Collaboration before competition: How smart city entrepreneurs co-create temporary ecosystems to build capacity for learning

Paul G. Oliver [a], Luca Mora [a,b,*], Jun Zhang [c]

[a] *Edinburgh Napier University, The Business School, Scotland, UK*
[b] *Tallinn University of Technology, Academy of Architecture and Urban Studies & FinEst Centre for Smart Cities, Estonia*
[c] *The University of Sheffield, Information School, England, UK*

A B S T R A C T

This article explores how smart city entrepreneurs (SCEs) learn to address urban sustainability challenges with innovative digital products and services. SCEs embody social, digital, and urban entrepreneurialism features and play a pivotal role in advancing smart city development. But despite their importance, little is known about the knowledge, skills, and competencies required to become an SCE. Grounded in entrepreneurial learning theory, our study helps fill this gap. Using the city of Edinburgh, UK, as our empirical setting, we examine the learning process of 34 SCEs. Our findings offer three core contributions. First, we show that collaborative learning is a key driver of innovation in the smart city domain. SCEs significantly benefit from collaborative efforts rather than competitive strategies alone. Second, we show that these collaborations develop in temporary ecosystems that contribute to enhancing the innovative capacities of SCEs. Building on these findings, we expand entrepreneurial learning theory, highlighting the critical yet overlooked role of temporary ecosystems and intermediaries in stimulating collaboration and knowledge exchange among SCEs. Third, we provide practical recommendations for policymakers, emphasizing the importance of supporting the development of strategic learning capacities and diverse learning modalities for SCEs.

1. Introduction

This article focuses on entrepreneurial learning practices and aims to provide an initial understanding of how smart city entrepreneurs (SCEs) learn, particularly within the context of start-up businesses. In our investigation we use a novel empirical lens, focusing on how these entrepreneurs acquire, utilize, and leverage knowledge, skills, and competencies in developing innovative urban solutions. Unlike other entrepreneurs, SCEs engage with public authorities, balance commercial and social objectives, and integrate new digital solutions within city infrastructure (Bibri, 2021). Entrepreneurs operating in the smart city domain leverage digital technologies, such as Internet of Things (IoT) applications, big data analytics, and artificial intelligence, to develop new products and services that address urban challenges and improve the quality of life for city residents (Girardi and Temporelli, 2017). This focus on sustainable urban development requires SCEs to innovate in ways that prioritize long-term sustainability and regulatory compliance over purely market-driven growth (Anthony, 2024).

Research examining SCEs has grown in recent years, with

entrepreneurs playing an integral role in facilitating digital innovation and addressing urban challenges (Yigitcanlar et al., 2020). Their entrepreneurial initiatives have proven indispensable in developing and implementing a wide range of smart city initiatives (Yigitcanlar and Kamruzzaman, 2018) in many different application areas, such as energy management, urban mobility, municipal waste management, public safety, and healthcare, among others (Bjørner, 2021).

Research also clarifies that the uniqueness of SCEs lies in their capability to encompass features belonging to social, digital, and urban entrepreneurialism—a capability that requires a combination of technical expertise, business acumen, and an in-depth understanding of urban development dynamics (Kummitha, 2019). While regular entrepreneurs may operate within a single domain, SCEs need to coordinate across multiple disciplines—digital technology, urban planning, and social governance—to create effective digital innovations (Webb et al., 2018).

Recent smart city studies show that SCEs offer a pivotal contribution to bottom-up and place-based sustainable urban development, especially those operating in start-up businesses (Panori et al., 2021; Sarma

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and Sunny, 2017). In fact, numerous scholars are calling for more research examining how local innovation ecosystems can best support the flourishing of SCEs (Granstrand and Holgersson, 2020; Zhao et al., 2020). To address these research gaps, we pose the following research question: *How does entrepreneurial learning theory evolve in the framework of smart city entrepreneurship?*

Among the most relevant yet overlooked factors affecting their survival and growth are entrepreneurial education and training (Nuseir et al., 2020), which have received limited attention in smart city research (Ercan and Kutay, 2022). We know little about the knowledge, skills, and competencies that individuals should possess to become SCEs. In contrast, smart city literature has focused more on challenges like access to funding and resources (Khan et al., 2020), regulatory and legal constraints (Kummitha and Crutzen, 2019), and the limited understanding of smart city development (Ma and Lam, 2019).

Entrepreneurial learning is a dynamic social process that allows businesses to gain a competitive advantage by transforming experiences into knowledge (Dutta and Crossan, 2005; Lattacher and Wdowiak, 2020; Politis, 2005; Shane and Venkataraman, 2000). Moreover, all types of businesses commonly practice it, and academics and practitioners consider it a fundamental part of developing technology-based companies (Rae, 2006; Van Veldhoven and Vanthienen, 2022). Therefore, by using entrepreneurial learning as a theoretical lens, we address the following research question: *how does entrepreneurial learning theory evolve in the framework of smart city entrepreneurship?* We provide new insights into how SCEs gain and utilize knowledge, experience, skills, and competencies to develop their offerings by focusing on start-up businesses.

Given the exploratory nature of our study, we only selected one empirical setting, represented by the city of Edinburgh, UK. Interviews with 34 start-up entrepreneurs operating in the smart city domain informed our research. This qualitative data was examined by using an abductive approach that builds on a Gioia-inspired methodology (Gioia et al., 2012).

Our study builds on existing smart city and entrepreneurial ecosystem research by addressing competition as a primary driver of smart city entrepreneurship (Marchesani et al., 2023; Primario et al., 2024) and highlighting the role of collaborative learning. While entrepreneurial ecosystem theory recognizes the coexistence of competition and collaboration in entrepreneurial processes (Stam and van de Ven, 2021), our study expands this view by demonstrating how SCEs construct temporary ecosystems that prioritize collaboration over competition. This approach reflects a broader trend in entrepreneurial ecosystems, where collaborative models, including open-source networks and shared resources, are increasingly valued for their capacity to stimulate innovation (Marshall and Gigliotti, 2020; Berk and Saxenian, 2022). Such a collaborative focus is essential for building learning capacity, offering new pathways for entrepreneurial learning and innovation that address urban sustainability challenges.

Our findings offer new insights into how collaboration shapes the entrepreneurial learning process in smart city contexts. They reveal two critical and interrelated factors – *collaboration before competition* and *building capacity for learning* – that influence the learning processes of SCEs. Additionally, our findings highlight the role of *temporary learning ecosystems* in providing SCEs with accessible collaborative spaces to acquire, share, and apply entrepreneurial knowledge through unique entrepreneurial events (Minniti and Bygrave, 2001). These time-bound ecosystems create structured opportunities for SCEs to engage in targeted learning experiences, often facilitated through partnerships and time-limited projects. Within these collaborative spaces, entrepreneurs gain access to key resources that accelerate learning and support business growth. Moreover, our findings suggest that collaborative knowledge-sharing within these ecosystems fosters unconscious learning, enabling entrepreneurs to internalize new ideas and approaches to urban innovation development through direct engagement and hands-on experience.

These learning processes (formal, non-formal, and informal) help SCEs enhance their understanding of multiple socioeconomic aspects of smart city development, and they are stimulated by intermediaries through real-life collaborative scenarios, breaking down social barriers and nurturing cross-scale linkages and multi-level social interactions (Holman et al., 1997). Learning intermediaries also facilitate partnerships that connect SCEs with established entrepreneurs, government bodies, and local authorities. Through such partnerships, supported by public funding and commercial contracts, SCEs gain access to essential resources and networks, thereby enhancing their potential for innovation and contributing to the broader urban development agenda in smart cities.

Our study expands current entrepreneurial learning theories, while showing that prioritizing collaboration over competition can help foster learning capacity and innovation in the smart city domain. The research also addresses the gap in non-formal entrepreneurial learning, highlighting the need for clarity between informal and non-formal learning in entrepreneurship literature (Rogers, 2014).

This article is structured as follows. Section 2 reviews the extant literature on entrepreneurial learning about start-up entrepreneurs using Politis' (2005) entrepreneurial learning framework, which underpins this study. Section 3 explains the methodology that we used for data collection and analysis. Section 4 presents the findings of the study, and Section 5 discusses their theoretical and practical implications. Section 5 also details the limitations of the study while offering recommendations for future research. The article concludes with Section 6, where we take stock of our findings and highlight critical remarks.

2. Theoretical framing

Politis (2005) provides the most comprehensive theoretical framework to examine how SCEs manage entrepreneurial learning as a process. Her research considers the intersection between entrepreneurs' experience and the knowledge they acquire, and it contends that entrepreneurial learning is an experiential process of developing new knowledge (see Fig. 1). The conceptual analysis proposed by Politis (2005) suggests that entrepreneurs learn from their past experiences to gain "practical wisdom" (p. 401) on future entrepreneurial actions, which leads to a transformation process. This research results in an entrepreneurial learning framework that includes four interrelated components: *entrepreneurs' career experience*, *entrepreneurial knowledge*, *transformation process*, and *factors influencing the transformation process*.

The following discussion presents this entrepreneurial learning framework by connecting the most up-to-date developments in entrepreneurial learning theory with literature streams that explore core areas linking smart city development to entrepreneurship. Examples include digital innovation (Rae, 2006, 2017), innovation ecosystems (Khurana and Dutta, 2021), and dynamic capabilities (Lecler and Kinghorn, 2014).

2.1. Entrepreneurs' career experience

Prior experience helps SCEs to understand, make decisions, and act upon new venture opportunities (Kirkley, 2016), which are more prevalent when entrepreneurs learn from failure (Amankwah-Amoah et al., 2022; Daspit et al., 2023). Entrepreneurs typically replicate actions that were successful and promising in the past while discarding activities that failed, implying a continuous update of their "subjective stock of knowledge" (Minniti and Bygrave, 2001, p. 5). However, SCEs depend on their strong ethics and intense emotional drive to overcome obstacles to create positive social impact and promote sustainable urban development (Perng et al., 2018). Based on entrepreneurship theory, a deep sense of purpose (Newman et al., 2021) and a commitment to a vision of a more sustainable, equitable, and livable urban future typically fuel this entrepreneurial passion (Heinonen et al., 2017). SCEs often possess a unique combination of technical expertise, creativity, and social
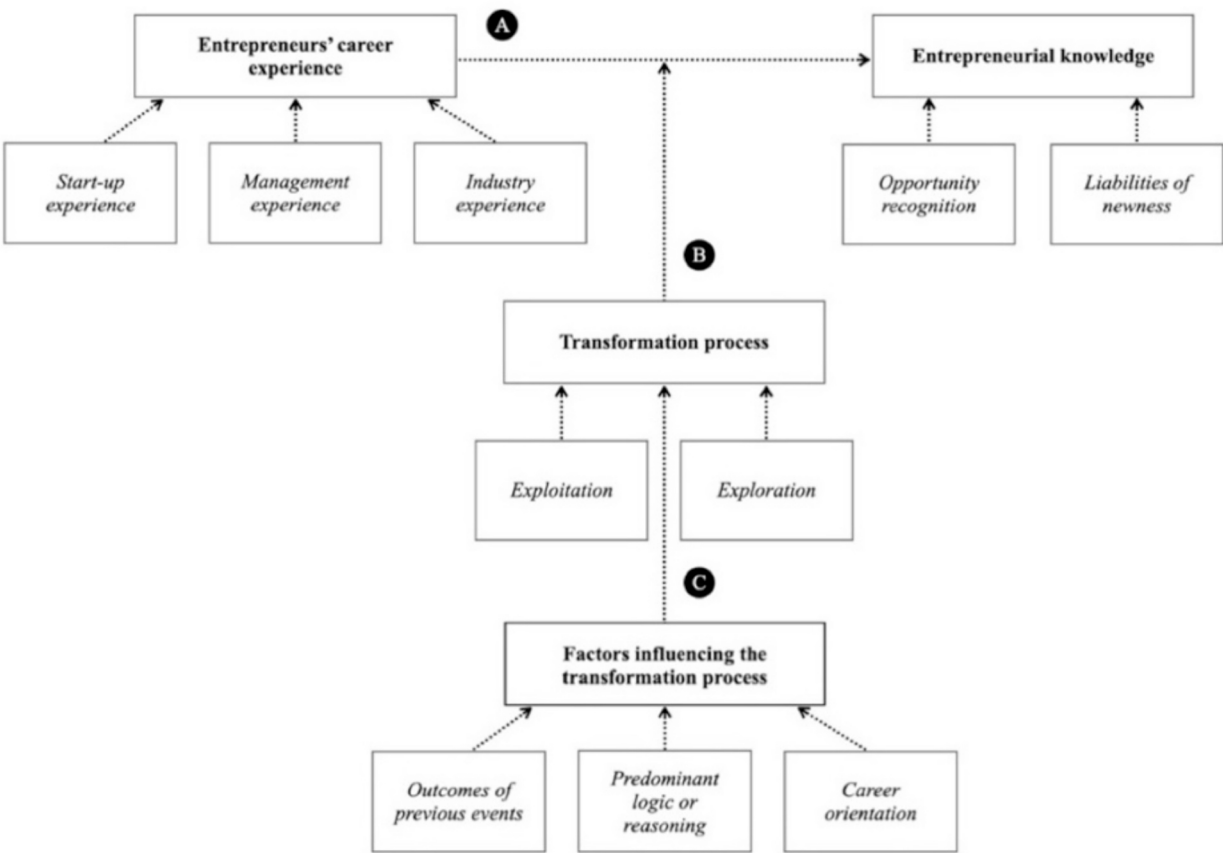
Fig. 1. Politis' (2005) entrepreneurial learning framework.

consciousness, which enables them to identify and drive dynamic capabilities for innovation and social impact relative to their own experiences (Linde et al., 2021).

As a term, experiential learning is referred to and practiced in various theoretical and practical domains, although it is relevant to entrepreneurial learning (Ahmad et al., 2018; Kolb, 1984). Experiential learning involves constructing knowledge and meaning from real-life experience (Yardley et al., 2012) to address in-depth problems using innovative solutions (Birken et al., 2017). Informal learning activities, which allow entrepreneurs to fully synthesize and reflect on their experiences to transition from theory to practice, are increasingly considered the key to employee success in the workplace (Keith et al., 2016). However, depending on their background, SCEs may have varying degrees of industry experience, which can harm their business performance (Spanjer and Van Witteloostuijn, 2017). This tendency explains why SCEs maximize previous business experience and knowledge in the early stages of start-up development to help exploit new opportunities and deal with uncertainty (Kuratko, 2005).

From an andragogical perspective, three recognized modes of learning differ in structure, purpose, and setting (UNESCO, 2009): formal, informal, and non-formal (see Table 1). Formal learning refers to structured and intentional learning within a formal educational system, such as a school, college, or university (Debarliev et al., 2022). Informal learning is self-directed and unstructured and can occur in various settings, such as at home, in the workplace, or in the community. Informal learning is often unplanned and spontaneous and does not usually result

Table 1
Modes of learning (UNESCO, 2009).

	Formal	Non-formal	Informal
Type of learning	Full-time educational pathway	Complementary learning activities	Self-directed learning
Learning intention	Structured, planned, and facilitated	Structured, planned, and facilitated	Unstructured, spontaneous, self-motivated
Context for learning	Schools, colleges, universities	Courses, workshops, seminars, training	Anywhere
Learning output	Diplomas and degrees	Skills and capabilities	Personal development and self-fulfillment

in a formal certification or degree (Salvi et al., 2022). Non-formal learning refers to learning outside the formal education system but is still structured and intentional. It is usually provided by non-profit organizations, community-based groups, or employers to supplement or enhance formal education or to address specific learning needs (Rogers, 2014).

There is a connection between entrepreneurial passion and learning intention. Highly passionate individuals are more likely to engage in learning activities that can help them develop the knowledge and skills needed to succeed. For example, this may include engaging with different modes of learning, such as formal education and training

combined with experiential learning through trial and error. Regardless of an SCE's background, they carry some "unique knowledge" from their previous career experience (Staniewski, 2016, p. 5149).

2.2. Entrepreneurial knowledge

SCEs acquire new entrepreneurial knowledge when dealing with new ventures by developing specialized skills and competencies through continuous engagement in practical entrepreneurial activities (Jack and Anderson, 1999). Previous studies have classified entrepreneurial learning practices into three successive stages: opportunity recognition, discovery, and creation (Marhamat et al., 2019). Although this classification considers opportunity an objective entity that a business eventually attempts to obtain, it is also considered socially constructed, as entrepreneurs consistently engage with the outside world to achieve a desired goal (Companys and McMullen, 2007).

An accurate sense of opportunity arises from the learning capabilities of SCEs, such as how they nurture social networks within their existing ecosystem from which new business ideas emerge (Ozgen and Baron, 2007). For instance, an entrepreneur's social networks often constrain their knowledge about relevant entrepreneurial practices and appropriate digital technologies, significantly impacting the effectiveness of entrepreneurial activities (Forbes, 2014). According to Shan and Lu (2020), this constraint indicates that entrepreneurs who have a more extensive and more tightly knit social network comprising several businesses and political connections will be able to more easily access the capital and human resources required for seizing new opportunities (Ramos-Rodriguez et al., 2010). In other words, the extent to which the self-efficacy of SCEs increases depends upon their confidence level in their capability to leverage networks for learning enhancement. Such network-driven self-efficacy fosters optimistic expectations regarding business performance and encourages entrepreneurs to achieve future goals despite challenges (Shen et al., 2021). However, many new SCEs fail at the early stages of development because they lack the contextual knowledge required to deal with uncertainty and capitalize on opportunities (Drnovšek et al., 2010).

Entrepreneurial attitude drives how SCEs implement their learning (Real et al., 2014). They often play a dominant role as a leader within the business, establishing open organizational practices, policies, and regulations to motivate and manage employees (Etse et al., 2021). Under these operational constraints, staff in most small businesses collaborate to develop dynamic processes intended to react to any form of ongoing change (Lee et al., 2014; Vatne and Taylor, 2018). However, different social, political, and technological developments can hinder learning for individuals and organizations. (Turovskiy et al., 2021). Therefore, the trade-off between utilizing internally rigid organizational assets and learning about the constantly changing and technology-driven local-global environment is necessary to drive or facilitate further learning (Lee et al., 2021).

2.3. Transformation process

Prior studies have researched how entrepreneurs transform unique career experiences into actual knowledge (Wiklund et al., 2019). However, issues around astuteness and agility in managing changes have been left unexamined, mainly regarding decision-making conditions of uncertainty within and outside of a business (Mora et al., 2023). SCEs may need to question the status quo, critically reflect on what went wrong, and devise alternative strategies. According to Haynie et al. (2010), they rely on two possible methods for change management when transforming prior experiences, both failures and successes, into actions: repeating past actions if the preceding experience was successful and exploring new actions if the initial experience was a failure. Therefore, the transformation process is metacognitive, implying that entrepreneurs learn from failure (Slettli, 2019).

When cognition integrates with prior knowledge and experience, entrepreneurs can focus on the value of knowledge-sharing to sustain the organization's and its employees' growth (Goh et al., 2012). Entrepreneurship is typically taught at an organizational level and is frequently mediated by entrepreneurial learning to encourage entrepreneurial intent at an individual level (Hou et al., 2022). Krueger Jr et al. (2000) describe this stimulation as an intention-based cognitive process that builds entrepreneurs' ability to predict future societal and technological changes and makes them "sensing learners" (Baggen et al., 2016, p. 194). However, beyond mere intentions, successful SCEs strategically use the resources at hand, including existing knowledge, skills, and competencies, to facilitate the development of dynamic capabilities, resulting in unanticipated learning outcomes that transform the way they do business (Lecler and Kinghorn, 2014).

Entrepreneurial ambidexterity is essential in supporting how SCEs manage knowledge and develop dynamic capabilities to sustain their organization's performance for competitive advantage (Santoro et al., 2021). Digital technologies have altered the mechanisms for "identification, development, co-development, and assessment" (Teece et al., 2016, p. 332) of new opportunities with an increased awareness of potential competitors. To compete, according to extant theory, SCEs should have the dynamic capabilities needed to capture the value of these opportunities and decide how to capitalize on them (Yeow et al., 2018). For instance, co-creation as a form of digital exploration for SCEs involves engaging with various stakeholders, including customers, employees, partners, and suppliers, to create innovative products and services jointly. By leveraging digital tools and technologies, entrepreneurs can develop a more collaborative, efficient, and creative environment for co-creation (Hisrich and Soltanifar, 2021). This has led some pioneering SCEs to acquire strategic assets for successful business model transformations, emphasizing the significance of possessing dynamic capabilities (Kumar et al., 2020).

2.4. Factors influencing the transformation process

Minniti and Bygrave (2001) highlight the importance of previous experiences in shaping an entrepreneurial approach to future ventures. Both successful and unsuccessful outcomes of earlier events can impact the decision-making process of entrepreneurs and their overall approach to new business opportunities (Staniewski, 2016). For example, pre-existing knowledge and experience are seen as valuable resources when an entrepreneur starts a new venture, whether a success or failure, as they provide an opportunity to learn more about their resilience and the development of "anti-fragility capabilities" (Amankwah-Amoah et al., 2022, p. 1745). Some studies refer to entrepreneurial failure as events that inform their learning (Hogarth and Karelaia, 2012) and the process of "unlearning" from past success and failure (Martignoni and Keil, 2021). However, there is increasing scholarly interest in the learning experiences that SCEs can encounter through working with intermediaries (Woolley and Macgregor, 2021).

Intermediaries are individuals, community groups, or organizations

that act as agents or brokers in innovation processes involving two or more parties (Howells and Thomas, 2022). They are on hand to facilitate learning experiences within ecosystems between SCEs working in innovation clusters (van Rijnsoever, 2022) with the ability to synthesize and manage knowledge iteratively (Horváth and Szabó, 2019). An ecosystem refers to a network of organizations, individuals, and resources that work together to create an environment for innovation and entrepreneurship, which includes a variety of components, such as incubators, accelerators, co-working spaces, investors, mentors, and other entrepreneurs (Ianioglo, 2022). SCEs tend to use entrepreneurial and innovation ecosystems to support the early-stage development, launch, and growth of their businesses (Mitra et al., 2022). However, there is a lack of clarity in ecosystem literature relating to issues of trust, knowledge dynamics, cooperation, and competition (Scaringella and Radziwon, 2018). Scholars widely regard ecosystems as an essential component of a successful start-up entrepreneur's strategy (Elbahjaoui, 2021; Madaleno et al., 2021), which is relevant to an SCE who may have limited resources and expertise (Mitra et al., 2022).

Outcomes of previous experiences can influence the development of an SCE's predominant logic and reasoning, as they provide valuable lessons and insights that shape the approach to new ventures (Toutain et al., 2017). However, developing an entrepreneurial mindset and employing appropriate reasoning methods are essential before they can effectively learn from and apply insights gained from previous events (Kooskora, 2021). Missing opportunities to identify, explore, and build meaningful relationships with key stakeholders can manifest feelings of self-doubt, loss of identity, and over-competitiveness, thus hindering the entrepreneur's ability to build capacity for learning and self-efficacy (Pihie et al., 2014; Melović et al., 2020). To fight against these barriers, SCEs try to engage in a process of self-regulation to identify their capability gaps (Winkler et al., 2023).

As evidenced by extant literature, experiential learning capabilities are frequently associated with entrepreneurial orientation (Anderson et al., 2009), which refers to the extent to which an organization is innovative and proactive, as well as its ability to take and manage risks. Career and entrepreneurial orientations are two distinct approaches or mindsets related to an individual's professional life and aspirations. Career orientation refers to how individuals approach their professional lives, focusing on long-term goals, skills development, and career advancement within an organizational context (Hirschi and Koen, 2021). On the other hand, entrepreneurial orientation refers to a mindset that prioritizes innovation, risk-taking, and self-directed initiative (Kiyabo and Isaga, 2020). Career orientation is centered on professional development within an organizational context. In contrast, entrepreneurial orientation emphasizes risk-taking, innovation, and the pursuit of entrepreneurial ventures, although many individuals possess a blend of both orientations (Wales et al., 2021).

3. Research methodology

Our methodology was inspired by Gioia et al. (2012) and followed a three-step process. Rather than applying a purely deductive approach, we adopted an abductive strategy that allowed for an iterative movement between empirical findings and existing theoretical frameworks. Abductive reasoning enabled us to explore unexpected insights that emerged from the data while refining and extending entrepreneurial learning theory (Azungah, 2018). First, we aligned our research question with the study's empirical setting. Second, we conducted semi-structured interviews to gain insights into the learning dynamics of SCEs. Third, we systematically analyzed the interview data, allowing

theoretical constructs to emerge while iteratively refining our understanding through engagement with relevant literature.

3.1. Research question and empirical setting

Positioned within our theoretical framing (see Section 2) is the following research question: *how does entrepreneurial learning theory evolve in the framework of smart city entrepreneurship?* To answer this question, we focused on the entrepreneurial learning processes of SCEs in start-ups operating in Edinburgh. This city was chosen due to its burgeoning reputation, becoming a sustainable smart city hub with grassroots entrepreneurship at its core (The City of Edinburgh Council, 2020).

According to a recent survey by *Virgin Money*, Edinburgh was voted the second-best city in the UK to start a business (Brisinger, 2023). Moreover, the broad perception of Edinburgh's ecosystem of technology start-ups is that it is a close-knit community with accessible and affordable working spaces and an abundance of government-led initiatives to support bottom-up innovation (Wheaton, 2016). Moreover, Edinburgh is one of seven cities in the UK to benefit from the upcoming UKRI-led 'Strength in Places' fund with an overall investment of £300 million to support the top-down development of start-up and scale-up businesses (UK Government, 2021). However, there remains a need for government initiatives that stimulate 'inclusive growth' by using digital innovation "to improve the efficiency of urban services and generate new economic opportunities in cities" (OECD, 2020, p. 8).

3.2. Data collection

In total, we reached out to 124 candidates identified through desktop research. All candidates were invited to interview, and, using a snowball technique (Parker et al., 2019), they were also asked to recommend other potential start-up entrepreneurs to contact. Overall, 34 Edinburgh-based SCEs representing various industries were accepted to participate in the study. To be eligible for selection, participants needed to identify as either the founder or co-founder of a registered Edinburgh-based technology start-up with direct involvement in smart city development. Participants were a mix of individuals who had started a business for the first time, had been running their start-up for less than three years, or were in the process of scaling up.

Once participants were identified, data from the insights platform *Crunchbase* were used to screen essential business information about each SCE's respective company, including *company description*, *industry*, *number of employees*, *funding sources*, *and names of founders* or *co-founders*. These participants reflect the heterogeneity of start-up entrepreneurs working in Edinburgh's smart city domain, representing a broad scope of industries, such as robotics, telecommunications, mobility, creative industries, and finance, with varied socio-cultural, economic, and educational backgrounds. Semi-structured interviews were conducted online via *Zoom*, with conversations lasting between 40 and 60 minutes. Each interview was recorded and automatically transcribed using the transcription software *Otter, which was* converted to a Word file and then manually proofread to ensure that the contents reached the highest level of quality.

Table 2 provides an overview of the participants included in this study, detailing their industry, business stage, years in operation, primary focus, and approach to learning.

Table 2
Overview of participants in the study.

Participant Code	Industry/Sector	Stage of Business	Years in Business	Primary Focus	Learning Approach
I.01	Tech	Scaling	4	Data analytics	Formal
I.02	Design	Early stage	2	Creative design	Informal
I.03	Media	Established	6	Digital experiences	Non-formal
I.04	Gaming	Early stage	3	Game development	Informal
I.05	App development	Scaling	5	Mobile apps	Formal
I.06	Energy	Established	7	Renewable energy	Formal
I.07	Biotech	Scaling	5	Microfluidics	Informal
I.08	Consulting	Established	8	IT infrastructure	Formal
I.09	Urban solutions	Scaling	6	Smart cities	Non-formal
I.10	Real estate tech	Established	6	Property data insights	Formal
I.11	Real estate tech	Early stage	2	Property data insights	Formal
I.12	Robotics	Early stage	3	AI-driven robotics	Formal
I.13	Marketing	Scaling	5	Digital marketplaces	Informal
I.14	Sustainability	Established	7	Eco-innovation	Informal
I.15	Creative arts	Scaling	6	Cultural impact	Non-formal
I.16	Product design	Early stage	2	Digital manufacturing	Formal
I.17	Finance	Established	8	Blockchain solutions	Non-formal
I.18	Energy tech	Early stage	3	Green energy	Formal
I.19	Communication tech	Scaling	5	Li-fi technology	Informal
I.20	Fintech	Early stage	2	Secure data integration	Non-formal
I.21	Fintech	Scaling	5	Secure data integration	Non-formal
I.22	Cybersecurity	Established	7	Data protection	Formal
I.23	Biotech	Early stage	2	Algal tech	Informal
I.24	Analytics	Scaling	6	Waste management	Non-formal
I.25	Research	Established	5	AI research	Formal
I.26	Legal tech	Early stage	3	Legal compliance	Non-formal
I.27	AI solutions	Established	6	Predictive analytics	Formal
I.28	AI solutions	Scaling	4	Computer vision	Informal
I.29	Finance	Scaling	6	AI systems	Formal
I.30	Fintech	Established	8	Fintech Integration	Non-formal
I.31	Cybersecurity	Early stage	2	Secure tech	Informal
I.32	Mobility	Scaling	5	Shared mobility	Formal
I.33	Sustainability	Scaling	6	Climate intelligence	Non-formal
I.34	Engineering	Established	7	Infrastructure automation	Formal

3.3. Coding of participants

The data presented in this study were derived from semi-structured interviews with 34 SCEs in Edinburgh, chosen for their active involvement in smart city initiatives. Each interviewee has been assigned a unique code (e.g., "I.02", "I.18") to maintain confidentiality while allowing for precise referencing of interview data throughout the manuscript. This coding system ensures the anonymity of our participants while providing a clear trail of evidence for the claims and findings reported in the study (Saldaña, 2009). The interviewees were selected to represent a diverse range of industries within the smart city domain, encompassing areas such as robotics, telecommunications, mobility, creative industries, and finance. This diversity provides a broad perspective on the entrepreneurial learning processes in smart city contexts, contributing to the depth and reliability of our findings.

3.4. Coding of interview data

The raw interview material was organized, visualized, and synthesized using the data analysis software *NVivo*. This enabled us to manage and analyze large qualitative datasets effectively, ensuring a comprehensive and detailed examination of entrepreneurial learning processes (Kraiwanit et al., 2023). To provide a rigorous and systematic analysis, we employed the Gioia method, known for its structured approach to qualitative research, which facilitated the identification and interpretation of complex patterns within the interview data (Gioia et al., 2012).

We identified emerging concepts to create initial codes (first order) that defined different aspects of smart city entrepreneurial learning. We then clustered these codes into similar themes (second order), which we linked to the theoretical dimensions framing entrepreneurial learning (third order). Therefore, as we moved from second to third-order coding, empirical data was gradually connected to the extant theory; concepts

and themes were attached to the components of Politis' (2005) entrepreneurial learning framework—*entrepreneurs' career experience, entrepreneurial knowledge, transformation process*, and *factors influencing the transformation process* (see Fig. 1). Therefore, "data and existing theory [were] considered in tandem" (Collins and Stockton, 2018).

To ensure the robustness of our findings, we incorporated triangulation by cross-verifying data from multiple sources and conducted member checking by sharing preliminary findings with participants for their feedback and confirmation (Jonsen and Jehn, 2009; Lincoln and Guba, 1985). Once we completed the coding, we collectively validated the results through open discussions and finalized them by creating the data structure (see Table 1). From the initial phase of manual coding, we identified 504 coded passages. We grouped these into 75 first-order codes as we became more familiar with the data and moved deeper into the clustering process. *Appendix A* shows a sample of the most representative quotes associated with these codes, which are labeled with numerical identifiers for easy reference (e.g., I.18). This process continued with clustering second-order themes, which we then linked to the components of Politis' (2005) entrepreneurial learning framework. Five theoretical dimensions overlap with existing components of the framework, whereas the remaining two represent additions.

4. Findings

In this section, we present our findings, illustrated in Table 3. There was a consensus from interviewees that collaboration before competition is a significant factor influencing the transformation process of SCEs who co-create what we define as temporary ecosystems to build capacity for learning.

Table 3
Data structure.

Concepts	Themes	Theoretical dimensions
First order	Second order	Third order
• Investing time to grow the business • Government contracts generate most of the income • Managing multiple funding grants to support the business growth • Angel investors are more interested in the innovation potential	Financial support and start-up growth	Entrepreneurs' career experience
• Building reputation and managing risk • Protecting and managing proprietary data and information	Managing reputational risk	
• Cannot do R&D and maintenance simultaneously due to limited resources • Nurturing a culture of success with limited resources	Managing limited resources	
• Achieve gender parity in management • Overcoming cultural barriers in facing customers	Managing cultural diversity	
• Managing change to ensure people do things correctly • Motivation through incentivizing tasks	Maximizing management of people for decision-making	
• Developing user engagement tools • The product(s) is (are) embedded in the services	Smart services for customer engagement	
• New innovations are always high-risk but not necessarily reckless • The balance between innovation and stability • Entrepreneurs should focus on human impact rather than using technology as a tool	Learning to balance stability, innovation, and growth	
• Industry experience as a foundation for learning • Lack of domain knowledge restricts learning • Theory-practice nexus • Intense learning experience when running own company	Continuous interplay between domain knowledge and experiential learning	Entrepreneurial knowledge
• Personal passion for sustainability drives new business creation • Personal values and character align with sustainability	Passion for environmental sustainability	
• Formal education builds foundational knowledge and validates ideas • Formal, non-formal, or informal learning to acquire domain-relevant knowledge	Recognition of foundational learning	
• Bespoke platform to work with stakeholders • Building an integrated business intelligence platform	Data-driven business intelligence platforms	

Table 3 (*continued*)

Concepts	Themes	Theoretical dimensions
First order	Second order	Third order
• Leveraging emerging technologies to address existing problems • Root cause analysis	Instruments for critical thinking and problem-solving	Transformation process
• Pragmatism and competence as a strategic approach • Clients are always a top priority in decision-making • Appropriate and rational market positioning	Pragmatic smart cities approach	
• Business acumen • Age impacts motivation • Respect the value of other people's opinions • Being accountable to other people • Diverse expertise within a team helps to solve problems	Cultivating a growth business mindset	
• Identifying market gaps for data-driven business • Offering meaningful products or services	Meaningful strategies for SCEs	
• Challenges of scaling up the business • Clear long-term vision for a sustainable future • Managing change based on the consequence of the previous change • Agile approach to goal setting • Readjusting organizational structure and managing changes	Managing change in-line with smart city initiatives	
• The mindset of an entrepreneur is to overcome obstacles • Building resilience through learning from failure	Learning from adversity	Factors influencing the transformation process
• Regular meetings between founders and stakeholders • Transparency helps to build trust and facilitates shared learning	Targeted leadership engagement	
• Encouraging open innovation to explore new knowledge • Co-creating ideas via stakeholders in different contexts • Feedback from partners • Building cultural affinity within the organization	Co-evolving with stakeholders	
• Establishing partnerships within the entrepreneurial ecosystem • Collaborative learning with other companies • Need to build a network from the bottom up • Building and maneuvering networks to create new opportunities • Acquiring (??) knowledge and skills	Collaboration before competition	
• Establishing good rapport with like-minded people • Working closely with people you trust	Learning from mentors	

Table 3 (*continued*)

Concepts	Themes	Theoretical dimensions
First order	Second order	Third order
• Strong personal relationships with mature collaborators		
• Key person dependency makes it difficult to work with larger companies	Opportunities and barriers to collaborative learning	
• Working with local partners		
• Policies, regulations, and restrictions within a sector		
• Biases and stereotypes can create barriers		
• Knowledge of the government sector provides a competitive advantage	Smart city knowledge exchange for solving problems	
• Consult with experts to make informed decisions		
• Provide workforce with training		
• Building various teams with different roles in the company		
• A first principles approach is taken when dealing with opportunities or challenges	Experiential or self-regulated learning	
• Initial judgment through instinct and gut feeling		
• Recognizing and acting on new opportunities		
• Support from local communities and educational incubators	Temporary ecosystems for learning	
• Accelerator programs facilitate new entrepreneurial opportunities		
• Identifying key capabilities from universities		

4.1. Entrepreneurs' career experience

Gaining industry experience is about informal knowledge exchange, with an emphasis on diverse business expertise (I.18); for example, a project-based approach can assist in identifying 'unknown' knowledge, such as specialized skills that are not part of an SCE's capabilities (I.12). Furthermore, SCE wants to help their team to become familiar with various aspects of product development to improve processes and automated systems for scale-up (I.14).

Although an SCE cannot be an expert in everything, such as having a clear understanding of government policies and regulations for data management (I.23), formal knowledge of complex theories (e.g., evolutionary economics, complexity, systems theories) offers support to overcome obstacles and better understand the market (I.25). SCEs sometimes struggle to collaborate with specific smart city stakeholders, such as local government officials, due to a lack of experience in this type of engagement and a tendency to perceive only potential barriers. One participant explains, "A lot of other companies... steer clear of it because they don't really understand how it works" (I.08). A knowledgeable SCE can, however, establish appropriate governance procedures early in the process, which enables them to work with public sector officials effectively and vice versa.

The findings suggest that without appropriate formal education or training, they would make ad hoc decisions without being aware of their competence level (I.33). Therefore, providing employees with training opportunities is considered a priority. However, SCEs prefer to encourage informal online research to experiment with problem-solving before supplementing this knowledge with short training sessions (I.09). Smart city collaborations drive progress within a team because a business requires multiple people to create and receive value for it to have an impact (I.07).

Previous industry experiences working with regulatory groups enable SCEs to collaborate and bring specialists into the company to help solve problems, which can result in the formation of new working groups and aids the company's learning-by-doing process (I.13). For example, multi-year background in engineering or scientific research provides a deep understanding of the sustainability issues that must be addressed when running a specific type of smart-city-oriented organization (I.16). Therefore, in addition to having some foundational experience to structure the business upon, SCEs recognize the need for a more structured approach in certain areas. As one participant reflects:

"But there are places where we definitely need a formal structure... I think it has played a role because it's giving me a foundation to build upon. So being a polymath and learning about different things." (I.03).

This perspective showcases that while a broad and adaptable skill set is invaluable, there are moments when the complexity and formality of business practices necessitate a more rigid framework for growth and scalability. For SCEs with prior industry experience, new experiences do not imply relearning but instead learning in a new environment. Therefore, once the process of informal learning (e.g., quality or procurement systems) is complete, an SCE simply works within the boundaries of that system (I.07).

Our data reflects that when SCEs come from a different domain or industry, they often lack essential skills and competencies, limiting their ability to use other management tools for learning and development (I.14). For example, when attempting to implement technological infrastructure to support the development of products and services, such as high-speed charging stations for electric buses, incremental innovation is necessary because otherwise there is a high financial risk (I.18).

SCEs try to be patient and understand the difference in working with public sector organizations and intermediaries, which necessitates an incremental approach to achieve client satisfaction due to government regulations and the types of low-risk technologies employed (I.20). For instance, a platform-driven product roadmap can strike a balance between incremental technological advancements, radical innovation with research and development, day-to-day economic sustainability of the business and market-driven exploration for new opportunities (I.24). Adapting the strategy to different situations can grow in significance, such as implementing a minimalist approach to product development to focus solely on the core business, which entails assisting clients and becoming more of an ecosystem player (I.06, I.03).

Our findings show that SCEs can implement lean business models and test products quickly, receiving almost instant customer feedback, bringing them to market, and then reducing the investment required. Therefore, it becomes easier to move back a step in the process and rectify any errors (I.06). Breaking down the corporate 'monolith' supports the building of resilience into the company's infrastructure, which results in more robust and manageable micro-services (I.17). SCEs may develop digital products or services that are ahead of the market and must wait to commercially release them although, conversely, this can help raise awareness about specific technological solutions (I.11). For example, emerging technologies, such as robotics, can be used create new solutions for environmental sustainability issues, such as the development of cost-effective waste management processes (I.12). For SCEs, this can be achieved through informal research, by consolidating information from different realms and using it to understand existing problems a smart city industry (e.g., smart mobility), and then apply that knowledge to the business problem, such as the development of battery technologies and charging infrastructures. According to one of our respondents:

"When you think about the nature of the problem, that is the thing that we need to solve. And I think that our general approach has been to become an expert in a domain and then think about how that can apply to the business problem, which we're trying to solve." (I.18).

Our data reveals that SCEs can predict how sustainability issues (e.g.,

zero emissions) and technological advancements (e.g., electric vehicles) will affect the market over the next decade by examining past and current trends and using domain expertise. This enables SCEs to begin long-term planning for what is required to support this type of development (I.18). SCEs tend to adopt low-risk strategies during the incubation period as they feel incompetent and, therefore must strategize with every decision (I.02). A new SCE might begin by creating value propositions, which develop into customer engagement and working with customers or partners, which ultimately results in understanding the context for smart city problem solving (I.29). Smart city start-ups are challenging to categorize conventionally as they are part-sustainable and part-technological, with potential overlap into other industries as well (I.23).

4.2. Entrepreneurial knowledge

Our data shows that the discovery and recognition of new entrepreneurial opportunities emerge due to limited resources available for SCEs to sustain their business. To avoid going into debt, human resources—especially one's own time— become the most valuable resource for keeping the company afloat and growing (I.02). SCEs often emphasize the benefits of legislative changes as catalysts for securing significant contracts and fostering innovation, as one participant states: "In 2019, we won a half million-pound contract from Defra, which basically, the UK Government has said that all waste will be digitally tracked across the UK" (I.24).

SCEs highlighted that, in the early stages of development, they must recognize the importance of self-sufficiency with continuous network expansion, which they can accomplish with limited resources by combining public funding, start-up awards, and commercial loans (I.07). Building long-term partnerships with the public sector can lead to stable opportunities and growth, as another participant notes: "With public sector or large organizations, like utilities, just having long term relationships that lead to kind of opportunities… with grant funding" (I.09).

For example, writing a public sector tender may create opportunities for building partnerships and generating income. Still, it is often a challenging process for new SCEs due to their lack of knowledge and high levels of uncertainty. Therefore, our findings reveal that SCEs tend to remain in their comfort zone to test new ideas by first working with existing clients (I.10). One participant provides an example of how adaptability to new standards is crucial for SCEs, enabling them to leverage internal capabilities and meet evolving governmental requirements:

"The UK Government has created a standards-based approach to identity; they've launched this 'UK digital identity and attributes trust framework'… We were aware of that policy coming out, and we then, you know, funded the business appropriately. We could focus a team on that work so that we could then deliver a third required standard." (I.26).

SCEs also stressed the importance of building a business based on a passion for sustainable development. This enables them to organically develop a strong foundation of authentic digital products and services, supporting loyal customers' growth (I.02). However, our findings show that SCEs openly collaborate and share knowledge and ideas to stimulate growth (I.05).

Identifying new opportunities also involves market research, assessments of available technologies and their potential applications, and developing a roadmap for the future based on sufficient data to test a hypothesis (I.17). However, lack of technological skills can lead to issues of trust and transparency in the usage of data, which forces SCEs to develop alternative systems that are more ethically responsible in their execution (I.24). SCEs may possess specific competencies, such as the ability to offer value-based work, although they typically need a long time to build confidence and develop their profile in the business ecosystem (I.34).

4.3. Transformation process

In the context of this study, working with larger organizations, such as local councils, can be challenging for SCEs when senior personnel micromanage decisions and do not give autonomy to people lower in the hierarchy (I.26), resulting in delays and frustration on the part of SCEs (I.18). However, once a local council responds and initiates a dialogue, it provides valuable insights for SCEs, who can then use this informal knowledge and experience to leverage collaborations with other councils. Therefore, an SCE can work in a commercial capacity and be supported by the Scottish Government's public funding and sustainability initiatives. According to one of our respondents:

"We are supported by the likes of Scottish Enterprise, and SDI, which obviously is funded by the Scottish Government. We've done stuff with Zero Waste Scotland, of course, in Scotland. So, we have a relationship there from a commercial business scaling perspective." (I.24).

When SCEs collaborate with public and private sector organizations, clear boundaries must be established in terms of meeting government regulations and policies, such as environmental requirements and meeting key performance indicators (I.12). Working with regulatory bodies within an industry enables SCEs to develop meaningful relationships (I.18), which helps when applying for public tenders, as intermediaries can advise SCEs on how to meet the necessary regulations (I.20). Furthermore, following UK standards and regulations can provide an SCE with global validation that they are operating at a high level (I.21).

Our data shows that, when analyzing competitors within the industry and across industries, SCEs gain insights into the drivers of innovation and policymaking (I.24). With multiple co-founders, decision-making should be straightforward, as minor decisions tend to be passed by individual founders without conflict, and a democratic decision-making system in place (I.23). However, SCEs must attend meetings with stakeholders (e.g., government regulators, investors, potential clients) on a regular basis to listen to their needs actively (I.25). When learning collectively as an organization, SCEs are more likely to begin with a human-led problem rather than a technological one, using a design-led approach (I.30).

Co-creating with customers through social media is a transformative way of interacting to identify market demand and build a community of knowledge sharing (I.04). Working with partners also aids in obtaining valuable feedback to accelerate development and gain a macro perspective on the business (I.03). Partnerships are a critical component of an SCE's cultural statement, emphasizing collaboration with partners and customers whereby customers are treated as partners (I.32). However, SCEs believe that individual needs are of high importance when delivering a bespoke platform to multiple stakeholders, including end users, businesses, and partners, in various ways (I.14). Given that there may be ownership issues with environmental data on cooperative platforms, one solution could be for users to become part owners of the start-up business, working openly with SCEs on member-owned platforms (I.15).

SCEs can manage environmental data (e.g., waste management) on a bespoke platform, which can then be licensed to private companies or national governments and support informed decision-making in that sector (I.24). Rather than writing sustainability reports based on historical data that quickly become obsolete, SCEs are now considering using real-time data. This can be shared on a platform as a live reporting tool for addressing issues of compliance and resource efficiency and fundamentally addressing an industry's sustainable development goals (I.24). Research and development may facilitate the design of autonomous systems for measuring environmental sustainability elements related to business, increasing data accuracy, and reducing the number of resources required (I.23). An SCE can use a business intelligence platform to import, clean and analyze data from databases, emails, videos, survey responses and other sources. These data analyses provide mobile, desktop, and real-time business intelligence to stakeholders,

allowing them to act on insights and improve their operations (I.29). By developing these business intelligence platforms, SCEs can integrate data and make them easily accessible to businesses and customizable to different stakeholder needs (I.33). Rather than selling the platforms, SCEs use them to accelerate product development by selling tailor-made products to their clients (I.33).

Our data reveals that SCEs can capture and leverage knowledge in different forms to support a more structured approach to education and training within the company. For example, formal learning lays the foundation for developing novel digital solutions, which can then evolve into viable products or services (I.25). SCEs with a formal educational background can often complement the capabilities of domain experts in identifying opportunities and overcoming challenges (I.10). In contrast, informal resources (e.g., articles, videos, podcasts, and social media posts) provide domain knowledge from influential personalities in a variety of industries and ecosystems (I.16). Self-directed research, such as reading academic and industry articles, having conversations with practitioners, at all levels, allows SCEs to acquire knowledge about a particular domain problem to understand better how they can deal with adversity and mitigate risks (I.18). This formal to informal learning process allows SCEs to become an expert in a topic or subject and then apply that expertise to the start-up business (I.18, I.23).

4.4. Factors influencing the transformation process

Our data suggests that SCEs can build capacity for learning, individually and as an organization, through the process of continuously learning by doing (I.34). Building capacity for learning often starts with resilience and a hands-on approach to tackling challenges, as one entrepreneur emphasized:

"It's more about your resilience to mistakes and then getting it right... being careful of where the educational sources come from because people can have very different experiences to you". (I.16).

Direct involvement in product development is not just about innovation but also about the deep, practical learning that occurs, as a participant explains: "I've pretty much learned by doing. So, I've been involved with the development since day one" (I.17). Once the value of continuous learning is recognized. How it may advance the company's long-term vision, that mindset shifts (I.29).

Building trust with clients requires an SCE to manage big data for them; they can collect and analyze data on customer behavior, market trends, and performance metrics (I.10). Fundamental issues within the domain can be addressed and potentially resolved by leveraging data to develop new technological products and services (I.32); for instance, using data platforms to improve processes related to environmental sustainability to acquire domain expertise and establish a unique selling point (I.24). Conferences and other networking activities, professional groups and umbrella organizations can initially assist in introducing SCEs to stakeholders and communities relevant to their domain. Mentors can provide guidance, feedback, and support and help entrepreneurs build their learning capacity. "It's a large organization with annual conferences, and we've been there twice already... they have a nice community as well for alga production, we are engaging with them" (I.23). This type of collaborative learning can help them gain insights into new technologies, business models, and approaches.

SCEs comprehend how they can work with competitors to attract new clients and customers, highlighting the significance of shared goals and collective endeavors (I.11). Collaborative learning through intermediaries necessitates striking a balance between incorporating partners' ideas and how those fit into the company's vision, which involves some trial and error (I.14). SCEs can benefit from forming partnerships with well-established companies (I.32) as well as collaborating with other smart city stakeholders, such as local authorities, through public funding and commercial contracts (I.24).

In exploring collaboration over competition, SCEs emphasize the necessity of balancing individual goals with communal advancements.

One participant expressed:

"We've spoken to a lot of people on the energy infrastructure side who are experts, but the insights and the knowledge that you get from them is relatively shallow. So, once we have the basic information... we end up not working with those partners much, but we get the basic knowledge, and then we try to improve on that, take that away ourselves, and become experts on it." (I.18)

This initial engagement with partners for fundamental insights before doing more in-depth independent research highlights a strategic approach to collaboration by SCEs.

Our findings show that intermediaries—i.e., incubators or accelerators—orchestrate an SCE's entrepreneurial learning process by co-creating a sustainable smart city ecosystem[1] through simulated activities and events. Essentially, they connect SCEs in the early stages of development with other smart city actors by sharing knowledge, resources, and expertise, leading to innovative solutions that can benefit all parties involved. By working together, entrepreneurs can leverage each other's networks and access new markets, customers, and funding opportunities.

Incubators may also provide a low-cost workspace to run their start-up business, and this provides further opportunities for networking and collaboration (I.05). Collaboration within incubators allows SCEs to pool their resources and knowledge to overcome individual challenges and accelerate their growth (I.04). Many incubators are based in educational institutions to support and share resources with students and members of the local community. As one participant vividly illustrates:

"Building the network is something we have to spend time on actively and to maintain it because knowing other people, knowing similar companies... because if we get to meet them and we get to talk to them, that's where we get most of the tips on where the industry is going ahead" (I.12).

This statement reflects the active, ongoing effort required to cultivate and nurture relationships that yield valuable industry insights and foster a collaborative spirit.

Accelerators facilitate meetings with high-level smart city actors, such as policymakers, who provide feedback on funding applications and whether the respective start-up meets relevant criteria (I.20). Conversely, private and public funding programs, for example, the Scottish Funding Council, offer learning resources as well as formal training, mentoring and targeted learning within the smart city domain (I.29). Participants are competitors from one perspective. Still, from another point of view, they have a similar mindset and are at a similar stage in their entrepreneurial learning process (I.05), which allows them to collaborate without socio-political barriers temporarily. By working together, SCEs can develop solutions that address the needs and interests of all stakeholders, including citizens, businesses, and government agencies. This can help build trust and support for smart city initiatives and ensure they are accessible and beneficial for everyone.

5. Discussion

Our study shows how SCEs prioritize collaboration over competition through the creation of temporary ecosystems for learning. These ecosystems allow SCEs to interact, network, problem-solve, and innovate

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[1] A smart city ecosystem is a network of actors working towards urban innovation through smart city project implementation, policy frameworks, and public-private partnerships. In contrast, the concept of temporary ecosystem introduced in this paper is a short-lived collaborative learning space where smart city entrepreneurs engage with intermediaries and other stakeholders to develop skills, share knowledge, and experiment with new solutions in a flexible, low risk setting.
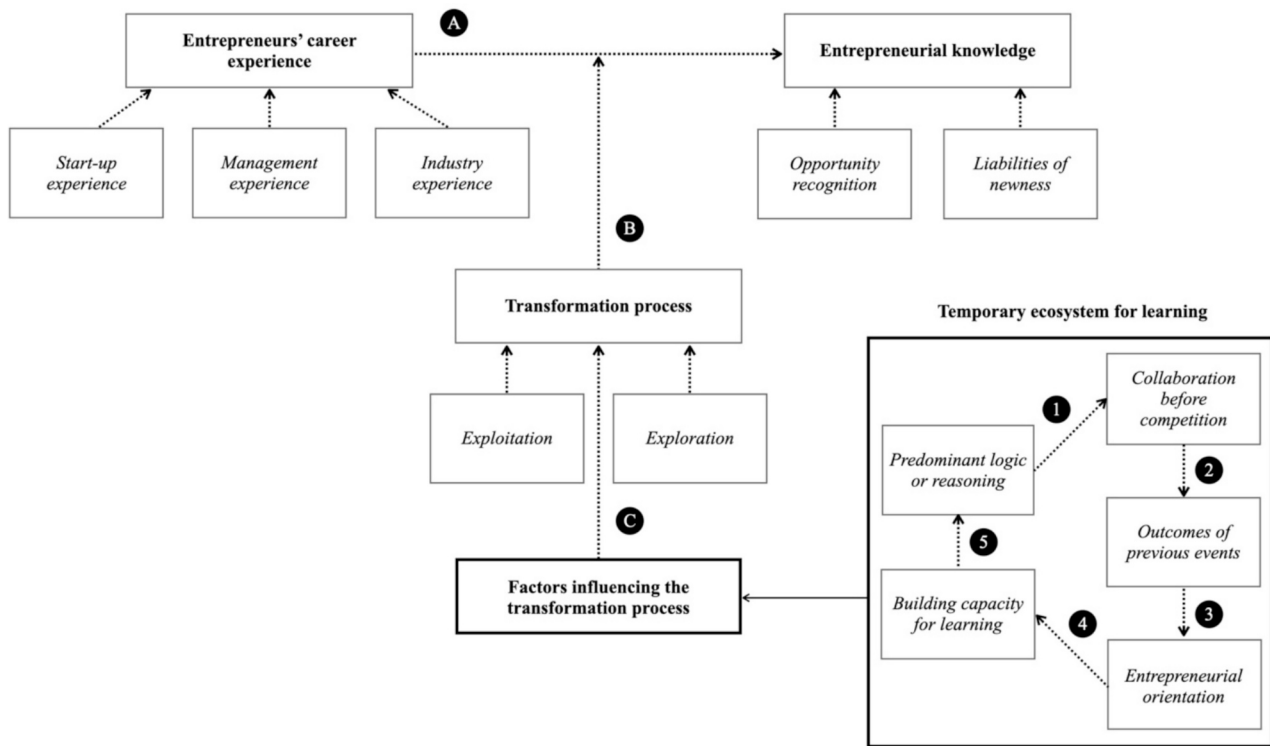
Fig. 2. Expanded entrepreneurial learning framework, adapted from (Politis, 2005).

together, facilitating the development of their entrepreneurial learning capacities. Rather than engaging competitively, SCEs informally share knowledge within non-formal learning environments that replicate real-life smart city challenges. Based on these findings, we propose an expansion of Politis' (2005) entrepreneurial learning framework, incorporating previously overlooked factors that influence the transformation process of SCEs.

5.1. Factors influencing the transformation process of SCEs

As represented in Fig. 2, we examine the key factors that influence the transformation process of SCEs in the context of how they learn: *collaboration before competition* and *building learning capacity*, which are new to entrepreneurship learning theory, and the three existing factors: *predominant logic or reasoning, outcomes of previous events*, and *entrepreneurial orientation*.

For SCEs with relevant domain knowledge or experience, it is easier to engage with other societal actors (e.g., local authorities) in accordance with a top-down approach to supporting collaboration. However, many SCEs enter the domain as individuals with little or no knowledge and lack the skills and competencies to engage with other actors to build experiential knowledge (Janowski et al., 2018). Despite SCEs run start-up businesses that work with other firms as collaborators, their communication and co-evolution strategies bind them together (Cozzolino et al., 2021). This means that, while having different missions and objectives and making their own decisions, the *predominant logic or reasoning* of SCEs is to collaborate and support one another (Ritala et al., 2018), which can be achieved through the co-creation of what we define as *temporary ecosystems for learning* (see Circle 1).

Our findings evidence the pivotal role of intermediaries in cooperating with SCEs and help them identify gaps in capabilities individually, which can feed into their own business. By co-creating temporary ecosystems for learning, participants can freely network, discuss relevant topics, and, in some cases, develop new ideas and concepts for digital products and services. For example, working with intermediaries on research and development projects that align with a SCE's expertise can

reinforce their expansion of dynamic capabilities and provide opportunities for informal learning (Enkel and Sagmeister, 2020), which occurs intentionally within a non-formal setting (Rogers, 2014). Moreover, we found that they encourage this mutually beneficial prioritization of *collaboration before competition* between SCEs and high-level city actors, such as policymakers, who can offer feedback about entrepreneurial events, like funding applications or advice about whether start-ups meet relevant criteria. This replicates what Minniti and Bygrave (2001) refer to as "outcomes of previous events" and are effective for SCEs to simulate "real-life" experiences and gain valuable experience within a safe learning space (see Circle 2).

As a result of appropriate *entrepreneurial orientation* (Kiyabo and Isaga, 2020), SCEs can identify, explore, and build meaningful relationships with central figures within the smart city domain (see Circle 3). This can eradicate feelings of self-doubt, loss of identity, and over-competitiveness, thus building the SCE's learning capacity and self-efficacy (Lex et al., 2020; Akmaliah et al., 2014). They continue to orientate their learning through self-regulation to identify themselves as a specific type of entrepreneurial learner. Entrepreneurial orientation is a strategic mindset emphasizing innovation, risk-taking, proactiveness, autonomy, and competitive aggressiveness (Al-Mamary and Alshallaqi, 2022). *Building learning capacity* involves developing the ability to learn, adapt, and improve continuously over time. Temporary ecosystems can help SCEs build learning capacity within their start-ups by fostering a culture of innovation and experimentation. By incorporating these elements of entrepreneurial orientation into their own start-up business, SCEs can create a culture that values different modes of entrepreneurial learning, nurturing an environment where employees are encouraged to learn and grow over time (see Circle 4).

Temporary ecosystems for learning allow for place-based growth to support the sharing of disparate local knowledge between multiple smart city actors working in the city, which could be considered an ecosystem in itself; however, their engagement in networks of learning relates to multiple ecosystems which are not only the ones in which they are located (Ooms et al., 2020). Therefore, for Edinburgh-based SCEs, collaboratively building knowledge requires a multi-ecosystem

approach, as our findings show that most SCEs will work with an intermediary to co-create a network of learning, which is then repeated. This iterative process creates a snowball effect in which SCEs may co-create multiple temporary ecosystems for learning to generate new knowledge and build learning capacity to facilitate the development of smart city products and services (see Circle 5).

5.2. Theoretical implications

Our study contributes to entrepreneurial learning theory by introducing new theoretical concepts sourced from observing that SCEs prioritize collaboration over competition to build learning capacity. Entrepreneurial learning theory tends to focus on individual logic, past event outcomes, and entrepreneurial orientation, whereas our research emphasizes the importance of temporary ecosystems for learning, where SCEs, regardless of their domain knowledge, engage with intermediaries to collaboratively address capability gaps and foster innovation (Cozzolino et al., 2021; Janowski et al., 2024).

Moreover, our study extends the entrepreneurial learning literature by introducing the concept of temporary ecosystems in the context of non-formal learning. This novel theoretical perspective emphasizes the importance of collaborative, experience-based learning environments that transcend traditional formal and informal educational settings (Debarliev et al., 2020; Salvi et al., 2022). SCEs differ from general innovation-driven entrepreneurs through their urban-centric focus (Yigitcanlar and Kamruzzaman, 2018) and deep engagement with public sector frameworks and city-level regulatory environments (Scaringella and Radziwon, 2018). These distinctive factors highlight the need for a tailored theoretical understanding of SCEs as contributors to sustainable urban development and community well-being within smart city development (Kummitha, 2019).

This study also emphasizes the significance of distinguishing between collaborative (complementary) and competitive (substitute) relationships, as well as examining the interaction of actors, artifacts, and activities (Granstrand and Holgersson, 2020). We affirm that *collaboration* and *competition* can co-exist and co-evolve within the same innovation space or even multiple spaces simultaneously. Despite their apparent polarity, more possibilities emerge for creating and sharing value as collaborating competitors when we focus on the relationship between collaboration and competition, considering actors and artifacts as systems rather than in singularity.

By pooling knowledge, resources, and expertise, these SCEs can enhance their collective learning capacity and tackle common challenges more effectively. It is particularly apparent that SCEs are not necessarily consciously aware of how their diverse knowledge can be shared to build relevant skills (e.g., computer programming or data management) and competencies (e.g., performance expectations, attitudes, and behaviors). Therefore, in a temporary ecosystem for learning, intermediaries can facilitate local knowledge spillover between SCEs, which is in-line with Omobhude and Chen's (2019) understanding of collaborative learning activities with an emphasis on filling specific gaps in knowledge over competitiveness. This builds on Yang and Zhang's (2021) understanding of 'coopetition' as SCEs would instead share expertise and resources to co-create digital products and services of *mutual value* based on personal passion and trust.

Lans et al. (2008) identified support and guidance, external interaction, internal communication, and task characteristics as critical factors in the work environment influencing entrepreneurial learning. We add to this understanding by demonstrating the specific benefits of public funding and collaborative ecosystems for smart city entrepreneurs. By highlighting the role of these ecosystems, we provide a new lens through which to understand and support the learning processes that drive innovation in the smart city domain. However, less attention is given to the process of *non-formal* entrepreneurial learning in an industry setting, with some notable exceptions, including Domínguez Figaredo and Paz Trillo (2014) and Williams Middleton et al. (2020).

Comparing our findings with those of Kummitha (2019), who emphasized the bidirectional relationship between entrepreneurship and smart cities, we extend this understanding by showing how smart city entrepreneurs specifically benefit from public funding and collaborative ecosystems for innovation. This alignment with Kummitha's identification of technological firms initiating socio-technical transitions further reinforces the importance of supportive environments for entrepreneurial success in smart cities.

Our study reflects how learners can engage more with non-formal learning activities with flexibility and contribution to the content, timing, and amount of interaction (Rogers, 2005). Although, informal learning is more challenging for the learner to recognize and understand its relation to any new learning because it is essentially unconscious, which is why it is so effective in a practical setting. Our findings emphasize a gap in entrepreneurship literature in that SCEs do not clearly distinguish between the nuances of mode and form when referring to informal and non-formal learning, which, as terms, are used interchangeably. This study challenges this lack of clarity, reflected more broadly in entrepreneurial learning and entrepreneurship literature.

The purpose of a temporary ecosystem for learning is to create an accessible space for SCEs to informally acquire, share, and apply intangible entrepreneurial knowledge with like-minded peers – i.e., other SCEs in similar circumstances with identical needs. For example, this might be done by replicating a specific industry/domain, such as smart mobility, while incorporating characteristics from those entrepreneurial and innovation ecosystems (Escribano et al., 2020). Unlike in a typical informal learning setting, which is unstructured and without clear intention or timeline (Rogers, 2014), a temporary ecosystem can provide the necessary boundaries for meaningful collaborative learning experiences through the simulation of unique 'entrepreneurial events' (Minniti and Bygrave, 2001; Politis, 2005). Experiential learning scenarios, such as these, are about *doing* first and then *learning* afterward (Chang et al., 2024) and provide SCEs with an opportunity for intermediaries to recreate a real-life industry experience within a safe and structured learning environment.

This intentional push for collaborative knowledge-sharing can trigger other forms of unconscious learning (Rogers, 2014), which are stimulated by activities set by intermediaries within a temporary ecosystem for learning. Often, when SCEs engage in this way, if they are able to build superficial knowledge about a topic, they can then invest a considerable amount of time extensively studying the subject autodidactically to deepen their learning and develop dynamic capabilities (Gupta and Bose, 2019). When they become experts, they can then formally integrate this knowledge into the start-up's short- and long-term planning (Mora et al., 2019).

Intermediaries simulate real-life collaborative scenarios between two or more competitors but without the expected social, political, and cultural barriers (Cantner et al., 2021). They can disrupt the conventional learning process as they break down social barriers between SCEs and other participants (i.e., smart city actors) who would not usually get a chance to interact in the same space – whether it be physical or virtual. At this point, hierarchical changes and, instead, new potential for cross-scale linkages and multi-level social interactions between participants emerge (Cash et al., 2006) as they share personal knowledge and experiences from their own practice through non-formal learning. For example, SCEs may have the opportunity to interact with and experientially learn from local smart city actors working in the public sector. In fact, our findings show that, within these temporary ecosystems, participants simulate real-life scenarios, such as deliberation of polycentric governance systems, on a small scale but without the restrictive boundaries of institutional power (Heikkila et al., 2011).

These types of informal learning interactions within a non-formal context (Rogers, 2014) can have a transformative impact on an SCE's learning capacity, although intermediaries are available to provide resources, collaborative support, and educational scaffolding, if needed

(Oliver and Oliver, 2022). Despite being an effective learning process with a structured purpose and collaborative intent (Krouska et al., 2022), it does not necessarily occur in a linear fashion, as SCEs may be engaged in multiple iterations of learning with different intermediaries simultaneously.

5.3. Practical and policy implications

This research contributes to the smart city domain by exploring the role of entrepreneurial collaboration in shaping urban innovation and development. By demonstrating the significance of temporary ecosystems for learning capacity building, the study highlights the importance of facilitating collaboration among diverse stakeholders in smart city initiatives. This has practical implications for urban policy and planning, suggesting that promoting entrepreneurial collaborative learning should be a top priority in smart city strategies.

Due to limited resources—including human, financial, and technological, through different forms of knowledge—SCEs seize opportunities to pivot their business towards value co-creation by collaborating with other SCEs in similar circumstances (Baggen et al., 2016). From a practical perspective, our findings reveal that SCEs can utilize diverse intelligence captured through different modes of learning to enhance their existing systems of innovation by developing a capacity for collaborative learning (Panori et al., 2021). Digital technologies can also be used to capture the occurrence of an entrepreneurial event which can become useful information and/or data to propagate across an entire business (Sengupta et al., 2021). Therefore, when something in the business world happens, they can immediately act on it—for example, during an incubator workshop, an SCE may trigger a business process or store data for analytics later. Therefore, in real-time, they are learning how to use data to manage an opportunity or threat (Chan et al., 2022) whilst at the same time building learning capacity.

Our study suggests that SCEs sometimes struggle to work and learn at the same time in isolation and may benefit from openly sharing their personal experiences in a non-formal setting. These experiences are converted into new knowledge, which, in turn, provides opportunities for new experiences (Politis, 2005). Such processes can then be replicated within the SCE's own organization to strengthen internal capacity for further learning (Barrutia et al., 2022) for education and training purposes. Prioritizing collaboration over competition between SCEs can help to build meaningful relationships based on trust as well as establish clear boundaries and an understanding of complementary knowledge, skills, and competencies (Scaringella and Radziwon, 2018).

Many of the SCEs in this study began their respective ventures as a passion project, working with one or more individuals who are utilizing technological solutions for sustainable and inclusive development to address problems within the socio-economic contexts of the city (Lee et al., 2021). Nevertheless, they need to deal with both private and public sectors in the development of their start-ups, which triggers the need for collaboration (Ozgen and Baron, 2007). Our findings reveal a lack of understanding from SCEs about how to develop learning capabilities in-line with critical public mechanisms, such as government policies and regulations, which can restrict the organic development of viable smart city solutions from the bottom up (Belli et al., 2023).

In addition to temporarily collaborating with governments and local authorities through public funding and commercial contracts, SCEs form intra-organizational partnerships with well-established companies and, as they are more technically advanced, have a deeper understanding of customers and the market, which can help accelerate innovation of a new start-up (Harrison and Leitch, 2005). In exchange, SCEs can offer a fresh perspective on the industry or domain by developing innovative and commercially feasible ideas. However, to successfully manage this bi-directional flow of organizational learning (Secundo et al., 2017), partners must have a positive synergy with shared values and goals on primary concerns such as environmental sustainability, which can be challenging when entrepreneurs are used to playing a dominant

leadership role (Etse et al., 2021). In this sense, intermediaries help participants prioritize collaboration over competition by nurturing a culture of learning through partnerships. For instance, SCEs benefit from forming alliances with well-established entrepreneurs as well as cooperating with governments and local authorities through public funding and commercial contracts.

5.4. Limitations and recommendations for future research

Despite its meaningful theoretical and practical inferences, this study has some limitations that should be carefully considered. First, data were only collected from the city of Edinburgh, UK, so there is limited scope in terms of the generalizability of the outcomes. There is potential to expand the sample to Scotland or even the UK. Second, the study concentrated on SCEs as the main focal point, although it would be helpful to get the perspectives from other smart city actors to try and align learning capabilities and the use of temporary ecosystems for learning. Regarding future research, there is scope for comparative studies of SCEs from other regions of the UK as well as internationally to identify the factors that influence the transformation process in other smart city domains with varied socio-economic environments.

6. Conclusion

Overall, we propose a new conceptual model that expands on Politis' (2005) entrepreneurial learning framework and reveals how SCEs can differentiate their entrepreneurial learning processes by working with intermediaries and other SCE actors in the development of new smart city products and services. However, they must reflect on the knowledge that they have acquired through their temporary ecosystem and how it can be used more effectively for the benefit of the organization (Mezirow, 2006).

The conceptual model (see Fig. 2) shows that SCEs can work together to create temporary ecosystems for learning, which in turn foster learning capacity, innovation, and long-term success. By pooling knowledge, resources, and expertise, these entrepreneurs can enhance their collective learning capacity and tackle common challenges more effectively. SCEs offer dynamic, innovative solutions to smart city problems from a perspective that is clearly different from other smart city stakeholders. In highlighting SCEs as a distinct cohort, our findings reveal their unique role in advancing sustainable urban solutions through collaborative, ecosystem-driven approaches (Bjørner, 2021). Their contributions to urban innovation, as well social and environmental transformations of smart cities, differentiate them from other types of entrepreneurs, where the integration of diverse stakeholder needs is paramount (Janowski et al., 2018).

Our comprehensive methodological approach, including member checking, provided a robust framework for understanding the learning processes of SCEs. It is the responsibility of an SCE to capture relevant knowledge to be disseminated digitally across the organization in an accessible way that can be understood by the broadest possible audience of employees within the company. Non-formal entrepreneurial learning in industry settings has received less attention, and this study addresses that gap by emphasizing the importance of non-formal learning activities. It also highlights the lack of clarity in distinguishing between informal and non-formal learning in entrepreneurship literature.

This study makes significant contributions to the field: it introduces the concept of temporary ecosystems as a novel framework for understanding non-formal learning among smart city entrepreneurs, demonstrates the critical role of public funding and collaborative ecosystems in fostering innovation, and offers actionable insights for policymakers to prioritize collaborative environments. These contributions advance both theoretical understanding and practical application in the domain of smart city entrepreneurship.

Temporary ecosystems for learning provide an accessible space for SCEs to acquire, share, and apply intangible entrepreneurial knowledge

with like-minded peers through the simulation of unique 'entrepreneurial events. Collaborative knowledge-sharing triggers other forms of unconscious learning, which are stimulated by intermediaries within a temporary ecosystem for learning. Intermediaries simulate real-life collaborative scenarios between competitors, breaking down social barriers and initiating cross-scale linkages and multi-level social interactions. This non-linear learning process, involving multiple intermediaries, has a structured purpose and collaborative intent, contributing to SCEs' learning capacity and long-term success. Ultimately, emphasizing collaboration before competition allows smart city actors to address complex urban challenges collectively, strengthening the overall resilience and adaptability of smart cities.

Practically, the study shows that SCEs can utilize diverse intelligence captured through different modes of learning to enhance their innovation systems by developing strategic learning capacity. Policymakers need in-depth knowledge about the specificities of each territory and ecosystem to offer recommendations. Understanding temporary ecosystem strategies on a local and regional level will encourage more collaborative forms of governance. Furthermore, SCEs need to deal with both private and public sectors, which triggers the need for collaboration. The study reveals a lack of understanding among SCEs about developing capacity for learning in-line with public mechanisms, such as government policies and regulations.

CRediT authorship contribution statement

Paul G. Oliver: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Luca Mora:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jun Zhang:** Writing – original draft, Formal analysis, Data curation, Conceptualization.

Author Statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process. He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

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Appendix A. Representative quotes

This appendix includes selected quotes from interviews with smart city entrepreneurs. These quotes are organized according to the theoretical dimensions used in our study, illustrating various aspects of entrepreneurial learning in the smart city context.

Theoretical dimensions	Representative quotations
Entrepreneurs' career experience	"I had full oversight across almost everything that was happening in the business, and that meant I could go very deep into those different parts of the business to build up my knowledge and my expertise. And that would mean working with, you know, people like the regulator, the FCA." (I.18)
	"Yeah, for sure. I mean, in my work, I do a lot of project work involving a lot of project management. That helps a lot. You must know your resource gap and get the team ready. For sure, that helps because it's not directly relevant in terms of technical skills, which is not directly relevant to what I do. Internal robotics is a different skill set." (I.12)
	"We really needed to get ourselves up to speed on all aspects of product development, engineering, user experience, and all the things that we kind of need to do at the core, and then how we use systems and built-in processes so that we can automate things like on board and you know, for scale." (I.14)
	"When it comes to legal regulations and these kinds of things, I've quickly realized that coming from a science background, I can't possibly take time to learn everything." (I.23)
	"We must go into what evolutionary economics or complexity complex systems are, which is kind of the area and multi-agent system, that sort of thing so because it's this internet disciplinary thing. I just must look for four special subfields within those areas and then just be very creative on how we bring those together." (I.25)
	"A lot of other companies I speak to who aren't involved in the government sector kind of steer clear of it because they don't really understand how it works. They see a lot of hurdles in getting contracts and so on. But we started off with a bit of a background in working with public sector and governments." (I.08)
	"In my learning process as an entrepreneur, I think my sort of ad hoc approach has significant limits that I've come to realize. And a little bit more formal training would have helped significantly, and I should have done more." (I.33)
	"There are training courses available… but largely even, they would probably do a bit of online research to find out what might be the way to deploy or get around a problem and just go ahead and do it, which very much suits us as a business." (I.09)
	"First and foremost, it's a group of people all trying to do the same thing, and then that could sort of tell you can't build a company as a single person. And you can't build something useful without other people also finding it useful. So, collaboration is the main driver of progress; more perspectives are needed." (I.07)
	"We just bring people together. And that's what we're doing. We will go on to create additional working groups and bring people together, people in the know. It's probably more informal at this moment in time… we're bringing people in for specific skill sets." (I.13)
	"I don't have my industry expertise; I'd spent like 20 years of my life writing code as part of my day-to-day life as an engineer and a scientist. And so, it's kind of intimately connected to that knowledge of understanding." (I.16)
	"But there are places where we need a formal structure. And that was the best example to connect that in terms of prior to forming the company for the industry experience. I think it has played a role because it's giving me a foundation upon which to build. So being a polymath and learning about different things." (I.03)
	"My previous experience in business got to the point where I was leading teams and a [smart city] consultancy firm, winning some pieces of work… So, you learn as you go, especially when you've got a team looking up to you need to make it look as if you know what you're doing time, even if you don't necessarily really know what you're doing" (I.09)

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Theoretical dimensions	Representative quotations
	"So again, I wasn't even relearning. I was learning to apply them to a new space… which I think did give me some advantage, you know, in being able to progress in the field of microcredit." (I.07)
	"I come from a digital marketing background, not a kind of engineering background. So, learning about how we build a product in a scalable way, we've needed to bring in the experts, and then from the growth perspective, kind of scaling an app." (I.14)
	"That is something that is improving all the time. And so, there is incremental innovation along that kind of strand of the business. But the more radical side is putting in building a lot of very, very high speed, charging infrastructure, which, to make it work, you do need the vehicles to be using it; you don't want to spend several million pounds on building that, and then nobody uses it. So, there's kind of a mix." (I.18)
	"Our idea was that we weren't disruptive; we were just trying to improve what they already did. From the beginning, we weren't the type to go and sort of run high-risk things, but nuclear was never badged as that. It was more of a because of its say, it's sort of regulatory technology, which by its nature is probably a bit dull" (I.20)
	"It's kind of fundamentally driven by deployments of our platform. We have a product roadmap, which takes us forward, you know, a couple of years. Yeah. And we know, okay, this is what we want to do, and this is how we want to develop it; these are the things we want to bring into it." (I.24)
	"The core business is to make us independent, truly independent localities, and focus on digitalization in buildings. The first phase is helping the individual property owners. The more we get data from different kinds of buildings and different buildings, the more we are creating a more general understanding of how the hell the buildings behave. So, we're becoming more and more of an ecosystem player." (I.06)
	"You have to be careful if you try to overreach or overspend the fund, a development that turns out not to be viable, where you are kind of locked in any way. So, you really need a lot of upfront planning. And it can be difficult because sometimes they almost want you to know what you are going to achieve or do." (I.07)
	"So, if you know, I suppose, a bit of background knowledge from a previous business understanding, having built stuff for this market before, we saw the opportunity to take some new regulation and technology that come along to solve an existing problem. (I.21)
	"The project approach has lots of advantages. But our internal projects are about the next generation of the sensor and the next set of features and capabilities, so the project that, from a project point of view, is right. And I guess that's from a strategic point of view of how you run the company. It's important that people know what they do and know what the constraints are." (I.10)
	"Project-based [strategies] are better because you can set up smaller milestones and smaller goals and kind of achieve them accordingly. But I think you must wear a different hat according to the different situation and how it plays out because it's a constantly evolving situation… we work quite a lot with Agile and Scrum frameworks and strategic approaches there in terms of meeting our milestones and goals." (I.03)
	"I think the keyword is that you do as a person as a new business, you don't become inward, you're constantly engaged with the customer, you can't engage with the problem, you're living the problem. So, in a way, it's iterative. It's not like there's a problem, and they'll go and solve it for six months. You're constantly going back. It's dynamic, is agile." (I.30)
	"The business model has been created to avoid huge investments. So, we'll be using the lean business development model where we are focusing on minimum viable products, and we're testing every product part separately and trying to do it as fast as we can. And that reduces the investments we needed that we need." (I.06)
	"Yeah, so we spent a lot of time building resilience into the infrastructure. So, a lot of development last year went about changing how the infrastructure works. We effectively built a monolith previously, and we wanted to break that down into microservices to make our services more robust and more manageable." (I.17)
	"So, realizing that there's going to be a lag time, there's going to be a period where, you know, we're developing solutions that the industry needs, and we know that the industry needs, but it's going to take time for that to catch up." (I.11)
	"I have skills in software engineering, and I do enjoy working on type-related projects. And it well wasn't started as an opportunity. It was just for me; I want to do something to reduce the waste." (I.12)
	"When you think about the nature of the problem, that is the thing that we need to solve. And I think that our general approach has been to become an expert in a domain and then think about how that can apply to the business problem, which we're trying to solve." (I.18)
	"Trends change relatively quickly; lots of companies come and go. I would say that if you take a decade's view, how do you think public transport can just be improved over a decade? How do we work, do projects, and build stuff today that is contributing to that decade-long trend? So, I think that's how we think about it. And that's, you know, how we're thinking about kind of zero-emission and electric vehicles." (I.18)
	"I'm very conscious that I'm in that incubation stage, that sort of tender infancy of business. And I am, because of that, adopting a low-risk strategy, to where the only time I move forward into something is when I've seen, calculated, and analyzed a viable business opportunity." (I.02)
	"So, you're becoming familiar with all these key notions, you do some canvassing, you start formulating these value propositions, you start turning engagements with potential customers and partners. And you start to understand what it really means, what problems people have, and whether what you're doing makes sense in the context of people's problems, or you need to adapt a little bit." (I.29)
	"The case of learning from what has worked and what is not as well as taking on board the customer engagements and just getting a general feel for what the market needs." (I.19)
	"Well, it's often a bit of an issue to engage with others because we don't fall into the standard categories that you want to engage with … we're part of a biotech industry, and what we do is 100 % biotech. The biotech industry is mostly about drug development and pharma. And date is not really the production they think of so we can, it's hard to position ourselves in a particular type of industry." (I.23)
Entrepreneurial knowledge	"And because it's a service-based, you know, business model. It's really the biggest resource as the human resource, the time that I put into it. And because I'm building it, it's my baby. I am doing everything I can to make sure we're growing, we're expanding." (I.02)
	"In 2019, we won a half million-pound contract from Defra, which basically, the UK Government has said that all waste will be digitally tracked across the UK. And this is in the Environment Act, which came into force at the end of 2021. And so, in 2020, they invited us to build a prototype of that system." (I.24)
	"We got a smart-R&D grant from Scottish Enterprise about two years ago. We sort of used that to do some feasibility assessment around the user space insurance, which can really solve the problem of medical, lack of data in the insurance world for mobility players, which then also leads to some kind of poor experience for end consumers when they are renting and utilizing vehicles, there's lots of damages, claims, etc., which we are trying to solve." (I.32)
	"In Scotland only, so we're kind of lucky that we chose to set up here, we won the Higgs EDGE award. And as part of that, is… £60,000 is a commercial loan. And again, you can leverage that commercial loan against grant funding. So, we didn't take investment, but we got a combination of debt, our own funds, and some other awards, competition wins, like private competition wins, that you can use as leverage for grant funding." (I.07)
	"With public sector or large organizations, like utilities, just having long-term relationships that lead to kind of opportunities… with grant funding, we are better in with the partner to get it secured directly from the customer, which is normally procured either via framework contracts, which is another written market or by just open tenders, which is kind of another route to market as well." (I.09)
	"So, when something comes along, we would figure out if it was a good fit. And if it was relevant, we have the capabilities internally to deliver against it. What might we need to do from an investment perspective to meet that objective? So, one example would be, at the

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Theoretical dimensions	Representative quotations
	moment, the UK Government has created a standards-based approach to identity; they've launched this 'UK digital identity and attributes trust framework'… We were aware of that policy coming out, and we then you know, funded the business appropriately. We could focus a team on that work so that we could then deliver a third required standard." (I.26)
	"I've just focused on what I love doing. And that's where my passion has been built in. My clientele has grown back in January. It was such an explosive month and one of my biggest clients in January, they'd come to me because two of my clients who didn't know each other recommended me, you see what I mean? So, it's been a journey of building something special." (I.02)
	"So, it was very much, there was plenty of work to go around for anybody, and we weren't all in the same spaces. But we're all learning similar things and being exposed to similar experiences. To us, like just a lot of knowledge sharing because it wasn't like, 'You need to sign this NDA before we have a conversation.' Everything was free flowing, and I think it really promoted stimulated growth, and you know, positive relationships." (I.05)
	"If you don't really know what you're buying as an organization because it's a new thing, it's a new problem you're trying to solve; it's much harder to write a tender document. Therefore, what I found is with new things, whatever the size of the organization, they tend to try a bit first, and then if it works, then they buy more of it. And then it gets to a stage where, okay, we're like these types of solutions; we now must go to tender." (I.10)
	"The criteria there, where we were looking at opportunities, was things like, what's the market? What's the total addressable market? Who are the incumbents in that market? If any? What is the technology that we would be disrupting in that market? How would that technology work? How difficult is it to develop it? How defensible is it? And then what would be a roadmap and funding or cost requirement to build an MVP?" (I.17)
	"We think that one of the opportunities there is that there is actually very poor data and visibility and trust in terms of knowledge about what's happening to all that material, you know, where it's being generated, how much of it there is, what is it, what is it, where it's being moved, where it's being processed and transformed. And so, we're trying to build a few like a digital twin, almost have that global kind of waste system." (I.24)
	"You need to be able to present your ideas in a clear and succinct fashion that is kind of easily accessible to different audiences… I mean, I had quite a bit of public engagement activities… at this Science Festival and stuff where things must be a little bit more accessible, having helped but otherwise. Yeah, I've been doing some advising for a standardization body, but I haven't been working with any, let's say government, local councils." (I.29)
	"Our value proposition is partially that we genuinely generate better results than they can be done by humans alone. We propose a human-machine hybrid, but that tends to work better. And the other part of our value proposition is that it is much quicker to develop routes to deal with unforeseen circumstances or found dates or anything like that." (I.34)
Transformation process	"When we work with larger companies, what we've found… it is just so difficult to get anything done. When it's a founder, chief exec, or somebody very senior level, who's micromanaging decisions, and they don't give autonomy to people further down the chain." (I.26)
	"Unfortunately, we haven't had much success with anybody else. We've had, I wouldn't say, pushback, but we've not given public transport as one of the core pillars or the public transport strategy as one of the pillars of the Scottish Government's program for government. And they want to decarbonize and reduce emissions." (I.18)
	"We are supported by the likes of Scottish Enterprise and SDI, which are obviously funded by the Scottish Government. We've done stuff with Zero Waste Scotland, of course, in Scotland. So, we have a relationship there from a commercial business scaling perspective." (I.24)
	"We only end up interested in the data, all the sensor, installations, implementations, and maintenance, will be outsourced, and that they will be outsourced to local partners… So that gives us a flexibility that gives us the local knowledge that we always go back, because that's all the nature of our business idea." (I.06)
	"We're talking with a Glasgow City Council, and we're talking with Mavis Valley Recycling, which is a private company for the Council, and they have budget constraints, but at the same time, they also have other constraints, for example, they need to make sure they recycle waste properly, we need to make sure they're meeting like a Scottish environmental requirements, nothing goes to landfill they have to have a number of performance matrix might rather than just profit." (I.12)
	"I could go very deep into those different parts of the business to build up my knowledge and my expertise. And that would mean working with people like the regulator, the FCA. But also working with, like large industry players, like the banks." (I.18)
	"What is the FCA looking for because for this application? To sort of get a handle on it. What sort of things are they looking for? What are they assessing? And sometimes it's just good to double-check and check that we're going in the right direction." (I.20)
	"You know, we've been pulling it in from all over the world because we can, yeah, and so I do wonder about that. I mean, the one thing we have is that we're under UK financial services regulation. So, that's huge. I mean, that's the best in the world as far as we're concerned." (I.21)
	"I also take the view that it's important that I do a lot of this is to kind of really try to open one's mind and look around at what's happening, look at what is happening across our whole industry, the waste industry around the sector. Look at what other people are doing, look at, you know, looking at other innovations and policies and understanding what the drivers are." (I.24)
	"Day-to-day decisions that are quick and easy, and if they won't make a huge difference, I make myself, and also if one of the other four founders have a decision to make there, they're more than welcome to make small decisions, any big decisions we make during a shareholder meeting." (I.23)
	"I'm always engaged with stakeholders. Yeah, so this involved the government regulators, investors, institutional investors, and potential clients. So, I'm usually quite active in attending things like conferences or just in meetings with these stakeholders, and mainly listening to their needs." (I.25)
	"So, some are using emergent technology for that project without necessarily knowing that technologies can be here to stay because there are so many different frameworks that come, and they've been popular for a year or two. And then they kind of facilitate, but they never fully adopted. So, there's always a lot of thought and consideration that goes into technology choice when you're starting a new project." (I.05)
	"You're dealing with, to start off, a human problem… entrepreneurs shouldn't start with technology. Don't start with a whizzy idea. It's about focusing on something that's not working. Okay, friction or a problem." (I.30)
	"We currently have a little bit of a partnership between our fans on Facebook. So, whenever we mast something about an object, like a stinging nettle, or we ask some questions about the recipes that they've made with it, there's a lot of knowledge flow from the customers back to us. And I've just learned a lot through that." (I.04)
	"As we were growing, getting the right partners helps you to kind of jump through and look at the horizon on what the big picture looks like. It was kind of get some interesting partners, big partners… when you work with them, they want you to succeed because if you're successful, they're successful. So, it helps to get several insights and good feedback from them." (I.03)
	"Innovation, partnership, kind of collaboration, being customer-centric, and then being resilient and kind of open with both our customers and partners. We pay huge attention to partnership because it's not just a partnership; it's external. It's also our customers; we treat them as our partners. Although, you know, you're making money by giving them a service, but at the same time, we are investing in them for a longer period." (I.32)
	"It's got multiple different audience types that will all be leveraging the core technology, but in different ways. So, for example, the end users, the charities, the businesses, the partners, the other partners that we have, for example, we've got banks that we work with, so it's all about giving people all the time and resources that they need to enable that positive impact, but in the ways that they need it" (I.14)

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Theoretical dimensions	Representative quotations
	"But I'm really interested to see what happens with things like those more cooperative platforms… especially when it comes to things like emissions data, environmental data, and such. And this sort of ownership of data can become quite problematic if you, if you're to users, 'give me all your data,' then I own that data. And it becomes a more cooperative model where you become a part owner of the company" (I.15)
	"We license to companies that produce waste and want to know what's happening to that material. We then license it to recyclers who want to understand where all that material is so that they can invest in capacity or report it to their customers. And then we're also doing that for cities and national governments that want to get a better handle on what's happening across the waste sector." (I.24)
	"We've developed a lab-based system that automatically measures how the algae grow in a fully autonomous system. And we're able to deliver results fast and in a really accurate manner, instead of having an army of technicians in the white lab because of the measurements, so our computational framework and the machinery we build automate and make it a lot quicker to optimize our production" (I.23)
	"Product definition is still a little bit of a moving target. But what I can tell you for certain is that one of them will be a business intelligence platform. So, we built this initially as a tool to demonstrate the capability of our technology… it was difficult to explain to people what a neural network is and what sort of data you can extract." (I.29)
	"Our platform allows you to quickly develop a mapping application where someone can put in a bunch of locations, then they immediately get a whole bunch of data from satellites, etc., and the data that they get, and the way that the data is interrogated defines the application if you will. So, you could have an application related to water." (I.33)
	"I knew here in Edinburgh that I was going to launch my company; I wanted to learn more about businesses. So, I did an MSc at Napier in Corporate Strategy and Finance. I did the whole MSC except for the thesis. I thought it was very important for me to learn, and it was also kind of a theory on business." (I.25)
	"The one area where we did not have the knowledge, which was finance and accounting… we ended up with the guy who ran the entrepreneurship program at Edinburgh [University], who liked the idea so much that he jumped on board and became our CFO." (I.33)
	"My supervisor at the time I was doing my PhD went and became a lecturer at Heriot-Watt while I was studying at the University of Edinburgh, and she was a fellow… but that was still not difficult for me to be supervised. But it did mean that when it came to the IP generated, it became joint IP between the two Universities." (I.07)
	"It was just really off the back of a conversation about… today's challenge, and I don't know how to solve it. So, a very informal sort of introduction to it, but I found the NHS is also a very formal organization. It has procurement rules and its normal way of buying services as it writes a request for proposals or a request to tender and it will go out and say you know; this is what I want." (I.10)
	"It's usually informal resources in terms of books and podcasts and stuff like that. And, if you're trying to build the type of business that we're trying to build, then there are certain people that you listen to." (I.16)
	"I think the way that we've mitigated those risks is doing the research, even though it might not be directly applicable. But doing research, going to write research papers, or speaking to people that have gotten knowledge of something that's kind of adjacent to it, which in theory means it should work, or just looking at other companies, you know, like Tesla." (I.18)
	"Once you know how to read a scientific paper, once you know where to look if you want to know or learn about a particular field, once you get involved in it and want to go to a conference and talk to people who have been in this field for a long time, then you can do this for any field of science. So, I worked with virology for my thesis work. And that's what my expertise would be." (I.23)
	"But I don't use that, don't I? However, it taught me how to engage with other scientists, how to present at a conference, how to read papers, how to reach out to collaboration partners, and these skills are universal." (I.23)
Factors influencing the transformation process	"And that's okay, and it's more about your resilience to mistakes and then getting it right. And so, guess I think the kind of things I would say is like being careful of where the educational sources come from, because people can have very different experiences to you." (I.16)
	"I've pretty much learned by doing. So, I've been involved with the development since day one. Originally, it was me and two other developers who started this. I'm still involved with all the technical development sprint planning, feature planning and all those things. And so, for me, you do learn by desk research, looking at kind of people in the marketplace in the sector who are credible, again, in our sector that can very well work widely." (I.17)
	"The general kind of emotional resilience from trying things, learning that they don't work, learning why they work, and then moving on. That's something that, you know, is very draining when you do it for the first while, and then you build a bit of resilience and build a bit of normality around." (I.34)
	"The problems our clients have are they've got multiple buildings with hundreds of people working in them; they don't know, because you can't see everything all the time. So, you need a way of seeing through data to understand what's being used and how well that resource and our focus now is becoming very much more on how to use that data to save carbon and meet ESG targets that companies have all recently signed up to." (I.10)
	"This is a huge initiative on our part … Today, a classic example is driverless cars, right? So, you may be familiar with all the debates going around driverless cars and insurance. Like, if there's a crash, who is liable and exits the car? Yeah. Is the company who sold the car? Or is it the driver or the owner of the car? Those kinds of fundamental issues are how mobility is very much closely linked with insurance." (I.32)
	"Looking at environmental impacts and environmental management within a business context, waste is always something that's part of that whole equation… because we saw that there was a real challenge there but a real opportunity specifically around data and knowledge of what happens to that material." (I.24)
	"AlgaEurope seems to be a kind of an umbrella organization to collect all the European algae producers and researchers, and it's a large organization with annual conferences, and we've been there twice already … and they have a nice community as well for alga production, we are engaging with them. There are certainly specific bodies; compared to other industries, we're a small and growing sector." (I.23)
	"We advise the UK Government, we've got a big contract with the UK Government for the major conductivity project across the UK, we're the advisors to it. So that just, that just makes people look up and take notice and see… And they're talking about appointments for the Welsh Government, the Scottish Government, all these things just add up to the credibility and the signal, and all these guys are you guys are obviously good." (I.08)
	"I'm an entrepreneur. I guess I kind of said do it instinctively, I mean, the definition of this various definition of entrepreneurs and, you know, somebody maps the mindset of an entrepreneur to the criminal mindset. So, there is an inherent thing there about trying to get around obstacles and trying to work out how to, you know, how to sort of overcome kind of obstacles and problems and that kind of thing." (I.24)
	"So obviously, after that stage epic, I was very focused on the sort of the pure research element of it. And I wasn't studying them to think about the bigger picture, which was the site, I would say, now. So, from that point on, it was, you know, a sort of a mindset shift. I started thinking about it." (I.29)
	"We had to go and find people that could help us conceive design, manufacture, you know, produce, manufacture, prototype, the hardware. And we had to kind of learn what works and what doesn't kind of along the way. So, we needed partners to do that." (I.11)
	"I think it's being clear about what it is that you're trying to do, and you know, whilst, at the same time, the partners will have loads and loads of ideas, it's kind of trying not to deviate too far from your vision as to make sure that everything that we do is going to be worthwhile doing so. So, we've chosen the partners that we work with carefully." (I.14)
	"We've spoken to a lot of people on the energy infrastructure side who are experts, but the insights and the knowledge that you get from them is relatively shallow. So, once we have the basic information… we end up not working with those partners much, but we get the basic knowledge, and then we try to improve on that, take that away ourselves, and become experts on it." (I.18)

(*continued*)

Theoretical dimensions	Representative quotations
	"We're supported by the likes of Scottish Enterprise, and SDI, which is funded by the Scottish Government. We've done stuff with Zero-Waste Scotland, of course in Scotland. So, we have a relationship there from a commercial business scaling perspective. But the government is potentially a customer for what we do" (I.24)
	"Going back to the ecosystem approach, [we] believe in working with partners and delivering the impact of digitization. Further, because it's not a land grab exercise for us, I think this industry is big, and we can't solve all the problems by working in isolation. So, from day one, we realized the value of partners." (I.32)
	"There was a little bit of a pecking order with some more established businesses. A bigger one, they would refer work down to the size above us. And then we were the size below the next company. If somebody came in, they were just chuck it our way. And if something was too big, or wasn't appropriate for us, again, we quickly learned that and being good at introducing people to other people and facilitating success" (I.05)
	"When you're starting something out, you have to collaborate, to just get your idea known about to, to be able to learn… working together with people, respecting where each other's boundaries are, but working, you know, to move things forward is critical." (I.10)
	"Collaborating with other companies is important for corporate learning, as well as individual learning. And you're even to the point where some people are in the same space; they're competitive, but you can still get something out of collaborating. It's an incredibly cost-effective way of doing things because … you're not working in a silo, you can learn, you can see what's worked, what hasn't worked." (I.10)
	"Building the network is something we must actively spend time on and maintain because knowing other people, knowing similar companies… because if we get to meet them, and we get to talk to them, that's where we get most of the tips on where the industry is going ahead. And we also like to think that we do our part in that." (I.23)
	"We spoke, we spoke to Baillie Gifford, we spoke to JP Morgan, we spoke to State Street, we spoke to Bank of New York Mellon, we spoke to a lot of the smaller asset managers, insurance firms Aegon. And started to understand from our buyers what are the challenges." (I.13)
	"That's why I mean, we have a full-time business development manager now who brings this network of contacts. So, yeah, I think it's good to identify gaps in the business early on and try to fill them with roles that benefit the company. Yeah, and crucially important, really, both in terms of insights, listening, understanding, but also testing ideas." (I.29)
	"I'd say, entrepreneurial opportunity, or any kind of event that I can take part of, so it's been part of lots of accelerators. It started with Creative Bridge." (I.04)
	"[BRT] has been a massive influence on us. Even just that, we very quickly grew out of the resource that they could provide from a learning point of view because we were out there in the wild learning from other businesses… but the space that they provided and the opportunities that they provided because of being connected with them were invaluable." (I.05)
	"IP Accelerator program which significantly increased their recycling efficiency and increased the quality of output … Then I went to their site twice to just have a look at the challenge they're currently facing. It's just they're having the problem we already know in the industry, like a manual with a sorting process and the low-quality output, and for Glasgow city council really wanting to be at the forefront of it, databases lesson policy." (I.12)
	"So just get an idea, a handle on what the FCA is looking for because this was before the application, so as sort of get a handle on? What sort of things they're looking for… and sometimes just good to double check and check we're going in the right direction." (I.20)
	"We have been fortunate to be part of a couple of programs. So, you know, I mentioned the IQ funding. We also had funding from Scottish Enterprise through the Highgrove spin-off program, which comes with a package, not only funding but also a set of business models." (I.29)
	"But we're all learning similar things and being exposed to similar experiences. To us, it's just a lot of knowledge sharing because it wasn't like, 'You need to sign this NDA before we have a conversation.' Everything was free-flowing, and I think it really promoted stimulated growth, and you know, positive relationships." (I.05)

Data availability

The authors do not have permission to share data.

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Dr Paul G. Oliver is a Lecturer in Digital Innovation and Entrepreneurship at The Business School of Edinburgh Napier University.

Dr Luca Mora is a Professor of Urban Innovation at The Business School of Edinburgh Napier University and at Tallinn University of Technology, where he is affiliated with the Academy of Architecture and Urban Studies and the FinEst Centre for Smart Cities

Dr Jun Zhang is currently working as a Lecturer in Information Systems at Sheffield University.