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Quintuple Helix, the Informal Economy and Sustainable-Smart Innovations: Lessons to be learned from a transdisciplinary student project

Carolien van den Berg[1][0000-0002-2243-8375] and Belinda Verster [2][0000-0002-2243-8375]

[1] Information Systems Department, University of the Western Cape, Cape Town, South Africa
[2] Department of Town and Regional Planning, Cape Peninsula University of Technology, Cape Town, South Africa
cvandenberg@uwc.ac.za and versterb@cput.ac.za

Abstract. This paper explores how the informal economy can act as a catalyst for sustainability and digital innovation through student-led interventions in marginalised communities. Drawing on a transdisciplinary project situated in the informal settlement of Dunoon, Cape Town, we apply the Quintuple Helix (QH) framework to examine how collaborative innovation unfolds across academia, government, industry, civil society, and the natural environment. The study investigates how student teams co-designed context-specific digital solutions in partnership with community and institutional actors. Our research is guided by the question: What insights does the QH framework offer for guiding transdisciplinary student projects focused on the informal economy? Using thematic analysis of student artefacts, reflections, stakeholder feedback, and researcher observations, we evaluate how knowledge co-creation contributes to sustainable-smart innovation. Findings highlight the importance of community engagement, inter-institutional collaboration, and sustainability-oriented design, while also identifying challenges such as limited industry involvement and scalability.

Keywords: Information Systems Education, Informal Economy, Digital Innovation, Quintuple Helix, Design Thinking, Innovation-Based Learning

1 Introduction

This paper presents findings from a transdisciplinary student project that investigated how digital interventions can address sustainability challenges within the informal economy of Dunoon, a marginalised settlement in Cape Town, South Africa. The informal economy has often been regarded as a challenge to urban planning and economic regulation, yet it plays a critical role in mitigating poverty and unemployment, especially in contexts marked by high youth unemployment and inadequate service delivery [1–3]. Rather than viewing informality as a deficit to be formalised, this paper adopts a more inclusive perspective, recognising it as an adaptive and innovative system. In this context, student teams from three universities worked with community members to co-design sustainable-smart innovations. These digital solutions aimed to address locally

relevant issues such as waste management, informal trade logistics, and skills development. The project was explicitly aligned with several Sustainable Development Goals (SDGs), notably SDG 1 (No Poverty), SDG 8 (Decent Work and Economic Growth), SDG 10 (Reduced Inequalities), and SDG 11 (Sustainable Cities and Communities)

To analyse the dynamics of collaboration within this complex environment, we apply the Quintuple Helix (QH) framework [4]. As an evolution of the Triple and Quadruple Helix models [5, 6], QH integrates five stakeholder systems: academia, industry, government, civil society, and the natural environment. It is particularly well-suited for sustainability-focused innovation because it explicitly includes environmental and social dimensions as drivers of knowledge creation and transformation.

The study is guided by the question: What insights does the QH framework offer for guiding transdisciplinary student projects focused on the informal economy? Through thematic analysis of student artefacts, reflective journals, partner feedback, and researcher observations, we examine how QH-informed collaboration contributes to context-sensitive, inclusive innovation. By embedding sustainability principles and digital co-creation into an educational setting, this work offers a practical model for engaging higher education in addressing real-world challenges in marginalised communities.

The paper is organised as follows: a theoretical overview of the literature to position the QH framework, followed by a discussion on the importance and challenges of the informal economy and the concepts embedded in the learning environment. The next section provides background on the student project, followed by the research methodology and the discussion and findings from the analysis of the QH framework.

2 Quintuple Helix Framework

The Quintuple Helix (QH) framework [4] represents an evolution of the innovation system frameworks that preceded it, namely the Triple Helix [5] and the Quadruple Helix [6]. This development was necessitated by the increasing complexity of innovation processes in the 21st century, where traditional models proved insufficient to capture the multifaceted dynamics of knowledge production and societal needs [7].

The original Triple Helix model identified three key actors, Academia (Universities), Industry, and Government, whose interplay fosters innovation. While effective, this model did not account for the growing role of broader societal participation in knowledge creation. The introduction of a fourth helix, Civil Society, recognised that end-users and communities influence technological development through their demand and participation [4]. This inclusion emphasised that knowledge generation and innovation are not exclusive to institutional actors but are co-produced with societal stakeholders. Building on this foundation, the QH further incorporated the Environment as a fifth dimension [4] to present an analytical framework where knowledge and innovation are connected with the environment.

As argued by Carayannis and Campbell [8] “The Quintuple Helix innovation system optimises societies and economies by fostering smart, sustainable, inclusive, and resilient development through cyber-physical ecosystems aligned with Industry 5.0 and Society 5.0”.

Sustainability concerns have become critical in innovation discourse, requiring an integrated model that considers ecological impacts alongside economic and technological advancements [9, 10]. This addition ensures that innovation systems are aligned with long-term sustainable development goals by balancing technological progress with environmental responsibility. By adding these two helices of civil society and the natural environment, a comprehensive lens for analysing complex socioeconomic systems is provided [7]. This is of particular value when working in informal settlements, which are one of the most complex urban phenomena of our time.

The application of the QH framework as an analytical framework for reviewing the outcome of student projects during the fourth iteration in 2024 has the benefit of including a transdisciplinary focus to integrate different perspectives. It can be applied as a framework for understanding the complex relationships and interactions between various partners involved in innovation processes. It furthermore supports the concepts that we incorporate in our learning environment, such as Society 5.0, as it relates to the digital social innovations generated by student teams, as well as the inclusion of local lived knowledge within collaborative partnerships. It can also help to identify gaps or areas where collaboration or intervention may be needed to achieve the desired outcomes.

3 The Informal Economy: Its Importance and Challenges in South Africa

The informal economy plays a significant role in South Africa's broader economic landscape by generating employment opportunities and contributing to economic growth [11]. According to Musara and Nieuwenhuizen [12], South Africa's informal sector employs over 3.2 million individuals, accounting for approximately 19% of the country's total workforce. Despite these substantial contributions, the informal economy remains largely untapped in terms of policy support and investment, which limits its potential to address socio-economic challenges such as poverty and unemployment. To enhance its impact, greater efforts are required to integrate alternative resources, such as digital technologies, to foster growth and sustainability within the informal sector [13].

Despite its importance, the informal economy in South Africa faces numerous challenges that hinder its growth and integration into the broader economy. Key barriers include inadequate social protection, poor infrastructure, ineffective government policies, and restricted access to credit [11]. Additional challenges include low capitalisation, limited technology adoption, and insufficient support structures for informal enterprises. Daramola and Etim [14] further emphasise the barriers of inadequate digital skills, unreliable government support, high electricity costs, expensive internet access, and various health and safety concerns.

As mentioned above, integrating information and communication technologies (ICTs) also presents challenges for the informal economy, such as low adoption rates, lack of customised ICT solutions, and unequal access to digital resources [15]. These

findings suggest that addressing digital and ICT adoption challenges is crucial for enhancing the productivity and sustainability of the informal sector. Overcoming these barriers requires targeted policies that recognise the informal economy as a legitimate sector, investment in digital literacy, and the provision of affordable technological solutions tailored to the needs of the informal sector.

Digital technologies have emerged as transformative tools for economic growth, particularly within the informal sector, such as e-commerce, financial services, supply chain management and efficiency [16-18]. Despite these opportunities, it also raises new risks in the form of digital exclusion or adverse incorporation [19]. Furthermore, the adoption of digital technologies within the informal economy remains limited, necessitating further research to explore the impact and implications of technology on informal enterprises [20].

4 Inclusive Design Through Sustainable-Smart Innovation

Our learning environment is informed by several key concepts that are critical for addressing contemporary challenges and fostering sustainable development. These concepts serve as guiding principles in the student projects to infuse inter- and transdisciplinary collaboration, societal engagement, and ethical considerations in higher education and beyond. The key focus is on sustainable-smart innovations, particularly in marginalised settings, where digital sustainability intertwines with inclusive innovation. Fig. 1 provides an overview of the concepts that we apply.

Fig. 1. Key Concepts for Inclusive Design Through Sustainable-Smart Innovation

Sustainable-smart innovations in this project are co-created through the collaboration of academia, industry, government, and communities to develop technology-enabled solutions that respond to real-world challenges. Our use of the term sustainable-smart

innovation aligns with broader digital transformation goals, yet it is grounded explicitly in the socio-material realities of informal economies. This framing deliberately departs from more technologically deterministic models by centring community co-creation, the value of local knowledge, and ecological responsibility as foundational design principles. This approach resonates with the concept of Digital Social Innovation (DSI) as articulated by Serpa and Ferreira [21], which highlights the convergence of technological advancement, social needs, and inclusive innovation ecosystems. Rather than positioning technology as the sole driver of change, the emphasis is placed on collaborative processes that involve diverse stakeholders in shaping equitable and context-sensitive solutions. In doing so, sustainable-smart innovation becomes not only a means of technological progress but a pathway toward building more just, resilient, and inclusive societies.

Society 5.0 envisions an inclusive, technology-driven society that enhances social well-being and quality of life. It moves beyond economic competitiveness to emphasise co-created knowledge within public-private partnerships [7, 22]. Though relatively new in Africa, its principles of leveraging technology for social good, inclusivity, and sustainable development align with local challenges. This framework helps students critically engage with sustainability, resilience, and the agility needed for rapid socio-technological changes [23, 24].

Sustainable Development Goals (SDGs) provide a framework to consider sustainability both as an objective to be achieved and a method to get there [25]. Sustainability encompasses social development, economic development and environmental protection and within this framing, digital sustainability refers to "the development, deployment, and utilisation of digital resources and artefacts toward improving the environment, society, and economic welfare" [26]. What this highlights is the need to continuously think and act with sustainability in mind, thus not only as an end-of-project achievement but also as a driver of activities and thought. This dual role underscores the importance of tailoring sustainability strategies to specific socio-economic and environmental contexts, thus being highly context-sensitive. Several SDGs provide guidance in our engagement with the informal economy in the context of the specific informal community. SDG 8 (Decent Work and Economic Growth) is especially relevant, with targets 8.1, 8.2, and 8.4 emphasising sustainable and inclusive economic growth, innovation, and the circular economy [27]. SDG 1 (No Poverty), through targets 1.1, 1.4, and 1.5, underscores the importance of eradicating poverty, expanding access to technology, and building resilience to sustainability-related shocks and disasters. SDG 11 (Sustainable Cities and Communities) is closely aligned with our work, particularly target 11.6, which addresses the reduction of environmental impact, an urgent issue in informal economies where waste management remains a significant challenge. Lastly, SDG 10 (Reduced Inequalities), and in particular targets 10.2 and 10.3, promotes the social, economic, and political inclusion of all, and calls for the reduction of inequality through equal opportunity and equitable outcomes [27].

Partnerships: The growing urgency to address the future of our societies and planet requires collaborative partnerships that co-create sustainable solutions whilst enabling the equilibrium between ecological, economic and social concerns. This complex endeavour calls for an inter/transdisciplinary focus to circumvent the narrow lenses of

disciplinary boundaries [28]. The application of a QH approach can integrate different perspectives to set the stage for sustainability priorities and considerations.

Local knowledge or local knowing refers to the know-how derived from the day-to-day lived realities of community members and students as members of their community. We recognise the value of local lived knowledge by valuing the intimate understanding that local communities often have of their environment and the challenges they face and that this knowledge should be used to inform and guide sustainable development efforts. We adhere to the following principles for engagement:

- Community knowledge is central to the projects and their associated technological solutions, resulting in unique perspectives and experiences.
- Complex social issues and context-specific environmental and economic challenges often cannot be well understood or resolved by "expert" research.
- Interventions from outside the community often have disappointing results with little uptake. This point is specifically relevant in the South African context with its resource shortages.
- Communities should have equal inclusion and collaboration in the identification, research, and resolution of community issues [29].

Collaborative technology development, reflection, and joint deliberation with respect for local agency and innovation can open new avenues toward responsible and societally oriented knowledge production and ethical technology development. We require solutions that are 'fit for purpose' to ensure alignment within the context of the user, thus striving for more equality and less coloniality in the (digital) society [30].

This study does not treat the informal economy, the student learning environment, and the QH framework as competing lenses, but rather as interdependent components. The informal economy provides a context where sustainability challenges are acute; the student project offers an interventionist platform and the QH framework enables a multi-stakeholder analysis of how innovation is co-produced across sectors. Together, these layers serve to interrogate the potential and limitations of transdisciplinary, sustainability-driven digital innovation.

5 The Student Project

This interdisciplinary student project was launched in 2021 and we are reporting on the fourth iteration that took place in 2024. Each of the previous iterations saw significant changes in the project, such as shifting the focus from numerous communities to a single community and including an international academic partner. Another substantive shift was changing the project theme from generalised community sustainability challenges to focusing solely on the informal economy as a significant contributor to sustainability and a driver for digital innovations.

The iteration in 2024 was rolled out as a Collaborative Online International Learning (COIL) project with student groups from Urban Planning (CPUT), Information Systems (UWC) and a multidisciplinary group of students from the Innovative Studio at Avans University of Applied Sciences (Netherlands).

The one constant throughout the four years was the application of Design Thinking as a method to structure the project in phases, as illustrated in Fig. 2.

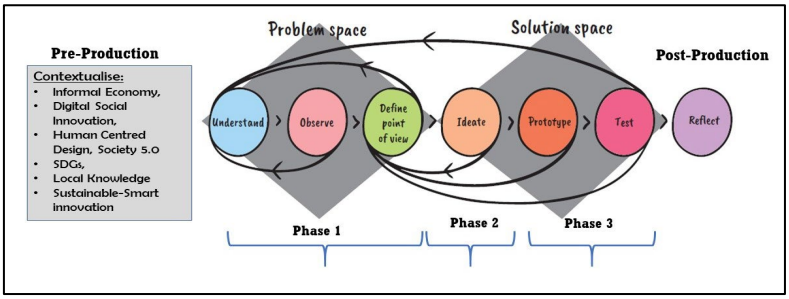

Fig. 2. Project Design Phases and Learning Activities (Adapted from Design Thinking Toolbook)

The main objective of the student project is to develop community-specific digital innovations for local sustainability challenges.

6 Methodology

The paper presents an analysis of findings from the fourth iteration of a longitudinal Design-Based Research (DBR) study. DBR is a methodological approach where researchers first develop an in-depth understanding of a problem before testing and refining solutions over multiple iterations [31]. This approach is particularly effective in developing both theoretical insights and practical solutions in collaboration with stakeholders within authentic settings.

To explore our research question, the QH framework was applied as an analytical lens, integrating Mode 3 knowledge application, which emphasises innovation networks and knowledge clusters within student projects [8]. For this iteration, we adopted a thematic analysis approach to examine artefacts generated by student teams, including design documentation, reflective journals, group presentations, and fieldwork notes, as well as observational notes from researchers and structured feedback from community and industry partners. Data collection occurred over four months, aligned with the project cycle.

A hybrid coding approach was used, combining inductive and deductive methods. Initially, a set of sensitising concepts drawn from the QH framework and literature was used to guide deductive coding (e.g., community engagement, sustainability, digital innovation). This was complemented by inductive coding to allow emergent themes to surface from student reflections and community feedback. Coding was conducted using ATLAS.ti and intercoder reliability was strengthened through independent coding by two researchers, followed by consensus meetings to resolve discrepancies. To ensure rigour, we triangulated across data types and participant groups, used member checking where feasible, and maintained a clear audit trail. The aim was to explore the contributions of each helix within the collaborative learning process, while identifying patterns of inclusive innovation and sustainability impact. This analysis has helped to identify

gaps and develop interventions for future iterations while also contributing theoretical and practical insights.

Participants in the study included 35 BCom IS Honours students, 20 students from the Advanced Diploma in Urban and Regional Planning and 20 students from Avans University. The group project was integral to the overall learning outcomes and was assessed in the academic modules. Ethical approval for the study was obtained from both universities, and permission was granted by students for the inclusion of their reflections and findings in the analysis.

By employing DBR in a longitudinal framework, this study systematically refines design principles and explores sustainable-smart innovations through a transdisciplinary learning approach. The fourth iteration contributes to this ongoing process by incorporating broader stakeholder engagement and leveraging insights to enhance future interventions.

7 Findings and Discussion

Table 1 was used to analyse the data and identify gaps that can be addressed in subsequent iterations of the project.

7.1 Civil Society Helix

The Civil Society Helix in the QH framework emphasises the critical role of active community involvement in shaping project outcomes, assessing social impact, and fostering knowledge exchange among project stakeholders. Meaningful engagement with residents in Dunoon is an essential component to ensure that the proposed solutions address real challenges and promote sustainable-smart innovations aligned with social inclusion and equity.

Active Community Engagement: The effectiveness of the Civil Society Helix hinges on sustained and active community participation. Understanding local lived experiences is central to this initiative, and students conduct interviews and engage with community members to gain firsthand insights into the problems they face. This participatory approach ensures that potential solutions are co-developed rather than externally imposed. The reflections from students illustrate the significance of this engagement:

> *"One of the most valuable aspects of this assignment was the opportunity to conduct interviews and visit the Dunoon township. This interaction with the Dunoon residents allowed us to gather valuable insights and understand the challenges and needs of the community". (SJ)*

This interaction reinforced the importance of co-creation, where the voices and needs of the community guided project development. The project's success underscores the power of community-led initiatives:

> *"The success of this project serves as a testament to the power of community-led initiatives and the importance of engaging with local stakeholders in the development process. By putting the needs and voices of the community at the*

forefront, we were able to create solutions that are not only effective but also sustainable and empowering". (G2)

Fig. 3 depicts some examples of the student engagement in the community of Dunoon.

Fig. 3. Community Engagement

Prototyping and Knowledge Exchange: Another key measurement of the Civil Society Helix is the impact of potential solutions on addressing real community challenges. As part of the project, student groups developed prototype specifications, ensuring the feasibility of implementing solutions in the community. These prototypes included functional and non-functional requirements, user interface (UI) and user experience (UX) design, system architecture, database structures, security measures, and material selection for hardware components.

To enhance sustainability, the 2025 student cohort will refine these prototypes through further community testing, allowing for iterative improvements. The next phase, scheduled for 2026, will focus on piloting selected solutions within Dunoon. This phased approach ensures that solutions evolve in direct response to community feedback, reinforcing long-term engagement and impact.

Knowledge Exchange and Societal Impact: An essential outcome of this initiative is the reciprocal knowledge exchange between students, community members, and project partners. Student reflections highlight how their understanding of community dynamics evolved through immersive participation:

"What stood out was, irrespective of the evident poverty and the lack of basic infrastructure, there is an atmosphere of community spirit and resourcefulness among the residents. We realised that there is an ongoing effort to improve living conditions and access to basic services. We believe that projects such as this will enable us to work towards inclusive and sustainable economic development." (G4)

While the full impact from the community's perspective is still unfolding, early indications suggest that the quality and relevance of student-led solutions improve each year due to increased community engagement. Students consistently highlight this

engagement as one of the most valuable aspects of their learning experience. The iterative nature of this project ensures that both students and community members benefit from an evolving, collaborative, and impactful approach to sustainable development.

7.2 Government Helix

The Government Helix within the QH framework underscores the role of government in enabling, supporting, and sustaining projects that drive socio-economic and environmental transformation. In this initiative, collaboration with local government has been instrumental in shaping student projects, aligning them with municipal policy objectives, and ensuring their long-term relevance.

Alignment with Local Policy: Since the 2023 project iteration, local officials have actively contributed through guest lectures, site visits, and student feedback. This collaboration formed part of the Cape Higher Education Consortium – City of Cape Town Annual Research Programme, which funded the initial iteration and supported the dissemination of student work through the City's Urban Planning and Design Department. Dunoon, identified as a priority intervention area, presents complex socio-economic and environmental challenges. Due to resource constraints, the City relies on external academic contributions, as echoed by a local government representative:

> *"Dunoon is a priority area…But because the City cannot prioritise it all at the same time, it is very important to make use of external assistance…We therefore fully support and appreciate the work that the students and their lecturers do in this area through the academic institutions' programmes". (LK CoCT, 2024)*

The City also provided strategic policy documents, including the Municipal Spatial Development Framework and Environmental Strategy, enabling students to anchor their work within a broader planning framework.

Funding and Institutional Support: Financial support through the Consortium further demonstrated the City's investment in higher education partnerships. The project aligns with local development goals such as "Resilience for Inclusive Development, Infrastructure and Sustainability, and Citizenship and Democracy", focusing on innovation, environmental justice, and community voice. However, to sustain the initiative beyond early-stage funding, deeper integration into municipal processes is needed. Embedding student-developed solutions into planning mechanisms and enabling pilot implementations would help realise their long-term value**.**

Long-Term Viability and Challenges: While the project has benefited from City support, its long-term viability will depend on deeper collaboration, such as integrating student solutions into municipal planning processes and facilitating pilot implementations. One major challenge in government-community collaboration is the power imbalance between local government and civil society, often shaped by political

influences. This dynamic, exacerbated by South Africa's apartheid legacy, has created mistrust among community members, making engagement efforts more complex. As noted in student reflections, access to community members willing to participate in the project was at times difficult.

> *"On-site, we sometimes experienced challenges in gaining access to community members…due to political influences that create mistrust between the community and outsiders". (G5)*

To address this, the project engages trusted community champions (e.g. NGOs) who facilitate communication and foster inclusion. Students also critically explored broader governance questions, especially around the informal economy's role in cities like Dunoon. Their reflections raised key provocations: How can formality be introduced without compromising flexibility? Who advocates for informal workers, and how can collaboration foster meaningful change?

These questions underscore the need for inclusive governance that supports grassroots entrepreneurship rather than stifling it. Informality should be recognised as an adaptive solution to gaps in state capacity. Municipal frameworks must accommodate this by offering flexible permits, integrated planning, and regulatory environments that protect informal livelihoods.

Sustained collaboration between local government, academia, and communities will be vital in translating student innovations into actionable solutions that advance inclusive urban development.

Moving forward, continued engagement with municipal structures and expanded government collaboration will be critical in translating academic work into actionable urban solutions that benefit both the local government and the communities they serve.

7.3 Industry Helix

While this project has successfully engaged governmental actors and community stakeholders, industry participation has been limited. The current economic climate and negative forecast in South Africa resulted in a lack of appetite from industry partners to venture into the risky student innovation space. The limited active industry involvement constrains the potential for sustainable-smart innovations to be commercialised, scaled, and integrated into existing economic structures. Industry engagement within the helix framework is essential for achieving practical relevance and co-creation to ensure that the innovations are aligned with real-world economic and technological needs. Furthermore, industry involvement can enhance the potential for solutions to be commercialised and sustained beyond the project lifecycle and provide students with professional skills, increasing their employability and entrepreneurial potential.

Currently, industry engagement in the project is limited and primarily takes the form of advisory contributions, such as guest lectures, feedback on student projects, and occasional input from local entrepreneurs based in the target community. Several barriers hinder more active and sustained involvement. These include limited recognition of the commercial potential of student-driven innovations, concerns about the risks of

engaging in politically sensitive and informal economic contexts, and the absence of structured mechanisms to support long-term industry collaboration. At present, industry engagement is largely confined to advisory roles, such as guest lectures, project reviews by industry representatives and participation from local entrepreneurs operating within the project's geographical focus. The barriers to deeper engagement include limited awareness of the commercial viability of student-led innovations. The risks are roles than others associated with engagement in politically complex and informal economic settings, and a lack of structured engagement mechanisms to facilitate sustained industry participation.

The absence of robust industry engagement represents a gap in the project's holistic impact, necessitating a structured approach to industry collaboration. Integrating the Industry Helix into the project's existing framework is essential to ensure the long-term sustainability and impact of student-led innovations. By shifting from passive advisory roles to active co-creation and implementation, industry stakeholders can contribute meaningfully to inclusive economic development. The inclusion of a co-creation workshop with selected partners from industry is planned for the 2025 iteration. Project partners are also in discussion with venture capitalists to explore the commercialisation of selected solutions and consider options for developing the prototypes to a stage closer to commercialisation, with the assistance of the Technology Transfer Office at one of the universities.

7.4 Academic Helix

This helix emphasises the importance of academic research and knowledge transfer in driving innovation. In the review of the Academic Helix evidence of the learning outcomes, student engagement and research and innovation are presented to determine the strengths and current limitations.

The overarching learning objective was to equip students with valuable skills, knowledge, and mindset shifts to address complex community challenges, navigate uncertainty, and contribute to sustainable development through digital social innovations. The design of the project featured six learning outcomes:

- Interdisciplinary Collaboration: As discussed, the students worked in diverse teams to leverage multidisciplinary expertise. The outcome of their collaboration and learning was assessed through team meeting records, reflection questionnaires, blogs, and peer assessments.
- Embedding sustainability in the design and interpreting the complexity of wicked problems within the informal sector. Their understanding of complexity was evaluated through literature reviews, site visit videos, and project presentations to partners.
- Creative Thinking and Problem-Solving: Using design thinking and human-centred design approaches, students demonstrated empathy and incorporated community perspectives into problem definition and solution development. This was measured through project documentation, prototype testing, decision matrices, and reflective

questionnaires. The design of the final prototypes was also scrutinised to ensure that students understood the users and their unique requirements.

- Developing Digital and Technological Skills: Students utilised various digital tools and technologies throughout the project, including prototype development. Their proficiency was assessed based on the quality of outputs in each project phase.
- Practical Application of Interdisciplinary Knowledge: Students translated theoretical concepts into practical, contextually relevant solutions with tangible social impact. The quality and relevance of prototypes served as a key measure of success.
- Reflective and Ethical Practices: Students demonstrated a commitment to social and environmental justice principles. Ethical practices were evaluated through project presentations and adherence to a Team Code of Conduct document.

The lecturers from the three universities reviewed the outcomes and found that the collaboration successfully enhanced the educational experience for students from all participating universities. Participants reported high levels of satisfaction with the shared resources and expertise, the quality and diversity of educational materials and tools and the exchange of knowledge and best practices, fostering a culture of continuous improvement.

The focus of our review was more on the limitations identified to improve future iterations. Limitations included aspects such as the challenges in reconciling conflicting disciplinary approaches, leading to delays in decision-making. The imbalances in contribution, with some students taking on more leadership roles than others. The cultural and language barriers within diverse teams occasionally hinder effective communication. We also identified that some groups struggled to fully grasp the interconnectedness of sustainability challenges, leading to oversimplified solutions. Some prototypes also lacked feasibility due to resource constraints or limited understanding of the community's technical capabilities. A few groups struggled to balance creativity with practicality, resulting in solutions that were innovative but not implementable. Some of the solutions were overly reliant on technology, neglecting low-tech alternatives that might have been more appropriate.

Research and Innovation: The results from the projects have been published in journal publications and conference proceedings by the researchers, including publications with students. These outputs are contributing to knowledge on the impact of inter and transdisciplinary projects situated in marginalised settings that apply concepts such as digital social innovation, SDGs, local knowledge and collaborative partnerships. It has also contributed to collaboration with other institutions and researchers working in similar settings. However, the outputs are still largely academic and more collaboration between academia, industry, and community stakeholders is required to bridge the gap between research and implementation. We are currently working on actions to deepen community involvement through more targeted workshops with partners in the informal economy and securing funding for pilot projects. Some of the solutions developed are being tested further in the community at present, as illustrated in Fig. 4.

Fig. 4. Prototypes being tested further with community partners

7.5 Natural Environment Helix

The fifth helix of the QH framework focuses on bringing knowledge from the natural environment into innovation projects. This helix is the most vulnerable of the helices and requires special care [32]. This helix represents ecological actors that typically serve as resource bases for both production and daily survival. In this project, nature was centralised by framing the community challenges in the context of sustainability. The challenge that was put to student groups was to translate the global SDGs into actionable, locally relevant objectives applicable to their specific project theme.

Because of the complex nature of the natural environment within not only urban settings but especially informal settings, student groups had to be guided by both global and local sustainability frameworks. The SDGs with their associated targets were prominent in this project, with students tasked with relating primary and secondary SDGs to their specific informal economy challenge at both the problem exploration and solution development stages.

By focusing on the SDGs, students were made aware of their role as custodians of the natural environment and that this responsibility will become ever more important as pressure increases on natural resources such as clean, fresh water, quality food and breathable air. All of these life-supporting elements are directly impacted by human activity in general and specifically by economic activities.

As mentioned above, economic activities have harmed life-supporting environmental systems primarily through unsustainable practices that deplete resources and increase pollutants [33]. At a local scale, the same can be said about the informal economy that is characterised by excessive litter, dumping of excess products and the associated human health threats [34]. The lack of sufficient waste management practices was a major concern for student groups, as many focused their attention on developing a response to this challenge. Sustainable-smart innovations such as a water drone to clean debris from the informal traders that end up in the local river, recycling and

upcycling apps and sensors to monitor the closest communal waste dumpster and alert the local authorities when it should be emptied, are some responsive solutions.

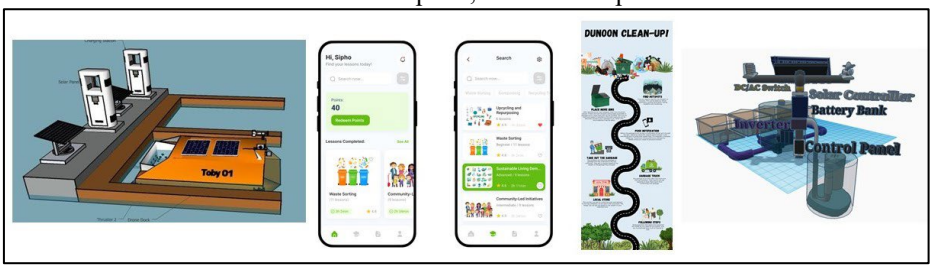

Fig. 5. Water drone and low-data recycling/upcycling application.

A further concern that both community members and student groups recognised was the resource usage in the community. Resource optimisation strategies were found to be limited but did exist in the form of recycling and repurposing initiatives such as the retreading of used tyres and the reselling of second-hand clothing. Unfortunately, very few creative recycling outputs were found and there might be a potential for upskilling community members in culturally-appropriate arts and crafts for the tourist markets.

By embedding the sustainability principles within every aspect of this student project, we sensitised students, as future leaders, to concepts such as the SDGs, sustainable-smart cities and Society 5.0. Further, as the environment is usually the most vulnerable stakeholder in the QH, the solutions that groups co-developed had to illustrate both the short-term and long-term environmental footprint.

In future project iterations, this helix will continue to be prominent in the interdisciplinary student project as it provides an opportunity to consider the natural environment not only as a provider (resources) and receiver (pollutants) of human activities but also as an active contributor to new knowledge which is desperately needed in the current ecological instability we are experiencing.

8 Conclusion

This paper has demonstrated the potential of the QH framework to guide transdisciplinary student projects in addressing complex sustainability challenges within the informal economy. By integrating academia, industry, government, civil society, and the natural environment, the project in Dunoon, Cape Town, has highlighted the importance of collaborative knowledge co-creation in fostering sustainable-smart innovations. The findings reveal that active community engagement, interdisciplinary collaboration, and alignment with sustainability principles are critical to developing contextually relevant solutions to real-world challenges. However, the study also identifies key limitations, such as the lack of robust industry involvement and the challenges of translating prototypes into implemented solutions.

To enhance the impact of such initiatives, future iterations should focus on deepening partnerships with industry stakeholders, securing funding for pilot projects, and fostering long-term community engagement. Additionally, greater emphasis should be

placed on scaling and commercialising student-led innovations to ensure their sustainability beyond the academic context. By addressing these gaps, transdisciplinary projects can play a transformative role in empowering informal economy actors, driving digital innovation, and contributing to the SDGs. Ultimately, this study underscores the value of the QH framework as a tool for fostering inclusive, sustainable, and impactful innovation in marginalised communities.

9 References

[1] E. Etim and O. Daramola, "The informal sector and economic growth of South Africa and Nigeria: A comparative systematic review," *Journal of Open Innovation: Technology, Market, and Complexity*, vol. 6, no. 4, pp. 1–26, 2020, doi: 10.3390/joitmc6040134.

[2] S. Smit, "Connecting the urban informal settlement to the city: A systems approach," PhD Dissertation, Stellenbosch, 2019. doi: 10.32964/tj18.4.

[3] S. N. Mkulisi and A. Sathiya Susuman, "Examining the Influence of Socio-Economic and Demographic Transformation on Employment In the Informal Sector From 2017 To 2020," *J Asian Afr Stud*, 2024, doi: 10.1177/00219096241296125.

[4] E. G. Carayannis and D. F. J. Campbell, "Triple helix, Quadruple Helix and Quintuple Helix and how do Knowledge, Innovation and the Environment relate to Each other? a proposed framework for a trans-disciplinary analysis of sustainable development and social ecology," *International Journal of Social Ecology and Sustainable Development*, vol. 1, no. 1, pp. 41–69, 2010, doi: 10.4018/jsesd.2010010105.

[5] H. Etzkowitz and L. Leydesdorff, "The dynamics of innovation: From National Systems and 'mode 2' to a Triple Helix of university-industry-government relations," *Res Policy*, vol. 29, no. 2, pp. 109–123, 2000, doi: 10.1016/S0048-7333(99)00055-4.

[6] E. G. Carayannis and D. F. J. Campbell, "'Mode 3' and 'Quadruple Helix': Toward a 21st century fractal innovation ecosystem," *International Journal of Technology Management*, vol. 46, no. 3–4, pp. 201–234, 2009, doi: 10.1504/ijtm.2009.023374.

[7] S. Bartoloni *et al.*, "Towards designing society 5.0 solutions: The new Quintuple Helix - Design Thinking approach to technology," *Technovation*, vol. 113, no. September 2020, p. 102413, 2022, doi: 10.1016/j.technovation.2021.102413.

[8] E. G. Carayannis and D. F. J. Campbell, "Towards an Emerging Unified Theory of Helix Architectures (EUTOHA): Focus on the Quintuple Innovation Helix Framework as the Integrative Device," *Triple Helix*, vol. 6, no. 3, pp. 1–11, 2022, doi: 10.1163/21971927-bja10028.

[9] I. O. Pappas, P. Mikalef, Y. K. Dwivedi, L. Jaccheri, and J. Krogstie, "Responsible Digital Transformation for a Sustainable Society," *Information Systems*

Frontiers, vol. 25, no. 3, pp. 945–953, 2023, doi: 10.1007/s10796-023-10406-5.

[10] E. G. Carayannis, T. D. Barth, and D. F. Campbell, "The Quintuple Helix innovation model: global warming as a challenge and driver for innovation," *J Innov Entrep*, vol. 1, no. 1, p. 2, 2012, doi: 10.1186/2192-5372-1-2.

[11] L. M. Petersen and A. J. E. Charman, "The scope and scale of the informal food economy of South African urban residential townships: Results of a small-area micro-enterprise census," *Dev South Afr*, vol. 35, no. 1, pp. 1–23, 2018, doi: 10.1080/0376835X.2017.1363643.

[12] M. Musara and C. Nieuwenhuizen, "Informal sector entrepreneurship, individual entrepreneurial orientation and the emergence of entrepreneurial leadership," *Africa Journal of Management*, pp. 194–213, 2020, doi: 10.1080/23322373.2020.1777817.

[13] A. Q. Ebrahim and C. L. van den Berg, "The barriers to technology adoption among businesses in the informal economy in Cape Town," *S Afr J Inf Manag*, vol. 26, no. 1, pp. 1–13, 2024, doi: 10.4102/sajim.v26i1.1872.

[14] O. Daramola and E. Etim, "Affordances of digital platforms in sub-Saharan Africa: An analytical review," *Electronic Journal of Information Systems in Developing Countries*, vol. 88, no. 4, pp. 1–21, 2022, doi: 10.1002/isd2.12213.

[15] N. Mramba, J. Rumanyika, M. Apiola, and J. Suhonen, "ICT for informal workers in Sub-Saharan Africa: Systematic review and analysis," *2017 IEEE AFRICON: Science, Technology and Innovation for Africa, AFRICON 2017*, pp. 486–491, 2017, doi: 10.1109/AFRCON.2017.8095530.

[16] P. Nguimkeu and C. Okou, "A Tale of Africa Today: Balancing the Lives and Livelihoods of Informal Workers During the COVID-19 Pandemic," *A Tale of Africa Today: Balancing the Lives and Livelihoods of Informal Workers During the COVID-19 Pandemic*, no. 1, pp. 1–8, 2020, doi: 10.1596/34582.

[17] M. J. Sousa and Á. Rocha, "Digital learning: Developing skills for digital transformation of organizations," *Future Generation Computer Systems*, vol. 91, pp. 327–334, 2019, doi: 10.1016/j.future.2018.08.048.

[18] D. Girollet, "Digital inclusion and performance of informal firms in sub-Saharan Africa," Docteur, Université de Bordeaux, 2023.

[19] R. Heeks, "Digital inequality beyond the digital divide: conceptualizing adverse digital incorporation in the global South," *Inf Technol Dev*, vol. 28, no. 4, pp. 688–704, 2022, doi: 10.1080/02681102.2022.2068492.

[20] M. A. Chen, "Technology, informal workers and cities: insights from Ahmedabad (India), Durban (South Africa) and Lima (Peru)," *Environ Urban*, vol. 28, no. 2, pp. 405–422, 2016, doi: 10.1177/0956247816655986.

[21] S. Serpa and C. M. Ferreira, "Society 5.0 and Sustainability Digital Innovations: A Social Process," *Jouranl of Organizational Culture, Communications and Conflicts*, vol. 23, no. 1, pp. 1–14, 2019.

[22] B. M. Fukuyama, "Society 5.0: Aiming for a New Human-Centered Society," *Japan Spotlight*, vol. 27, no. 5, pp. 47–50, 2018.

[23] P. Mishra, P. Thakur, and G. Singh, "Sustainable Smart City to Society 5.0: State-of-the-Art and Research Challenges," *South African Institute of Electical Engineers*, vol. 113, no. 4, pp. 152–164, 2022.

[24] J. Rosak-Szyrocka, S. A. Apostu, J. Ali Turi, and A. Tanveer, "University 4.0 Sustainable Development in the Way of Society 5.0," *Sustainability (Switzerland)*, vol. 14, no. 23, pp. 1–17, 2022, doi: 10.3390/su142316043.

[25] W. Leal Filho *et al.*, "A framework for the implementation of the Sustainable Development Goals in university programmes," *J Clean Prod*, vol. 299, 2021, doi: 10.1016/j.jclepro.2021.126915.

[26] J. Kotlarsky, I. Oshri, and N. Sekulic, "Digital Sustainability in Information Systems Research: Conceptual Foundations and Future Directions," *J Assoc Inf Syst*, vol. 24, no. 4, pp. 936–952, 2023, doi: 10.17705/1jais.00825.

[27] United Nations, "The SDGs in Action," United Nations Development Programme. Accessed: Feb. 13, 2025. [Online]. Available: https://www.undp.org/sustainable-development-goals

[28] A. Horn, A. Scheffelaar, E. Urias, and M. B. M. Zweekhorst, "Training students for complex sustainability issues: a literature review on the design of inter- and transdisciplinary higher education," *International Journal of Sustainability in Higher Education*, vol. 24, no. 1, pp. 1–27, 2023, doi: 10.1108/IJSHE-03-2021-0111.

[29] D. Burns, J. Howard, E. Lopez-Franco, T. Shahrokh, and J. Wheeler, "Work with us: How people and organisations can catalyse sustainable change," 2013. doi: https://hdl.handle.net/20.500.12413/13763.

[30] J. H. Kroeze, "Digital coloniality: An Ubuntu perspective," *Scandinavian Journal of Information Systems*, vol. 36, no. 2, pp. 175–216, 2024.

[31] S. McKenney and T. C. Reeves, "Educational design research: Portraying, conducting, and enhancing productive scholarship," *Med Educ*, vol. 55, no. 1, pp. 82–92, 2021, doi: 10.1111/medu.14280.

[32] L. Donati, G. Stefani, and M. Bellandi, "The Evolutionary Emergence of Quintuple Helix Coalitions: A Case Study of Place-Based Sustainability Transition," *Triple Helix*, vol. 3, no. 3, pp. 1–31, 2023, doi: 10.1163/21971927-12340010.

[33] C. Folke *et al.*, "Our future in the Anthropocene biosphere," *Ambio*, vol. 50, no. 4, pp. 834–869, 2021, doi: 10.1007/s13280-021-01544-8.

[34] X. S. Grangxabe *et al.*, "The Escalation of Informal Settlement and the High Levels of Illegal Dumping Post-Apartheid: Systematic Review," *Challenges*, vol. 14, no. 3, p. 38, 2023, doi: 10.3390/challe14030038