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Collaborative innovation for sustainability in Nordic cities

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ABSTRACT

New integrative, collaborative, and innovative approaches are needed to overcome global sustainability challenges. Exploring the diversity of collaborative innovation in six Nordic cities, this study aims to advance our understanding of collaborative innovation for sustainability in urban contexts. By adopting a multiple case approach, we investigate 49 cases aiming at collaborative innovation for sustainability, including co-working spaces, Fab labs, green public procurement, hackathons, hubs, makerspaces, participatory budgeting, and living labs. Our findings reveal a diverse range of models supporting collaborative innovation for sustainability. Further, we develop a conceptual framework that identifies four archetypes of collaborative innovation and apply it to analyse how those archetypes advance sustainability. The results illustrate how collaborative innovation archetypes contribute to sustainability in urban areas.

1. Introduction

Global sustainability challenges are sparking fierce debate in the contemporary society. Cities are viewed as particularly important arenas for sustainability issues because most of the population across the globe live in urban areas, and urbanization is likely to continue over the coming decades. While cities around the world increasingly contribute to combatting the global climate change, they face numerous local environmental and social challenges, including air pollution and crowding, traffic congestion, noise, safety issues and poor housing conditions, along with increasing educational and socioeconomic divide (Nevens et al., 2013; Hofstad and Torfing, 2015; Kılkış, 2016).

Sustainability encompasses simultaneously environmental protection, economic performance, and societal welfare (Glavic and Lukman, 2007). Subsequently, previous literature provides numerous and versatile definitions of sustainability (cf. Brundtland Commission, 1987; Glavic and Lukman, 2007; Johnston et al., 2007). The 1987 report of the World Commission on Environment and Development provided a useful definition of sustainable development as *"meeting the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland Commission, 1987).

Innovation is crucial to achieve diverse global sustainability goals (Hall et al., 2018; Lupova-Henry and Dotti, 2019). However, policymakers and academics have extensively debated about suitable strategies and innovation approaches to encourage sustainability (Boons and Lüdeke-Freund, 2013; Lupova-Henry and Dotti, 2019). For example, cities increasingly innovate for sustainability with diverse actors (Sørensen and Torfing, 2011) by establishing living labs that are *physical and virtual environments in which various stakeholders aim at solving challenges via collaboration and collective ideation* (Hossain et al., 2019; Steen and van Bueren, 2017; Leminen et al., 2017).

Therefore, this study focuses on how collaborative innovation (CI) models contribute to sustainability in urban contexts. In line with Najafi-Tavani et al. (2018: 193), we consider CI as *"the actor's interaction and co-creation with different parties such as, but not limited to, suppliers, customers, competitors, and research organizations for the purpose of developing new services and products"*. Drawing on Liedtke et al. (2015), this study emphasizes the role of different "CI models" as means for social interaction and innovation processes in which users and other actors participate in collaboration for sustainability innovation.

This point of interest has been already identified in the sustainability literature. It has been argued that innovation for sustainability is becoming increasingly collaborative, user-focused, and open to the co-creation of solutions (Inigo and Albareda, 2016). Due to growing

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concerns regarding sustainability in cities, new integrative and collaborative approaches to innovation are essential (Kılkış, 2016). CI is an important vehicle for the promotion of sustainability in urban contexts (Kreijns et al., 2018; Rodrigues and Franco, 2018; Zimmerling et al., 2017). By 'CI models' we refer to the variety of the structures or methods that are used for CI purposes. The innovation landscape of urban contexts has witnessed numerous CI models, including Fab labs, demonstration sites, hackerspaces, hackathons, participatory budgeting, and living labs.

Prior studies have not only demonstrated how CI models foster sustainability (Hamalainen et al., 2018; Kreijns et al., 2018; Niaros et al., 2017; Rainville, 2017), but have also identified research gaps regarding CI and the urban context. For example, it is unclear how seemingly different CI models relate to each other, canvasing similarities and differences (Leminen et al., 2019). The implications of urban contexts for CI models remain mostly unexplored (Bergvall-Kåreborn et al., 2015; Dourish, 2006). More specifically, a wider discussion that crosses boundaries of CI models and the urban context connecting diverse stakeholders for sustainability is largely missing in the literature (Leminen et al., 2020).

While much of the research on CI models focuses on the interaction between two actors, literature on multi-actor networks in terms of regional, industry or research collaborations that enable organizations to discover and commercialize innovations is scarce (West and Bogers, 2014). Scholars point out that it is crucial to understand the organization and implementation of CI models (Tucci et al., 2016). Although collaboration for innovation is diverse, research is scarce on comparing different CI models that focus on sustainability. Also, we still have limited knowledge on the performance of different CI models aiming at sustainability in cities.

By addressing the research gaps, this study aims to understand the CI for sustainability in urban contexts by exploring and conceptualising the diversity in CI models. Our specific objectives are as follows: 1) classify the different CI models into archetypes and analyse their main characteristics, and 2) analyse the implications of CI archetypes on sustainability in cities. The study applies a two-step research design, consisting of development of a conceptual framework based on CI literature and testing the framework with a qualitative approach.

The study contributes to the literatures on sustainability and CI in multiple ways. *First*, it develops a conceptual framework on CI models in urban contexts. *Second*, it identifies four archetypes of CI and discuss their relations to each other. *Third*, it advances the concepts of "space" and "place" emphasising the role of urban contexts in CI models for sustainability. *Fourth*, it puts forward the relevance of CI for sustainability in urban contexts.

The article is organized as follows. Next, it reviews previous literature on CI models to construct a conceptual framework for analysing CI archetypes and CI for sustainability. Then, it describes the methodology and data collection. Thereafter, it analyses the collected data by applying the framework and discusses the findings of a multi-case study of CI for sustainability. Finally, it provides implications and suggests further research avenues.

2. Theoretical background

Until the 1970s, sustainability referred to a firm's profitability and long-term survival, and it was only later that the environmental and societal aspects were added (Gavrilescu, 2004). In 2015, the United Nations General Assembly launched 17 sustainable development goals, including poverty, climate change, peace, and justice (United Nations, 2015). Unsurprisingly, previous literature is inconsistent about definitions, constructs and dimensions of sustainability (cf. Moore et al., 2017; Saunila et al., 2018). However, the sustainability concept is typically compiled around three interlinked pillars: environmental, economic, and social (Glavic and Lukman, 2007; Saunila et al., 2018; Hutchins et al., 2019; Purvis et al., 2019).

A seminal definition of "environmental sustainability" by Goodland (1995) refers to "*improving human welfare by protecting the sources of raw materials used for human needs and ensuring that the sinks for human wastes are not exceeded, to prevent harm to humans*". It describes the maintenance of natural capital contributing to the quality of the environment on a long-term basis (Vintro et al., 2014). "Economic sustainability" can be observed from at least two aspects: financial performance of companies (e.g., cost reductions) and that of external stakeholders (e.g., improving citizen's wellbeing) (Sheth et al., 2011; Saunila et al., 2018). Following McKenzie (2004), "social sustainability" is "*a positive condition within communities, and a process within communities that can achieve that condition*". It describes the wellbeing of people and their right of being cherished members to improve their living conditions, including human capital development, job creation, health and safety (Castillo et al., 2007; Holden, 2012; Saunila et al., 2018).

Previous literature describes a variety of CI models, including coworking spaces, hubs, testbeds, makerspaces, green public procurement, public–private–people partnerships (4Ps), quadruple helices (QH), hackathons, and urban living labs (cf. Bogers et al., 2017; Leminen et al., 2017). Despite the diversity of such CI models, there is little research that would compare those models or study the performance of different models. Further, West and Bogers (2014) argue that prior research on CI focuses on the dyadic interaction between two actors, whereas complex networks in terms of regional, industry or research collaboration that enable firms to discover and commercialize innovations are ever more common today.

In specific, living labs is a CI model gaining growing attention in sustainability studies (Greve et al., 2020; Leminen et al., 2017). Many projects testing living lab methodologies focus on urban sustainability and low carbon challenges (Evans and Karvonen, 2011; Voytenko et al., 2016). Previous research (Nyström et al., 2014; Leminen et al., 2017; Nevens et al., 2013) shows that living labs can enhance innovation to improve people's lives in smart city initiatives that emphasise environmental and social sustainability. Thus, this article recognizes the importance of living labs and defines them in accordance with Westerlund and Leminen (2011, p 20) as "*physical regions or virtual realities, or interaction spaces, in which stakeholders form public–private–people partnerships (4P) of companies, public agencies, universities, users, and other stakeholders, all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts*".

Sustainability studies have proposed diverse conceptualisations for living labs, especially in urban contexts (Martin et al., 2018; Voytenko et al., 2016). Voytenko et al. (2016) note that urban living labs for sustainability initiatives have varied objectives and apply numerous types of innovation methods. Keeping in mind the generic definition of living labs, living labs have specific characteristics in the urban context. *First*, they are sociotechnical platforms with shared resources, collaboration framework, and real-life settings that enable CI (Ballon et al., 2018). *Second*, they include various innovation structures and networks, resulting in diverse CI that engage diverse and multiple stakeholders aiming at innovation together (Leminen et al., 2017). *Third*, they emphasise the diversity of CI activities and methods aligned with representative governance and open standards (Westerlund et al., 2018). *Fourth*, they consider CI outcomes to include new knowledge, validated solutions, professional development, and social impacts specifically on urban contexts (Hossain et al., 2019).

Prior literature has called for more research on innovation for sustainability in real-life settings (Caniglia et al., 2017; Hossain et al., 2019). All these descriptions of living labs especially in urban contexts depict living labs as platforms for open and collaborative innovation, thus enabling wide social interaction and challenging former innovation practices. Besides living labs, previous research has explored numerous other CI models. Appendix A shows definitions and classifications of selected CI models based on the literature review. The following section will further discuss the theoretical background to build a framework for

analysing the diverse CI models.

2.1. Theoretical background of the framework

Drawing on the literature on CI for sustainability, the present study identified four distinct groups of articles (see Chapter 3 on research design). The articles were grouped into four groups based on i) the role of innovation context and ii) the number of stakeholders. The concepts of 'space' and 'place' were used to address different contexts, and 'dyadic' and 'multifold' types of relationships to refer to the number of stakeholders. To design and interpret innovation contexts, several factors such as innovation activities, location, and structure are essential to understand 'space' and 'place', (Bergvall-Kåreborn et al., 2015). The concept of *space* is characterized by objectivity and scholarly knowledge (Dourish, 2006), while *place* encompasses culture, a sense of subjectivity, practical knowledge, and tradition (Schultze and Boland, 2000).

A space turns into a place when activities and meanings are attributed to a particular situation (Harrison and Dourish, 1996). For example, an urban real-life context is a place. It has meaning for those who live in the city and, thus, we term it as a place (Dourish, 2006). The soul of a place is formed largely by people's experiences with it, and a place represents a sense of belonging (Alexander, 1979; Harrison and Tatar, 2008). Further, norms and practices may create a sense of place even though they are not necessarily related to a geographical location (Harrison and Tatar, 2008; Massey, 1994). For example, living labs can transform into different places based on involved actors, selected methods, and provided facilitation as well as applying the principles of openness and realism in diverse spaces (Bergvall-Kåreborn et al., 2015). In living labs, a real-life context such as a place becomes a crucial part of the CI model; meanings entangled in the context influence innovation endeavours and steer the outputs of CI (Leminen et al., 2020). Space and place are two important parameters to assess the innovation context of different CI models. Space helps to understand the purpose of an initiative and prior level of academic knowledge related to it, and place means important environment to implement that knowledge in practice. Hence, considering space and place together can provide a holistic understanding of CI for sustainability.

In dyadic relationships, two stakeholders are involved in innovation activities, while in *multifold* relationships, more than two stakeholders are involved (Leminen et al., 2017). Dyadic relationships are common in various CI models, such as testbeds (Ballon et al., 2018), co-working spaces (Fuzi, 2015), makerspaces (Bradley, 2018), and Fab labs (Hamalainen et al., 2018). However, *multifold relationships* encompass typically triple helix and quadruple helix models (Carayanis and Campbell, 2010) as well as public–private–people partnerships (4Ps) (Torvinen and Ulkuniemi, 2016). Understanding the nature and the number of stakeholders is important to know, because various dimensions that are essential to consider attain a well-rounded perspective of the dynamics in CI initiatives. Without knowing the number of stakeholders and their roles in CI initiatives, it would be challenging to gain a comprehensive understanding of CI initiatives and their values for sustainability in urban contexts.

For granular understanding, we categorised the selected articles about CI for sustainability into four groups, which are the basis for the CI archetypes in the proposed framework (Fig. 1). The first group of articles, referred to as (I), focuses on narrow social interaction in dyadic relationships and development activities in the context of "space", characterized by objectivity. The CI literature offers a broad discussion of testbeds and co-working spaces in urban contexts. A *testbed* is a standardized setting to test products, services, and technologies. *Co-working spaces* are shared, proactive, and community-oriented workspaces existing in accelerators, incubators, or existing business structures such as art centers, coffee shops, and serviced offices (Fuzi, 2015). Such collaborative work settings support shared flexible facilities and access to a network of professionals and entrepreneurs. Co-working spaces may contribute to an interaction between actors through

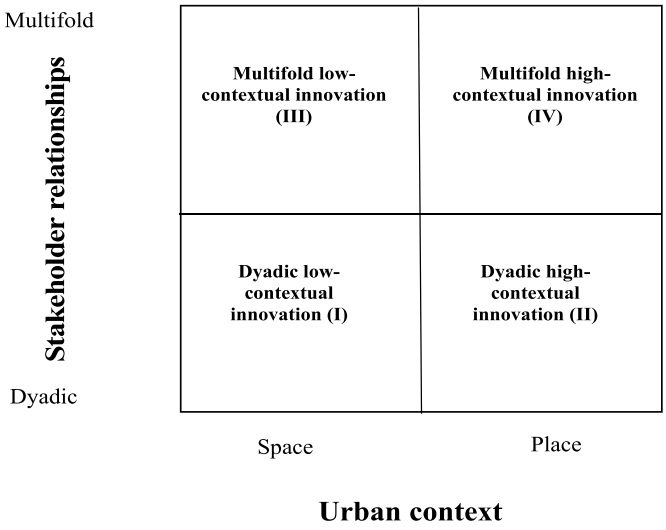

Fig. 1. A conceptual framework on CI in urban contexts.

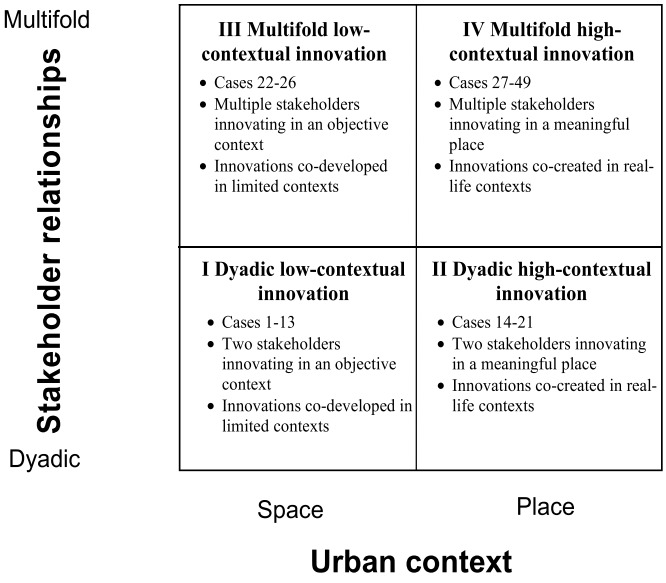

Fig. 2. Synthesis on the analysed CI cases for sustainability in urban contexts.

spaces, projects, and events (Capdevila, 2015). However, co-working space has a relatively insignificant contextual role in enhancing innovations as people share spaces and facilities but do their own things. Libraries and public open spaces are increasingly seen as '*hubs*' or 'makerspaces', where "spaces" support not only creative production such as entrepreneurial activities, but also social gathering for targeted learning (Leorke et al., 2018). The study labels the first group as '*dyadic low-contextual innovation*'.

The second group of articles referred to as (II), also focuses on narrow social interactions and dyadic relationships, but development activities are realised in a deeper contextual setting, where a "place" is characterized by subjectivity and creates meaning for participants in CI. Among other models, the literature describes practices such as Fab labs, and hackerspaces that fall under this group. Participatory budgeting and green public procurement also belong to this group, because they rely on dyadic relationships, but focus on development of places with meaning for participants. *Makerspaces* stem from the do-it-yourself (DIY) movement whereas *hackerspaces* rely on the hack culture (Bradley, 2018; Kohtala and Hyysalo, 2015). *Fab labs* enable access to tools for digital fabrication (Hamalainen et al., 2018) for individuals to design and

produce their own products using small-scale digital manufacturing devices for their own purposes (Gershenfeld, 2008). These settings share the values of collaboration, openness, community, accessibility and sustainability, and environmental impacts of green procurement (Cheng et al., 2018). Fablabbing fosters local communities to utilize local resources in a responsible and sustainable way (Kohtala, 2015). Maker practitioners increasingly assess the environmental sustainability and represent themselves for design-friendly conditions (Kohtala and Hyysalo, 2015). *Participatory budgeting* assumes that citizens are direct decision makers in their local urban contexts (Santos, 1998). Non-elected citizens participate in the allocation of public funds and make financial or budgetary decisions on a municipal and neighbourhood level (Sintomer et al., 2008). G*reen public procurement* stimulates innovations by given standards of green products and services, adapted to local contexts and meaningful places (Rainville, 2017). Hence, municipalities adapt green public procurement in their dialogue with companies who provide tenders for city operations and real-life needs to meet environmental considerations in bid processes. (Uttam and Le Lann Roos, 2015). We labelled the second group relying on deeper contextual real-life settings as '*dyadic high-contextual innovation*'.

The third group of articles, referred to as (III), illustrates the shift from dyadic to multifold stakeholder relationships, elaborating broader perspectives, social relationships, and resources brought in by multifold stakeholders involved in CI and development activities in the context of a space that is characterized by objectivity. The literature discusses such models as *3Ps, 4Ps, triple helix, and quadruple helix*. 3Ps and 4Ps are two models that are increasingly used for urban development (Hodge and Greve, 2007; Torvinen and Ulkuniemi, 2016; Roehrich et al., 2014). Also triple helix and quadruple helix are key concepts that contribute to sustainable urban development. Deakin and Reid (2018) examine sustainable energy consumption in smart cities applying the triple helix model and Smol et al. (2018) discuss circular economy by quadruple helix model. Hodge and Greve (2009) view 3Ps model as cooperative institutional arrangements between public and private sector actors. Van Ham and Koppenjan (2001) assume a model where public and private actors commonly develop products and services and share risks, costs, and resources. There are many stakeholders involved in innovation activities, leading to broad perspectives, resources, and social interaction. Some of these CI models are unlinked to real-life settings, and consequently, the space has a relatively insignificant contextual role in enhancing innovations; thus, we labelled the third group as '*multifold low-contextual innovation*'.

The fourth group of articles, referred to as (IV), focuses on broad perspectives, social relationships, and resources with multifold stakeholders involved in CI and development activities in real-life settings, that is, in a place that has meaning and subjectivity. Such CI models include demonstration sites, hackathons, urban transition labs, living labs and urban living labs. For example, a *demonstration site,* built in a local real-life setting, may foster technologies for waste management (Kreijns et al., 2018), clean energy technologies and adaption of eco-innovation (Bossink, 2018; Heiskanen et al., 2015). *Hackathons* have progressively been adapted for intensive and collaborative but short-term events to foster learning and CI between numerous and diverse stakeholders, developing solutions for practical challenges (Lyndon et al., 2018). Perng et al. (2018) propose that hackathons foster making living more sustainable in smart cities, as hackathons aim at providing solutions for given creativity and innovation challenges. *Urban living labs* (ULLs) address numerous sustainability challenges (Camere and Karana, 2018; Martin et al., 2018). ULLs are slightly different from conventional living labs because they explicitly focus on finding sustainable solutions for pressing problems such as energy and climate change in urban contexts such as cities (Nevens et al., 2013). ULLs help cities accelerate sustainable transactions (Steen and van Bueren, 2017). In these examples, the place has an important contextual role in enhancing CI, and therefore we labelled the fourth group as '*multifold high-contextual innovation*'.

2.2. Framework for analysing diverse CI models

As pointed out above, the constructed framework (Fig. 1) employs the concepts of "space" and "place" to better understand different innovation contexts (Bergvall-Kåreborn et al., 2015). Applying the 2-by-2 matrix approach that requires two descriptive dimensions, each with discrete and reflective options, the framework builds on two chosen dimensions in CI, namely "stakeholder relationships" and the "urban context" (cf. Bergvall-Kåreborn et al., 2015; Westerlund and Leminen, 2011; Cloke et al., 1991).

This framework exhibits four CI archetypes, and it is useful to map out and categorise different CI models for sustainability. For example, multifold relationships in triple-helix networks foster innovation (Ivanova and Leydesdorff, 2014), and broad social interaction in multifold relationships may lead to improved innovation outcomes (Russell and Smorodinskaya, 2018). Further, broad social relationships have deep implications, especially for social sustainability (Nyström et al., 2014; Leminen et al., 2020).

The urban context dimension includes space and place. Bergvall-Kåreborn et al. (2015) argue that place signifies things that are challenging to transfer and replicate. It comprises three features, namely investment in value and meaning, location, and material form. The place often reflects innovation activities, and experimentation may change the direction of innovation activities. The essential prevalence of real-life contexts brings along environmental considerations, that is, real-life settings tend to have a substantial emphasis on environmental sustainability (Greve et al., 2020). Hence, the selected framework categories are an important basis to assess sustainability of different types of CI initiatives.

The next sections after presenting the research design, analyse diverse cases that represent archetypes of CI based on their urban contexts (space and place) and stakeholder relationships (dyadic and multifold) as illustrated in Fig. 1.

3. Research design

This study applies a two-step research design, consisting of development of conceptual CI archetypes based on CI literature, and after that with a qualitative approach, we have tested the conceptual framework. In the first step, for the purpose of understanding the diversity of CI models we draw various innovation and development endeavours for sustainability. We searched for CI literature related to concepts of co-working space, hub, testbed, Fab lab, hackerspace, makerspace, participatory budgeting, green public procurement, innovation intermediary, public-private partnership (3P), public-private-people partnerships (4Ps), triple helix (TH), quadruple helix (QH), demonstration site, hackathon, living lab, urban living lab (ULL), and urban transition lab in city contexts (cf. Bogers et al., 2017; Leminen et al., 2017).

We chose these concepts because extant on CI research suggests such models for understanding sustainability in cities (cf. Camere and Karana, 2018; Cheng et al., 2018; Kohtala and Hyysalo, 2015; Hamalainen et al., 2018). We went through literature focusing on various CI models applied for sustainability purposes in urban contexts (cf. Hossain et al., 2019; Greve et al., 2020). Rather than conducting a bibliometric or systematic literature review, we searched for relevant peer-reviewed scientific research articles written in English language in three research databases, namely Scopus, Web of Science and Google Scholar. Because of the variety of CI models, we used the following search strings: "collaborative innovation & co-working space", "collaborative innovation & hub", "collaborative innovation & testbed", "collaborative innovation & Fab lab", "collaborative innovation & hackerspace", "collaborative innovation & makerspace", "collaborative innovation & participatory budgeting", "collaborative innovation & green public procurement", "collaborative innovation & innovation intermediary", "collaborative innovation & public-private partnership", "collaborative innovation & public-private-people partnerships", "collaborative

innovation & triple helix", "collaborative innovation & quadruple helix", "collaborative innovation & demonstration site", "collaborative innovation & hackathon", "collaborative innovation & living lab", "collaborative innovation & urban living lab", "collaborative innovation & urban transition lab". After identifying CI articles, we used separate search terms "Sustainability", "Environmental sustainability", and "Social sustainability" to identify sustainability as well as its environmental and social dimensions in the selected CI articles. Besides that, we applied the snowballing technique to add articles based on the read articles. After that, we selected and classified relevant CI literature by themes to reveal how various CI models are used for sustainability in urban contexts. We included the papers that revealed the role of CI models for sustainability and excluded the papers that focused on other aspects such as technology or did not concern with urban contexts. The preliminary decision of inclusion was based on the article titles, and after reading the abstracts, two of the researchers looked through around 200 papers, read thoroughly almost 100 papers, and selected 31 papers based on which the framework was built.

Next, we applied a qualitative multiple case study technique and well accepted criteria and their tactics for case studies including construct validity (using multiple sources of evidence), external validity (replication logic), and reliability (case study protocol, data set for case studies) (Yin, 2011, see p. 33), based on structured interviews with 118 informants in European urban CI contexts (see Appendix C, Cases). The case study approach is useful because it allows the researchers to address several research questions or objectives simultaneously (Jensen and Rodgers, 2001). Inspired by previous debate on the "lab" versus "living" in real-life settings (Ballon et al., 2005; Veeckman and van der Graaf, 2015), living labs in urban contexts were selected as a research setting. Living labs involve heterogeneous participants and contribute to our understanding of a novel and sparsely explored perspective to sustainability (Leminen et al., 2017). According to Yin (2011), using the case study approach requires primary data collection to orderly create a data set. Hence, the present study relies on interviews to create a data set of CI participants' narratives.

The interviews were mainly focused on single, isolated cases, but covered elements from other cases as well. The interviewees were drawn from 49 cases in six cities of a Nordic country. The population of these cities varies from about 200,000 to 700,000. We label the country as Nordic (European country) for the confidentiality reasons of CI cases and their representatives. We chose these cities to explore the various CI models that support sustainability in *urban* contexts. In general, Nordic countries are frontrunners not only in contributing to the living lab movement, but also in advancing sustainability. Therefore, they offer an interesting context to study the diversity of CI, and the use of CI for sustainability (see, for example, Hossain et al., 2019; Nyström et al., 2014; Leminen et al., 2017). Prior research in a similar context is beneficial, as Yin (2009) argues, because this allows for comparability with other research findings on the topic(s). Case selection criteria for the cases in this study were as follows: each case should (a) exemplify CI endeavours, (b) engage multiple actors to develop a product, service, concept, or innovation, (c) have diverse collaborative activities in urban contexts, and (d) facilitate CI for environmental or social sustainability in the urban context.

3.1. Data collection

The interviews were conducted face-to-face in 2017, each interview ranging from 60 to 90 min. The interviewees were involved with various CI models, and included CEOs, citizens, civil servants, directors, managers, professors, and researchers along with project coordinators and technical specialists. While many interviewees were identified based on publicly available information suggesting their role(s) in a CI model, additional informants were identified and contacted based on the referrals by interviewees during the data collection. Thus, a sufficient number of interviewees could be reached to gain in-depth insight into each case. The interviews were recorded and transcribed for the purposes of analysis and interpretation.

Through the 118 interviews, rich information was collected on a variety of themes (cf. Patton, 1990) related to CI and sustainability by following case study protocol (see Appendix B, Interview themes). Following the suggestions in previous methodological research (Jensen and Rodgers, 2001), the chosen 49 cases were systematized to understand the diversity of CI models, their endeavours, and different actors in those cases (Leminen et al., 2012). Additional data on the cases were collected from secondary sources including bulletins, magazines, reports, and websites. Secondary data were used to further illustrate the investigated cases, gain additional insight on innovation activities, and verify any potential issues or inconsistencies emerging from the interviews. The identities of interviewees and details of the investigated cases are withheld in this article for confidentiality reasons.

3.2. Data analysis

Stakeholders, in terms of the interviewees and their organizations, are participants in CI models, and as such, the cases represent CI. Along with their innovation activities, they are the main unit of analysis in the study. Choosing this unit is in concordance with Yin (2011) who argues that previous research should guide the selection of the unit of analysis. In the present study, the stakeholders' narratives reflected both their own activities and those of others in the CI endeavours. The data analysis process included open coding, two-round focused coding, and theorizing from the collected data. Table 1 shows an overview of data analysis and the phases of the study.

We conducted a content analysis of the data, following the guidelines by Roberts (1997), Neuendorf (2002) and Elo et al. (2014). The results from the verbatim transcribed documents were coded by two researchers and results were compared collectively to ensure accuracy of data (Elo et al., 2014). The initial coding offered a preliminary understanding of innovation activities, and we identified a diversity of CI models. Thereafter, CI endeavours, urban contexts, and stakeholders for sustainability were identified. In this phase, the identified CI models were coded and compared by two researchers with previous studies, especially findings related to stakeholders (Leminen et al., 2012; Nyström et al., 2014) and contexts (Tuan, 1977; Bergvall-Kåreborn et al., 2015). Finally, the conceptual framework (Fig. 1) was used to understand how to develop the four archetypes of CI for sustainability (Fig. 2), and to arrive at the main findings. Reporting of the findings

Table 1
Data analysis process using qualitative multiple case study technique.

Data analysis phases	Task	Outcome
1. Open coding	• Organize data set • Identify CI models and informants	Overview of CI models: networks, informant, type of informant, and time of interview
2. Focused coding round 1	• Identify and briefly describe innovation activities in CI models	Overview on innovation activities resulted in identifying diversity of CI
3. Focused coding round 2	• Analyse innovation through the identified CI models and stakeholders as well as contexts • Special attention paid to innovations related to sustainability • Compare data to theory	Detecting CI through previously identified stakeholders (Leminen et al., 2012; Nyström et al., 2014) and contexts (Tuan, 1977; Bergvall-Kåreborn et al., 2015).
4. Theorizing the codes	• Synthesize phases 1 to 3: analyse identified modes in CI from sustainability perspective • Identify theoretical implications • Identify managerial implications	Classifying CI models resulting in (i) four archetypes of CIs and (ii) roles of archetypes for environmental and social sustainability (Fig. 2)

utilized quotations from the interview narratives, as suggested by Elo et al. (2014). The findings are elaborated in the following section.

4. Findings

The data were analysed by applying the framework (Fig. 2). The framework focuses on the multitude of social relationships and the characteristics of urban contexts, and it illustrates how diverse CI models support sustainability in different ways.

The framework demonstrates four CI archetypes: (1) dyadic low-contextual innovation, (2) dyadic high-contextual innovation, (3) multifold low-contextual innovation, and (4) multifold high-contextual innovation. In the following, we discuss sustainability and related actions through selected cases to exemplify each archetype and demonstrate how CI for sustainability takes place in them.

4.1. Dyadic low-contextual innovation

In the CI models belonging to the archetype of dyadic low-contextual innovation, two different stakeholders take part in the innovation activities for sustainability. Besides organizations, these innovation activities can involve a user community as a party. Stakeholder relationships in innovation and development activities are bilateral between the two participants. Because of the limited stakeholders, there are limited resources and perspectives involved, and their point of contact is not a real-life context, that is, the stakeholders do not attribute a specific meaning or experience to the urban context. Cases in the empirical material representing this kind of CI included co-working spaces, hubs, and makerspaces. In these cases, CI happen in collaboration between two actors or, for example, the city and its citizens. A space such as a library may serve as a hub where products or services are tested or validated by firms or the city. Typically, in these cases, even though innovation for sustainability may be expressed as the goal, in reality environmental and social sustainability are considered only to a certain extent, limited to, for example, testing sustainable services and products with citizens, however not in actual real-life settings. Citizens are rather passive, not active collaborators in this CI model. Furthermore, the space does not play an active role in the CI model. Examples include test settings for commercialization of products for elderly care or green buildings. Other examples are co-working spaces or shared laboratory facilities with shared resources and green office spaces for SMEs. Consider Case 2, where a hub serves as a prototyping setting, where a city collects experiences from sustainability aspects of products.

> *Prototyping environment where we can collect experiences from users … Then we focused on these kinds of socially significant innovations, where … for example … environment, sustainability, health, wellbeing … democracy, transparency, impact … we prioritized these kinds of things. (Case 2, Network Coordinator)*

Many makerspaces are in public libraries, where citizens can create and develop their own ideas or projects for sustainability. In the literature, a makerspace or hub is seen as an umbrella term and is positioned both into the archetype of dyadic low-contextual and dyadic high-contextual innovation. Here the makerspace or hub assume a space in a library where citizens create and develop their ideas by utilizing a broad variety of commercialized products and technologies enabled by a city.

4.2. Dyadic high-contextual innovation

The archetype of dyadic high-contextual innovation is based on stakeholder relationships, CI, and development activities between two stakeholders (actors, or groups of actors). Besides organizations, these innovation activities can involve a user community as a party. Comparing this archetype with the dyadic low-contextual innovation, the difference is that the dyadic high-contextual innovation occurs in a real-life setting with meanings or human experience. An urban context is often seen as an important and active element in innovation activities relying on the idea that users co-create, develop, validate, and test CI for sustainability. Accordingly, a group of user developers acts in real-life settings that are full of meaning and value (i.e., places), creating a source of an inspirational contextual setting.

We found different CI models, which could be identified belonging to the dyadic high-contextual archetype, including Fab labs, green public procurement, participatory budgeting, and user communities. A vivid example of aiming at sustainability is when a city uses a green public procurement process and arranges innovation competitions to find ideas for environmentally sustainable solutions. We address other examples of enhancing sustainability, where a city couples its procurement with a specific development or co-development activities and sharing costs or success between public and private parties. In addition, examples include participatory budgeting in the urban context. Participatory budgeting means that a city gives its citizens an opportunity to take part in its budgeting process, and citizens can make decisions on issues such as landscaping, trail maintenance, or leisure activities to directly affecting their real-life contexts. Participatory budgeting can be applied to a neighbourhood or a broader city area. For example, in Case 17 citizens take care of their own local forest, this thus an example of participatory budgeting enhancing citizen's active involvement in CI for social and environmental sustainability in a real-life setting.

> *An example of participatory budgeting could be that a citizen association … they could say that we can … take care of our forest work … So, the residents would have more responsibilities taking care of their own living surroundings. (Case 17, Maintenance Manager).*

Many of the cases employed a specific methodology, arranging innovation competitions for companies where ideas for better city services or for enhancing the city's dialogue with companies to develop and provide new sustainable products and services for the city and its needs are explored. Such models are called green public procurement. A city may bring an environmental and societal perspective in its procurement plans, encouraging CI while discouraging, for example, the use of material from rainforests or endangered species in furniture (Case 10).

> *My most important task is to bring responsibility issues into the city's procurement processes … We have this procurement law defining that, in every public procurement process, we have to take environmental and societal perspectives into account … We required tracking of wood; so that the suppliers had to have a method to show that the wood was not coming from illegal sources, such as rainforests or endangered species. (Case 10, Specialist)*

Further examples belonging to this archetype include user communities where citizens together with companies develop new environmentally and socially sustainable concepts. Also, Fab labs, where citizens or companies develop solutions for their own needs and share their outcomes with the Fab lab network are examples of dyadic high-contextual CI archetype. In the latter, environmental sustainability may be accomplished both through shared resources and sustainable solutions, while social sustainability is associated with developing and improving sustainability of community.

There were two actors or actor groups involved in these cases, while a real-life context, "place", is an active participant in CI. Case 18 describes a Fab lab where citizens or companies are not only developing solutions for their own problems but also share their results with the Fab lab network. Fab lab promotes local manufacturing, which reduces transportation of commodity.

> *We have a very active Nordic cooperation going on, and in several themes, we are involved in global cooperation, too. From Fab labs we are moving to Fab Cities … Fab City is a city that is committed to be materially independent by 50% on food, energy, and commodity production by the*

year 2054 … No other way reduces the carbon footprint enough. (Case 18, Manager)

Case 21 describes a community of youngsters that the city collaborates with for developing neighbourhoods. For example, Minecraft, a video game, was used as a platform to ideate, co-create, test, and validate the city neighbourhood by brick-and-mortar surroundings. This way, the community is encouraged to take an active role in CI endeavours of the city, but also responsibility of neighbourhood planning, development and preservation. Such co-creation supports social and environmental sustainability in urban contexts; the voices of youngsters were considered in the city planning process and sustainable activities and results were co-created.

We had put the plan of the new neighbourhood centre into the Minecraft-[City] game, and then we asked young people to come to the library and play the game. They generated ideas about what kinds of activities there should be in the brick-and-mortar surroundings … such as a community pet shop where children who cannot take a pet home could have a shared pet … It was interesting to see what a virtual city context like this makes possible. (Case 21, Network coordinator)

4.3. Multifold low-contextual innovation

In the archetype of multifold low-contextual innovation, the urban context represents a space without a specific meaning. Compared to the dyadic low-contextual innovation, broader stakeholder relationships, perspectives, and resources are involved in CI. These kinds of multifold low-contextual innovations were found in testing facilities and spaces and communities, where many types of stakeholders or groups of stakeholders took part in CI activities in a quadruple helix model. This archetype also includes a city's efforts to develop a suburb with citizens and estate owners into a special locality colonised by high-standard workplaces. Another example is a city that organized events for different parties to boost the growth of companies by benefitting a triple helix model. Other examples of multifold low-contextual innovations include a project where two cities dedicated streets to collective efforts to curb climate change and offered the streets as test environments for companies to take part in the efforts. However, in these initiatives the spaces were merely used as test environments, and not as "places" offering valuable inputs to CI endeavours. In Case 22, a whole street ("Climate Street") was used as a platform to co-create environmentally sustainable solutions.

Climate Street … By narrowing down the area to this particular street, it is possible to raise the bar of activities towards environmental friendliness. So, they offer there something, for example, they test things how a housing cooperative can act in more environmentally friendly ways. So, the street is used as a platform … They have launched calls for piloting projects there … (Case 22, Specialist)

Case 23 is a city neighbourhood of highly skilled workplaces and a platform for the development of initiatives for carpooling, electric bikes, and that tackles the last mile problem as alternatives to owning cars. Also, here the spaces were used as test environments, not as "places" with meaning and inputs to CI.

We have had pilots concerning carpools, electric bikes, and other things there that would tackle the last mile problem … We have thought about a loop or ring line that could go around the offices, shopping malls and the airport. There is a lot of space there to play around with these. I cannot see the end of it in the near future. (Case 23, Director of Economic Development)

Case 26 is an innovation intermediary that organizes co-development events for citizens to avoid textile waste and to recycle resources wisely. The focus of such events was to develop new ideas, how to use textile waste, which would otherwise be transported into landfill. Such redesign may support environmental sustainability, if taken into use. Likewise, there was no real-life context here, a place, involved in CI.

They have different themes; how to prevent textile waste, or how to recycle resources wisely and develop ideas … A university of applied sciences had this project where … there are teams where the people probably would not meet each other anywhere else but at the event … It is a good thing. (Case 26, Community Facilitator)

4.4. Multifold high-contextual innovation

The archetype of multifold high-contextual innovation emphasizes the importance and meaning of places, the real-life contexts where innovations happen (Hossain et al., 2019). Furthermore, in this archetype, there are many types of actors taking part in stakeholder relationships and innovation activities. The examples of multifold high-contextual innovation archetype include hackathons, urban transition labs, and diverse living labs, where many actors or actor groups take part in CI. These actors can include a city, companies, citizens, and universities.

Living lab examples include empowering citizens to make their neighbourhood more attractive and co-create new product and service ideas. Moreover, smart city initiatives, aiming at sustainable solutions in cities, belong to this archetype. One example is 'School as a Service' initiative, developed in cooperation with students, universities, companies, and a city. The underlying idea of the School as a Service concept is the usage of available resources rather than building new infrastructures, enabling environmental sustainability in this way.

Further multifold high-contextual innovation examples found in the cases include hackathons for circular economy or where a city opens its decision and mobility data, based on which new sustainable products and services can be developed. An example of such results is an application for public transportation, which many citizens in the city use to plan their daily schedules rather than using their own cars. This example shows that a meaningful place can also be virtual, a digital twin of a city.

Many types of citizen- or resident-driven actions with a city, companies and universities for sustainability were found in the cases. Citizens may, for example, be active and make their suburbs more attractive, or co-create new products and services. Additionally, real-life co-creation settings were found consisting of both virtual and physical places with meaning. Real-life settings, where the city opens its service provisioning or dedicates a part of the city for smart city initiatives also represent multifold high-contextual innovations. Such contexts support environmental sustainability through new environmentally sustainable products and services. Case 27 is a living lab that empowers citizens to make their neighbourhood more attractive and sustainable. Among the activities, citizens employ urban farming in gardening boxes and arrange festivals that promote citizen empowerment and social sustainability.

We have a field and open space there in [Suburb], so of course it is possible to bring gardening boxes there … So, it was … what customers wanted. And when the residents do it, they take care of it.… And there are companies involved, too, who build or own land, or offer services in the area … There are a lot of buildings that use geothermal heat, solar energy, and all kinds of mixed systems and different kinds of pilots …. (Case 27, Project Director)

Case 28 is a neighbourhood that aims to develop the area in an environmentally sustainable way. Here, a living lab gathers diverse stakeholders including the city, citizens, universities, and companies to CI activities under a broad variety of themes (urban gardens, biogas power plant).

In [Neighbourhood] there are so many different levels of development going on. There are urban people and grassroots actors, but there are also

such big themes as circular economy, sustainability, smart solutions. They can be then robotic cars … or open data sharing and stuff …. The city has an idea that it is a sort of piloting platform today and in the future, too …. they want to develop a sort of sustainable and self-sufficient neighborhood … Themes like … urban gardens … biogas power plant … sharing spaces, transport, cars, saunas, kitchens. (Case 28, Researcher)

Case 36 concerns a neighbourhood of a city, a living lab for open and smart city initiatives to ideate, test, validate, and co-create sustainable products, services, and systems with citizens, city, companies, and universities. Many of the activities were conducted by rapid experimenting, called "innovation buzz".

We have a program of rapid experiments, where we buy half-finished service prototypes from start-ups for different kinds of smart city challenges. Then there are residents who test, co-develop or they can take bigger roles. In co-design workshops there are researchers, and different kinds of associations. We have made efforts to get so-called innovation buzz around these service experiments. (Case 36, Program Director)

Case 46 is a hackathon in which six cities have opened certain datasets for open data initiatives. Citizens, students, and companies co-created services and products based on such datasets as a data specialist describes it. Open data initiatives are conducted also for opening environmental data, such as air quality data, for citizens.

Six cities have agreed on opening certain datasets. Specifically, data on air quality … maintenance trucks' movement … library …. The quality of public transport data has been improved, too. (Case 46, Data Specialist)

4.5. Concluding remarks on sustainability in the archetypes of CI

This study found that the four archetypes of CI support sustainability in diverse ways. To put it differently, the present study suggests that sustainability in the urban city context is realised differently in diverse CI archetypes. The archetypes generate benefits in terms of environmental or social sustainability, and they demonstrate realization of sustainability when implemented, as illustrated through case examples.

In the first archetype, *dyadic low-contextual innovation*, environmental and social sustainability are predominantly realised through co-developing sustainable services and products. It can also be realised when a city arranges, for example, innovation contests to collect ideas about environmentally sustainable services or products. Moreover, environmental sustainability is realised in co-working spaces through shared resources or green office spaces. However, implications on sustainability are somewhat limited because both stakeholder relationships and urban real-life contexts are limited. For example, hubs and makerspaces belong to this archetype.

In the second archetype, *dyadic high-contextual innovation*, new environmentally and socially sustainable concepts are developed. This development takes place, for example, in user communities where the real-life context brings valuable inputs and outputs to CI and increases sustainability. Here, because of the intense involvement of urban real-life contexts, implications on environmental sustainability are usually more extensive than for social sustainability, although active involvement of citizens in CI – if applied in this archetype – may increase their empowerment, responsibility, awareness, and participation in the society. For example, participatory budgeting and user communities belong to this archetype.

In the third archetype, *multifold low-contextual innovation*, wider social sustainability can be delivered through employing broad perspectives, resources, and social relationships, when testing and validating products and services for climate initiatives or when creating platforms or innovation intermediaries for CI. However, merely the variety of stakeholders involved in initiatives, or cities offering testing platforms do not build on real-life contexts with meanings. Therefore, in this archetype, environmental sustainability can be accomplished, but rather narrowly through shared resources, as well as through launching new environmentally sustainable products and services. For example, 4Ps belong to this archetype.

In the fourth archetype, *multifold high-contextual innovation*, broad implications on both environmental and social sustainability can be accomplished by employing real-life contexts and broad perspectives, resources, and social relationships. Inter alia, it includes empowering citizens to co-create new product and service ideas in urban real-life contexts, citizens taking responsibility of their neighbourhood, and through shared resources and new environmentally sustainable products and services. Living labs, hackathons and smart city initiatives belong to this archetype, aiming at environmentally and socially sustainable solutions in cities, as well as hackathons for circular economy or open data initiatives.

5. Discussion and conclusion

This study focused on the intersection of sustainability and CI. While there are numerous global sustainability challenges, cities make a particularly important context to discuss CI for sustainability because of the increasing urbanization and the various environmental and social sustainability challenges resulting from their rapidly growing populations. Many cities across the globe actively aim at solving their sustainability challenges, and city governments wish to involve their citizens into such efforts, thereby trying to apply more than a few CI models.

The study pursued understanding CI for sustainability in urban areas by exploring and conceptualising the diversity of CI models. Therefore, it contributes to the existing and growing literature on CI in general in four ways. First, based on the literature, a conceptual framework (Fig. 1) was developed to analyse various CI models. The framework identified four CI archetypes (Fig. 2): (i) *dyadic low-contextual innovation*, (ii) *dyadic high-contextual innovation*, (iii) *multifold low-contextual innovation*, and (iv) *multifold high-contextual innovation*. Second, a set of empirical cases of CI were analysed using the proposed framework. That way, it was possible to show how diverse CI models contribute differently to sustainability in urban areas. Third, the study advances the concepts of *"space"* and "*place*", suggesting that in sustainable CI, not just the stakeholder relationships are important, but also the innovation context plays a crucial role. Fourth, the study discusses the importance of CI models and their implications for environmental and social sustainability in urban contexts.

5.1. Constructed conceptual framework

This study constructed a novel conceptual framework to characterize CI in cities for sustainability (Fig. 1). The framework builds on two dimensions, namely stakeholder relationships *(dyadic/multifold*) and urban contexts *(space/place*) where innovations that enhance sustainability emerge and are co-developed. Studies in the extant literature regarding the sustainable CI landscape are limited. Of the few existing studies, Cohen et al. (2016) promote the city as a driver for innovation activities and Caniglia et al. (2017) suggest a typology of sustainability initiatives according to the type of interventions and experimentations. In contrast, the present study established a conceptual framework to illuminate the similarities and differences between various CI models, with an assumption that diversity of relationships and the type of urban context play important roles in CI for sustainability. This may be the beginning of a new path toward unification of the common foundation of efforts involving CI models for sustainability.

This study contributes to the literature on sustainability by categorizing seemingly different CI models in urban contexts that pursue sustainability. We propose that varied CI efforts can be typified into four distinct CI archetypes, and that those archetypes reflect similarities and differences between CI models. Our study shares a view of prior research that emphasizes the importance of stakeholders for sustainability

performance (Sheth et al., 2011). Consequently, recognizing the meaning attached to spaces, we also suggest that relationships and interactions between different stakeholders and real-life settings promote the emergence of social and environmental innovations in urban contexts. Engaging heterogeneous stakeholders in urban CI enhances learning between the stakeholders and innovation endeavors.

Previous research has distinguished between lab-like (space) and real-life (place) environments related to sustainability innovation (Buhl et al., 2017; Hossain et al., 2019; Voytenko et al., 2016). Further, CI literature in the context of sustainability has addressed space and place in innovation activities (cf. Niaros et al., 2017; Rainville, 2017). While the literature on living labs has briefly addressed the roles of "space" and "place" in innovation activities (Bergvall-Kåreborn et al., 2015), the present study provides a comprehensive understanding of the role of space and place in CI. These two concepts should be applied beyond research on living labs to highlight urban contexts and their roles in CI and particularly the distinct CI models for sustainability.

5.2. Stakeholder relationships and urban contexts in CI for environmental and social sustainability

Prior studies have suggested the role of CI for environmental and social sustainability. However, such studies are inconsistent about the participation of stakeholders. For example, Laurian and Crawford (2016) did not find any significant role for public participation for environmental sustainability. While Hofstad and Torfing (2015) propose that CI aims to integrate multiple stakeholders for development and realization of sustainability. Whereas environmental and social sustainability create serious challenges for modern cities, the present study underlines the role of the four CI archetypes in supporting environmental and social sustainability.

The extant literature is scattered regarding different CI models related to environmental sustainability (Engez et al., 2021; Kohtala and Hyysalo, 2015; Uttam and Le Lann Roos, 2015). The results of our study showed that environmental sustainability was embedded in different ways in all the studied CI models in the urban contexts. Our study explains that the "space" dimension in an urban context includes CI models that merely focus on limited participation of citizens in the development of CI that support environmental sustainability. For example, archetype I (the dyadic low contextual innovation) supports collecting experiences of product prototypes for environmental sustainability and may advance sharing of limited resources (see Case 2). In the archetype III (the multifold low-contextual innovation) the diversity of stakeholders increases. Regardless, such CI models – as the context is lab-like – largely assume limited participation (that is, experimenting and learning among stakeholders) for developing products and services that embed environmental sustainability such as carpooling (Case 23). Therefore, our study proposes that dyadic low-contextual innovation and multifold low-contextual innovation archetypes often are dedicated to environmental sustainability innovation endeavours by limited participation of stakeholders.

In opposite of "a space", the concept of "a place" supports environmental sustainability more extensively by bonding the endeavours to real-life contexts and thus, putting them into practice. Innovation activities involve stakeholders in real-life contexts and emphasise environmental sustainability, but at the same time empower people and increase their environmental and social awareness. For example, in the archetype II (the dyadic high-contextual innovation) citizens co-create solutions for grand environmental sustainability challenges benefitting an entire Fab lab network (Case 18). Conversely, archetype IV (the multifold high-contextual innovation) focuses on innovation endeavours and contributes to the discussion by emphasising the role of "place" and CI (such as living labs) for environmental sustainability in urban contexts (see case 28). Hence, integrating multifold stakeholders as part of CI activities for environmental sustainability in real-life contexts help to eliminate characteristics of products and services that prohibit scaling up CI for markets.

Previous literature on social sustainability suggests coupling social sustainability with a broad variety of stakeholders to develop and improve sustainability in communities (Colantonio, 2009; Holden, 2012). Involvement of different stakeholders enables to identify priorities for social sustainability (Weingaertner and Moberg, 2014). The present study provides new support for the prior findings of social sustainability by analysing a multitude of different participants in the CI archetype III (multifold low-contextual innovation) and the CI archetype IV (multifold high-contextual innovation) that promote social innovations in context of cities and engagement of democratic initiatives by multifold and diverse participants.

Urban contexts provide "places" in the framework (Fig. 1) to create meanings for CI activities. For example, citizens may act as co-creators of a Minecraft platform application in CI archetype II, dyadic high-contextual innovation (Case 21), or become active developers of multifold high-contextual innovation (archetype IV) to make their neighbourhood more attractive (Case 27). Previously, the emerging living lab literature has documented citizens being active participators in the development of their neighbourhood and wellbeing (Leminen et al., 2012; Leminen et al., 2015). Such broad social interactions may also lead to improved innovation outcomes (Russell and Smorodinskaya, 2018), and bring along deeper implications, especially regarding social sustainability (Nyström et al., 2014; Leminen et al., 2020). CI archetypes (III) and (IV) support social sustainability as such when engaging multiple diverse stakeholders. CI archetypes II and IV boost social sustainability through high-contextual places. The study proposes that in addition to multiple stakeholders, also a "place" in CI models should be understood as "a booster" of social sustainability. Hence, these CI models support social sustainability in urban contexts.

This study contributes to the sustainability discussion by emphasising the roles that urban contexts and relationships between different stakeholders play in pursuit of environmental and social sustainability.

5.3. Managerial and research implications

This study extends the literature to a new conceptual framework for analysing CI in the fields of environmental and social sustainability. Our study highlights that engaging multifold stakeholders (archetypes III or IV) enhance collaborative innovation for social sustainability. Similar co-creating in in high contextual innovation places (archetypes (II or IV) foster emergence of social sustainability. Our study emphasizes that engaging and co-creating multifold different stakeholder in high-contextual place is likely to support emergence of social innovation (archetype IV). While engaging multifold stakeholders (archetypes II or IV) as part of CI activities enhances environmental sustainability for example by eliminating characteristics of products and services that prohibit scaling up CI for markets.Such framework and the identified four archetypes of CI are particularly interesting to a variety of managers and those city government officials responsible for innovation and industry-public sector collaboration, who may see the diversity of opportunities that applying such archetypes for CI with various stakeholders might bring to their specific contexts. Further, such archetypes, representing the diversity of CI models, are coupled with a broad diversity of CI outcomes. Specifically, the framework and its two dimensions, namely urban contexts in terms of space and place, as well as stakeholder relationships in terms of dyadic and multifold, provide conceptual tools for understanding a desired landscape of CI. Furthermore, the framework constitutes a conceptual tool for researchers to structure various CI models. This can help them tackle the issues related to CI development and scaling up of CI models to enhance sustainability; a fact that is largely missing from the existing literature.

5.4. Limitations and future studies

This study has some limitations. First, it focused on the focal actors of

CI in only one Nordic country. The CI landscape certainly deserves research in broader geographic and cultural contexts to examine whether such factors affect the models and their performance. Further, this study focused on sustainability in urban contexts, highlighting how sustainability processes are embedded in diverse CI models. Despite the importance of real-life settings, studies revealing the meaning of place and space remain sparse (Bergvall-Kåreborn et al., 2015). Hence, there is a need for further research on diverse CI and CI models considering 'space' and 'place' in urban contexts and well as rural contexts. Further, there is a need for larger data sets to better understand the diverse CI models and their underlying assumptions and innovation mechanisms for environmental and social sustainability.

In addition, our study focused on the role of CI for sustainability and particularly its environmental and social dimensions rather than attempting to describe causal relationships between various sustainability dimensions or structures as suggested by McKenzie (2004). Finally, our study did not focus on quantifying sustainability or its dimensions (McKenzie, 2004; Saunila et al., 2018). Therefore, this study suggests that CI models' roles on sustainability dimensions and structures and possible causal relations between them but also innovation performance associated with the varied CI models could be analysed using quantitative approaches.

CRediT authorship contribution statement

Seppo Leminen: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Preparation, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Mervi Rajahonka:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Preparation, Writing – review & editing, Visualization, Funding acquisition. **Mika Westerlund:** Conceptualization, Methodology, Software, Formal analysis, Resources, Data curation, Writing – original draft, Preparation, Writing – review & editing, Visualization, Funding acquisition. **Mokter Hossain:** Writing – original draft, Writing – review & editing, Funding acquisition, all their own parts.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A Classifications and definitions of collaborative innovation

Classification	Definition	Authors
Collaborative innovation, CI	*"The actor's interaction and co-creation with different parties such as, but not limited to, suppliers, customers, competitors, and research organizations for the purpose of developing new services and products."*	Najafi-Tavani et al., (2018), 193
Collaborative innovation model, CI model	The diversity of named structures or methods that are used for CI purposes	Authors' own elaboration
Co-working space (I)	Shared, proactive and community-oriented workspaces; collaborative work settings providing support, shared flexible facilities, and access to a network of professionals and entrepreneurs, which share the values of collaboration, openness, community, accessibility, and sustainability; might be combined with accelerators, incubators, or existing business structures such as art centers, coffee shops and serviced offices.	Fuzi (2015)
Testbed (I)	A standardized laboratory setting used for testing new technologies, products, and services and protected from the hazards of testing in a live or production	Ballon et al. (2005)
Makerspace (I)	An umbrella for community-run physical places where people can utilize local manufacturing technologies.	Niaros et al. (2017)
Hub (I)	Enriched space for creative production, innovation and entrepreneurial Activity	Leorke et al. (2018)
Fab lab (II)	Open access facilities equipped with tools for all phase of the technology development process, including design, fabrication, testing and debugging, monitoring and analysis, and documentation.	Hamalainen et al. (2018)
Hackerspace (II)	Any community-run physical place where people can meet and work on creative projects	Niaros et al. (2017)
Participatory budgeting (II)	Participation of non-elected citizens in the allocation of public finances. A methodological definition: (1) the financial and/or budgetary dimension discussed; (2) the city level has to be involved, neighbourhood level not enough; (3) repeated process; (4) must include specific meetings/forum; (5) some accountability on the output required.	Sintomer et al. (2008)
Green Public Procurement (GPP) (II)	Purchasing that reduces environmental impacts across product or service life cycles.	Rainville (2017)
Innovation intermediary (III)	*An organization or body that acts [as] an agent or broker in any aspect of the innovation process between two or more parties*, 912.	Kant and Kanda (2019)
Public–private partnerships (PPP, 3Ps) (III)	Companies, public agencies, and universities (various institutions) participate in innovation activities	Hossain et al. (2019)
Public–private–people partnerships (PPPP, 4Ps) (III)	Companies, public, agencies, universities (various institutions) and users participate in innovation activities	Hossain et al. (2019)
Triple helix (TH) (III)	Innovation model that focuses on the interaction of the state, academia, and industry.	Carayanis and Campbell (2010)
Quadruple helix (QH) (III)	Innovation model that focuses on the interaction of the state, academia, industry and public.	Carayanis and Campbell (2010)
Demonstration site (IV)	A real-life setting to test ideas and start new research and as practise site and field lab for students.	Kreijns et al. (2018)
Hackathon (IV)	Quick prototyping events to create technical innovations for perceived challenges in smart cities.	Perng et al. (2018)
Living lab (IV)	*"physical regions or virtual realities, or interaction spaces, in which stakeholders form public–private–people partnerships (4Ps) of companies, public agencies, universities, users, and other stakeholders, all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts."*	Westerlund and Leminen, 2011, 20
Urban living lab (ULL) (IV)	Involve citizens in city development to make urban areas better suited to their needs; goal to generate public value; role of citizens more comprehensive than in other types of living labs. Citizens have a natural motivation to participate in shaping their environment through a sense of place, being at home.	Veeckman and van der Graaf (2015)
Urban transition lab (IV)	*Facilitated sites for creating (social) innovation and within which social change agents can initiate or inflict urban sustainability transitions.*	Nevens et al., (2013), 115

Appendix B. Interview themes

1. Background questions
   - Interviewees' background, tasks, and areas of responsibility.
   - How do you understand collaborative innovation? Tell us what collaborative innovation is not.
   - Interviewees' role and tasks in the city's collaborative innovation model.
   - Which collaborative innovation models are used in cities e.g., makerspaces, hackerspaces, Fab labs, co-creation spaces, living labs?
2. Foundation of collaborative innovation model and its operations
   - How did the collaborative innovation model start? What have been the driving forces?
   - What are the principles and/or assumptions of your collaborative innovation models?
   - Are operations managed from top or bottom or a combination of these? Can you give an example of top and/or bottom managed activities?
   - What procedures, models and processes are used in the collaborative innovation models?
   - What concepts/methods are used in the collaborative innovation models?
   - Do you use platforms in a collaborative innovation model(s)? What is the role of the platform you use in your collaborative innovation activities?
   - Which facilities or areas are used in a collaborative innovation model(s)?
3. Organization of collaborative innovation model
   - How is the activity organized and managed? Who is involved and in what role? What is particularly successful in the organization model?
   - Who in your organization is involved in a collaborative innovation model and in what roles?
   - How would you describe operations?
   - What is the structure of a collaborative innovation model (Distributed, Distributed multiplex, Centralized, Else, what?)
   - What networks are collaborative innovation model connected? Which actors are involved in the collaborative innovation model network? What is your and your organization's role in the collaborative innovation model network?
   - How are users involved in the collaborative innovation model? What user groups are there in the collaborative innovation model? In what role?
4. Objective of collaborative innovation model
   - What goals or objectives have been set for the collaborative innovation models?
   - How does the collaborative innovation support/develop the "core business" of your organization (and what is it)?
5. Implementation of collaborative innovation model
   - Do you use real-life environments in collaborative innovation models? Which? Why?
   - What happens in a collaborative innovation model(s)?/What happens during development? (progress in time) (Linear versus nonlinear, Phases, Activities, Inputs and resources, Results)
6. Results of collaborative innovation model
   - What are the benefits for an individual and/or organization of collaborative model?
   - What are the results of collaborative innovation for your own organization?
   - What results have been achieved with activities in collaborative innovation model?
   - Who benefits from the results produced by collaborative innovation model? How will the results be used?

Appendix C. Collaborative innovation cases in the urban contexts

Case/Mode (Anchored to)	Meaning of urban context	Stakeholders	Type/Objective of collaborative innovation model
Case 1/I location	Space	City or companies, citizens	Hub: A library as a meeting place and showroom to validate and test services and products of companies and the city with a city, citizens, or companies. Environmental sustainability of services and products is considered.
Case 2/I location	Space	City or companies, citizens	Hub: A library as a showroom or as a test setting for commercialized products of elderly care. Environmental sustainability of services and products is considered.
Case 3/I location	Space	City or companies, citizens	Hub: A location, as a showroom or as a test setting for commercialized products of elderly care by companies or the city. Environmental sustainability of services and products is considered.
Case 4/I location	Space	Citizens, city	Makerspace: A library in a makerspace network, enabled by the city, where citizens create and develop their ideas by utilizing a broad variety of commercialized products, and services technologies. Environmental sustainability of services and products is considered.
Case 5/I location	Space	Citizens, city	Makerspace: A library in a makerspace network, enabled by the city, where citizens create and develop their ideas by utilizing a broad variety of commercialized products, and services technologies. Environmental sustainability of services and products is considered.
Case 6/I concept	Space	City, companies	Green public procurement: An innovation competition to find ideas, and solution for environmentally sustainable service provisions of a city from companies.
Case 7/I location	Space	City, companies	Hub, a library as public space to work within municipal services. Environmental sustainability of services and products is considered.
Case 8/I location	Space	Company, Companies	Commercial co-working space that offers services to boost companies to growth. Environmental sustainability through shared resources and offering green office spaces.
Case 9/I location	Space	Company, companies	Test bed: Shared laboratory facilities for SMEs, in the facility of bigger industrial player, a co-working place in the chemical industry. Environmental sustainability through shared resources and offering green spaces.
Case 10/I concept	Space	City, companies	Green public procurement: Market dialogue between the city and companies to acquire and develop new environmentally sustainable products and services for the city.
Case 11/I concept	Space	City, companies	Green public procurement: Innovative purchasing with which the city acquires environmentally sustainable services by coupling a part of its acquisition to a specific development and co-development activities.

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Case/Mode (Anchored to)	Meaning of urban context	Stakeholders	Type/Objective of collaborative innovation model
Case 12/I concept	Space	City, companies,	Green public procurement: Shared service and facility development model for 'a health center' in a city neighbourhood, where upside and downside of life cycle costs are shared between the participants (Alliance model)
Case 13/I concept	Space	City, companies,	Green public procurement: Shared service and facility development model for 'a tunnel' in the city, where upside and downside of implementation success are shared between the participants (Alliance model)
Case 14/II concept	Place	Users, city	City's participatory budgeting for supporting the leisure activities of youth in the city and neighbourhoods. Environmental sustainability of activities is considered.
Case 15/II concept	Place	Citizens, city	City's participatory budgeting: citizens decide about flower planting in their neighbourhood. Environmental sustainability through citizens taking responsibility of their greener neighbourhoods.
Case 16/II Concept	Place	Citizens, city	City's participatory budgeting: citizens decide about flower planting in their neighbourhood. Environmental sustainability through citizens taking responsibility of their greener neighbourhoods.
Case 17/II concept	Place	Citizens, city	City's participatory budgeting: citizens decide about winter maintenance of fairways in their neighbourhood. Environmental sustainability through citizens taking responsibility of their neighbourhoods.
Case 18/II concept	Place	University, citizens or companies	Fab lab as 'a do-it-yourself space', where citizens or SMEs develop solutions for their needs, and share their outcomes with a Fab lab network, and may benefit results of prior work. Environmental sustainability through shared resources and trough development of environmentally sustainable solutions.
Case 19/II residents	Place	Citizens, companies	User community: A block of house and its communal residential concepts developed by residents and companies. Environmental sustainability of concepts is considered.
Case 20/II residents	Place	Citizens, city	User community: A vegan street food café developed by a community of citizens and supported by the city.
Case 21/II concept	Place	City, citizens (youngsters)	User community: A Minecraft game as a platform to co-design, co-develop, and co-create a neighbourhood of the city and its services by citizens. Environmental sustainability is considered.
Case 22/III location	Space	City, companies, citizens	Public-private partnerships: A street of the city for ideating, testing, co-developing, and validating products and services for "climate initiatives".
Case 23/III location	Space	City, companies, landowners, citizens	Public-private-people partnerships: A neighbourhood of the city as highly skilled workplaces as a platform for development initiatives to ideate, test, validate, co-develop product, services and systems with city, companies (and citizens). Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 24/III concept	Space	University, students, companies, public organizations	Innovation intermediary: A start-up hub and a community operating by a university to ideate, develop, validate, and test products, services of companies, and public organizations. Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 25/III location	Space	Companies, city, students, universities	Innovation intermediary: Space that organizes collision events between participants and to foster the growth of companies. Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 26/III location	Space	City, companies, citizens	Innovation intermediary: Space and community to organize collision and co-development events between participants, and to foster the growth of companies. Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 27/IV residents	Place	Citizens, city, companies, universities	Living lab: Empower citizens to make their neighbourhood more attractive and co-create new product and service ideas in an urban area. Environmental sustainability through citizens taking responsibility of their neighbourhood, shared resources and new environmentally sustainable products and services.
Case 28/IV location	Place	City, citizens, universities, companies	Living lab: Development of city's new neighbourhood involving city, citizens, universities, companies. Environmental sustainability through citizens taking responsibility of their greener neighbourhoods.
Case 29/IV recidents	Place	City, citizens, companies	Living lab: Empower citizens to help them improve their neighbourhood more attractive and co-create new product and service ideas in an urban area. Environmental sustainability through citizens taking responsibility of their neighbourhood, shared resources and new environmentally sustainable products and services.
Case 30/IV residents	Place	City, citizens, companies	Living lab: Empower citizens to develop and co-create skate ramps with the community and city. Environmental sustainability through citizens taking responsibility of their neighbourhoods.
Case 31/IV location	Place	University, companies, citizens and students, city	Living lab: Smart City Network, a real-life authentic development and test setting including virtual and the physical space, hybrid space for the 5G small cell network. Environmental sustainability of services and products is considered.
Case 32/IV location	Place	Companies, city, universities, citizens	Living lab: Residential area living lab, zero-energy houses in a new residential area.
Case 33/IV concept	Place	Students, companies, city, universities	Living lab: Develop services for 'School as Service' in cooperation with students, companies, city and universities. Environmental sustainability through citizens taking responsibility of their neighbourhood, shared resources and new environmentally sustainable products and services.
Case 34/IV concept	Place	City, citizens, companies, universities	Living lab: Service Centre as a meeting place to ideate, develop, validate, and test services, and products with the city, citizens, companies, and universities. Environmental sustainability of services and products is considered.
Case 35/IV concept	Place	Citizens, city, companies, universities	Living lab: A library as a meeting place to ideate, develop, validate, and test services and products with the city, citizens and companies. Environmental sustainability of services and products is considered.
Case 36/IV location	Place	Citizens, city, companies, universities	Living lab: A neighbourhood of the city as a platform for an open and smart city initiatives to ideate, test, validate, co-create product, services and systems with citizens, city, companies, and universities. Environmental sustainability of services and products is considered.
Case 37/IV concept	Place	City, students, companies	Living lab: An operating model that provides guidelines for co-creation, validation, testing, and ideation of services and products by schools and their students as well as companies in accordance with the new Finnish National Curriculum. Environmental sustainability of services and products is considered.

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Case/Mode (Anchored to)	Meaning of urban context	Stakeholders	Type/Objective of collaborative innovation model
Case 38/IV concept	Place	City, citizens, companies, universities	Living lab: Design for new services of a library such as makerspace and fairy birthday for kids, or with the city, citizens, companies, and universities. Environmental sustainability of services and products is considered.
Case 39/IV concept	Place	City, citizens, companies, universities	Urban transition lab: Co-creation and ideation of a new library and its services with the city, citizens, companies, and universities. Environmental sustainability of services and products is considered.
Case 40/IV concept	Place	University, companies, citizens and students, city	A hackathon for 5G enabled services with a city, citizens, companies, and universities. Environmental sustainability of services and products is considered.
Case 41/IV concept	Place	City, companies, citizens, universities	A hackathon for circular economy benefiting crickets in a commercial area of the city with the city, citizens, companies, and universities. Environmental sustainability through new environmentally sustainable products and services.
Case 42/IV concept	Place	City, citizens, companies	Living lab: An agile and limited experimenting for challenges of the city's own service provisioning or locations, with the city, citizens, and companies. Environmental sustainability through new environmentally sustainable products and services.
Case 43/IV concept	Place	City, citizens, companies	Living lab: An innovation methodology of a city, utilized in different locations or neighbourhoods, for development of city's service provisioning with the city, citizens, and companies. Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 44/IV concept	Place	City, citizens, companies	Living lab: An innovation methodology of the city, utilized in different locations or neighbourhoods, for challenges of city's service provisioning and city context per se, with the city, citizens, and companies. Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 45/IV concept	Place	City, citizens, companies	Living lab: An innovation methodology of the city, utilized in different locations or neighbourhoods, for challenges of city's service provisioning and city per se, with the city, citizens, and companies. Environmental sustainability through new environmentally sustainable products and services.
Case 46/IV data	Place	City, companies, citizens, students, university	Hackathon: Open data initiatives of a city, the city opens its decision data and movement data i.e., busses, own data resources for development of services and products by companies, citizens, and students. Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 47/IV data	Place	City, companies, citizens students, universities	Hackathon: Open data initiatives of a city, the city opens its decision data, own data resources for development of services and products by companies, citizens, and universities. Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 48/IV data	Place	City, companies, citizens, students, (university)	Hackathon: Open data initiatives of a city, the city opens its open vacancies as open data, for a development of services and products by companies, citizens, and students. Environmental sustainability through shared resources and new environmentally sustainable products and services.
Case 49/IV data	Place	City, companies, citizens, students, (university)	Hackathon: Open data initiatives of a city, the city opens its decision data and movement data i.e., traffic lights, own data resources for development of services and products by companies, citizens, and students. Environmental sustainability through shared resources and new environmentally sustainable products and services

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