems (i.e., environment) and contains one or more subsystems (i.e., parts) [17,56]. The systems could have nests where parts of the focal system could belong to and interact with more than one system on the same level as the focal system [14]. The systems could also have nests where the parts interact across levels with higher or lower level systems [57].

Complex systems change over time due to interactions through their open-nested nature [14]. This change could be non-linear, as complex systems have relations of difference rather than static linear interactions [23]. This could potentially lead to non-linear paths where the output could not be proportional to the input [54]. Non-linear change rarely comes in the form of evolution, which is an emergence (i.e., change) where disruption redundantly happens in lower level systems until radical change occurs [20].

2.3.2. Open Systems

Complex systems are open systems that allow for interaction between the focal system (i.e., the whole), its parts, and the environment, where they exchange information, energy, and matter [54]. Consequently, actors in a focal system need to adapt to disruption in the environment, and change comes in the form of adaption to changes in the environment [17]. Systems are differentiated from their environment by the boundaries defined by the observers. These definitions might differ between observers [19,52]. The boundary between the focal system and its environment is permeable [14].

2.3.3. Distributed Control

Given the nested structure of complex systems, there is no central control system [14,54]. As such, the parts might only have access to local information [54]. This is similar to distributed innovation, where stakeholders collaborate to innovate, sharing their skills, resources, and knowledge with no central control or proprietary [5]

Change from interactions with distributed control comes in the form of self-organisation, where patterns and structures emerge from the interactions of the parts without central control [54]. For complex systems, "order is an emergent property of disorder" [18] (p. 115), meaning that distributed control also leads to change over time, non-linear change, and evolution.

2.3.4. Hubs

Some parts are essential for progress [54]. Hubs may act as the connector for interaction between the different parts, or might have access to connections that other parts do not have [54]. Similarly to nested systems, interaction through hubs could cause change over time, non-linear change, and evolution.

At its lowest unit, a DI process's structure is composed of stakeholders. As such, a DI process, as a complex system, is the whole, with stakeholders and sub-DI processes as the parts, and the context of the process as the environment. The complexity mechanisms are the means for the DI process's stakeholders, as the parts, to interact with other parts, the DI process, and the environment [57], enacting change [23].

Stakeholder theory informs how to study the parts of the DI process, as it is used to understand the stakeholders' background [44], interest in the DI process [44,51,58,59], position (support/oppose) and needs in the process [44,58,59], responsibilities, decisions [44,60,61], power [15,44], resources (i.e., manpower, information, assets, funding, and time) [62], management of the process [5,7,63], and SWOT [64,65]. Most importantly, it is used to understand the stakeholders' interactions, relationships, collaborations, and changes over time in their roles, viewpoints, and goals, and changes in the DI process [44,66,67]. Complexity theory allows for the analysis of these stakeholders and their relationships and informs how these complexity mechanisms take shape in DI processes and are used in the interactions between the stakeholders, sub-DI processes, focal DI process, and the environment, and explains how these relationships evolve and how these interactions give rise to system-wide change through restructuring the system over time.

3. Materials and Methods

Two DI process case studies were conducted to understand how interaction through the complexity mechanisms happens in DI processes and how it enables innovation. A case study methodology was suitable as it allowed for an in-depth exploration of a contemporary phenomenon [68] (i.e., the DI processes) while it occurred.

Since this paper is exploratory, inductive, and descriptive rather than deductive, Eisenhardt's case study approach was used, as it encourages the use of multiple investigators,

multiple case studies, and multiple data collection sources for stronger substantiation, which for this study are interviews and participation in the projects or observing project meetings. Each case is analysed separately in the case analysis, and then the findings of this analysis are compared with other cases for cross-case pattern matching [69].

3.1. Case Studies

The case studies revolve around two DI research projects, 5G automation (5GA) and SMArt Livskraftig Landsbygd (SMALL). However, in the case studies, we focus on the projects as DI processes rather than research projects.

SMALL case study: This project aims to create smart, attractive, viable, and sustainable rural areas using existing digital technologies by implementing and evaluating digital solutions and developing collaborative models for digitalisation adapted to rural conditions. SMALL's DI process encompasses its precursors, a pre-study, and Digiby.

5GA case study: Under Luleå University of Technology's (LTU) 5G Innovation Hub North (5GIHN) umbrella, a three-year university-led project with multiple collaborative partners aims to innovate for industry-specific production automation. The industry is not specified to maintain the requested anonymity.

The two DI research projects are selected as both are complex and involve heterogeneous stakeholders; however, they are complex in two distinct ways, as SMALL is a larger scale DI process compared to 5GA. First, SMALL is constantly expanding by adding more villages and pilots, while 5GA could be considered closed in that it rarely adds more stakeholders. Second, SMALL constantly adds DTs to its scope, while 5GA focuses on 5G edge networks and its use cases in the target industry. Third, SMALL has a wider diversity of stakeholders, including researchers, municipalities, villagers, NGOs, etc. The 5GA project only has stakeholders who work in the technology field. Thus, while SMALL has expert and non-expert stakeholders in the DI and technology fields, 5GA only has expert stakeholders.

3.2. Data Collection

Two approaches were adopted to collect data, as seen in Table 1. First, semi-structured interviews were conducted. All participants in the case studies were invited for interviews with the aim that at least one representative from each stakeholder would be interviewed. The interviews, at a minimum, were 60 min. Depending on the stakeholders' involvement in the case studies, some follow-up interviews were conducted. Second, a researcher attended steering committee meetings as a project member in the SMALL case study, while a researcher attended meetings in the 5GA case study as an observer. During participation in the steering committee meetings (SMALL) and the observation of project meetings (5GA), notes were taken which, together with interviews, formed the basis for analysing the complexity mechanisms of DI processes.

The interview protocol was developed following stakeholder theory. As this would gather information about the parts of the DI process and their interaction with other parts, the process, and the environment. Complexity theory was intentionally not used to prevent prior assumptions of complexity and to derive the complexity findings from the data. The interviews focused on identifying the stakeholders' background; their description of the DI process [44,66,67]; their interests, needs, roles (i.e., responsibilities, decisions, and activities), power (i.e., the influence that the stakeholder has on decisions made) [15,44], legitimacy [51], and position (i.e., oppose/support the DI process) [58] etc.); and their resources (i.e., manpower, information, assets, funding, and time) [62] in the DI process. The interviews also covered the stakeholders' interactions and collaborations; changes over

time in their roles, viewpoints, and goals; and changes in the DI process [44,66,67]. Finally, they were asked about the management of the DI process [5,7,63] and SWOT [64,65].

Table 1. Data collection methods.

Data Collection Method	SMALL Case Study	5GA Case Study
Interviews	18 interviews: • 1 project manager/university researcher; • 4 university researchers; • 1 DT expert; • 5 municipality officials; • 7 villagers/pilot owners.	8 interviews: • 1 project manager/university researcher; • 2 university researchers; • 1 Edge cloud provider (a research institute); • 1 use case developer; • 1 core network provider; • 1 network provider; • 1 network performance evaluator.
Meetings	Steering committee meetings as a project member	4 meetings as an observer

3.3. Data Analysis

The interviews were recorded, transcribed, and analysed using MaxQDA 24, developed by Verbi Software GmbH, Berlin, Germany. Qualitative content analysis (QCA) was chosen as the analysis method as it enabled the use of the four complexity mechanisms we previously described and the changes they cause, instead of discovering themes (i.e., thematic coding and analysis) [70].

The meaning units of transcribed texts, i.e., words, sentences, or paragraphs about the same content or context [71], were assigned one or more codes (see Table 2) that related to one of the complexity mechanisms or change. The result of the QCA were used to understand what each complexity mechanism looked like in the two case studies. The codes related to change, like "path dependence" and "feedback loop" [54], indicated the mechanisms that the respondents saw as the causes of the change, while codes like "change over time", "adaption", "evolution", and "self-organisation" indicated the type of change that occurred [14,54]. The change type also reinforced the potential complexity mechanisms behind it. For instance, as previously mentioned, systems "adapt" to disruption and opportunities in the environment due to the open systems mechanism.

Table 2. Codes for representing the complexity mechanisms and change.

Complexity Mechanism Change	Codes
Nested systems	• System of systems (SoS); • Stakeholder (i.e., parts) operating across levels and scales of SoS; • Interactions with stakeholders in the same sub-DI process (i.e., higher level part); • Interactions across sub-DI processes (i.e., interactions with stakeholders from other sub-DI processes within the overarching case study of the DI process).

Table 2. *Cont.*

Complexity Mechanism Change	Codes
Open systems	• External entity (i.e., actors that are not part of the DI process); • Interaction with an external entity; • Mode of communication with the environment (i.e., with external entities); • Disruption from the environment; • Opportunity in the environment; • Needs from the environment.
Distributed control	• Orchestration instead of project management; • Ownership of responsibilities; • No central control; • Control is distributed among many actors; • Only access to local information.
Hubs	• Key connections; • Key resources; • Key skills.
Change	• Change over time; • Adaption; • Evolution; • Self-organisation; • Path dependence. • Feedback loop; • Non-linearity; • Unknowns; • Unpredictability; • Tipping point.

The notes taken during the steering committee meetings (SMALL) and project meetings (5GA) thus supported the interviews to obtain an overall picture of the DI process for the two cases in terms of (1) nested systems—interaction between stakeholders, (2) open systems—communication and influence from the environment, (3) distributed control—project management, (4) hubs—key factors, and (5) change—change, adaptation, and development. The notes were used to confirm the information gathered from the interviews and to provide additional context.

4. Results

The following subsections describe the findings from the case studies. First, we describe the cases' nested structures and how stakeholders interacted through them. Second, we describe the entities in the processes' environments, and the exchanges between the stakeholders of the processes and the environment and their effect on each other. Third, we describe distributed control and how it is managed. Fourth, we identify hubs in the processes and their role in stakeholder interaction. Finally, we describe the change over time from the stakeholders interacting through the mechanisms.

4.1. Nested Systems

SMALL is a DI process for the digitalisation of rural areas. It is nested in that it is composed of sub-DI processes (i.e., pilots) in villages in the Norrbotten and Västerbotten regions in Sweden. Figure 2 shows an excerpt of SMALL's nested DI processes. The Circles indicate DI processes and the rectangles indicate the stakeholders involved. The focal DI process, in this excerpt, is the youth building DI process. It started because the children wanted to enjoy the youth building but needed to obtain the key and contact the manager to book it, as the building was used for other activities. Through SMALL, they started a DI process for a digital lock using BankID—a personal eID used in Sweden. The children

can now digitally unlock the building and take charge of it while there, e.g., cleaning after themselves, ensuring no damage happens, etc. The villagers also use BankID to access the building for other activities. Next, they added screens in the building for the children to watch kids' shows, and currently, they have started a DI process to develop a booking system using BankID.

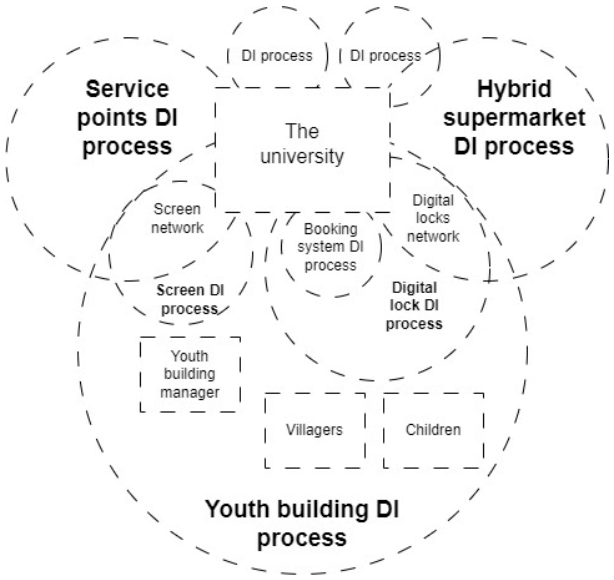


Figure 2. The nested systems of SMALL's DI process.

In the youth building DI process, the youth building manager, children, other villagers, and LTU are the stakeholders. This DI process shows how stakeholders in SMALL interact through the nested mechanism to foster DI in various ways. Stakeholders of SMALL's sub-DI processes have ad hoc interactions within and with the orchestrators to give updates, plan, and develop their innovations, ideate future innovations, and solve problems. For example, the youth building manager receives emails and schedules meetings with the children to obtain feedback and ideas. She then constantly talks with LTU and a municipality official (henceforth named Katherine) to give updates and discuss the potential ideas.

The stakeholders in SMALL also have scheduled interactions. SMALL has a biweekly steering committee meeting to plan, discuss the pilots' progress, and make decisions. There are also biannual meetings that involve all of SMALL's stakeholders. LTU has also formed networks for sub-DI processes using the same tools, which have frequent meetings. While the youth building DI process does not depend on other DI processes to progress, it interacts with other DI processes like a service point DI process and a hybrid supermarket DI process through their tool-specific networks' meetings and through attending SMALL's biannual meetings. In these meetings, the youth building manager enthusiastically meets with others and shares her experiences and ideas to help other DI processes and to get inspiration from them. Other interviewees state that the network meetings have helped them to share tips, ideas, thoughts, and experiences. It also has helped them to solve problems together, cooperate, and reduce isolation when using new tools. In one example, a village only had three to five residents; interacting and cooperating with bigger villages gave them access to more resources. Beyond this excerpt from SMALL, there are other pilots that are connected to each other, and the university, as an orchestrator, is in the middle, "as a spider in a web", as some of the interviewees stated.

While the pilots in SMALL are nested but independent of each other, in 5GA, the sub-DI processes depend on their nested mechanism for progress. The 5GA project consists of four work packages (WPs): Edge applications, Edge systems, network performance,

and pilot demonstration. As can be seen in Figure 3, these WPs can be divided into the three main DI processes to develop the 5G telecommunication network (5GTN), Edge cloud, and use cases. The 5GTN DI process delivers the network to the Edge cloud DI process, which delivers the Edge cloud to the use cases of the DI process. As seen in Figure 4, the progress within each sub-DI process is also dependent on the interactions of the stakeholders through their nested mechanisms. Each stakeholder depends on another for either a platform to build their innovation on or to receive feedback. These dependencies are akin to a customer–developer relationship.

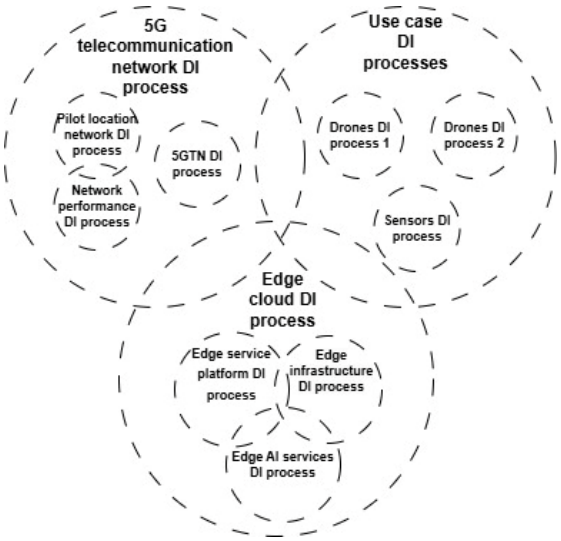


Figure 3. The nested systems of 5GA's DI process.

Contents layer	• Drone provider • Convergence sensor provider • LTU robotics	Layers connected through a standardized interface
Service layer	• Edge cloud provider • Drone provider • Convergence sensor provider • LTU robotics	
Network layer (LTU, pilot location)		
Logical transmission layer	• Network performance tester • Network provider • Network infrastructure provider	
Physical transport (equipment) layer	• Network performance tester • Network provider • Network infrastructure provider • Core network company	
Device layer		
Logical capabilities layer	• Edge cloud provider • LTU (pervasive and mobile computing) • LTU (robotics)	
Hardware layer	• Drone provider • Convergence sensor provider • Network infrastructure provider	

Figure 4. Stakeholder distribution in the layered modular architecture (Adapted from: [37]).

The 5GTN DI process has three sub-DI processes. The core network provider aims to provide the core network (i.e., the fibre optic cable network) for the network and network infrastructure providers to build their 5GTN. However, currently, the network and network infrastructure providers are using their own core network, where the network infrastructure provider mainly provides the physical transport layer (i.e., the network hardware), and the network provider manages the actual network operation (i.e., the logical transmission layer). LTU currently hosts one network—the 5GIHN—a 5G testbed, while a pilot location—a facility from the target industry—has another. Both test environments have been set up in previous projects, and their DI processes (i.e., the facility network DI process and 5GIHN

DI process) are proceeding in 5GA through re-design and testing. Moreover, the network performance provider evaluates the network's performance in the facility based on the other stakeholders' requirements and feedback in a third sub-DI process.

The 5G cloud DI process has three sub-DI processes. The Edge cloud provider is responsible for developing the Edge cloud infrastructure, service platform, and Edge AI services. They provide the Edge cloud infrastructure for the 5GIHN, while the 5G cloud infrastructure in the facility is provided by the network infrastructure provider. LTU's pervasive and mobile computing team is also conducting research to optimise the Edge system, for instance, determining where to best place software in the Edge nodes. Stakeholders of the 5G cloud DI process act as customers of the 5GTN DI process by using the networks in the facility and 5GIHN, where they give feedback about the networks' performance.

There are three use case DI processes. LTU's robotics team and the drone provider work separately on their DI processes to develop unmanned area vehicles (UVs). For instance, LTU's robotics team is developing an Edge-based architecture to control drones in the facility with the help of the Edge cloud provider. Moreover, a sensor provider is developing 5G-enabled sensors to detect structural changes in the facility. Stakeholders in the use case DI processes are customers of the other DI processes, where they give feedback.

All stakeholders meet periodically in a project-wide meeting to discuss project progress and future plans. The remaining interactions are for collaboration purposes, including daily close collaborations, ad hoc collaborations when interaction is needed, or periodical collaborations with a set schedule (e.g., WP1 meetings every 3 weeks). The stakeholders either work separately (e.g., the use case DI processes) or collaborate (e.g., 5GTN DI process) on sub-DI processes or, as previously mentioned, have a customer–developer relationship.

4.2. Open Systems

SMALL's precursors, a pre-study and Digiby, were products of their environment. For one, there was a digital divide between urban and rural areas. For another, urban citizens have a misconception that rural areas are only a source of natural resources. This has led to people moving from rural areas to cities, which risks the extinction of rural areas. SMALL's environment contains, among others, regions, municipalities, organisations, and villagers who do not participate in the pilots, other projects, and urban cities.

SMALL's stakeholders actively utilise the open systems mechanism to interact with outside stakeholders through meetings, seminars, conferences, social media, academic publications, and newsletters. Representatives from regions, municipalities, and organisations are sometimes invited to the steering group meetings. Moreover, LTU and Katherine go to networking events to promote SMALL. The widespread promotion of Digiby and its success led to the transition from SMALL reaching out to encourage new municipalities and villages to join SMALL, to them requesting to join. Katherine even connected two stakeholders who were not involved in the DI process to collaborate together. Mostly, LTU, as SMALL's orchestrators, and involved municipalities, as the pilots' orchestrators, are the main sources of communication with the stakeholders in the environment.

The 5GA project's environment contains, among others, organisations in the target industry, telecommunication, technology, UV companies, developers of equipment used in the target industry, and other projects. The 5GA project differs from SMALL in that it does not actively seek out expansion; consequently, interaction with other stakeholders and the addition of new stakeholders as collaborators in the DI process are opportunity-based rather than objectives. Its main means of interacting with the environment is through taking advantage of other projects that the contributing stakeholders are involved in.

DI processes are affected by and can affect their environment. DI processes need to change to adapt to unpredictability in the environment. SMALL's stakeholders had to adapt to the pandemic through virtual meetings. They also had to look into how to adapt to a post-ChatGPT era. Interaction with components in the environment could either inspire, contribute, or hinder. In both case studies, stakeholders use similar DI processes as inspiration. Moreover, as previously mentioned, 5GA uses 5GTNs, which were set up in previous projects. Similarly, in parallel to SMALL, some of the DI processes are part of two other projects, Predictive Movement and RörLA. On the other hand, hindrances could come from competitor DI processes. In addition, the DI processes' stakeholders have work separate from them. They could have other professions, work on other DI processes, be students or parents, etc. In SMALL, some of the stakeholders volunteer their own time to participate. Positively, the stakeholders could utilise their experience to benefit the DI process and their other professions. Negatively, the stakeholders might struggle to prioritise SMALL and 5GA over other duties.

4.3. Distributed Control

Both case studies have a person assigned as a project manager. However, while traditionally, project managers have had an involved role in a DI process, their role is now limited to administrative duties, e.g., arranging meetings, documentation, monitoring progress, managing the budget, reporting to the financer, etc. Alternatively, both DI processes have LTU as an orchestrator. In SMALL, they are responsible for fostering collaboration through communication, connecting stakeholders, promotion, finding potential stakeholders to add to the project and have more pilots, and disseminating knowledge. Also, since many of the stakeholders are villagers and municipalities that do not work in the technology sector, LTU guides them. In 5GA, since the stakeholders all work in the technology sector, the orchestrator's role is focused on fostering collaboration rather than mentorship.

SMALL aims to digitalise rural areas. This is hinged on developing tools that the villagers need rather than what the university thinks they need. It is also hinged on the villagers and municipalities continuing the DI processes after SMALL's research project is completed. Accordingly, SMALL follows a bottom-up approach to interaction and management; it is need-driven. The villagers explain their needs and ideas to LTU. LTU either finds it within the scope and budget of the project; in that case, they guide them in implementing their ideas, connect them with stakeholders to collaborate with, fund them, and monitor their progress. They also encourage the villagers and municipalities to share their experiences in SMALL meetings and external seminars. Otherwise, if it is out of scope, they connect the villagers and municipalities with potential stakeholders to collaborate with. Following this bottom-up approach ensures that the tools fit the needs, and the villagers feel ownership of the DI process and the tools. Interestingly, though, the only interviewee who stated that a top-down approach was followed was one of the funding organisations.

In 5GA, control is distributed since each stakeholder is responsible for their own tasks. Then, they interact frequently to collaborate in making decisions and ideation.

4.4. Hubs

Since the case studies are research projects, they have external financers. For the duration of the projects, these financers are hubs, since the continuation of the projects depends on their funding. After the projects end, for SMALL, the villagers and municipalities will need to find alternative funding to continue their DI processes, while 5GA's stakeholders have collaborated on previous projects and thus are expected to continue applying for more research projects and funding together.

SMALL also has multiple stakeholders who could be hubs. In their role as orchestrators, LTU is considered a hub for internal and external interaction. Katherine has also been labelled as a hub by the interviewees, as she is the one with a network of connections in rural Sweden. She travels on the ground, communicating with the different pilots and contacting potential new pilot locations. Both LTU and her have been labelled as satellites and "spiders in the web". In the nested systems, they are in the middle, connecting the different stakeholders and different pilots together. Another hub is idea champions; it is their constant advocating for their ideas and promotion that ensures that their sub-DI process continues and that their ideas expand to other implementations. The villagers and municipalities are also hubs; the pilots' continuity hinges on them. DI will not start in their villages if they choose not to participate in SMALL, and will not continue if they decide to leave the process; it will stall/die.

On the other hand, 5GA, unlike SMALL, does not have discernible hubs in its stakeholders. They are all equally dependent on each other. Moreover, if, for example, the network provider leaves 5GA, another one could be recruited.

4.5. Change over Time from Interactions Through the Complexity Mechanisms

This section will summarise the changes over time from interactions through the complexity mechanisms. As previously mentioned, due to their open system mechanism, rural areas needed to adapt to their environment; that is why SMALL and its two precursor projects started. The three research projects mark transition points in how the overarching DI process works. In the pre-study, LTU was the driver, where they utilised the open system mechanism by reaching out and conducting focus groups to gather information on the needs in rural areas. Digiby is the research project where the actual work to start the pilots happened. LTU was still the driver in reaching out to get villages and municipalities to join. Once they joined, LTU utilised the nested system mechanism to collaborate with the villages. They used the gathered needs from the pre-study to offer ideas and tools to the villages. In SMALL, due to the success of the pilots and the widespread promotion of Digiby, a gradual transition happened to a distributed control mechanism. Self-organisation patterns could be seen, where now, villages and municipalities reach in through the open system mechanism and ask to join SMALL, the needs and ideas come directly from the villagers, and in some villages, they are the initiators of their pilots.

Moreover, the success of Digiby caused a non-linear output; while the DI process was constantly expanding by adding new villages or new tools, the boundaries of the DI process were drastically redefined by adding Västerbotten to SMALL. Prior to that, the DI process targeted only Norrbotten. Focusing on the sub-DI processes, non-linearity could also be witnessed. The children now enjoy the responsibility of managing the youth building on their own. A hybrid supermarket DI process has changed the outlook of the villagers; there is now hope that people will not move to cities. Small ideas in one pilot propagated to more pilots and future ventures. The youth building manager, sharing her experience, encouraged other villages to participate. In a three-service-point DI process, what started as a service point sharing information about activities in the neighbouring Finnish village on screens is now a plan for a cross-country research project. On the other hand, interviewees perceive that the path of progress in SMALL could be hindered due to resisting villagers or stopping if the villagers abandon or do not take full responsibility for their sub-DI processes after SMALL is over.

The 5GA is a product of previous collaborations between the stakeholders. Thus far, it has changed by adding new collaborators and goals. They have steady progression in their sub-DI processes of developing the 5GTN, Edge cloud, and use cases. Even though they are constantly innovating, we note that, unlike the transition in how SMALL's DI process

works, there has been no change in how 5GA's DI process works. We assume that this is because the stakeholders are incumbents in DI processes. They are used to a certain way of working and collaborating. The stakeholders likely already went through transitions in how they worked in past DI processes. In comparison, SMALL as a concept is new to villages and municipalities in rural areas. They initially needed more guidance from LTU than later in the DI process.

5. Discussion

In the DI process, stakeholders are connected and interact through the complexity mechanisms; as such, the mechanisms are initially formulated, i.e., new nests, hubs, etc., at the start of the process, when the project managers or orchestrators decide whom to involve in the DI processes and who would collaborate together. Then, during the DI process, new mechanisms are created, and older ones are reformulated with the addition/removal of stakeholders, their interactions, and the formulation of new collaborations.

5.1. Different Shapes of the Complexity Mechanisms

The two case studies differ in how the complexity mechanisms are utilised. Both DI processes are nested because they are composed of sub-DI processes that are composed of sub-DI processes. Both case studies show interactions through their nested systems mechanism. The cases have nests where the stakeholders belong to and interact with more than one DI process on the same level [14], e.g., in SMALL, the university is part of the service point, hybrid supermarket, and youth building DI processes. Both case studies have stakeholders interact across levels with higher or lower level systems [57]. Stakeholders from one sub-DI process interact with stakeholders from other sub-DI processes (e.g., tool-specific networks) and with the main DI process (e.g., project-wide meetings). However, in SMALL, the sub-DI processes, while independent, are connected through networks or through LTU as a linchpin. In contrast, in 5GA, the sub-DI processes depend on each other.

As previously mentioned, open systems allow for interactions between the focal DI process and its environment [54]. This can be seen in SMALL, where the stakeholders actively exploit the open system mechanism to interact with stakeholders in its environment to expand, while in 5GA, the interaction with the environment is opportunity-based. While the two DI processes have no central control [14,54], they have different approaches for their distributed control mechanism. SMALL is bottom-up, where the villagers collaborate on their sub-DI process with the university and municipalities. The 5GA project has a laissez-faire approach; each stakeholder is either responsible for their sub-DI process or collaborates. Both have financers as hubs. SMALL also has LTU, Katherine, villagers, municipalities, and idea champions as hubs, while 5GA's stakeholders are equally dependent.

5.2. The Complexity Mechanisms Fostering and Hindering Innovation

In both case studies, interaction through the complexity mechanisms has led to change, including (1) change as innovation, (2) change in how the DI process works, and (3) change as boundary redefinition. While 5GA has steadily changed, SMALL has seen both steady change and evolution. Some might disagree that adopting tools like digital locks and screens is an evolutionary DI. However, as one of the interviewees stated, "You do not have to reinvent the wheel if it's already spinning somewhere". While to some, using these tools is nothing new, to the villagers, in the given setting, it was, and it led to drastic changes in the villages. Moreover, innovation could be radical or incremental [40].

The open systems mechanism of DI processes means that the environment can foster DI as a trigger, an inspiration, or it can be a hindrance to the process. A stakeholder might start a DI process to adapt to the conditions in the environment [17]. While in the DI process,

stakeholders could take inspiration from similar DI processes in the environment, they could also use their experience from their external work, and vice versa. However, sharing time with the stakeholders' external work could hinder the DI process. Stakeholders also need to ensure that they do not use one role to inappropriately affect the other, e.g., making a decision in one role to benefit the other at the expense of making the right decision in that situation. The DI process could also be hindered by competitors or resistance from opposers of the DI process. Furthermore, an unpredictable environmental disruption could either inspire (e.g., the launch of ChatGPT), leading to new ideas in the DI process or even triggering new DI processes, or disruptions can hinder (e.g., the pandemic) the DI process. Hindrance from the environment could lead to the DI process ceasing to exist, for example, if villagers moved to the city for better accessibility to services and technology. DI processes also affect the environment; other stakeholders might take inspiration from the DI process and start their own. The stakeholders holding the orchestrator role are a key resource for communication with the environment.

The nested systems and distributed control mechanisms of DI processes make different stakeholders have different boundary judgements of what constitutes the DI process [17]. In SMALL, LTU has a bird's eye view and thus defines the DI process to encompass all pilots, while stakeholders who are working on specific pilots see SMALL as only their sub-DI process. Any other pilots are considered another external entity. Consequently, there could be a silo effect, where the stakeholders might not have knowledge beyond their sub-DI process because stakeholders might only have access to local information [54]. Moreover, orchestrators and project managers might find it challenging to gather information and contribute to all sub-DI processes. The stakeholders in 5GA are experienced in the DI and technology fields; thus, even though they do not have explicitly defined responsibilities, they know how to work in distributed control. However, inexperienced stakeholders, like the villagers in SMALL, might need clearer definitions of their roles. One of the interviewed villagers stated, "I asked Katherine, what can we do? Katherine told me, no, but it comes from you. But I kind of do not know what really fits in the package".

Thus, DI processes need orchestration to facilitate communication, connect stakeholders, find potential collaborators, disseminate knowledge, and offer guidance. In addition, being transparent and keeping documentation could help stakeholders know what is happening in the DI process and where they could contribute and collaborate.

On the other hand, nested systems and distributed control could foster DI. In 5GA, they enable the different stakeholders to work on their core competencies while collaborating with others with competencies they could benefit from. In SMALL, the villagers having their own sub-DI process, enabling them to adapt the large scale of the overall DI process to fit the local needs and challenges. The villagers are free to refuse ideas and responsibilities that do not fit their needs. The villagers feel ownership of their sub-DI processes, although some of the interviewees have voiced concern about the propriety of the tools after the project ends, as they are funded by the project rather than the pilots. Also, distributed control fosters creativity as it is not strict. Innovation could come from anywhere instead of being top-down; for instance, the youth building DI process was initiated by the youth building manager rather than LTU suggesting it.

Hubs are an unavoidable double-edged mechanism. On the one hand, they foster DI by providing connections [54], resources, skills, and knowledge that are otherwise unattainable. On the other hand, there is a risk of losing access to those things if the hub leaves the DI process. This reliance on the hubs could cause them to have disproportionate power and might hinder distributed control. In DI processes stemming from research projects, financers fund the processes based on predetermined deliverables and periodic progress reports. That is unsuitable for bottom-up processes that rely on the unpredictability

of unknowns, like which villages will participate, what needs they will have, and what tools they will use? During Digiby, LTU could not predict the answers to these questions beforehand to includein the project proposal. Consequently, the financer rejected adding new pilots or tools that did not fall under the predetermined deliverables. A more flexible financer was chosen for SMALL to accommodate the unpredictability. It should be noted, however, that without Digiby's success—arguably due to its bottom-up approach allowing for the unpredictability of a need-driven approach—no financer would have taken the risk of working on such an unpredictable venture.

These four complexity mechanisms might foster (summarised in Table 3) or hinder innovation; the open-nested distributed control nature and the hubs provide the setting for interaction and collaboration across levels and with the environment to innovate. Interaction helps in ideation, as other stakeholders might have valuable ideas. Interaction gives access to resources, knowledge, and skills that are not in your possession, especially for smaller stakeholders like the startups in 5GA (i.e., the drone sensor provider). Even if the collaboration entails simply sharing their experience in seminars, it can reduce isolation. Stakeholders can obtain inspiration, learn new skills, help each other in problem-solving, and feel encouraged to pursue their ideas if they see others' success.

Table 3. Summary of how interaction through complexity mechanisms fosters DI.

Complexity Mechanism	Fostering DI
Open systems	• Trigger innovation for adaption. • Trigger innovation in the environment. • Take inspiration from similar DI processes. • Take inspiration from disruption in the environment, e.g., ChatGPT. • Use their experience from the stakeholders' external work and vice versa
Nested systems and distributed control	• Stakeholders can concentrate on working on their core competencies. • Benefiting from other stakeholders' competencies. • Foster creativity. • Adapt the overall DI process to local needs. • Innovation could be need-driven instead of top-down to fit needs. • Ownership over sub-DI processes (i.e., the part the stakeholder contributes to in the DI process). • Innovation could come from anywhere instead of being top-down. • Stakeholders can refuse ideas and responsibilities that do not fit their needs.
Hubs	• Provide otherwise unattainable connections, resources, skills, and knowledge.

6. Conclusions

DI is complex; however, research thus far has focused on the complexity of DI ecosystems. In this paper, we conducted two case studies that contributed to the theory of DI by shifting the focus from the ecosystems where stakeholders interrelate, co-exist, and co-evolve to implement, develop, exploit, and reuse DTs [6,7,11,31–34] to the complexity of the DI processes that these stakeholders go through to innovate [5,35–37], where DI processes lead to DI and the DI ecosystem to come to be through the initial implementation and development, or DI processes within the already existing DI ecosystems which can

co-evolve the ecosystem through reuse. We highlighted that DI processes get their complex nature from complexity mechanisms in their structure, i.e., nested systems, open systems, distributed control, and hubs. We also highlighted that stakeholders could exploit this complex nature by interacting through the complexity mechanisms to foster DI. We also found that change could occur in how the DI process works, in boundary redefinition, or change as innovation.

This could help researchers understand the complexity of the DI process to further research how the DI process' complexity causes change and innovation. With this understanding, researchers and practitioners could exploit the complexities to innovate, for example, by actively interacting with stakeholders in the environment for inspiration or potential collaboration. They also need to understand what complexity entails to manage it and avoid its pitfalls that cause hindrances. Moreover, although it is not the aim of this paper, complexity orchestration is important to handle nestedness and distributed control.

It should be noted that our findings mainly focused on each complexity mechanism separately, even though they are not mutually exclusive. We only made connections when we saw them, but future research could focus more on the connections between them. Furthermore, future research could focus on the orchestration of DI processes or on strategies to avoid their pitfalls.

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Abbreviations

The following abbreviations are used in this manuscript:

DI	Digital innovation
DT	Digital technology
ICT	Information and communication technology
HST	Hard system thinking
ANT	Actor-network theory
SST	Soft system thinking
LL	Living lab
IPO	Input–process–output
SoS	System of systems
5GA	5G automation
SMALL	SMArt Livskraftig Landsbygd
LTU	Luleå University of Technology
5GIHN	5G Innovation Hub North

QCA	Qualitative content analysis
WP	Work package
5GTN	5G telecommunication network
UVs	Unmanned area vehicles

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