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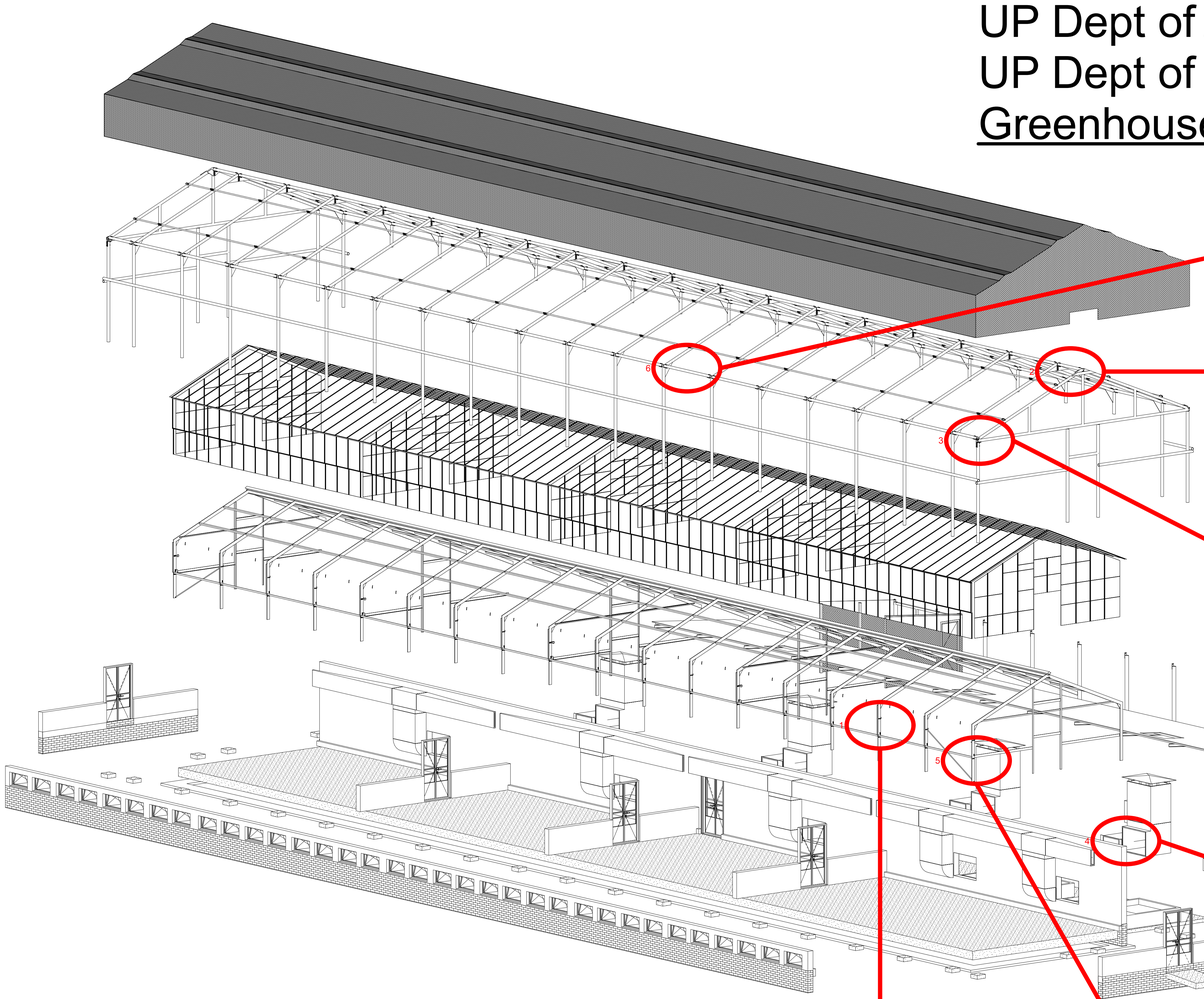
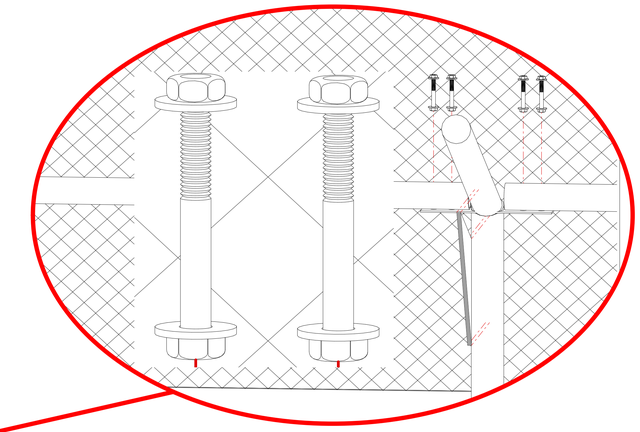
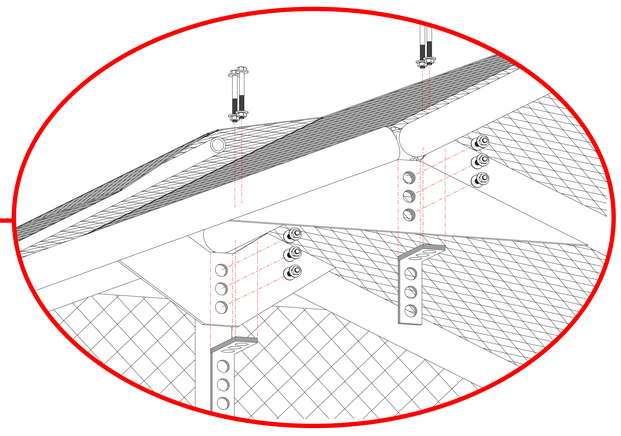
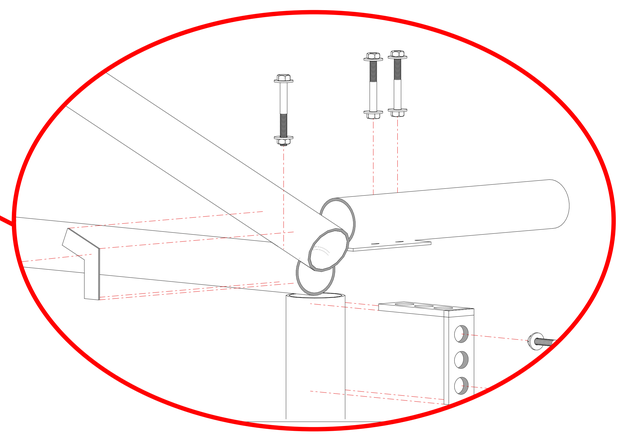
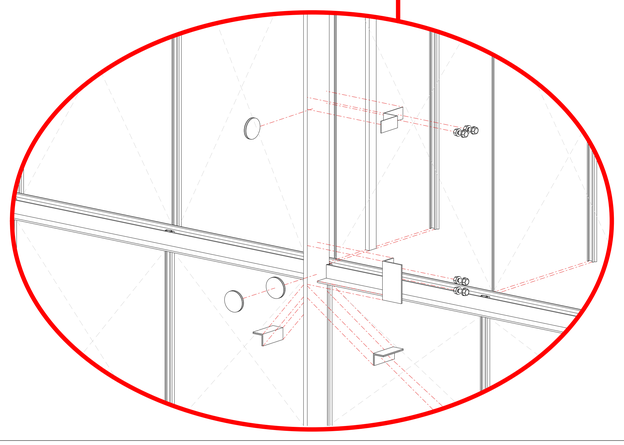
RFS 701 2023
HBIM FOR CIRCULARITY
DE / RE CONSTRUCTION
COLLABORATION BETWEEN
hpa &
UP Dept of Architecture &
UP Dept of Civil Engineering (Structural)
Greenhouse 01

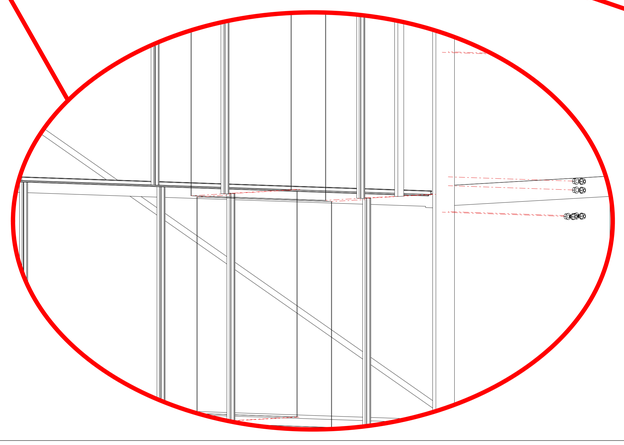


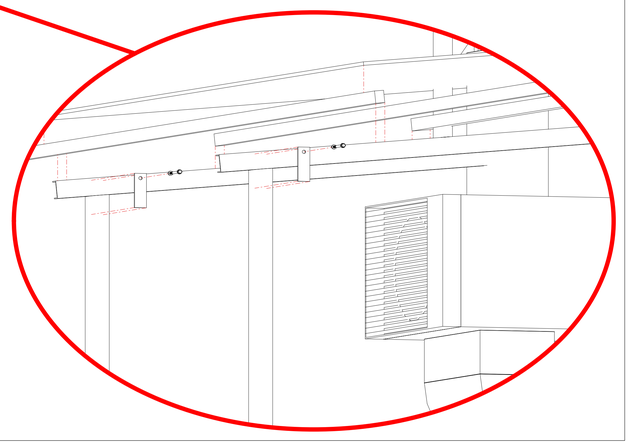












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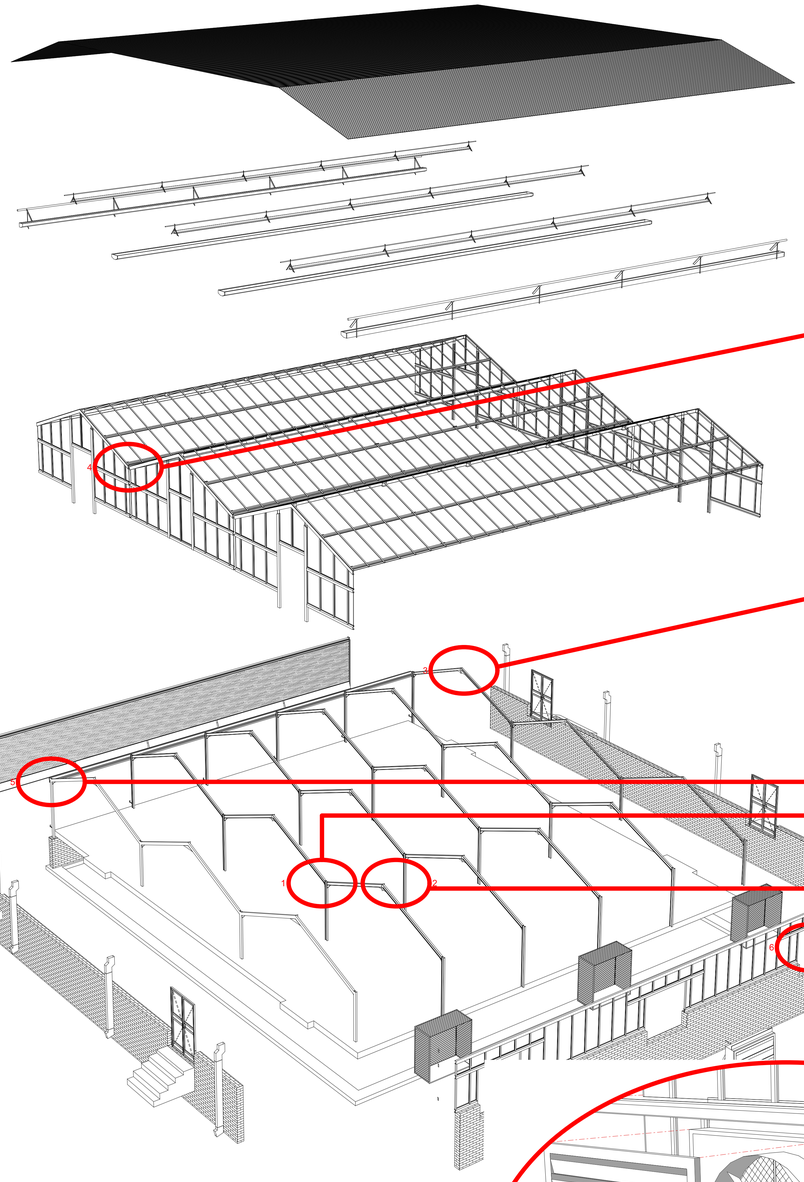

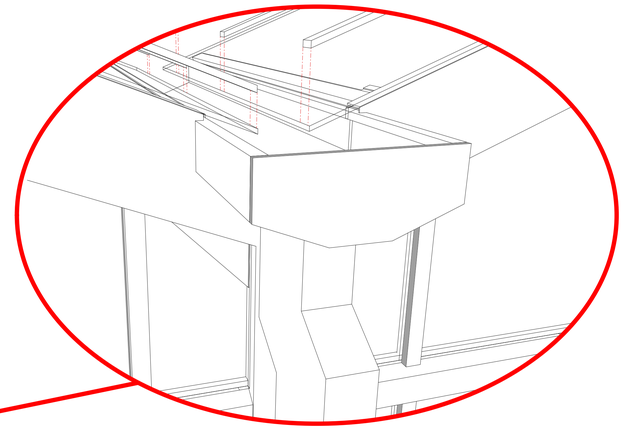

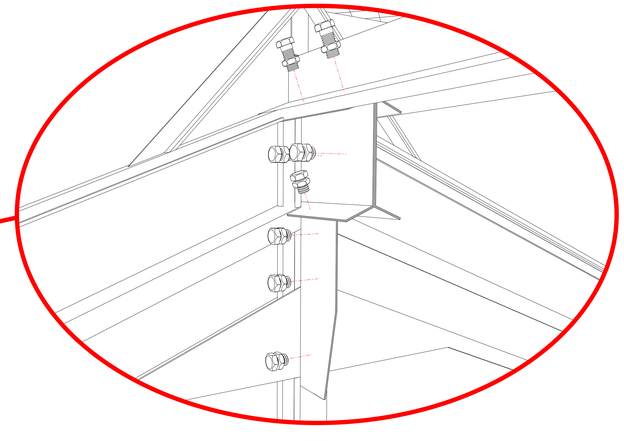

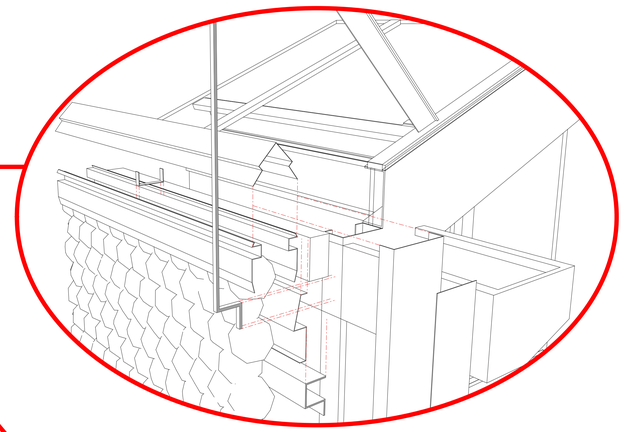

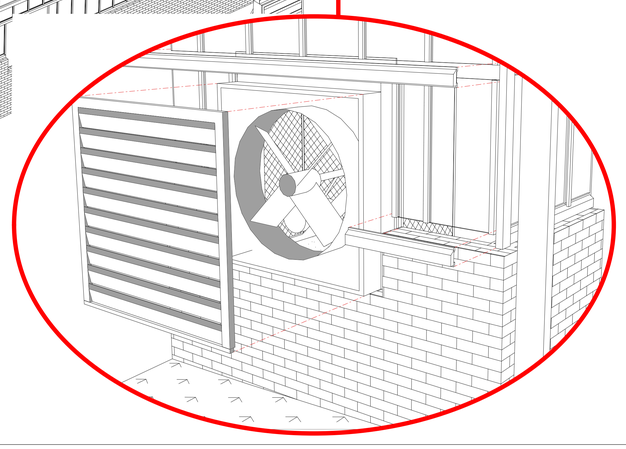

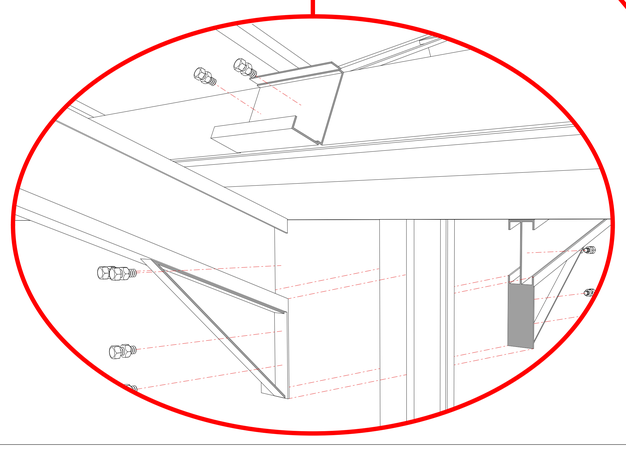

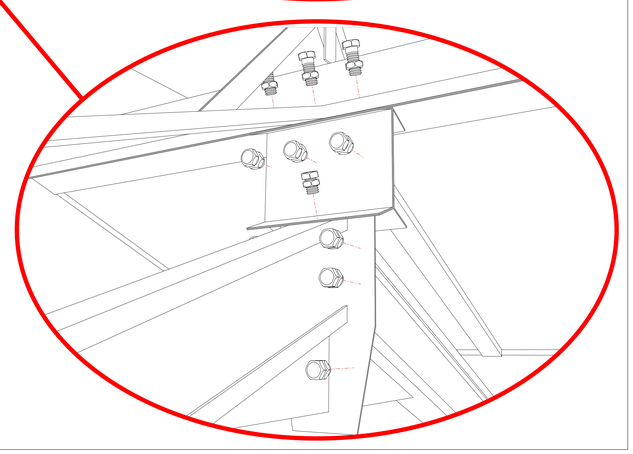

From Waste to Wisdom: Transforming Circular Construction through Transdisciplinary Education

Leveraging Building Information Modelling for Material Reuse in the Global South.

Introduction

The global construction industry significantly contributes to greenhouse gas emissions and resource depletion, exacerbated by substantial wastage and mounting construction waste. Adopting a circular value chain for building materials presents a compelling opportunity to combat these challenges, reducing emissions, dependency on raw materials, and wasteful practices.

Many built environment circularity initiatives tend to focus on end-of-life solutions, targeting the elimination of visible physical waste as a starting point. While this approach is useful in addressing immediate concerns, it falls short in fostering a fundamental paradigm shift among practitioners to tackle both the symptoms and root causes of wastage with a long-term perspective. Additionally, this conventional approach often stigmatizes waste as something useless or undesirable. To truly advance circularity, we must redefine the notion of waste from being valueless and reframe waste as the valuable untapped potential for physical materials.

To cultivate this new mindset among practitioners, a fundamental shift in education is necessary, transcending disciplinary siloes to promote a systemic and collaborative approach to circularity challenges. Currently, built environment education takes place within disciplinary siloes, resulting in fragmented perspectives on complex topics such as circularity. To address circularity challenges effectively, we must adopt a new systemic and collaborative approach that transcends individual disciplines, unlocks shared realities, and cultivates cooperative problem-solving behaviours about waste.

To achieve circular processes proactively, stakeholders throughout the building project lifecycle must be aligned with their intent and strategic objectives. Collaboration among architects, engineers, owners, consultants, and users is crucial from the project's start. Empowering practitioners with scalable circularity skills, such as transdisciplinary teamwork and creating shared realities about waste, is vital to addressing circularity challenges effectively. This calls for a radical shift in built environment education, equipping future professionals to champion circularity practices.

To catalyse this profound educational shift, it is imperative to overhaul traditional built environment education and instil a circularity and transdisciplinary mindset right from the outset. Spearheading this endeavour is a ground-breaking initiative jointly undertaken by the departments of civil engineering and architecture at the University of Pretoria in South Africa. Empowered by cutting-edge digital tools and techniques, postgraduate students from both disciplines unite in a collaborative project to explore novel methods for capturing material and structural information within BIM

models. These digital models play a pivotal role in constructing comprehensive material inventories, paving the way for the future "mining" of reusable resources in the vast ecosystem of the built environment. By fostering such innovation and cross-disciplinary cooperation, this transformative classroom is reshaping the very essence of sustainable construction practices and circularity realization.

Aligned with the United Nations' Sustainable Development Goals (UN SDGs), this transdisciplinary initiative addresses multiple facets of responsible resource consumption and waste reduction to foster sustainable urbanization, particularly in the Global South. Specifically, UN SDGs 9, 11, and 12 come into focus as students gain a deeper understanding of responsible resource consumption, develop technical skills in digital tools and Life-Cycle Assessment (LCA), and embrace the value of transdisciplinary works that will guide their future careers.

In this era of unprecedented environmental challenges, a symbiotic integration of circularity and education becomes paramount in reshaping the construction industry's future. Through collaborative efforts, innovative thinking, and a transdisciplinary approach, we can pave the way for a more sustainable and regenerative built environment that benefits both the present and future generations.

Case study description.

This project centres on two heritage greenhouses located at the University of Pretoria, South Africa. These structures will potentially be deconstructed, either for demolition or reconstruction. The property owner, University of Pretoria Facilities Management, has entrusted a local heritage architecture firm to oversee the initiative, allowing access to the greenhouse structures (Figure 1).

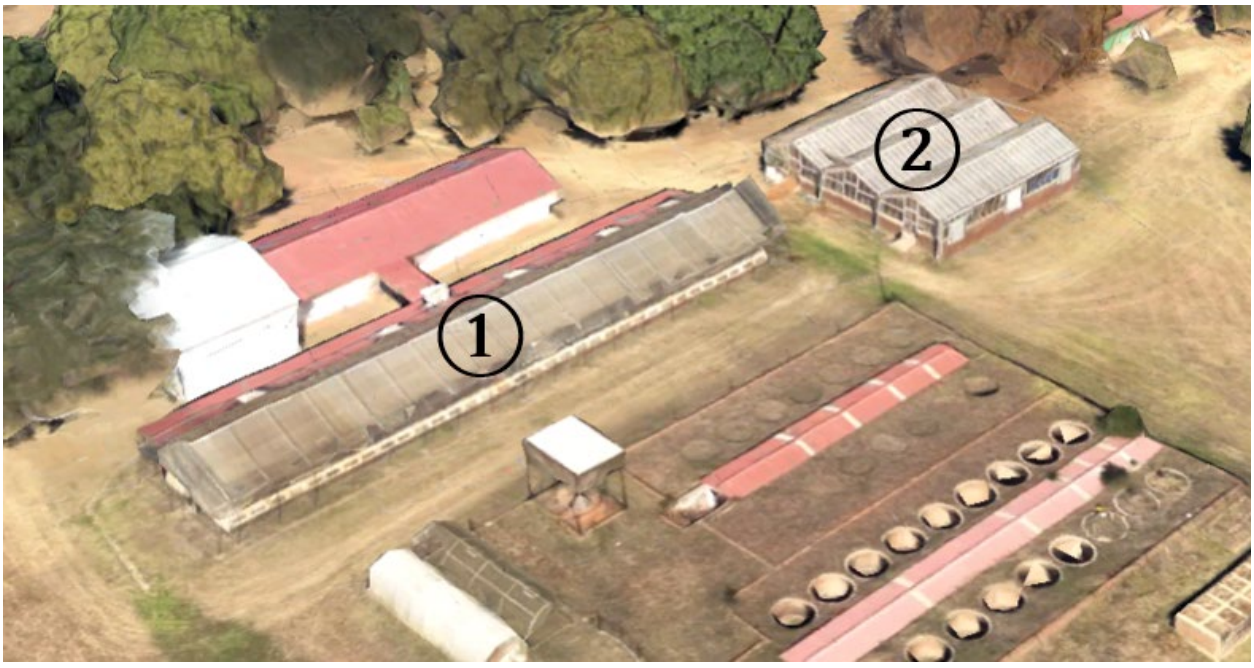

Figure 1: This project focuses on two steel-framed heritage greenhouses i.e. Greenhouse 1 and Greenhouse 2 (Davey & van der Merwe, 2023).

This postgraduate research unit involves a transdisciplinary student team of architecture, structural, and civil engineering students. Students utilize LiDAR and photogrammetry to scan the buildings. Together, they define a circularity-oriented BIM workflow, articulating appropriate levels of modelling detail, and systematically capture vital information for selective deconstruction and re-use. This hands-on, transdisciplinary approach underscores the significance of choosing appropriate physical and digital tools for specific tasks, emphasizing the effectiveness of even basic tools in gathering essential digital information (Figure 2).

(a)

(b)

(c)

Figure 2: Capturing relevant information for the BIM model involved a range of different tools, ranging from drone operated LiDAR and photogrammetry (a), to non-destructive material testing (b), and simple pick axes and shovels to determine foundation sizes (c). (Davey, van der Merwe 2023).

After thorough exterior and interior scans, a BIM model materialized from the resultant point cloud and field-work efforts. This model is continually updated as digital classification of crucial structural particulars improves (Figure 3), crafting a circularity-oriented material inventory.

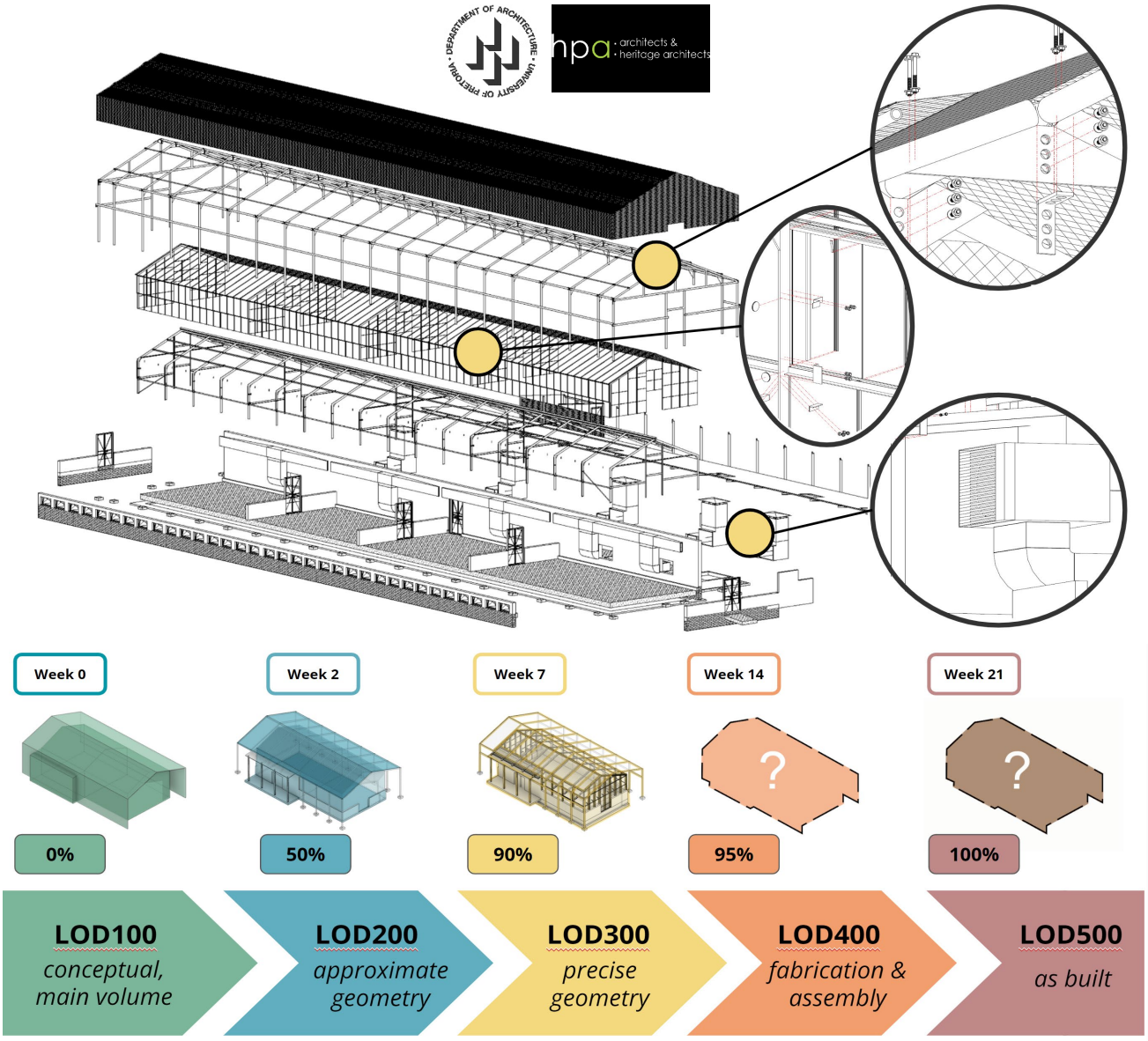

Figure 3: By week seven, the transdisciplinary team had built a shared LOD 300 BIM model for Greenhouse 1 (Potgieter, Davey, & van der Merwe, 2023).

By the seventh week, the students collaboratively showcased their progress during the quarterly exams, both as a transdisciplinary team and as individual researchers with distinct areas of specialization.

‘

Outcomes of the transdisciplinary classroom.

Initially, the original students crafted an organizational framework outlining roles and responsibilities (Figure 4). This initial representation underscored disciplinary boundaries, each confined to its designated domain. However, by the conclusion of the academic quarter, the students devised a refined flowchart for oral examination. Remarkably, in just seven weeks, disciplinary barriers dissolved, roles evolved, and fresh team members voluntarily integrated.

This transformative learning encounter can only occur within a transdisciplinary classroom, where students fully comprehend the significance of genuine collaboration and learning-by-doing. This innovative setting accentuates students' recognition of collaboration's immediate and long-term value, fostering novel insights, shared impacts, and diverse perspectives through collective learning. As students exchange methods, skills, and diverse viewpoints across disciplines, a dynamic learning environment emerges, mirroring the intricacies of real-world projects. This invaluable learning experience extends beyond textbooks and disciplinary boundaries.

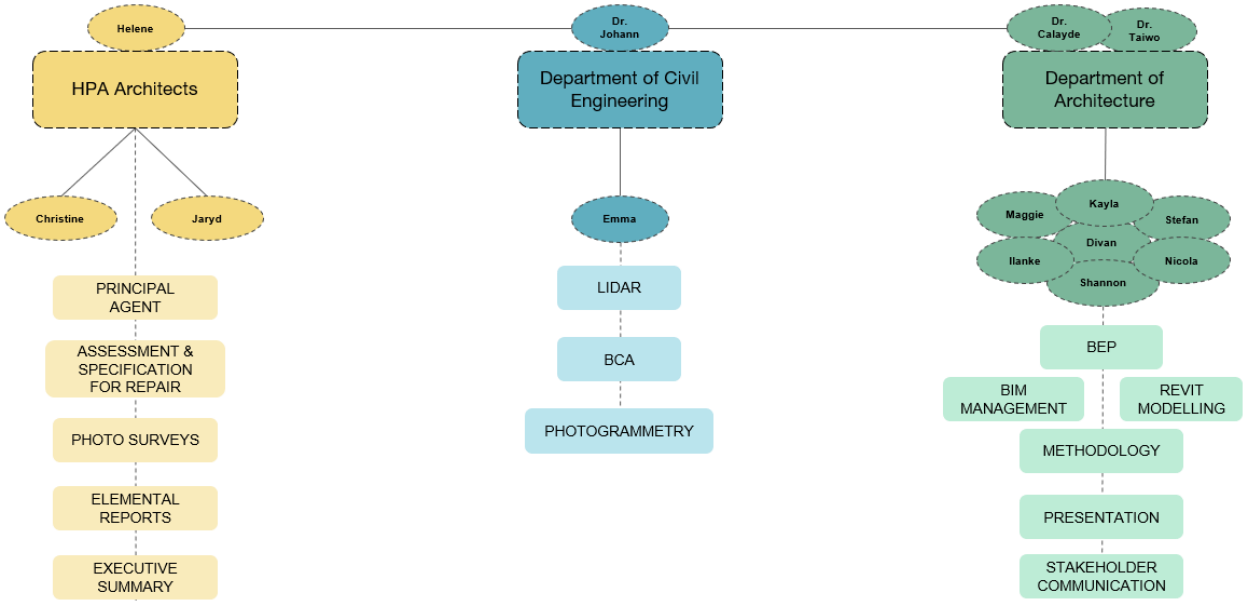

Figure 4: During the first week, students formulated their perception of the project within a discipline-specific organizational framework, rooted in their existing comprehension of tasks and roles. Distinct silos emerged for the client (represented by HPA Architects), engineering, and architecture roles (Student Exam Submission, Q2, Davey, van der Merwe 2023).

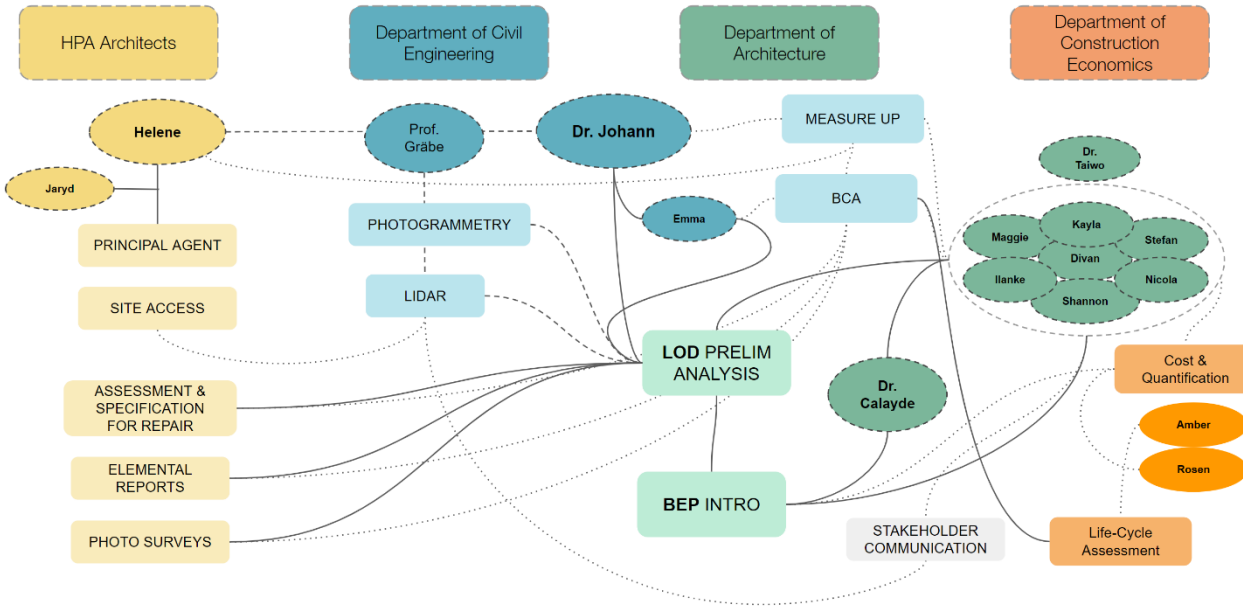

Figure 5: By the seventh week, a noteworthy transformation occurred as disciplinary silos within the organizational flowchart were dismantled, mirroring the emergence of an interactive, value-driven, and skill-sharing transdisciplinary project environment (Student Exam Submission, Q2, Davey, van der Merwe 2023).

While formally focussed on architecture and civil engineering students, the initiative attracted interest from students from other departments. As the original group struggled with how to quantify their models for varying detail levels, quantity surveying (QS) students voluntarily joined to help them. The QS students prepared presentations on QS methodologies, significantly impacting the original team's understanding and outcomes (Figure 6). This sensitized the entire student cohort to the QS discourse, an experience the original students will not encounter in traditional education settings. Furthermore, while the structural engineering student delved into her individual research on structural Life-Cycle Assessment (LCA), the QS team swiftly offered their disciplinary perspective on LCA as well. This additional perspective significantly enriched the comprehension and intricacy of LCA for all involved, intensifying the team's inquiry and kindling heightened enthusiasm for broader circularity concerns.

As such, this transdisciplinary learning environment organically transitioned into a flipped-classroom model, where diverse students mutually instructed each other in core disciplinary skills using shared BIM models. Cross-skilling within a shared digital ecosystem not only reshapes perspectives on the subject matter but also fosters collaboration, critical thinking, and creative complex-problem solving skills among all participants. The impacts of this transcended the student body, extending to the professional architectural team as well, who eagerly embraced the opportunity to glean deeper insights from new knowledge. As a result, the benefits extended to both students, industry professionals, and the postgraduate teaching team. Impressively, the student team attained an average mid-year exam score of 75% (A), underscoring their sustained enthusiasm and self-directed commitment to the project, even without extensive guidance from the teaching team.

Figure 6: Quantity Survey (QS) students voluntarily joined, enhancing the initiative through teaching QS tasks to the original team (Student-led Transdisciplinary Flipped-Classroom Q2, Davey, van der Merwe 2023).

The students (now including QS's) showcased their work at the BIM Harambee Conference (Figure 7), spotlighting the transdisciplinary classroom as a case study for built environment education. It highlighted collaborative learning via BIM workflows within the African context. The integration of transdisciplinary exposure within core curriculum gained recognition from both industry and academia, noted by numerous conference stakeholders. The presentation earned praise not only from industry experts but also external educators (Figure 8), leaving a lasting desire to support the continuity of this educational model. Significantly, specific students garnered job offers, fuelled not solely by technical expertise, but by their exceptional collaborative abilities. Their capacity to function harmoniously as a team and create shared value underscored the significance of these interpersonal skills, highlighting how their skills were recognized as invaluable assets in the professional workforce.

Figure 7: Transdisciplinary student team exhibiting their work at the BIM Harambee 2023 (Davey, 2023).

Dear [redacted]

Congratulations to the School of Architecture for offering the Future of Work BIM workshop. This workshop was an exemplary example of an education-industry collaboration that involved preparing our young designers, engineering and construction students for the challenging and rapidly changing technological environment.

We appreciate the extension of this invitation to fellow academics and look forward to continuing discussions and interactions relating to the topic.

Please extend these words of congratulations and appreciation to [redacted]

Regards,

[redacted]
Acting Vice-Dean Teaching and Learning

Figure 8: Sample of feedback from the BIM Harambee 2023, where the transdisciplinary classroom was demonstrated to both industry and educators alike (Davey, 2023).

Impact and scalability.

The project follows after a systems-thinking design studio and field work executed by the architecture students during the preceding academic quarter. While this studio primarily honed evidence-based design-thinking skills, it also sensitized students to a comprehensive understanding of waste issues in the construction sector and potential avenues for repurposing construction waste. Noteworthy student studies emerged from this studio, such as a comprehensive mapping of construction waste in Pretoria to elucidate material types and quantities (Figure 9 and Figure 10), and an exploration of waste utilization in building materials for informal settlements around Pretoria (Figure 11).

This exposure sensitised students to the broader global waste challenge, fuelling their motivation to seek practical solutions. The impact was palpable, as the majority of design students voluntarily enrolled in the advanced research unit (discussed in this application). These students were driven by a deep desire to cultivate practical and technical proficiencies to solve the global challenge and to develop methodologies and tools to address this overarching issue. The unique advantage of the transdisciplinary classroom setting allowed them to gain hands-on experience within a safe-to-fail experimental environment while preserving their core disciplinary competencies essential to their respective professional degrees.

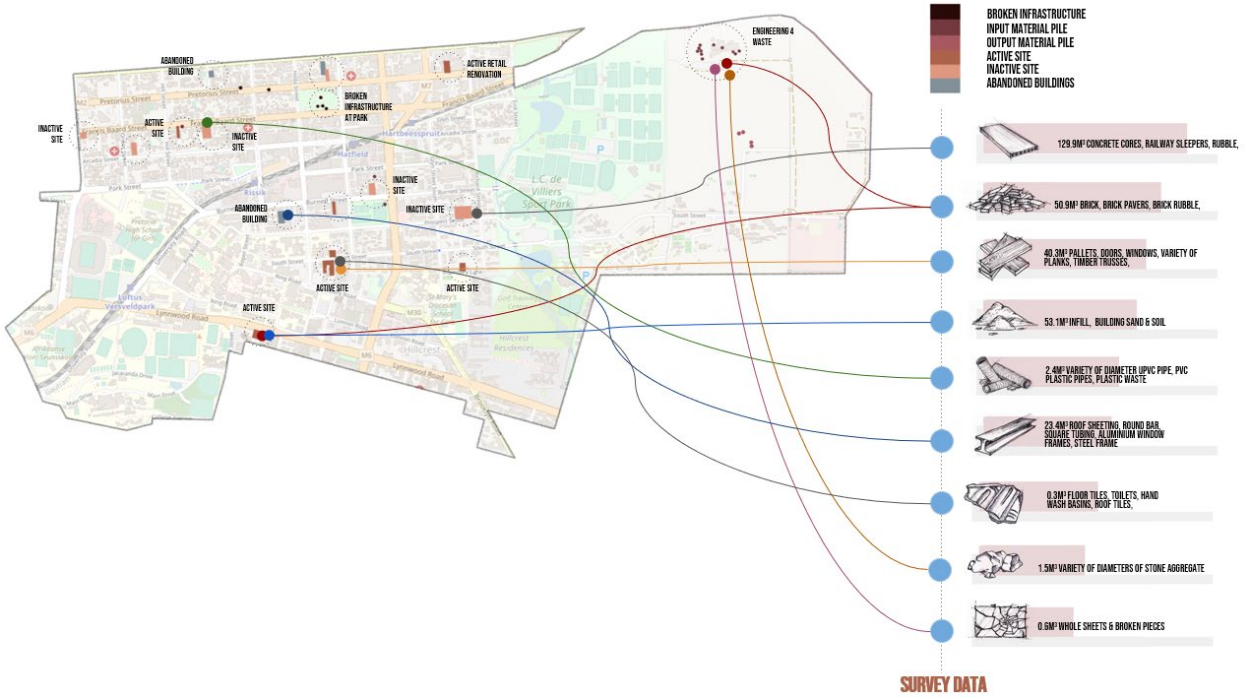

Figure 9: As part of a preceding design studio, architecture students mapped the distribution of construction waste over roughly 25 km² in the centre of Pretoria (Urban Strategy Studio Exam Submission Q1, Davey, 2023).

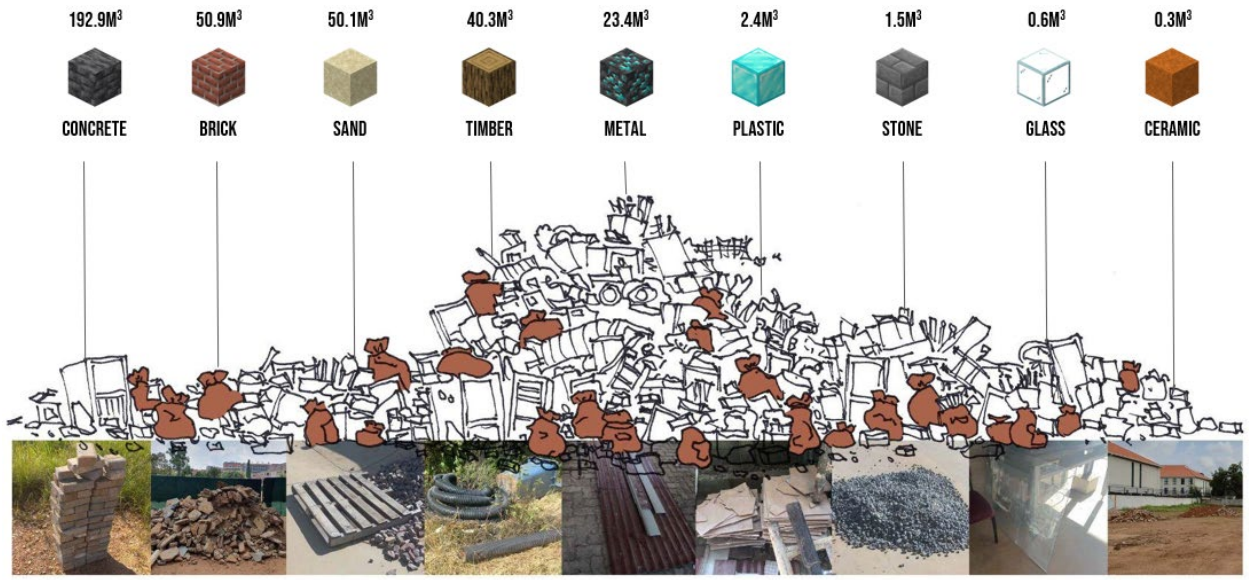

Figure 10: Insights from the preceding studio heightened students' awareness regarding the magnitude of waste generated by the construction industry (Urban Strategy Studio Exam Submission Q1, Davey, 2023).

Figure 11: The reality of material waste and re-use in South African informal urban environments (Van der Merwe, 2023).

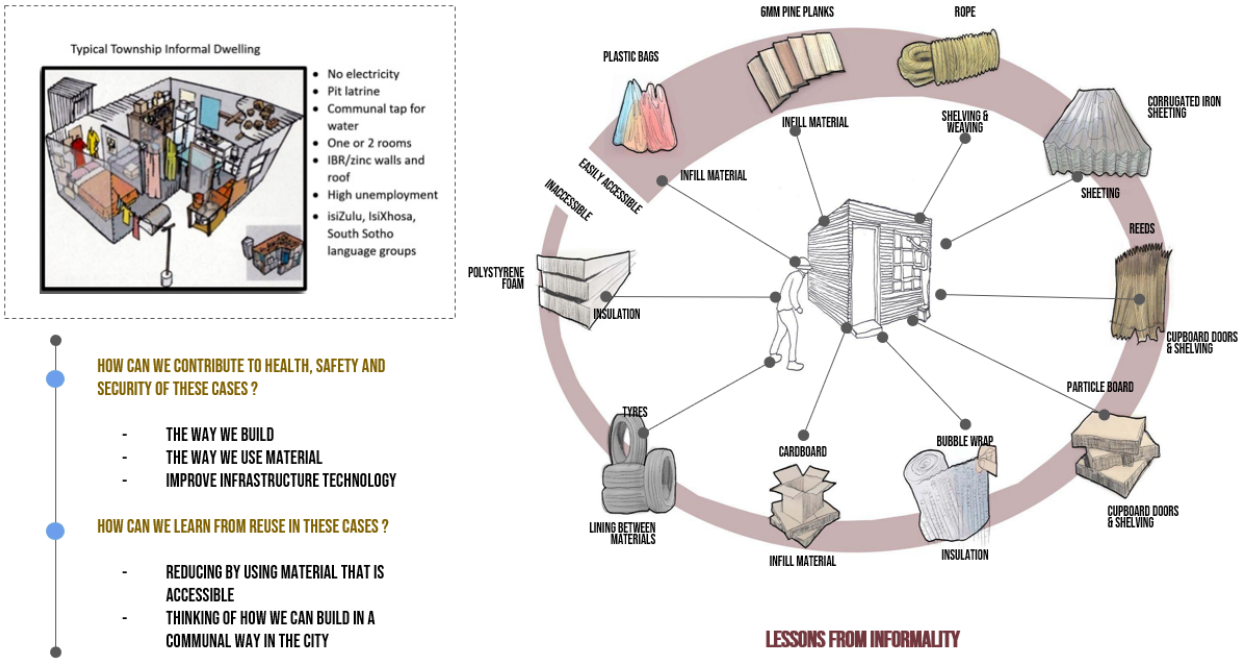

Figure 12: A student study investigating ways in which waste is used for construction of informal settlements around Pretoria. This explorative study forms the basis for subsequent interdisciplinary research at the University of Pretoria (Extracts from Urban Strategy Studio Exam Submission Q1, Davey, 2023).

Transforming built environment education.

To date, scarce examples of our education approach exist in published research. Existing literature discusses circularity and BIM, but often from narrow disciplinary views, isolated goals (e.g., Life-Cycle Analysis, logistics), or focusing solely on material end-of-life scenarios. Our work stands out for its holistic, transdisciplinary approach, spanning the entire design process with circularity at the core — a rarity in literature and classrooms. This approach investigates innovative methods for integrating circular design-for-reuse principles, extending beyond typical end-of-life scenarios or disciplinary siloes. The integration of transdisciplinary BIM in professional education, central to our approach, remains underexplored. Moreover, our project addresses the often-overlooked development of professional empathy skills, vital for industry transformation. Notably, our initiative operates in the global south (Africa), characterized by low skills, infrastructure barriers, and innovation challenges. By addressing these gaps, our project pioneers a distinct path amidst research, offering a practical, industry-aligned solution to circularity and sustainable construction complexities.

Our initiative showcases several innovative aspects:

Leveraging Existing Resources: Unlike many transdisciplinary initiatives that necessitate the creation of new teaching modules, our approach utilized pre-existing modules in architecture, civil engineering, and construction economics. This not only eliminated the need for additional resources but also bypassed administrative complexities. It offered our lecturing team a more experimental avenue for transdisciplinary education.

Focus on Professional Development: While many initiatives concentrate on generic sustainability topics, ours prioritized the development of professional skills. This ensures that the lessons learned are applicable to students' future careers, enhancing scalability.

Encouragement of Spontaneous Flipped Classrooms: We actively promoted spontaneous flipped classrooms. This approach not only enabled students to educate each other but also encouraged self-reflection on how they could contribute most effectively to the team. This enhances proficiency in both technical and interpersonal skills essential in the 4IR industry.

Dynamic Team Structure: Unlike traditional initiatives that group students into predefined teams to work on a single problem, our project involved the entire team collaboratively at the outset through BIM. As data and insights accumulated, students transitioned to pursue individual research questions. This prompted students to identify their most valuable contributions to the group.

Transferable skills for adaptation across contexts.

Our project's adaptability is process-driven, not tech-bound, enabling versatile implementation. This approach makes it readily applicable across diverse educational and professional settings, emphasizing individual development through real-world technology use. This holds particular significance given Africa's socio-technical context, necessitating a comprehensive and inclusive approach for advancing 4IR in the built environment, one that doesn't rely solely on high-end technological solutions alone.

Process-Oriented Foundation: Our project prioritizes a process-centric pedagogy over reliance on specific high-end technologies. This approach fosters flexibility and adaptability, allowing it to seamlessly integrate into various educational and professional settings.

Flexible Implementation: Unlike initiatives bound by particular technologies, our project's adaptability enables it to function effectively regardless of the available technology. This flexibility ensures broader applicability.

Holistic Skill Development: Our initiative places a strong emphasis on nurturing professional skills, making the acquired competencies transferable across diverse contexts.

Empowered Learning: Through student-centred education, our project encourages active participation and critical thinking, cultivating adaptable and self-aware individuals well-equipped for various environments.

Alignment with Industry Needs: Our project aligns closely with industry demands, preparing students to meet evolving professional requirements, thus ensuring direct applicability in real-world scenarios.

Proven Success and Scaling Plans: Building on prior recognition, we are poised for substantial scaling in 2024. Our prior achievements serve as a strong foundation for broader implementation.

The Future.

Given the promising trajectory and enthusiastic response, our project's growth potential is substantial. In the next 12-24 months, we will expand within our university to encompass urban planning, real estate, civil engineering, AI, IT, electronic engineering, and systems engineering, transforming our transdisciplinary unit into a comprehensive hub for innovation. Looking ahead 3-5 years, we anticipate significant enrolment growth, scaling by a factor of three in the first year and potentially a factor of five by year five. This will involve around 50 postgraduate students initially and potentially 150 thereafter, fostering a broader impact on sustainable practices across building, infrastructure, and city-scale projects. To amplify our influence, we'll disseminate our unique approach through scientific research articles and professional education publications. Collaborations with national, continental and international industry and academic partners are underway. Ultimately, our aim is to establish a pioneering model for circularity education, transdisciplinary collaboration, built environment research and innovation topics, and industry alignment, driving a sustainable future for the construction and built environment sectors in Africa.

Outlook and Reflection.

The pilot initiative outlined in this submission served as an experiment, paving the way for further transdisciplinary educational and research collaborations at the University of Pretoria. New topics have been identified for further research by the teaching team to investigate the building waste landscape at a greater scale, and to capture the building material stock of the University of Pretoria over all of its built environment ecosystems.

The endorsement received from industry during the BIM conference, coupled with enthusiastic student and industry engagement, motivates the rationale for expanding this initiative. This expansion could continue as informal collaborations or evolve into structured transdisciplinary teams within the faculty, all the while safeguarding the development of core disciplinary competencies.

Through field exposure and transdisciplinary teamwork, students have developed a shared comprehension of the crucial role of responsible resource consumption in the construction industry (UN SDG 12). This reinforced their understanding of how the built environment contributes to serving sustainable and intelligent cities in Africa (UN SDG's 9 and 11). Simultaneously, students have developed a broader spectrum of skills including conceptual, social, and practical dimensions to tackle these critical challenges. Through hands-on learning, students are now equipped to integrate these new perspectives into their future professional works.

Our ultimate vision rests on transdisciplinary classrooms serving as catalysts for significant, far-reaching transformations within the built environment. By nurturing well-rounded professionals adept at navigating complexity and seamlessly collaborating across disciplines, this approach strives to foster substantial and enduring change.